

MASS SYSTEMATICS OF HYPOTHETICAL NEUTRAL OBJECTS IN
HEAVY-ION COLLISIONS AND IN $e^+ +$ HEAVY-ION INTERACTIONS

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The mass systematics of hypothetical neutral objects in heavy-ion collisions and in $e^+ +$ heavy-ion interaction are studied.

I have a lot of nice memories with Gaja. Writing this paper, his figure is floating on my eyes and I hear his voice with his habitual expression, »you see«. I loved him and respected him because of his personality: sincerity, simplicity and cordiality. He was gone and his passing left me a deep sorrow. However, his presence will rest forever in my heart. His name will be left alive in the international nuclear physics community by virtue of the famous Alaga's rule and his other scientific achievements.

After the discovery of narrow e^+ peaks in heavy-ion collisions at Gesellschaft für Schwerionenforschung, Darmstadt m. b. h. (GSI)¹⁾ a number of related experiments have been performed at various institutions. Experiments by EPOS and ORANGE collaborations at GSI showed existence of several peaks²⁻⁵⁾. The EPOS group observed coincidence sum peaks of correlated e^+e^- pairs⁶⁾. The latest experimental results from the ORANGE group with a new coincidence apparatus provided a significant evidence for five sum peaks at 510 ± 16 , 640 ± 10 , 716 ± 10 , 809 ± 8 and 895 ± 10 keV⁷⁾. The scenario compatible with the results so far obtained is creation of unknown neutral object and subsequent decay by emitting correlated electron positron pair with the same energy.

Oak Ridge group reported an observation of electron and positron peaks at 335 and 345 keV, respectively in e^+e^- coincidence spectra in $e^+ +$ Th interactions⁸⁾. These peaks were discussed in connection with those at GSI, because the energy coincides fairly well with one of the peaks observed at GSI. However,

it turned out later that this structure was the Compton edge of photons scattering off electrons in the positron detector⁹⁾. We designed experiments of searching for a monochromatic electron peak at around 330 keV by using the INS large double-focusing electron spectrometer. In fact we observed a sharp line at 330.8 ± 1.0 keV with the experimental FWHM of 3.7 ± 0.5 keV¹⁰⁾ in case of Th and U targets while we failed to find a peak structure in the case of Ta target.

The recent experiments with a better instrumental resolution confirmed this line and furthermore gave an evidence for a 410 ± 1 keV line with the experimental FWHM of 2.4 ± 1.0 keV¹¹⁾. As the energies of the 331 and 410 keV lines are close to those of the 640 and 809 keV sum peak of GSI, the phenomena observed in e^+ + heavy-ion interactions could be concluded to have a common origin with those observed in heavy-ion collisions. One of the explanations is that the collision of heavy-ions simply provides the positrons (the broad background), which in turn scatter off individual nuclei. The fact that the experimental line width is limited by the experimental conditions implies that the decay occurs essentially at rest so that the mass of the hypothetical object obtained by the energy of the electron peak must be the invariant mass. The life time was deduced by the experimental FWHM and found to be longer than 2.7×10^{-19} s.

The energies of coincidence sum and singles electron peaks taken from the results of the ORANGE group at GSI and of the INS group were summarized in the second and third columns of Table 1 and the invariant masses deduced by the formulae: $M = E_{sum} + 2mc^2$ and $M = 2E_e + 2mc^2$, where the first and second formulae apply to the sum and singles peaks, respectively, were put in the fourth column. We postulate the peaks to be the excited states of an hypothetical object which would be an extended condensate, having an internal structure. This conjecture stimulated us to search for a regularity of the mass spectrum like in the case of baryon spectrum, where the mass formula $J \propto M^2$ is well known and the mass diagram is called Chew-Frautschi diagram.

Close inspection of the mass spectrum disclosed a hidden mass formula:

$$L \propto M^3,$$

where L is the angular momentum. In the fifth column are listed M_{exp}^3 (MeV³) and the relationship between L and M^3 is presented in Fig. 1. It shows a clear linearity. Supposing a linear relation $L = a + bM^3$, we determined the parameters a and b by least squares fit. The results are shown in Table 2, where the fit I is the result using the GSI data while the fit II comes from the calculation based on the masses for $L = 3$ and 4 obtained at INS and the masses for $L = 2$ and 5 obtained at GSI. The quantity γ is the linear-correlation coefficient which is a measure of the degree of the linear-correlation. The 6th and 8th columns show the calculated M^3 (MeV³) values based on the fit I and the fit II, respectively. The masses (keV) deduced from the calculated M^3 are presented in the 7th and 9th columns. The deviations $M_{exp} - M_{cal}$ are presented in the 10th and 11th columns separately according to the results from the fit I and the fit II, respectively. The experimental masses deviate from the calculated ones with a regular zigzag trend. This regularity may provide an evidence for the plausibility of the rule.

TABLE 1.

L	E_{exp} (GSI) (keV)	E_{exp} (INS) (keV)	M_{exp} (keV)	M_{exp}^2 (MeV ²)	M_{cut}^2 (I) (MeV ²)	M_{cut} (I) (keV)	M_{cut}^2 (II) (MeV ²)	M_{cut} (II) (keV)	$M_{exp} - M_{cut}$ (I) (keV)	$M_{exp} - M_{cut}$ (II) (keV)
0					1.396	1118	1.508	1147	—	—
1					2.539	1364	2.639	1381	—	—
2	540 ± 16		1562 (16)	3.81 ± 0.11	3.681	1544	3.770	1556	+18	+6
3	640 ± 10		1662 (10)	4.59 ± 0.08	4.824	1690	4.902	1698	-28	-15
4	809 ± 8	330.8 ± 1.0	1683.6 (20)	4.77 ± 0.02	5.966	1814	6.033	1819	+17	+23
5	895 ± 10	410 ± 1	1831 (8)	6.14 ± 0.08	7.109	1923	7.164	1926	-6	-9
6			1842 (2)	6.25 ± 0.02	8.251	2021	8.296	2023	—	—

Mass systematics.

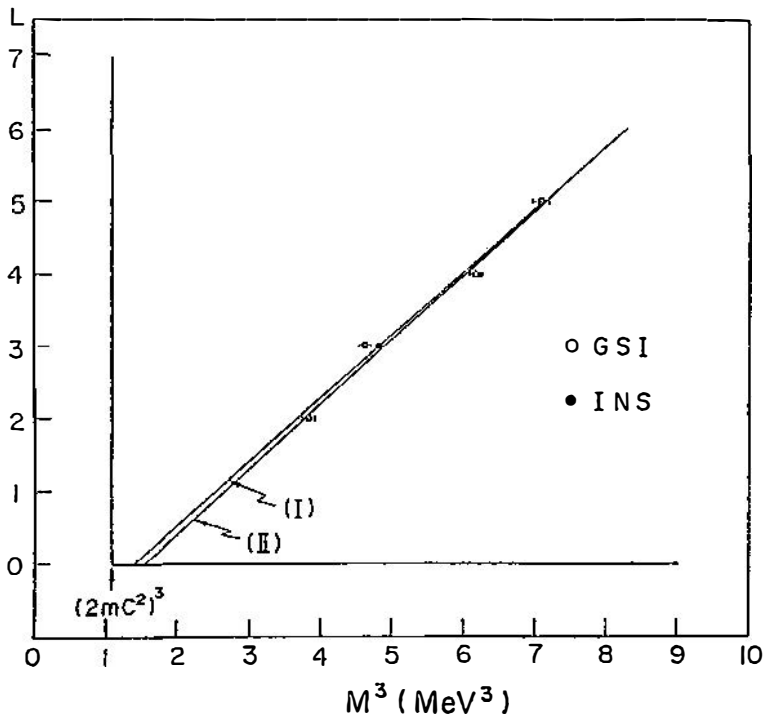


Fig. 1. Mass diagram.

TABLE 2.

$L = a + bM^3$			
	a	b	γ
I GSI	-1.222	0.875	0.992
II GSI + INS	-1.332	0.884	0.994

Parameters of mass trajectory.

The assignment of L to each excited state is based on the assumption that the ground state ($L = 0$) must be near $2mc^2$ (1022 keV). In fact the calculated ground state energies are 1118 keV and 1147 keV for the case of the fit I and the fit II, respectively. The values near $2mc^2$ may justify the L assignment to the states. So far, we discussed the mass spectrum as a series of excited states of a single kind of an object. However, it is quite possible that the object is an extended positron electron composite. If it was the case, the singlet 1S_0 and triplet 3S_1 states should be considered and can be expected to have series of excited states constructed on these different ground states which may correspond to even L and odd L series. Then, the zigzag trend above mentioned can be understandable as a natural consequence.

Now, the reason why the states of $L = 0$ and 1 have not been observed becomes evident because the energies of decaying electrons or positrons expected from the mass rule are $48 \sim 63$ and $171 \sim 180$ keV, being too low to be detected by the experimental techniques so far used. To find these states, therefore, we must perform gamma-gamma coincidence experiments. The experiments for this purpose were carried out at Berkeley^{1,2)} and a sum peak was observed at 1062 keV which is close to the ground state energy calculated by the present rule. However, the line has been later identified as due to nuclear deexcitation^{1,3)}. It should be mentioned that we used four peak energies reported in Ref. 7 to construct the present mass rule. The energy of 716 ± 10 keV can not be included in the mass rule. If that peak really existed, it could not be excluded to have another kind of object with a different configuration.

Several papers^{1,4-18)} discussed the phenomena in terms of a new strong-coupling phase of QED of which the features are similar to those of QCD, where the potential $V(r) \propto r$ governs. Using $V(r) \propto r$, people succeeded in reproducing the experimental mass spectrum with an adjustable string-tension parameter^{1,4,17)}. In this case the mean radius was obtained of order of $10^2 \sim 10^3$ fm. As the mass rule, $J \propto M^2$ of the baryon families results from the potential of $V(r) \propto r$, we may postulate the potential for this unknown neutral object to be $V(r) \propto r^2$ because of $L \propto M^3$ in the present case. The scale much larger than the nuclear scale might be accounted for by this rather shallow potential. The calculation with $V(r) \propto r^2$ has not been carried up to the present. If the radius of the object were really that large, many bounds^{1,9,20)} imposed by the beam-dump experiments and others would become invalid or easily explained^{2,1)}.

In conclusion, we found the mass trajectory which results from the potential $V(r) \propto r^2$. To reinforce the validity of the mass rule, we must investigate experimentally the existence of the 350 keV ($L = 1$) and 1000 keV ($L = 6$) sum peaks predicted by the rule. On the other hand, it is urgent to construct theoretically a model consistent with the characteristic features discussed in the present paper. Further investigations are waited.

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References

- 1) E. Berderman et al., GSI Scientific Report **1980** (1981) p. 128;
H. Bokemeyer et al., GSI Scientific Report **1980** (1981) p. 127;
- 2) J. Schweppe et al., Phys. Rev. Lett. **51** (1983) 2261;
- 3) M. Clemente et al., Phys. Lett. **137B** (1984) 41;
- 4) H. Tsertos et al., Phys. Lett. **162B** (1985) 273;
- 5) T. Cowan et al., Phys. Rev. Lett. **54** (1985) 1761;
- 6) T. Cowan et al., Phys. Rev. Lett. **56** (1986) 444;
- 7) W. Koenig et al., Phys. Lett. **218B** (1989) 12;

- 8) K. A. Erb et al., Phys. Lett. **181B** (1986) 52;
- 9) A. Schäfer, J. Phys. G: Nucl. Part. Phys. **15** (1989) 373; The interpretation of the results in Ref. 8 was presented in this paper;
- 10) M. Sakai et al., Phys. Rev. **C38** (1988) 1971;
- 11) M. Sakai et al., to be published;
- 12) K. Danzmann et al., Phys. Rev. Lett. **59** (1987) 1885;
- 13) K. Danzmann et al., Phys. Rev. Lett. **62** (1989);
- 14) L. S. Celenza et al., Phys. Rev. Lett. **57** (1986) 55;
- 15) D. G. Caldi and Alan Chodos, Phys. Rev. **D36** (1987) 2876;
- 16) Y. Jack Ng and Y. Kikuchi, Phys. Rev. **D36** (1987) 2880;
- 17) Paolo Cea, Phys. Rev. **D39** (1989) 340;
- 18) M. Inoue et al., HUPD-8809, IP-APSI-16-88, Hiroshima University;
- 19) A. Konaka et al., Phys. Rev. Lett. **57** (1986) 659;
- 20) E. M. Riordan et al., Phys. Rev. Lett. **59** (1987) 755;
- 21) The bounds were discussed in detail in Ref. 9.

SISTEMATIKA MASA HIPOTETSKIH NEUTRALNIH OBJEKATA U TEŠKOIONSКИM SUDARIMA I U INTERAKCIJAMA $e^+ +$ TEŠKI ION

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Proučavana je sistematika masa hipotetskih neutralnih objekata u teškoionskim sudarima i u interakcijama tipa $e^+ +$ teški ion.