An Improved thermometer for intermediate-mass fragments

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Contents

1. Background

- The temperature is one of the most important questions in the heavy-ion collision physics since it changes along the reaction process, which first increases in a very short time due to the compression of the system and then decrease with the expansion of the system in a long time.

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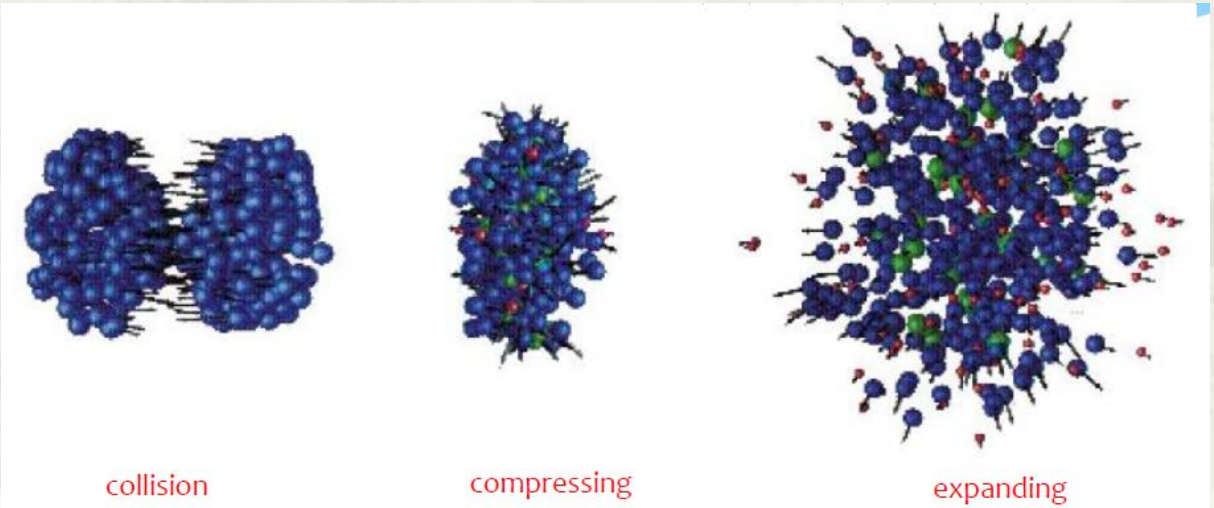

Heavy-ion nuclear reaction schematic diagram

1. Background

- For the many probes used to study the nuclear symmetry energy, such as the isoscaling method , the isobaric ratio method, and the isobaric yield ratio difference (IBD) method, *T* is a part of the probe and cannot be separated easily.

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1. Background

- A thermometer based on the isobaric yield ratio (IYR) has been proposed.

PHYSICAL REVIEW C **86**, 054611 (2012)

Temperature determined by isobaric yield ratios in heavy-ion collisions

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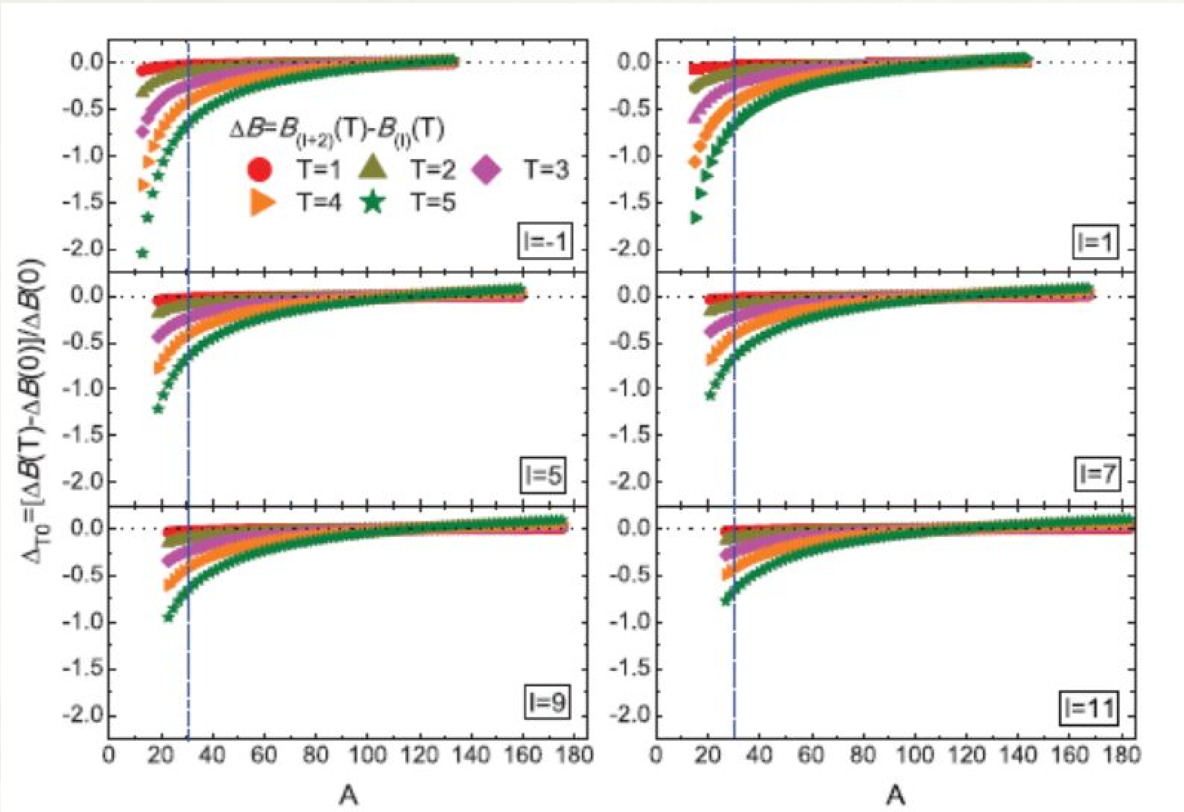
- The thermometer based on IYR extracts T and the difference of chemical potential $\Delta\mu(\Delta\mu=\mu_n-\mu_p)$ by fitting the isobaric yield ratio of two isobars.

$$\ln R(I+2, I, A) - \Delta S = (\Delta W + \Delta\mu)/T$$

Ma CW et al., PRC86 (2012) 054611

1. Background



$$\Delta B(T) = B_{(I+2)}(T) - B_{(I)}(T)$$

$$\Delta_{T0} \equiv [\Delta B(T) - \Delta B(0)]/\Delta B(0)$$

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- Δ_{T0} decrease as the mass becomes larger and similarly as T decrease.
- At T =1 MeV, Δ_{T0} of the $I = -1 \sim 11$ isobars are very close to zero.
- At $T \geq 3$ MeV, the A<50 isobars show relatively large Δ_{T0} and the value of Δ_{T0} is less than -0.1.

1. Background

- In a word, it has proved that the residue free energy between two isobars can be replaced by that of binding energy in the IYR method. The fitting formula of extracting *T* can be written as,

$$\ln R(I+2, I, A) - \Delta S = (\Delta B + \Delta\mu)/T$$

Ma CW et al., PRC86 (2012) 054611

2. Method

The new thermometer is developed by using the canonical ensemble theory.With the grand-canonical limation,the cross section of a fragment *σ(A,I)* has a form of

$$\sigma(A,I) = CA^{\tau}\exp\{[-F(A,I) + \mu_n N + \mu_p Z]/T\}$$

The isobaric yield ratio of isobars with I+2 and I is,

$$\ln R(A, I+2, I) = \ln[\sigma(A, I+2)/\sigma(A, I)]$$

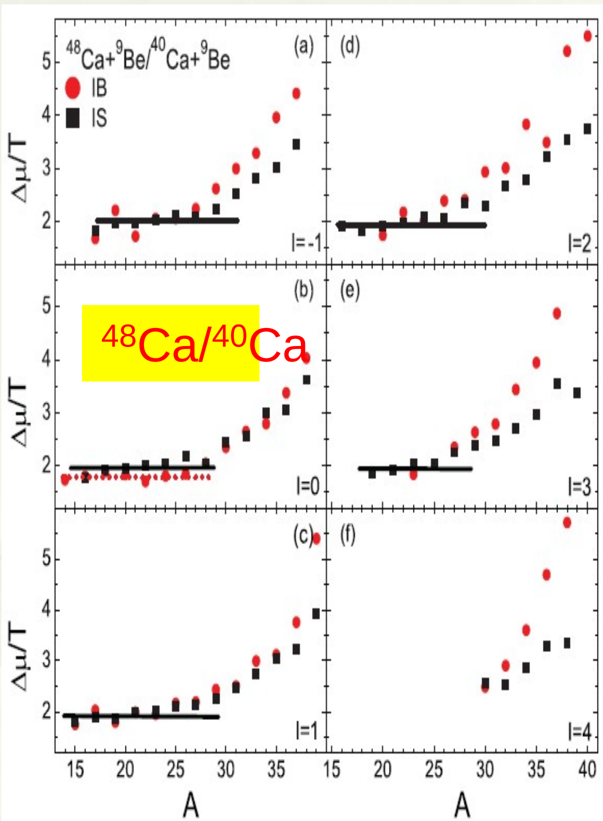
$$= [F(A,I) - F(A, I+2) + \Delta\mu]/T$$

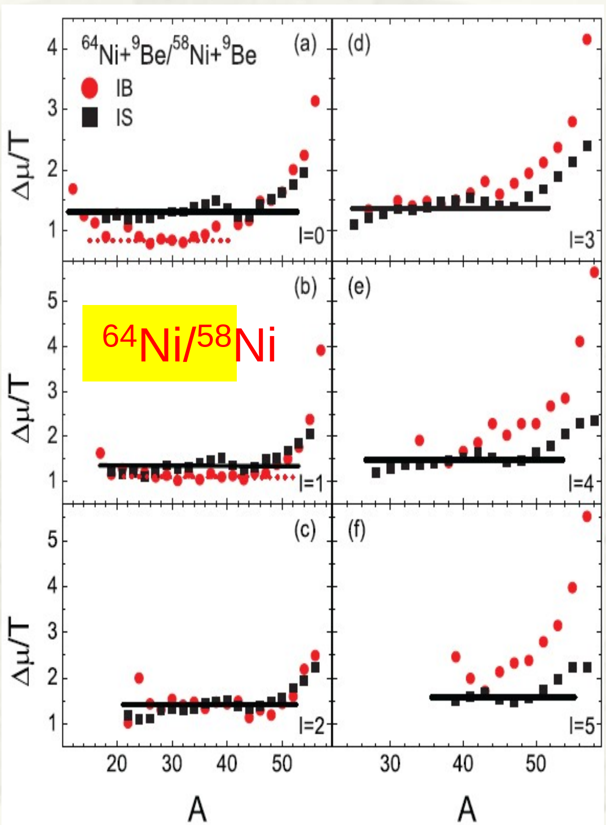
Similarly,for isobars with I and I-2,one has,

$$\ln R(A, I, I-2) = \ln[\sigma(A,I)/\sigma(A, I-2)]$$

$$= [F(A, I-2) - F(A,I) + \Delta\mu]/T$$

2. Method





- In the isobaric ratio difference(IBD) analysis, $\Delta\mu/T$ from the small A fragment changes very little, which means $\Delta\mu/T$ can be cancelled out in the difference between the IYRs.

Ma CW et al., PRC87(2013)034618.

2. Method

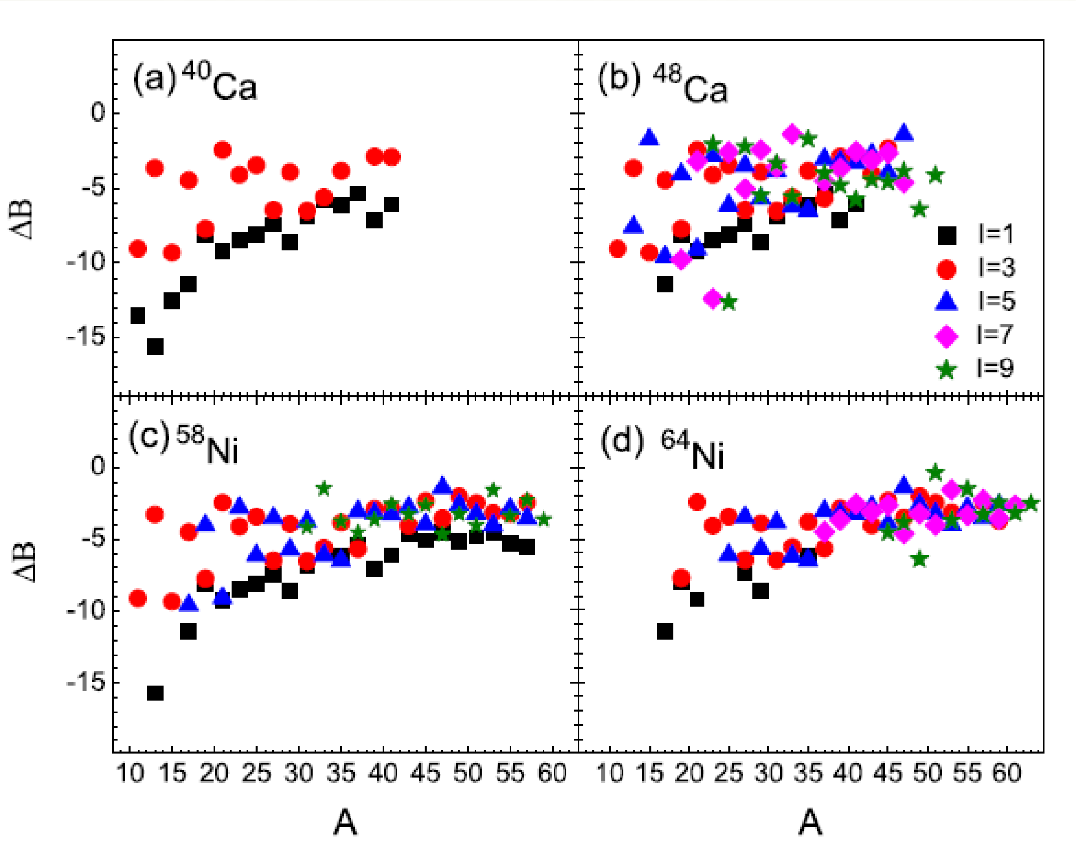
- The difference of IYRs can be written as,

$$\ln R(A,I+2,I)-\ln R(A,I,I-2)$$
$$=[2F(A,I)-F(A,I+2)-F(A,I-2)]/T$$

- For fragments having finite temperatures,it is proven that the residue free energy between two isobars can be replaced by that of binding energy*B(A,I)*. The improved method to obtain *T* from the difference between IYRs (labelled as T_{IB}) can be written as,

$$T_{IB}=\frac{2B(A,I)-B(A,I+2)-B(A,I-2)}{\ln R(A,I+2,I)-\ln R(A,I,I-2)}=\frac{\Delta B}{\Delta \ln R}$$

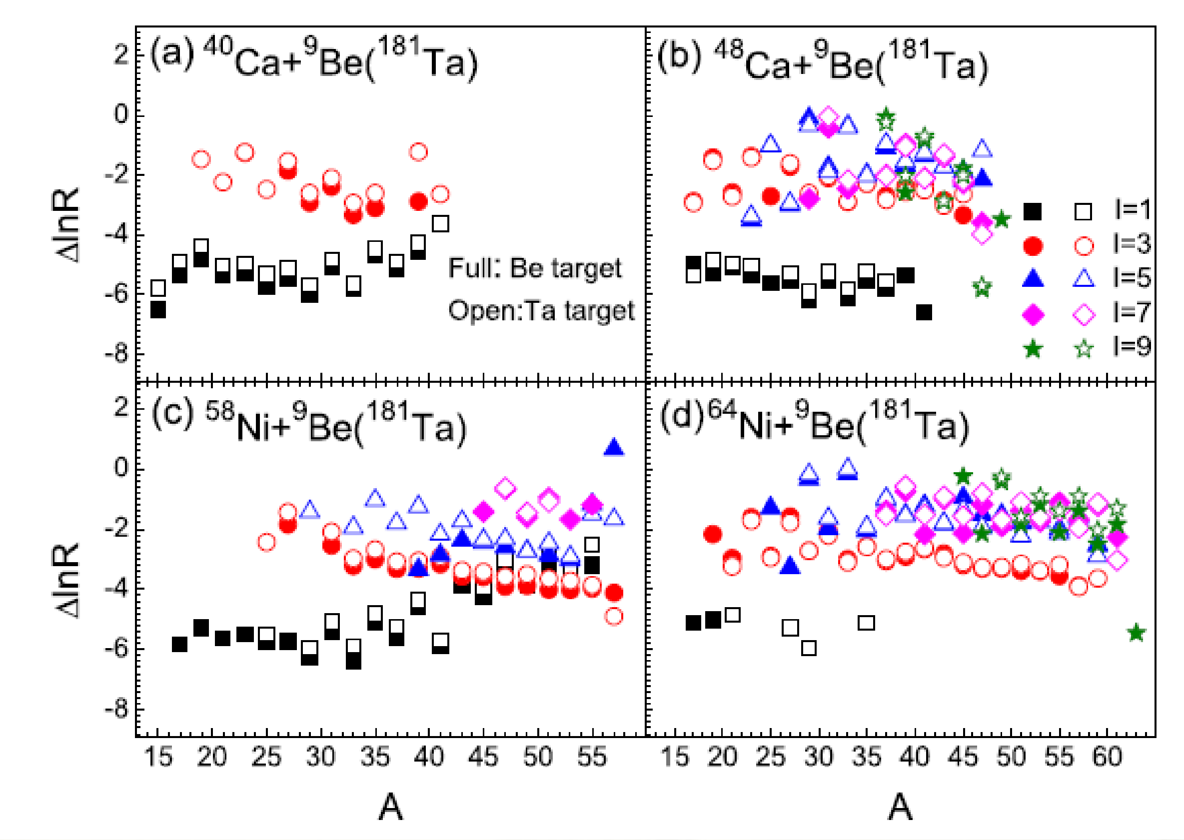
3.Results and Discussion



$\Delta B(MeV)$ for the related isobars in the 140AMeV$^{40,48}Ca+^{9}Be$ and $^{58,64}Ni+^{9}Be$ reactions.

- *ΔB* for the *I* = 1 fragments almost changes monotonically with *A*.
- Staggering is shown in the *ΔB* for *I* = 3, 5, and 7 fragments on the relative small *A* side.
- The staggering in *ΔB* becomes smaller for the *A* > 35 fragments.

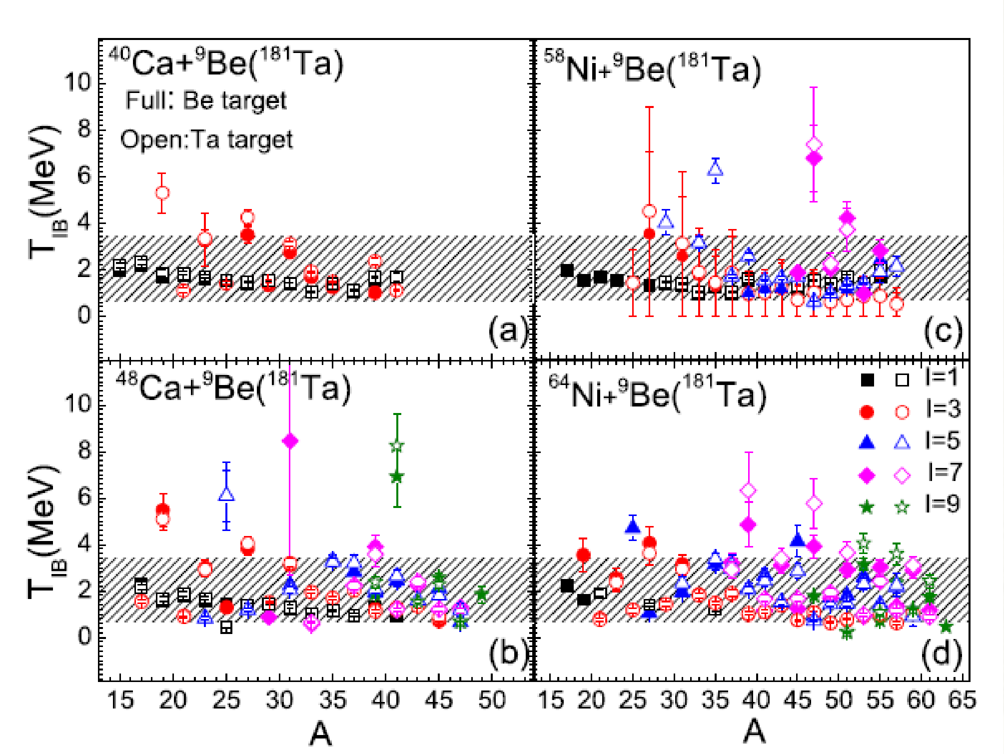
3.Results and Discussion



ΔlnR for the realated isobars in the 140AMeV^{40,48}Ca+^{9}Be(^{181}Ta) reactions

- For the I = 1 fragments, ΔlnR is almost constant on the small A side, but it increases with A when A > 40 and some staggering is shown when A > 30.
- For the I = 3, 5, and 7 fragments, an obvious staggering appears in ΔlnR on the small A side, but this staggering becomes very small when A is relative large.
- The target shows very little influence on the results of ΔlnR.

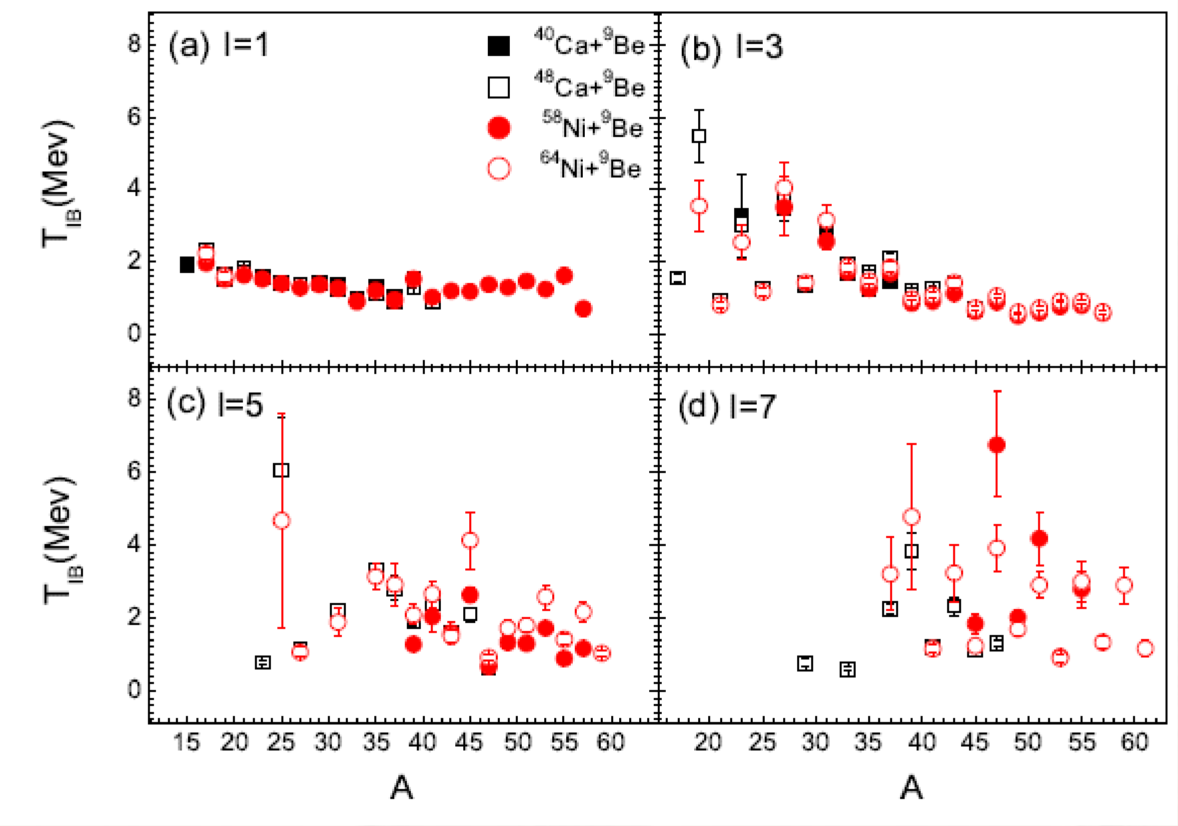
3.Results and Discussion



T_{IB} of the measured 140AMeV ^{40,48}Ca+^{9}Be(^{181}Ta) and ^{58,64}Ca+^{9}Be(^{181}Ta) reactions, and the shadowed area is 0.6MeV<T_{IB}<3.5MeV.

- T_{IB} from the I = 1 fragments is almost constant around 1.5 MeV in all the reactions.
- T_{IB} from the I = 3 fragments shows a relatively large staggering for the small A fragments.
- T_{IB} from the I = 5 fragments shows a small staggering. But the staggering phenomenon again appears in T_{IB} for I = 7 and 9 fragments.

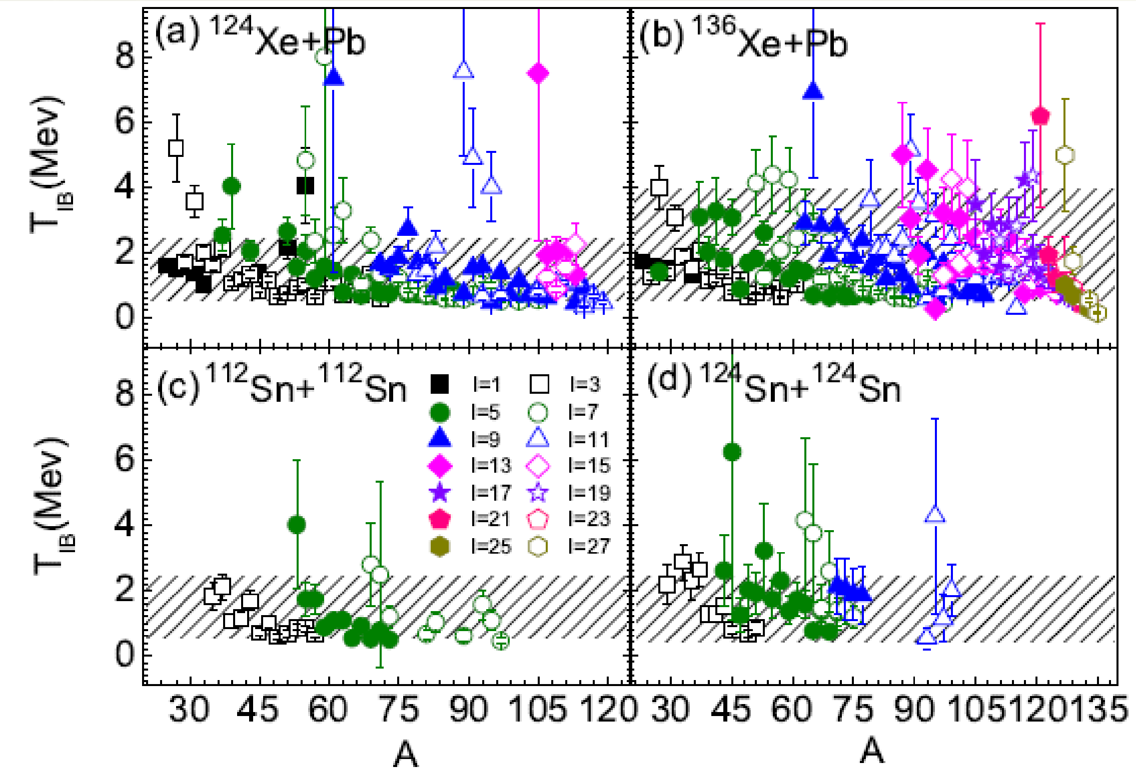
3.Results and Discussion



- T_{IB} is almost same for the I =1fragments, and is also almost same for the I = 3 fragments except the fragments having relative small A.
- Some obvious difference appears in T_{IB} of the I = 5 fragments, and the difference becomes even larger in the I = 7 fragments.

T_{IB} of the measured 140AMeV $^{40,48}Ca+^{9}Be(^{181}Ta)$ and $^{58,64}Ca+^{9}Be(^{181}Ta)$ reactions are plotted according to I

3.Results and Discussion

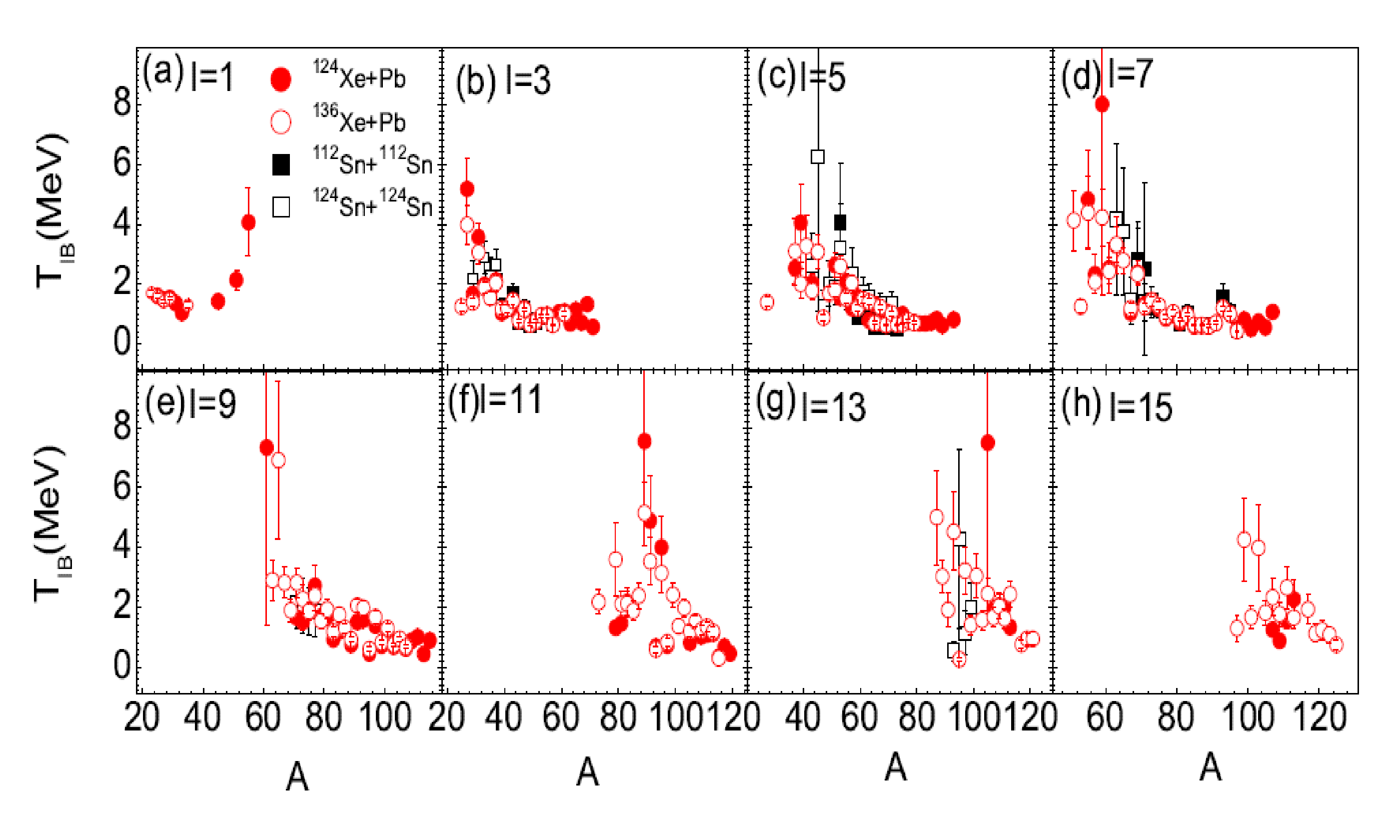


T_{IB} for fragments in the 1*A* GeV ^{124,136}Xe + Pb and ^{112,124}Sn+^{112,124}Sn reactions.

T_{IB} from the fragments in the ^{112,124}Sn have the similar trend to those in the ^{124,136}Xe reactions, most of which are in the range 0.5MeV<T_{IB}<2.5MeV.

- For most of the fragments in the ^{124}Xe reactions, T_{IB} falls in a range of 0.5 MeV < T_{IB} < 2.5 MeV comparing to that of 0.5 MeV < T_{IB} < 4 MeV for most of the fragments in the ^{136}Xe reactions, as shown by the shadowed areas.
- Staggering is shown in T_{IB} for the small *A* fragments with *I* = 3, 5, and 7 in both of the reactions, and in the fragments with *I* = 13 and 15 in the ^{136}Xe reaction.
- For fragment with the same I, T_{IB} decreases with A, while T_{IB} for the relative large A fragment tend to be constant.

3.Results and Discussion



For the fragments with the same A, T_{IB} is very similar, which indicates that in the isoscaling and IBD methods, it is reasonable to assume that the temperature of a specific fragment in two reactions are the same.

Comparison of T_{IB} for fragments with same I in the measured 1A GeV ^{124,136}Xe+Pb and ^{112,124}Sn +^{112,124}Sn reactions.

4.Summary

- An improved isobaric ratio thermometer(T_{IB}) for IMFs has been developed based on the difference between IYRs, in which the residual binding energy is used instead of the residue free energy.

- In contrast to the IYR thermometer, T_{IB} is obtained directly from fragments and avoids the fitting procedure in the IYR method, which makes T_{IB} become a direct probe to temperature.

- The values of T_{IB} for most considered intermediate-mass fragments are low.

Thank you for your attention!