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ENERGY-MASS DISTRIBUTIONS IN INDUCED FISSION

F. Plasil, D. S. Burnett, and S. G. Thompson

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ABSTRACT

Measurements of the energy and mass distributions of fission fragments produced by the bombardment of a number of relatively light elements with heavy ions and alpha particles are presented. The results have been interpreted in terms of an approximate version of the liquid drop model which applies to this region of elements. The energies of both fission fragments from every event considered have been measured with solid state detectors, recorded in a correlated manner, and transformed to give mass-total kinetic energy density-of-events distributions. In some cases, data at several bombarding energies have been obtained. Comparisons with liquid drop calculations were made and good agreement was found in the gross features of the distributions, and in the nuclear temperature dependence of the widths.

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INTRODUCTION

Recently Nix and Swiatecki have been able to expand the liquid drop theory of nuclear fission to consider dynamics as well as statics of charged liquid drops.[1] By solving the equations of motion for a fissioning system, and combining the results with the assumption of statistical equilibrium at the saddle, they have been able to calculate a bivariate distribution for the fission fragments. The two variables of this distribution are the mass of one fragment and the total kinetic energy released in the fission event. The measurement of such distributions and their comparison with theory is the subject of this paper. Two important features of these distributions are: (a) they are derived from basic principles, and using standard nuclear constants, thus leaving no room for adjustable parameters; (b) the width of the distributions is a function of the nuclear temperature at the saddle. In the theoretical calculations the nucleus was treated in the "spheroid approximation", which pictures the fissioning system as two spheroids that may be overlapped, tangent to each other, or separated. This approximation results in restricting the validity of this model to relatively light elements (lighter that about radium). For this reason we concern ourselves with bombardments of elements ranging from erbium to bismuth.

EXPERIMENTAL

The energies of both fission fragments from every event considered were measured with solid state detectors and recorded in a correlated manner. The energy data have been transformed to give mass-total kinetic energy density-of-events distributions. Spontaneous fission of Cf^{252} has been used to calibrate the detectors and the electronic system. Details of experimental procedure and of data processing are given in references 2 and 3. Table I gives the reactions studies. Heavy ions were used in some cases to enhance fissionability. Due to resulting high excitations, the problem of determining the nuclear temperature θ at fission was complicated by the possibility of fission following neutron evaporation. The method used in obtaining θ values of Table I is duscussed in reference 3.

RESULTS AND DISCUSSION

The measured distributions may be directly compared with the theoretical distributions after correcting for the effects of neutron evaporation. The method of correction is given in reference 2. Comparisons of the values of the average total kinetic energy released $\langle E_T \rangle$, and of the variances of overall mass, $\mu_2(A_1)$, and total kinetic energy, $\mu_2(E_T)$, distributions are given in Table I. (Variance is a measure of width of a distribution.) The agreement is seen to be remarkably good. The estimated errors in experimental quantities are up to ±0.5 in θ, ±6 MeV in $\langle E_T \rangle$, ±10 $(\text{MeV})^2$ in $\mu_2(E_T)$ and ±15 $(\text{amu})^2$ in $\mu_2(A_1)$.

As can be noted from the table the theoretical and experimental results are found to agree not only in terms of absolute magnitude, but also in their temperature dependence. More detailed comparisons and references are to be found in references 1, 2, and 3 of this paper. Certain disagreements do exist in the fine features of the distributions, especially in the heavy ion bombardments.[3] They may be in part due to angular momentum effects. It is hoped that further experimental investigation (with greater numbers of events and a larger range in θ values) coupled with a refinement of the theory (a hyperbolic neck inserted between the two spheroids has yielded excellent results in preliminary static calculations) will make it possible to explain the discrepancies and define the limits of the applicability of the liquid drop model to the fission process, at least for relatively light elements.

[1] J. R. Nix, University of California Radiation Laboratory Report UCRL-11338, March 1964.

[2] D. S. Burnett, University of California Radiation Laboratory Report UCRL-11006, October, 1963.

[3] F. Plasil, University of California Radiation Laboratory Report UCRL-11193, December, 1963.

TABLE I.

System	$Er^{170} + O^{16}$				$Yb^{174} + C^{12}$		$W^{182} + O^{16}$					$Au^{197}+He^4$	$Bi^{209}+He^4$
Bombarding Energy	165	151	136	120	125	109	165	144	127	115	102	70	65
Nuclear Temperature	2.06	1.91	1.73	1.49	1.70	1.53	2.07	1.87	1.70	1.55	1.37		
$\langle E_T \rangle$ Experiment	127	128	124	124	129	127	147	146	146	144	144	142	150
$\langle E_T \rangle$ Theory	131	131	131	131	131	131	143	143	143	143	143	142	150
$\mu_2(E_T)$ Experiment	106	96	97	89	104	94	135	116	108	96	85	69	74
$\mu_2(E_T)$ Theory	116	108	97	82	95	85	123	111	101	92	81	74	70
$\mu_2(A_1)$ Experiment	235	215	211	199	211	185	243	229	203	185	156	137	131
$\mu_2(A_1)$ Theory	249	235	213	186	211	190	205	186	170	155	137	147	126

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