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Suppression of fusion by breakup: Resolving the discrepancy between the reactions of ^{9}Be with ^{208}Pb and ^{209}Bi

M. Dasgupta, D. J. Hinde, S. L. Sheehy,* and B. Bouriquet†

Department of Nuclear Physics, Research School of Physics and Engineering, Building 57, Australian National University, Canberra, ACT 0200, Australia

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Complete fusion cross sections for ^{9}Be incident on ^{208}Pb and ^{209}Bi have been measured at energies greater than the fusion barrier to investigate the large differences in their reported complete fusion cross sections. Relative xn and fission cross sections are in good agreement. Thus, it is concluded that the differences arise from errors in absolute normalization in the previous measurements. The present measurements show that the above-barrier complete fusion cross sections for the reactions of ^{9}Be with ^{209}Bi and ^{208}Pb are very similar, which resolves the previously observed anomaly. Complete fusion for the reaction of ^{9}Be with ^{209}Bi is found to be suppressed by ∼32% compared to the expectations of a single-barrier penetration model, which is in close agreement with the value previously determined for the reaction with ^{208}Pb.

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I. INTRODUCTION

Intense research efforts are currently directed at understanding the structure and dominant reaction mechanisms of nuclei far from stability. One of the areas of interest is the effect on fusion dynamics of their unusual structure, for example, clustering, weak binding, and halos [1,2]. Experimentally, complexities arise from the many reaction outcomes, which, apart from transfer and complete fusion (CF) of the projectile with the target, also include incomplete fusion (ICF), where one or more of the breakup fragments are captured by the target. Theoretically, problems arise because the coupled-channels model cannot yet separate CF and ICF; the latter arises from breakup of the weakly bound nuclei. Thus, despite continued experimental efforts [3–9], a quantitative understanding of fusion of weakly bound n-rich nuclei has not yet been achieved [2].

An alternative approach to understanding the general problem is to study the weakly bound light stable nuclei [10–16], ^{6}Li, ^{7}Li, and ^{9}Be, for which intense beams are readily available. These have provided precise measurements of CF [11,14,16], which have been crucial both in developing an understanding of the effect of breakup on fusion and in the development of new theoretical models [14,17]. Studies of the $^{9}\mathrm{Be} + {}^{208}\mathrm{Pb}$ reaction, for example, provided the first unambiguous demonstration [11] of the reduction in above-barrier CF cross section compared with the expectations for well-bound nuclei. The weakly bound stable nuclei, along with ^{4}He, also play an important role as reference reactions [3–8] for measurements involving the radioactive nuclei ^{6}He, ^{8}He, and ^{10,11}Be. Breakup measurements with ^{6}Li, ^{7}Li, and ^{9}Be have experimental advantages because they mostly break up into charged fragments, which are easier to detect than neutrons. Furthermore, in reactions of ^{6}Li, ^{7}Li, and ^{9}Be with heavy targets, individual fusion products can be readily identified [16] because neutron evaporation following fusion is the dominant decay mode and the evaporation residues are α emitters. In combination, these result in CF being easily distinguished from ICF.

Fusion reactions with ^{6}Li, ^{7}Li, and ^{9}Be beams incident on ^{208}Pb and ^{209}Bi targets have been investigated using the α-decay technique by several groups [10–12,14–16,18]. Above-barrier CF cross sections for the reaction of ^{6}Li with ^{208}Pb [14] and ^{209}Bi [15] are in agreement [19] with each other (after scaling for barrier energies and radii), and both show a suppression of ∼34% [14,15]. However, the situation is not so clear for the ^{9}Be-induced reactions, where the measured CF cross sections for the $^{9}\mathrm{Be} + {}^{209}\mathrm{Bi}$ [12] system are ∼25% greater [20,21] than those for the neighboring $^{9}\mathrm{Be} + {}^{208}\mathrm{Pb}$ [11,16] system. Clouding the issue further, discrepancies exist even between the different sets of CF measurements for $^{9}\mathrm{Be} + {}^{209}\mathrm{Bi}$, which were carried out in different laboratories [3,12,18]. A large difference in above-barrier CF cross sections between reactions with ^{208}Pb and ^{209}Bi targets, if confirmed, would give important information on the mechanism of breakup and incomplete fusion in reactions of ^{9}Be.

Thus, it is desirable to resolve these differences and obtain a definitive set of data, both for comparison with measurements using ^{10,11}Be beams and for understanding the effect of weak binding on fusion in general. This article presents CF measurements for ^{9}Be incident on ^{208}Pb and ^{209}Bi targets. Measurements for both reactions were carried out with the same experimental equipment, during the same beam time, to ensure that possible sources of systematic error between the two reactions were minimized. A detailed comparison of the new results and those available in the literature is made to determine the probable reason for the disagreements between the different data sets.

II. EXPERIMENTAL DETAILS

The experiment was performed using pulsed ^{9}Be beams (1 ns on, 640 ns off) with energies (E_{beam}) of 44.0, 50.0, and

*Current address: University of Oxford, United Kingdom.

†Current address: Centre Européen de Recherche et de Formation Avancée en Calcul Scientifique, F-31057 Toulouse Cedex 01, France.

60.0 MeV from the 14UD tandem electrostatic accelerator at the Australian National University (ANU). Targets of ^{209}Bi (120 μg/cm^2 thick) and ^{208}PbS (enriched to >99%; 400 μg/cm^2 thick) were backed by 360 μg/cm^2 aluminum catcher foils to stop the evaporation residues. Once the beam of a particular energy was tuned through the accelerator, the measurements for the two targets were made by simply changing the targets, with the rest of the setup remaining completely unchanged. New targets and catchers were used for measurements where long-lived evaporation residues (ERs) were populated. The ERs were identified by their characteristic α-decay energies using an annular Si surface-barrier detector at a mean angle of 174° to the beam direction. Two Si surface-barrier detectors placed at angles of ±15° with respect to the beam direction were used to detect elastic scattering for normalization and thus to obtain absolute cross sections. The details of the experimental setup can be found in Ref. [16].

Fission was measured using large area (28.4 × 35.7 cm^2) multiwire proportional counters (MWPCs) [22–24], centered at 45° and −135° to the beam direction, located 18 cm from the target. The fission angular distribution was measured from 95° to 150°. Absolute cross sections for both ERs and fission were determined by performing a calibration using a ^{28}Si beam incident on a ^{196}Pt target at the subbarrier energy of 92.0 MeV, where the elastic scattering is described by Rutherford scattering at all angles. By detecting elastically scattered particles in the two monitor detectors, the annular detector, and the backward angle MWPC, absolute cross sections could be determined for all detected decay channels.

III. RESULTS OF α-DECAY AND FISSION MEASUREMENTS

Complete fusion of ^{9}Be with ^{208}Pb and ^{209}Bi forms the compound nuclei ^{217}Rn and ^{218}Fr, respectively, which cool predominantly by the evaporation of neutrons [16]. In the measured energy range, the evaporation of three to six neutrons occurs [16,18], resulting in the formation of $^{211-214}$Rn and $^{212-215}$Fr ERs, respectively, for the ^{208}Pb and ^{209}Bi targets. These residues are α active, with lifetimes ranging from 86 ns to 14.6 h. The decay of all the residues could be measured, and cross sections could be determined for each individual channel by making a series of measurements during and after the irradiations.

Also observed were the products of ICF, formed by the capture of the breakup fragments ^{4}He and ^{5}He by the target. The ICF ERs $^{210-212}$Po and $^{211-213}$At, formed after n-evaporation, are α active and can be separated from the products of CF. This separation of CF and ICF is unambiguous because the compound nuclei formed following CF do not have a significant α evaporation probability. For example, for the compound nucleus ^{217}Rn, it was measured [11] to be <3% following fusion of the well-bound nucleus ^{13}C with ^{204}Hg. In contrast, for reactions with significantly lighter target elements, the probability of charged particle evaporation from the compound nucleus formed following CF increases as a result of the reduced Coulomb barrier energy encountered by the evaporated particle. This results in some ERs that are the same as those formed by ICF, making it much more difficult to unambiguously separate CF from ICF.

The α spectra from the present measurements were fitted using the peak-fitting program FITEK [25], as described in Ref. [16]. In obtaining the cross sections for individual channels, account was taken of branching ratios, collection time, decay time, and dead times. Since the goal of the present experiment was to measure and compare the *CF* cross sections for ^{9}Be + ^{208}Pb and ^{9}Be + ^{209}Bi, only the Rn and Fr CF cross sections were evaluated. Comprehensive measurements of ICF cross sections for the ^{9}Be + ^{208}Pb reaction, in the energy range E_{beam} = 36.0–51.0 MeV, can be found in Ref. [16]. The cross sections determined for the observed xn channels are presented individually in Tables I and II for the ^{9}Be + ^{208}Pb and ^{9}Be + ^{209}Bi reactions, respectively. The uncertainties quoted are statistical only. Table I also gives cross sections for the ^{9}Be + ^{208}Pb reaction, measured using the same procedures (but in a separate experiment) using the

TABLE I. Cross sections for individual ERs and fission for the reaction of ^{9}Be with ^{208}Pb. These individual components are summed to obtain the CF cross sections given in the last column. The statistical uncertainties are given. The $E_{\text{c.m.}}$ is corrected for energy loss in the target.

E_{beam} (MeV)	$E_{\text{c.m.}}$ (MeV)	$\sigma_{3n}(^{214}\text{Rn})$ (mb)	$\sigma_{4n}(^{213}\text{Rn})$ (mb)	$\sigma_{5n}(^{212}\text{Rn})$ (mb)	$\sigma_{6n}(^{211}\text{Rn})$ (mb)	σ_{fission} (mb)	σ_{CF} (mb)
This work							
44.00	42.07	157.4 ± 5.8	70.2 ± 2.4			1.38 ± 0.03	229 ± 6
50.00	47.84	54.3 ± 2.8	429 ± 10	27.7 ± 4.1		9.70±0.06	521 ± 11
60.00	57.43	13.9 ± 1.0	160.4 ± 4.1	587 ± 9	27.7 ± 2.3	55.48 ± 0.15	845 ± 10
New ANU data							
45.00	42.92	154.9 ± 3.6	125 ± 10.			2.02 ± 0.05[b]	282 ± 11
48.00	45.89	89.1 ± 2.7	341 ± 11	7.8 ± 0.8[a]		6.15 ± 0.06	444 ± 11
51.00	48.80	36.0 ± 1.6	451 ± 11	57 ± 4[a]		12.8 ± 0.09[a]	557 ± 12
56.00	53.58	16.7 ± 1.5	311 ± 11	366 ± 9	3.5 ± 2.0[c]	34.8 ± 0.2	732 ± 14
61.00	58.33	9.1 ± 1.1	123 ± 8	622 ± 14	55 ± 6	69.1 ± 0.3	878 ± 17
70.00	67.03	5.6 ± 1.2	20.3 ± 3.6	310 ± 8	519 ± 59	166.6 ± 0.6	1022 ± 60

[a]From Ref. [16].
[b]Interpolated from Ref. [16].
[c]Extrapolated.

TABLE II. Cross sections for individual ERs and fission for the reaction of ^{9}Be with ^{209}Bi. These individual components are summed to obtain the CF cross sections given in the last column. The statistical uncertainties are given. The $E_{c.m.}$ is corrected for energy loss in the target.

E_{beam} (MeV)	$E_{c.m.}$ (MeV)	$\sigma_{2n}(^{216}$Fr) (mb)	$\sigma_{3n}(^{215}$Fr) (mb)	$\sigma_{4n}(^{214}$Fr) (mb)	$\sigma_{5n}(^{213}$Fr) (mb)	$\sigma_{6n}(^{212}$Fr) (mb)	$\sigma_{fission}$ (mb)	σ_{CF} (mb)
44.00	42.15	5.9 ± 2.3	173 ± 6	48.1 ± 2.6			8.53 ± 0.09	236 ± 7
50.00	47.91		72.6 ± 4.2	423 ± 11	8.6 ± 1.4		45.71 ± 0.23	550 ± 12
60.00	57.50		5.7 ± 1.5	191 ± 6	490.2 ± 12	10.2 ± 2.5	190.4 ± 0.6	887 ± 14

setup described in Ref. [16], which have not previously been reported.

The fission cross sections, determined following the procedure detailed in Refs. [22–24], are given in the penultimate columns of Tables I and II and are attributed to CF, as fission following ICF is expected to be negligible because of the lower angular momentum and excitation energy of the ICF products as well as their higher fission barriers [26]. The fission folding angle distributions were consistent with this expectation.

The CF cross sections, obtained by summing the individual xn channels and the fission cross sections, are given in the last columns of Tables I and II.

IV. COMPARISON OF DIFFERENT MEASUREMENT SETS

The ^{9}Be + ^{209}Bi reaction has previously been studied (i) at the Rikagaku Kenkyusho (RIKEN) ring cyclotron [3], where the 3n-channel cross sections were measured, (ii) at the 12UD tandem accelerator at University of Tsukuba [3], where cross sections for the 3n, 4n, and 5n evaporation channels and fission were measured, and (iii) at the tandem accelerator at the University of Munich [18], where cross sections were measured for the 2n, 3n, and 4n channels. The second and third measurements do not quite match with each other, and an average of these cross sections has more recently been used [12]. The comparison of the available measurements is made in two parts. First, the relative fission and xn cross sections are compared to check whether the measurements of the the individual decay modes of the compound nuclei are consistent. This procedure also checks the quoted beam energies in different data sets. In the second step, the absolute cross sections are compared to check for consistency in normalization.

A. Relative cross sections

The ratio of the individual xn cross section to the summed xn cross sections as a function of excitation energy of the compound nucleus is shown in Fig. 1 for the current (large symbols) and all previous measurements (small symbols) for the ^{9}Be + ^{209}Bi system. There is excellent agreement between all data sets, indicating that relative normalization of the different xn yields are all consistent. The upper diamond for the 2n channel from this work matches that measured previously. However, this is not a true representation of the 2n fraction. The 2n ER, ^{216}Fr, decays by a 9005 keV α particle. This is close in energy to the 9080 keV α particle emitted by the ^{213}At nucleus formed by the capture of the breakup α particle by the target (or by α transfer). The cross section for the formation of ^{213}At was estimated from the equivalent process in the reaction of ^{9}Be with ^{208}Pb. There the cross sections of the α capture product ^{212}Po at near- and above-barrier energies were found to remain constant at ∼13 mb. The cross section for ^{216}Fr was calculated (lower large diamond) by subtracting the contribution of ^{213}At, determined assuming its production cross section to be 13 ± 3 mb.

The ratios of fission cross sections to the CF cross sections are plotted against the center-of-mass energy $E_{c.m.}$ for the ^{9}Be + ^{208}Pb and ^{9}Be + ^{209}Bi reactions in Fig. 2. The measurements show that the ^{9}Be + ^{209}Bi reaction has a larger fission probability than ^{9}Be + ^{208}Pb, which is expected because of the larger fissility of the compound nucleus formed in the ^{9}Be + ^{209}Bi reaction. The different data sets are again in very good agreement, irrespective of whether the measurements were made in the same laboratory at different times (as for the ^{9}Be + ^{208}Pb reaction) or made at different laboratories, as in the case of ^{9}Be + ^{209}Bi.

These comparisons show that both the relative xn and fission cross sections and the quoted center-of-mass energies

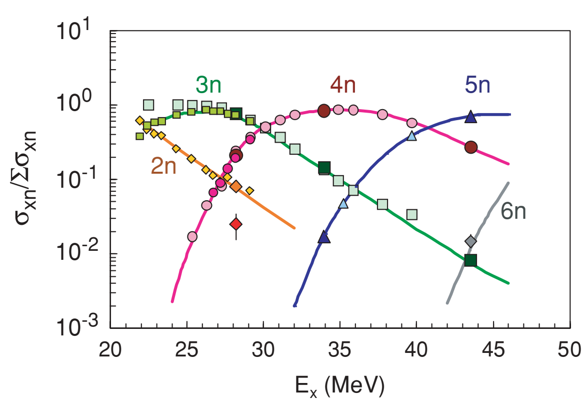

FIG. 1. (Color online) Proportion of individual xn channels as a function of the excitation energy (E_x) of the compound nucleus for the reaction of ^{9}Be with ^{209}Bi from this work (largest dark symbols), Tsukuba [3] (pale symbols), and Munich [18] (smaller symbols). The agreement between the different data sets demonstrates that the relative cross sections are correct for all the measurements. The 3n fractions for the measurements from Ref. [3] are slightly higher at the lowest energies, as the 2n evaporation cross sections were not measured. The lower large diamond from this work at $E_x = 28.1$ MeV corresponds to the 2n fraction after subtracting the contribution of an ICF channel, and the upper large diamond includes this contribution (see text), as was evidently the case in the previous measurement.

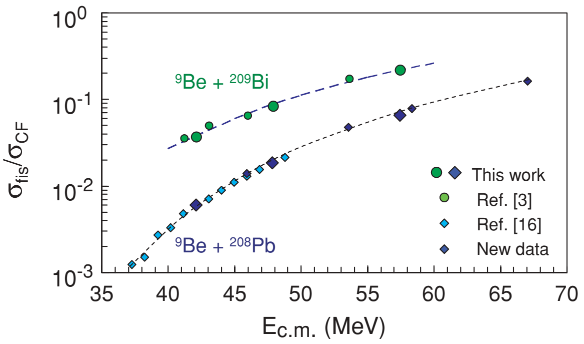

FIG. 2. (Color online) Ratio of the fission cross sections to the CF cross sections for the reactions of ^{9}Be with ^{208}Pb and ^{209}Bi. The different sets of measurements for each of the reactions agree well with each other. The lines guide the eye.

are consistent across all measurements made at three different laboratories.

B. Absolute cross sections

Having verified the consistency of the relative cross sections in the different measurements, the absolute values of CF cross sections are now compared, as it is here that the discrepancies must occur. For this comparison, the average fusion barrier energy for ^{9}Be + ^{208}Pb is taken to be 38.3 MeV, which was determined in Ref. [16] from the measured fusion barrier distribution. The average barrier for the ^{9}Be + ^{209}Bi system was obtained by scaling the experimental value for the ^{208}Pb reaction. This was done by choosing a Woods-Saxon parametrization of the nuclear potential that reproduced the experimental barrier of 38.3 MeV for the ^{9}Be + ^{208}Pb system and changing only the target mass and charge to determine the barrier for the ^{9}Be + ^{209}Bi system. The resulting average barrier energy is 38.76 MeV, which is used for making relative comparisons between the ^{208}Pb and ^{209}Bi targets. The CF cross sections ($\sigma_{CF} = \sigma_{xn} + \sigma_{\rm fission}$) are plotted in Fig. 3 as a function of $E_{\rm c.m.}$ divided by the average fusion barrier energy V_B. Because the two systems are very similar, the CF cross sections are compared directly without any further scaling of the cross sections by $(A_P^{1/3} + A_T^{1/3})^2$ [27]. The cross sections for ^{9}Be + ^{208}Pb from the present work match well with the previous measurements [16]. The cross sections for ^{9}Be + ^{209}Bi measured in the current work are close to those of ^{9}Be + ^{208}Pb, in agreement with expectations if the additional proton in ^{209}Bi plays no role in the breakup of ^{9}Be. However, the previously reported cross sections [12] for ^{9}Be + ^{209}Bi are substantially higher than the current results.

This disagreement is also seen in the individual xn cross sections. In particular, Fig. 4 shows the cross sections for the $3n$-evaporation product ^{215}Fr. The cross sections measured in RIKEN and reported in Ref. [3] have the largest cross sections (open triangles), followed by measurements performed in Tsukuba (open squares) [3]. The normalization of the Tsukuba cross sections used a single monitor detector placed at 20° with respect to the beam direction, making it susceptible to errors due to lack of knowledge of the beam angle and interaction point on the target. Two monitors placed

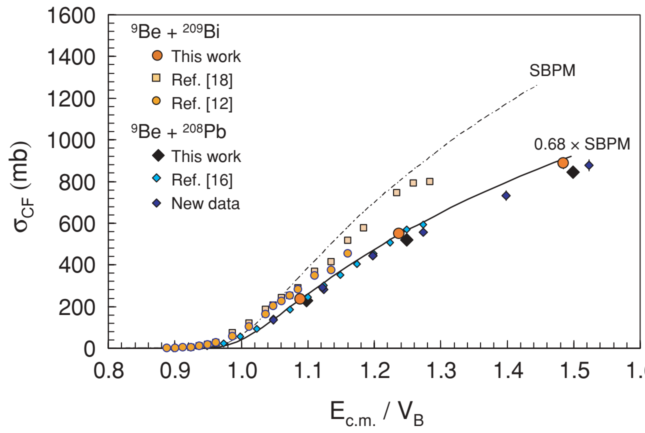

FIG. 3. (Color online) CF cross sections for the reactions ^{9}Be + ^{208}Pb and ^{9}Be + ^{209}Bi measured in different experiments as a function of $E_{\rm c.m.}$ divided by the average fusion barrier energy. The cross sections measured in this work for the ^{9}Be + ^{208}Pb reaction agree well with previous measurements. The present measurements for the ^{9}Be + ^{209}Bi reaction are lower than those reported in Refs. [18] and [12]. It is argued (see text) that this disagreement is caused by normalization error in Refs. [18] and [12]. The dashed line shows the single-barrier penetration model (SBPM) calculations for ^{9}Be + ^{209}Bi, and the full line is obtained by multiplying these calculations by a factor of 0.68. The latter agree well with the current measurements, showing that the CF for ^{9}Be + ^{209}Bi is only 68% of the expectations, in agreement with the value of $68^{+8}_{-7}\%$ found for reactions with ^{208}Pb nuclei [16].

symmetrically about the beam axis, as done in the current measurement, alleviates this problem. Thus, a normalization error in the absolute cross sections measured in Tsukuba [3] cannot be ruled out. Later measurements done in Munich, and reported in Ref. [18], are at some energies substantially

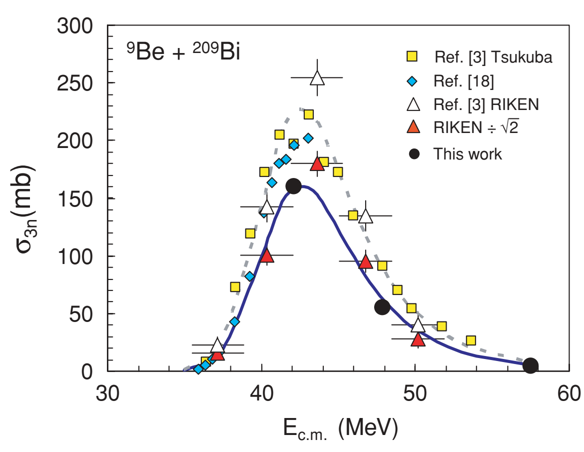

FIG. 4. (Color online) Cross sections for $3n$ evaporation from the compound nucleus formed following the complete fusion of ^{9}Be with ^{209}Bi. The deviations between the previous measurements demonstrate the problems with normalization. The cross sections measured at RIKEN, when divided by $\sqrt{2}$ to account for the target being at 45°, agree very well with the present measurements, showing that the renormalized RIKEN data are likely to be correct. The lines guide the eye.

lower than those measured in Tsukuba. Finally, a weighted average of these two measurements was adopted by the authors of Ref. [12]. However, these values are still greater than the current measurements.

C. Resolving the disagreement

The disagreements between the current data set and those measured previously, and among the previous measurements, seem most likely to be due to problems in normalization for one or more measurements. Evidence for the correct normalization of the present data, and those of Refs. [11,16], is discussed next.

Measuring the cross section for fusion of two well-bound, stable nuclei forming the same compound nucleus, using the same setup as used for the weakly bound nucleus and as done in Refs. [11] and [16], provides a good check of normalization. In Ref. [11], CF cross sections for ^{9}Be + ^{208}Pb and for the well-bound projectile ^{13}C fusing with ^{204}Hg were measured in the same experiment. Both these reactions lead to the formation of the same compound nucleus ^{217}Rn, and hence the compound-nucleus decay products are identical. It was found that the fusion cross sections for ^{13}C + ^{204}Hg agreed well with the predictions of the Bass model and also the single-barrier penetration calculations (which are identical to coupled-channel calculations at above-barrier energies). Thus, the measurements of Ref. [11] are likely to have the correct normalization. Data presented in Fig. 3 show that the current measurements match well with those reported previously [11], indicating that the current cross sections also have the correct normalization.

The experimental setup and procedures used for the ^{9}Be + ^{208}Pb system were the same for the later measurements of the ^{6,7}Li + ^{209}Bi reactions, reported in Ref. [16]. Any normalization problem in the former data would be likely to occur in the latter as well. A number of points, discussed next, support the correct normalization of the ^{6,7}Li + ^{209}Bi data. Associated with the ^{7}Li + ^{209}Bi experiment, fusion cross sections were measured for ^{18}O + ^{198}Pt (both reactions form the same compound nucleus), where substantial ICF is not expected. The fusion cross sections were found to agree well with model expectations [16], giving confidence in the CF cross sections for the ^{6,7}Li + ^{209}Bi reactions reported in Ref. [16]. Further confidence in these values comes from their close agreement with those measured by another group [10].

If we accept that the normalization of the current measurements is correct, then the cross sections for ^{9}Be + ^{209}Bi given in Ref. [12] must have a normalization error of about 20%. One normalization issue has come to light since the first publication of the ^{9}Be + ^{209}Bi cross sections. In Ref. [28], it was noted that in the original analysis of the RIKEN experiment, reported in Ref. [3], the effect of the target being inclined at 45° to the beam had not been taken into account in determining the ^{11}Be cross sections, reducing them by $1/\sqrt{2}$. This correction was also made to the ^{10}Be cross sections reported in Ref. [28]. For the RIKEN ^{9}Be measurements, the target was also at 45° to the beam and should also be scaled by the same factor of $1/\sqrt{2}$ [29]. After this correction, the RIKEN measurements of the CF $3n$ evaporation channel match the current measurements well, as shown in Fig. 4 by the filled triangles. Thus, the RIKEN data, measured with low-intensity beams, appear to have the correct normalization after accounting for the target being at 45°. It is the Tsukuba data that deviate the most from the corrected RIKEN cross sections and from those obtained in the present work.

It is thus concluded that the present measurements of CF cross sections for the ^{9}Be + ^{208}Pb and ^{9}Be + ^{209}Bi reactions, carried out using the same experimental setup and procedures, show that the cross sections at energies above the barrier are very similar. The reported disagreement between the two systems, which was not understood previously, seems to be only explicable through incorrect normalization of previous measurements for the ^{9}Be + ^{209}Bi reaction, in particular, for the Tsukuba data reported in Ref. [3].

The extensive analysis of the CF cross sections for ^{9}Be + ^{208}Pb showed [16] that the above-barrier cross sections are only 68^{+8}_{-7}% of those expected from the single-barrier penetration model. Such extensive analysis is not possible for the current measurements at three energies. However, an estimate of the CF suppression for the ^{209}Bi reaction can be obtained by comparing the measurements with a single-barrier penetration model with the reasonable assumption that the potential depth, radius, and diffuseness are the same as those used for the ^{9}Be + ^{208}Pb system. The single-barrier penetration model calculation for the ^{9}Be + ^{209}Bi reaction, for an average barrier of 38.76 MeV, is shown by the dashed line in Fig. 3. These calculations need only be reduced by ∼10% to bring them into agreement with the cross sections reported in Refs. [18] and [12], in contrast with the typical suppression of ∼30% found from systematics of reactions of weakly bound stable nuclei with heavy targets [26]. Scaling the single-barrier penetration model predictions by 0.68 (full line in Fig. 3) brings them into agreement with the ^{9}Be + ^{209}Bi CF cross sections measured in this work. This suppression for ^{209}Bi is very close to that for ^{208}Pb [16]. The similarity indicates that the additional proton in ^{209}Bi does not have a large influence on the breakup dynamics. This observation is in agreement with our recent subbarrier breakup measurements made for ^{9}Be incident on various targets, which show [30] that the breakup probability is almost identical for ^{9}Be incident on ^{208}Pb and ^{209}Bi target nuclei.

V. CONCLUSIONS

The CF cross sections for the ^{9}Be + ^{208}Pb and ^{9}Be + ^{209}Bi reactions have been measured at three energies above the barrier using the same experimental setup and under identical conditions. Contrary to the large differences found in previous experiments, the current measurements show that the cross sections for the two systems are very similar and that the additional proton in ^{209}Bi does not have a large effect on the breakup of ^{9}Be. This result is consistent with the conclusions drawn by comparing [19] the CF cross sections for the ^{6}Li + ^{208}Pb reaction [15] with those of ^{6}Li + ^{209}Bi [16]; they agree with each other when the differences in the fusion barrier energies are taken into account, and both systems show above-barrier suppression of CF of 34%. The current measurements for ^{9}Be + ^{209}Bi do not agree with those measured previously, and it is concluded that the previous measurements seem to have an error in normalization. Those cross sections (reported in Ref. [12]) should be reduced by ∼20%. An above-barrier CF suppression of ∼32% is deduced for the ^{9}Be + ^{209}Bi by comparing the current measurements with the expectations of the single-barrier penetration model. The interpretation of fusion cross sections for the ^{10,11}Be + ^{209}Bi reactions [28], which uses a comparison of their cross sections with those for the ^{9}Be + ^{209}Bi system, will need to be revisited in light of the current work.

Currently, there is a substantial body of experimental measurements of CF cross sections for weakly bound nuclei fusing with heavy targets, and data for fusion with medium-mass targets are becoming available. Together with data from breakup cross sections, which are currently being measured by many groups, these data sets should provide both excellent motivation and testing grounds for new models of fusion, ICF, and breakup of weakly bound nuclei.

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