SOME ASPECTS OF NUCLEUS-NUCLEUS COLLISIONS AT MEDIUM ENERGIES

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ABSTRACT

Selected aspects of nuclear reactions between heavy ions involving two- and three-body exit channels of comparable masses are reviewed. Correlation between energy dissipation and nucleon exchange in the case of deep inelastic collisions (DIC) involving two-body decay is discussed. Recent experimental results on fusion-fission and the three-body decay involving sequential fission of heavy and superheavy nuclei populated in DIC are presented. Finally, the possibility of a fast sequential splitting of an intermediate nucleus (fast fission) induced by the DIC process is discussed in the light of some recent results.

INTRODUCTION

With the availability of accelerators capable of accelerating a wide species of heavy ions of masses extending over the whole periodic table and a broad range of energies, it is now possible to study phenomena associated with the nucleus-nucleus collisions under different conditions. In the earlier studies of nuclear reactions with light projectiles like p, d and ^4He, the dominant reaction mechanism could be categorized either as a "compound nucleus" reaction or a "direct reaction". It is now seen that reactions induced by heavy ions exhibit also such characteristics which bridge the above two extreme situations. This bridging process has been given various names in the literature[1]: "Strongly damped collisions", "relaxation phenomena" or "the deep-inelastic collisions (DIC)". The DIC process involves conversion of a large fraction of the kinetic energy of the colliding nuclei into excitation energy with the simultaneous transfer of a significant orbital angular momentum into the fragment spins and exchange of a number of nucleons, although these collisions involve a very short contact time of about 10^{-21} sec. The ultimate result of the microscopic processes taking place during a nuclear encounter depends on the impact parameter or the l-wave involved and the initial collision energy and is governed by rate of energy and angular momentum dissipation conveniently parametrized by a radial and a tangential friction coefficient, rate of nucleon exchange parametrized by diffusion and drift coefficients, and finally Coulomb and nucleus-nucleus potentials between the colliding nuclei. These processes can be understood to a good degree on the basis of classical trajectory calculations[2], which show that trajectories for l-waves upto a critical value, l_{cr} can get trapped in the pocket exhibited by the total nucleus-nucleus potential, resulting in the fusion of the two nuclei. Only if such a "complete fusion" intermediate system decays after achieving equilibration in all the degrees of freedom, the intermediate state can be termed as a compound nucleus state. On the other hand, for cases where no trapping is involved, the result is the DIC process in which the two nuclei separate out promptly, after exchanging nucleons and dissipating energy which are expected to be quantitatively correlated with the contact time.

Thus, as shown in figure 1, the compound nucleus formation, the DIC process, and direct reactions involving a few nucleon transfer result from different regions of the l-waves. Although, both the DIC process and fission following fusion (or compound nucleus formation) result in a binary fragment split in the exit channel, these two processes are distinguishable on the

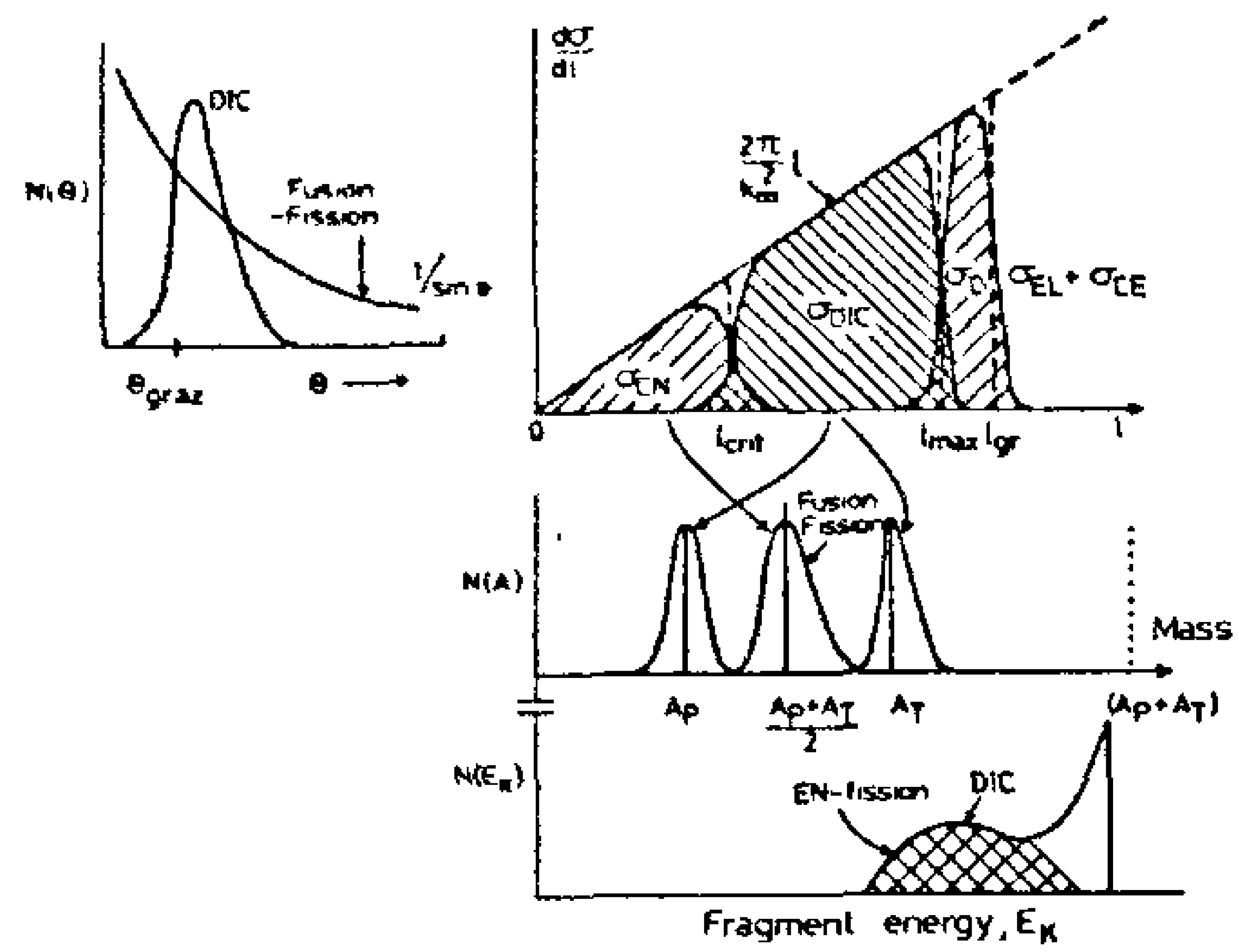

Figure 1. Decomposition of the total reaction cross-section into the cross-section σ_D for direct reactions, σ_{DIC} for deep inelastic collisions, and σ_{CF} for complete fusion. The expected shapes of fragment mass, kinetic energy and angular distributions for the deep inelastic collisions, and fusion-fission are also schematically shown.

basis of different mass, angle and kinetic energy distribution of the fission fragments for the two processes, as schematically shown in figure 1. In most cases where fission following complete fusion can be clearly distinguished from the DIC events, the study of fusion-fission can provide characteristics of fission of nuclei rotating with unusually high spins[3]. Sequential fission of the intermediate nuclei formed in DIC leading to three-body exit channel provides a way to study angular momentum transfer in DIC, and to study fission of superheavy nuclei[4] which may be temporarily populated in the DIC process. Study of fission following DIC is also an ideal process to search for fast fission phenomenon, as the existence of fast fission can be sensed by the presence of the proximity effects of the non-fissioning third fragment.

CORRELATION BETWEEN ENERGY DISSIPATION AND CHARGE OR MASS DISTRIBUTIONS IN DIC

Experimentally well established correlation[5-7] between the dissipated energy and the variance of the fragment charge or mass distribution in the DIC process has lent crucial support to the assumption that the nucleon exchange mechanism is an important source of energy loss in these reactions[1,7]. In these studies, the observed correlations between the fragment charge or mass distributions and the energy loss have been compared with the predictions of the one-body transport model[7] to infer if the observed energy loss can be accounted primarily by the nucleon exchange process. It is now recognised that the Fermion nature of the exchanged particles and the associated Pauli blocking effect should be included in a theoretical description of the correlation between energy dissipation and mass dispersion. While comparing the data on the measured variance, σ_Z^2, of the fragment charge distributions, versus the energy loss, E_{Loss}, with the model predictions[8], due consideration is made for the degree of neutron-proton correlations in the exchange process which determines[9] the value of the parameter x in the transformation

$$\sigma_A^2 = \left(\frac{A}{Z}\right)^x \sigma_Z^2$$

where σ_A^2 is the variance of the fragment mass distributions. For uncorrelated neutron-proton motion, $x = 1$, while for a fully correlated motion $x = 2$. Thus in these studies, a quantitative comparison of the data on σ_Z^2 (E_{loss}) with the model involved the parameter x, which introduced some ambiguity regarding the extent to which nucleon exchange process could account for the energy loss. We have recently pointed out that in order to deduce the contribution of the nucleon exchange process to the energy loss, it is important that the effect of correlations is considered not only in deducing the total number of exchanges N from σ_Z^2, but also on the transport model results in a mutually consistent way. In this earlier work[10], the transport model description was modified to include in the model, the effect of iso-spin correlations in the particle exchanges and it was found that the comparison of σ_Z^2 (E_{Loss}), data with this modified model was nearly independent of the knowledge of the degree of iso-spin correlations. This phenomenological approach thus provided a rather unambiguous way to determine the contribution of the particle exchange mechanism to the energy loss.

In a phenomenological approximation based on the transport model for tangential relative velocity, the mass dispersion and the kinetic energy E, are related as

$$E^{\frac{1}{2}} \simeq E_0^{\frac{1}{2}} - \frac{1}{2}\left(\frac{m}{\mu}E_F\right)^{\frac{1}{2}} \sigma_A^2 \qquad (1)$$

where E_0 is the initial collision energy; m is the nucleon mass, μ is the reduced mass of the system, E_F is the Fermi energy and E is the kinetic energy in relative motion during collisions above the Coulomb barrier V_c given by $E = E_{cm} - V_c(R_{int}) - E_{Loss}$. If one considers the effects of neutron-proton correlations in deducing σ_A^2 from σ_z^2, but not on the transport model results, one obtains following relationship:

$$E^{\frac{1}{2}} \simeq E_0^{\frac{1}{2}} - \frac{1}{2}\left(\frac{m}{\mu}E_F\right)^{\frac{1}{2}} \left(\frac{A}{z}\right)^{x} \sigma_z^2 \quad .(2)$$

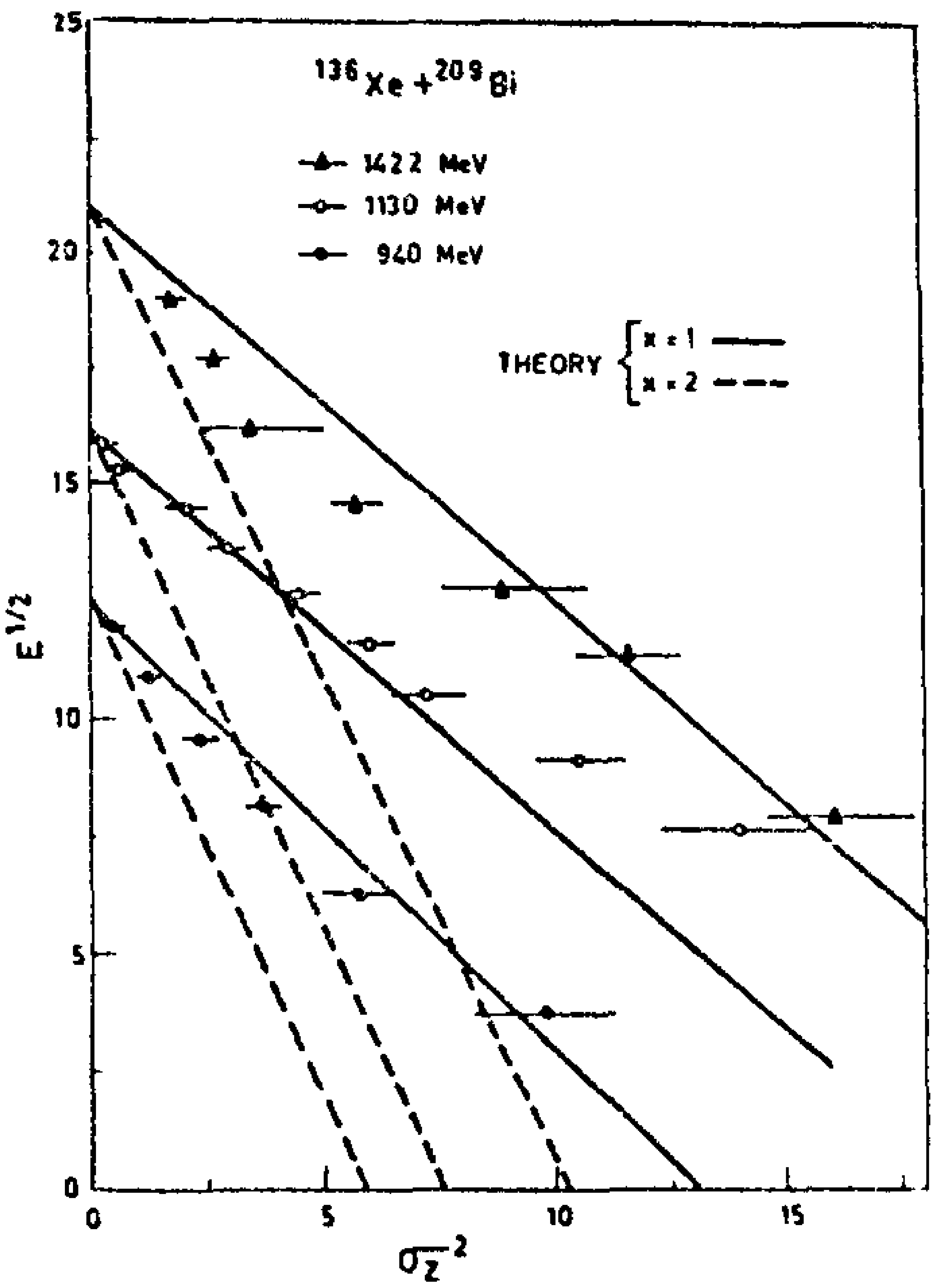

Figure 2. A plot of experimental data on E versus σ^2 for three different bombarding energies of ^{136}Xe on ^{209}Bi. The solid and dashed curves are the predictions of Eq. (2) for X = 1 and 2.

Thus, if one plots $E^{1/2}$ versus σ_z^2 one gets a straight line, the slope being given on the basis of Eq. (2). Figure 2 shows the results of analysis of the data[5,7,12] for the system $^{136}Xe + ^{209}Bi$ at the three bombarding energies of 940 Mev, 1130 Mev and 1422 Mev. It is seen from figure 2 that the data follow the slope reasonably well for $x = 1$. The value of E_F, the only parameter entering into the formulation, was taken to be 37 Mev. A serious disagreement with the data results if x is assumed to be 2. However, studies[13,14] in which both charge and mass distributions have been measured, show that at the energy losses involved, the neutron-proton motion is expected to be correlated. This descrepancy is resolved by including the effect of correlations also in the transport model in a manner which is consistent with the assumption of x in the transformation of σ_Z^2 to σ_A^2. It is then seen that nearly independent of the assumption of neutron-proton correlation, the following relationship holds:

$$E^{\frac{1}{2}} \simeq E_0^{\frac{1}{2}} - \frac{1}{2}\left(\frac{m}{\mu}E_F\right)^{\frac{1}{2}} \left(\frac{A}{z}\right) \sigma_z^2 \text{ . (3)}$$

However, the relationship between $E^{1/2}$ and σ_A^2 depends on the neutron-proton correlations and is given approximately by

$$E^{\frac{1}{2}} \simeq E_0^{\frac{1}{2}} - \frac{1}{2}\left(\frac{m}{\mu}E_F\right)^{\frac{1}{2}} \left(\frac{z}{A}\right)^{x-1} \sigma_A^2 \text{ . (4)}$$

Thus, the good fit to the data obtained in figure 1 with $x = 1$ imply that the energy loss at all the bombarding energies can be accounted reasonably well primarily by the nucleon exchange mechanism without much ambiguity arising from the absence of the knowledge of neutron-proton correlations. On the other hand, comparison of Eq. 1 and Eq. 4 shows that the basic theoretical relationships between $E^{1/2}$ versus σ_A^2 are different for uncorrelated and correlated motion. Figure 3 shows comparison of 'experimental' σ_A^2 versus $E^{1/2}$ for the system ^{86}Kr ^{166}Er with the model wherein good fit to the data is obtained only for fully correlated iso-spin exchanges ($x = 2$) for which there is also evidence from direct measurements of σ_z^2 and σ_A^2 for this reaction. Thus, in conclusion, experimental data on $\sigma_Z{}^2$ (E_{loss}) and $\sigma_A{}^2$ (E_{loss}) for most of the systems studied can be satisfactorily explained by the nucleon exchange mechanism based on the Fermi gas model description of nuclei.

HEAVY-ION FUSION ACCOMPANIED BY FISSION

While, the formation, of a "complete-fusion" system during nucleus-nucleus collision is characterized by the parameter l_{cr}, the intermediate rotating nucleus is predicted by the rotating liquid drop model[3] (RLDM) to have a non-zero fission barrier only for $l < l_f$. Thus the formation of a "complete fusion" system is accompanied by any of the following two situations:
(i) $l_f > l_{cr}$ (ii) $l_f < l_{cr}$.

Case I: $l_f > l_{cr}$

In this regime, characterized by the presence of fission barrier for all the partial waves leading to fusion, the fusion complex is expected to decay *via* truly equilibrated compound nucleus system. In this regime, analysis of the fragment angular distributions can provide information on the effective moment of inertia J_{eff} (hence, nuclear shape) at the rotating saddle point, on the basis of the statistical theory[15]. Such analysis[16] earlier carried out for alpha induced fusion reactions led to values of J_{eff} in agreement with the saddle shapes predicted by the liquid drop model. If one uses the predictions of RLDM for estimating J_{eff}, it is then possible to indirectly infer the values of l_{cr}, and hence the complete fusion cross-section through the relation

$$\sigma_{FV} = \pi \lambda\!\!\!^{-2} (l_{cr} + 1)^2,$$

where $\lambda\!\!\!^{-}$ is the De Broglie wave length corresponding to the collision energy. This provides a different approach to the determination of heavy-ion fusion cross-section by measuring fragment angular distributions alone, without going to more difficult absolute measurements of the fission and evaporation residue cross-sections. The published data[17] on fission fragment angular distributions in fission of ^{197}Au and ^{209}Bi by B, C, N and O ions in the bombarding energy range of 60 Mev to 120 Mev were analysed[18] by us taking into consideration the problem of multiple chance fission and the fusion cross-sections were indirectly deduced. The value of l_{cr} versus energy were also determined by trajectory calculations on the basis of the proximity potential[19], and it was seen that satisfactory fits to the data can be achieved only with the inclusion of one-body friction[20].

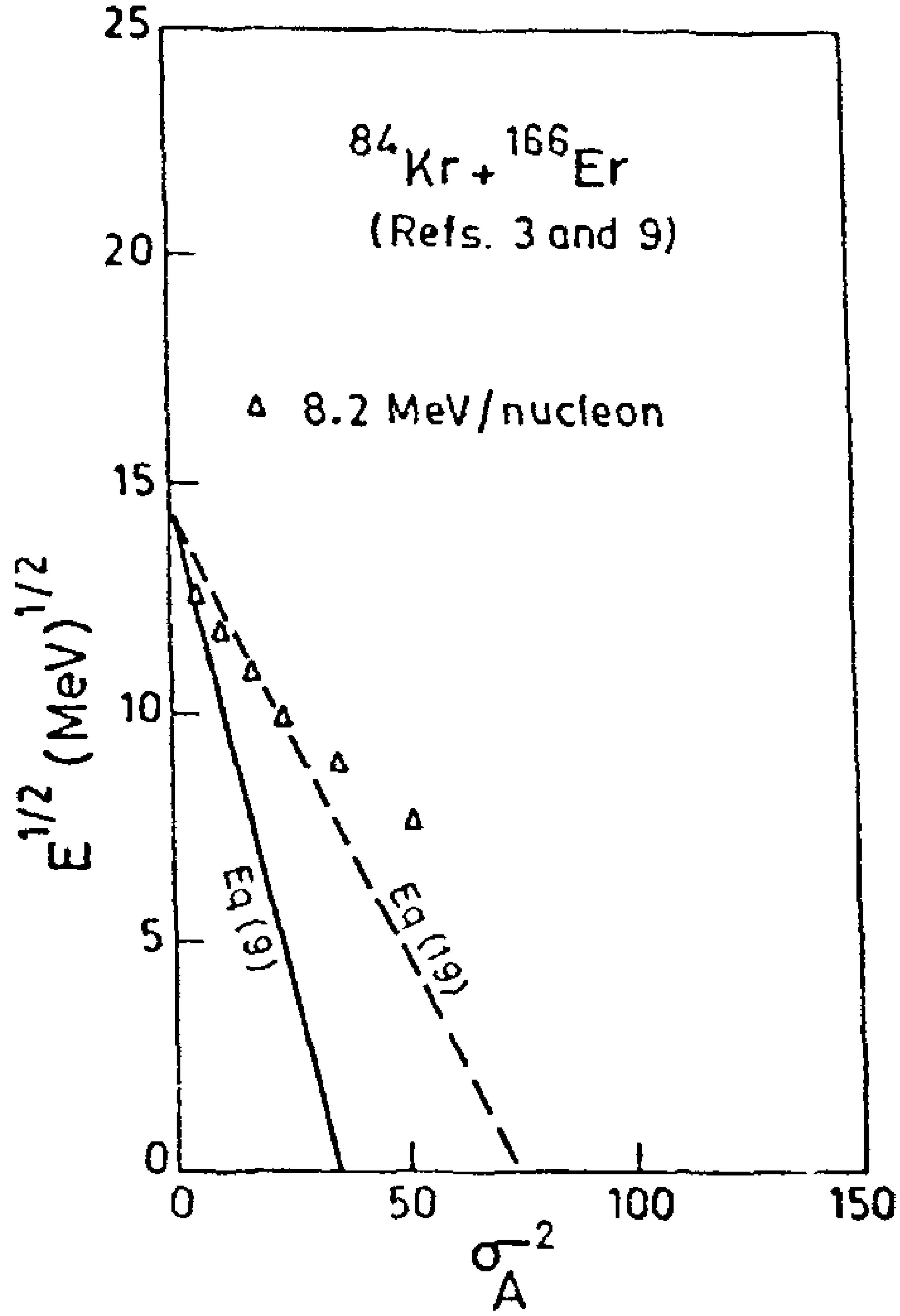

Figure 3. Plot of E_F as a function of the observed $\sigma_A{}^2$ for the system ^{86}Kr + ^{166}Er. The full lines refers to the theoretical prediction for the case of uncorrelated neutron-proton transfer, and the dashed line results if the theory is modified to include correlated motion.

The above method to deduce l_{cr} is suitable if one is dealing with a composite system characterized by the fissility paramater X, and rotation parameter Y for which saddle shapes could be extrapolated without much uncertainty, from those measured by alpha induced fission. In several other cases exploring unknown regions, it would be of greater interest to analyse the data to determine rotating saddle point shapes, by using either calculated or measured (through σ_{fusion}) values of l_{cr}. Recent theoretical calculations[21] suggest that in some cases the height and shape of the fission barrier of a rotating nucleus can get considerably modified due to the inclusion of the nuclear shell effects. Further studies on the fragment angular distributions in the heavy-ion induced reactions can provide a test to these models provided the excitation energies are chosen such that the shell effects are not wiped out[22].

Case 2: $l_f \quad l_{cr}$

In a number of heavy ion induced reactions induced by heavier projectiles such as ^{24}Mg, ^{40}Ar, ^{35}Cl, ^{86}Kr at E_{CM} of a few hundred MeV forming fusion systems with more than, say 150 particles, it has been observed that the cross-section for symmetric splitting into the two fragments is greater than that expected for l waves upto l_f. Thus it appears that the band of l-waves ($l_f < l < l_{cr}$) for which $B_f = 0$, also leads to reactions with symmetric splitting characterizing complete energy. mass and charge relaxation clearly separated from the DIC mass distributions. Thus, in these cases, the experimental situation is that the system has lived a rather long life to achieve mass equilibration, although the theoretical expectation for a nucleus with $B_f = 0$, is its fast decay *via* fission mode. A distinguishing experimental feature of the fission of nuclei with $B_f \doteq 0$ is the observation of an increase in the width of fragment mass distributions[23], as compared to that for the case of finite B_f. This feature is seen whether $B_f \sim 0$ is achieved by moving over to the superheavy region on a single system or by varying[24] the bombarding energy to populate l-waves above l_f.

Mechanism of the fission like process for $B_f \sim 0$ can also be probed by studying fragment angular distributions which, as mentioned earlier can be analysed to determine the saddle point shapes. Angular distribution measurements for very heavy nuclei $Z \gtrsim 109$ and large angular momentum were first measured[23] in the study of sequential fission of the heavy products produced in DIC, where the deduced values of K_0^2 were seen to be in serious disagreement with the values expected for a spherical saddle shape. Similar results have been recently reported[25] for the case of fusion-fission by bombarding ^{32}S on ^{232}Th, ^{238}U and ^{248}Cm where again one is dealing with nuclei having $B_f \simeq 0$. Explanations for this which have been forwarded in the past are based on the assumption that the system does not go through its saddle shape before fissioning. However, the observed angular distributions can also be understood if we take into account the fact that the expected saddle shape for a rotating nucleus is oblate and not spherical.

FISSION FOLLOWING DIC PROCESS

Considerable kinetic energy damping and angular momentum transfer during the DIC process may result in one or both of the fragments having sufficient excitation and spin to undergo subsequent fission. The great interest in the study of fission, following DIC stems from the fact that from such studies one can (i) investigate angular momentum transfer in DIC, (ii) study fission of superheavy nuclei transiently populated through the reaction mechanism of DIC, (iii) search for "fast" fission through the strong Coulomb and nuclear forces exerted by the heavy reaction partner.

Fission of equilibrated nucleus following DIC

A study of sequential fission following DIC has been undertaken by several groups. Using the heavy ion accelerator UNILAC at GSI Darmstadt, Specht and Co-workers[23,26] have been investigating fission following DIC with experimental techniques in which phase space of two and three (also sometimes four) body products are completely determined. The results of such measurements have been reported[23] for 7.5 MeV/u beams of ^{208}Pb and ^{238}U on various targets. In all of these studies, the observed three body events were consistent with the sequential fission following the DIC process, as the measured relative velocity of the two fission fragments was found to be independent of the variable parameters of DIC, and the centre of mass fragment kinetic energies deduced were in agreement with the fission systematics[29].

The results on the fragment kinetic energies, out of plane fragment angular distributions and fragment mass distributions in the sequential fission of projectile like nuclei in the reaction of

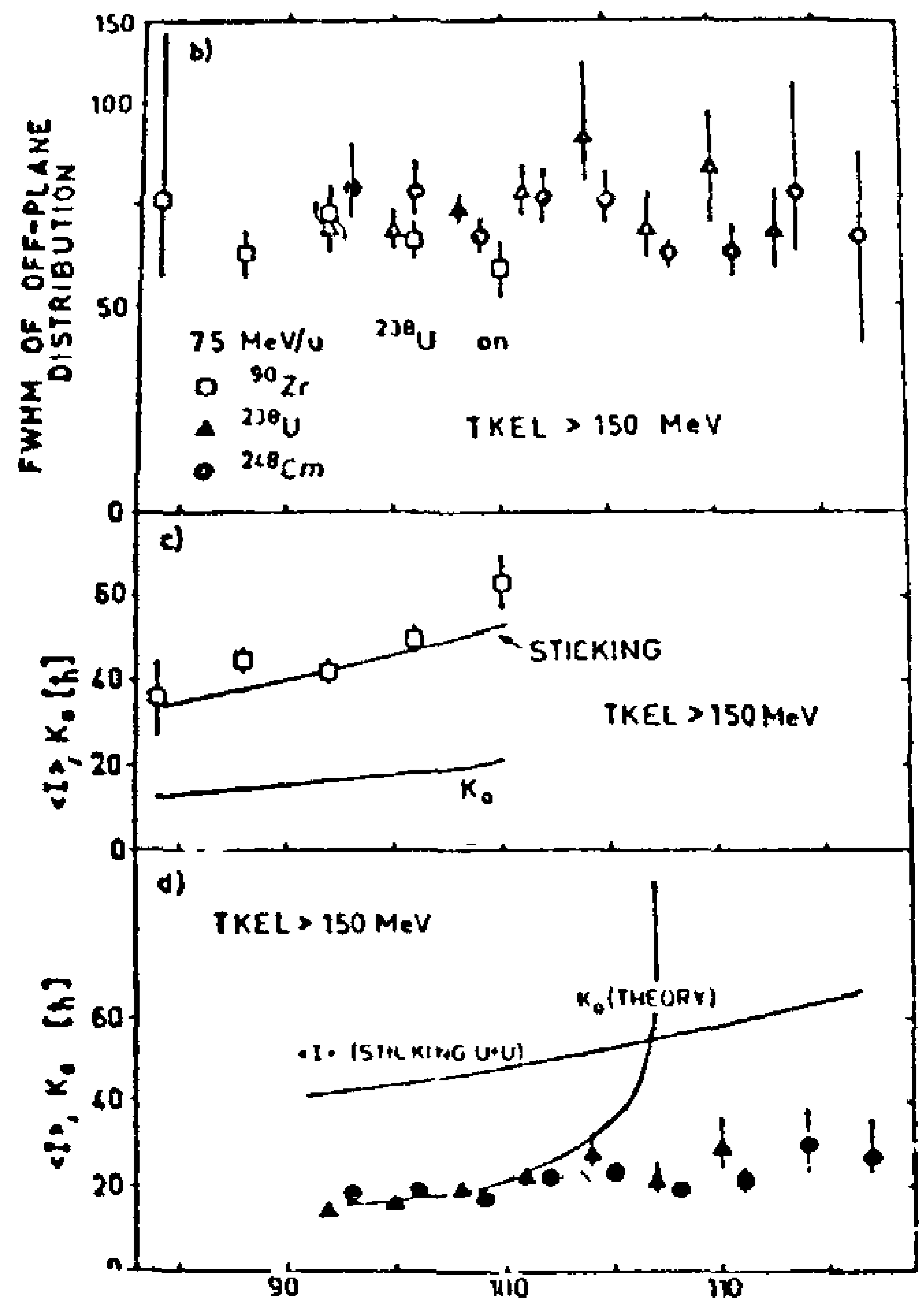

Figure 4. (a) Average fragment total kinetic energy compared with viola systematics; (b) FWHM of the out-of-plane fission fragment angular distributions; (c) average oriented spins I compared to sticking-model dependence (the K_0 values used are also shown); (d) extrapolated oriented spins and deduced effective values for K_0, compared to the LDM predictions; (e) width of the fragment mass distributions, defined as rms of A_1/A_1+A_2. All quantities are plotted *vs* the atomic number of the fissioning nucleus (taken from ref. 23).

7.5 MeV/nucleon ^{238}U, on several targets from ^{58}Ni to ^{248}Cm are shown in figure 4, as obtained in a series of measurements by Glassel *et al*[23]. It is interesting to note that the DIC process in the reactions of ^{238}U on ^{238}U and ^{248}Cm, can populate intermediate nuclei all the way upto $Z \sim 116$ of the superheavy region. Assuming that the equilibrated A/Z of these nuclei is same as that of the composite system, one would expect significant population of intermediate nuclei around the predicted[4] doubly magic($Z = 114$ and $N = 184$) superheavy nuclei in these reactions. Although these do not survive fission due to the presence of considerable angular momentum which reduces the barrier and excitation energy which wipes out the shell effect[22], these reactions do provide a way to study fission characteristics of the super-heavy nuclei. It is seen that in the fission of these hot nuclei, the Viola systematics[29] of the fragment kinetic energies hold all the way upto $Z = 116$. However, as was mentioned earlier, the fragment mass distributions become increasingly broader as one moves into the superheavy region. For nuclei with $Z \lesssim 100$, the analysis of the out-of-plane fragment angular distribution gives the transferred average oriented spins of the fragments which are in agreement with the expectations of the 'sticking' model dependence[1]. In this analysis the values of K_0 were those estimated with the values of J_{eff} given by the RLDM. The situation for $Z \gtrsim 110$ is quite different. In this region characterized by $B_f \simeq 0$, if the saddle shape is regarded as spherical ($J^{-1}_{eff} = 0$) the angular distributions should be isotropic which is contrary to the observation. The angular distributions for $Z > 108$ are found to be as anisotropic as those for $Z < 108$. Two alternatives have been put forward earlier[23] to explain the above behaviour: (i) an equilibrated saddle is reached before fission, but the quantum number K may not be conserved from saddle to scission such that the system drifts towards lower K, (ii) the system formed beyond its saddle point starts descending towards scission before reaching an equilibrated saddle and the angular distributions may be determined by the shape of an intermediate configuration. However, the anisotropic fragment angular distributions can also arise in the framework of an equilibrated saddle and without going to K-nonconservation from the consideration that the shape of this equilibrated saddle for rotating nuclei with $B_f \simeq 0$, is an oblate and not spherical.

Proximity effects as direct clock for measuring first scission to second scission time

The question of fast fission has usually been considered in the context of fusion-fission, where the intermediate fusion system may be formed with sufficient angular momentum so that $B_f \simeq 0$ and fission decay may proceed on a fast time scale. For fusion-fission case, there is no direct experimental probe for timing the dynamics of the reaction. But in the case of fast fission induced in a DIC product, the strong proximity effects expected between the fission pair and the non-fissioning third particles can provide a direct clock for measuring the time of scission of the intermediate system as measured from the zero time of first scission of the DIC process.

Recently, the existence of projectile splitting (fission) was suggested on the basis of inclusive data[30] for the 12.4 MeV/U ^{84}Kr on ^{90}Zr and ^{166}Er. First experimental evidence for strong proximity effects between the fission pair and the non-fissioning third particle were later found by carrying out kinematically complete experiments on the two-and three body exit channels in 12.4 MeV/U ^{84}Kr on ^{90}Zr and ^{166}Er, and 12.5 MeV/U ^{129}Xe on ^{122}Sn. These experiments were performed at the GSI heavy-ion accelerator employing position-sensitive parallel plate avlanche counter which enabled complete determination of the phase space available to two- and three-body events. The three body events were found to arise predominantly from a two step reaction, with large energy losses in the first step leading to fission in the second. For large energy losses, the probability of ternary events is found to be 10% of the binary. This is abnormally a large fission probability of the intermediate nuclei with mass ~ 125, as compared to the statistical model predictions even with the assumption of extreme (unrealistic) parameters: spins of

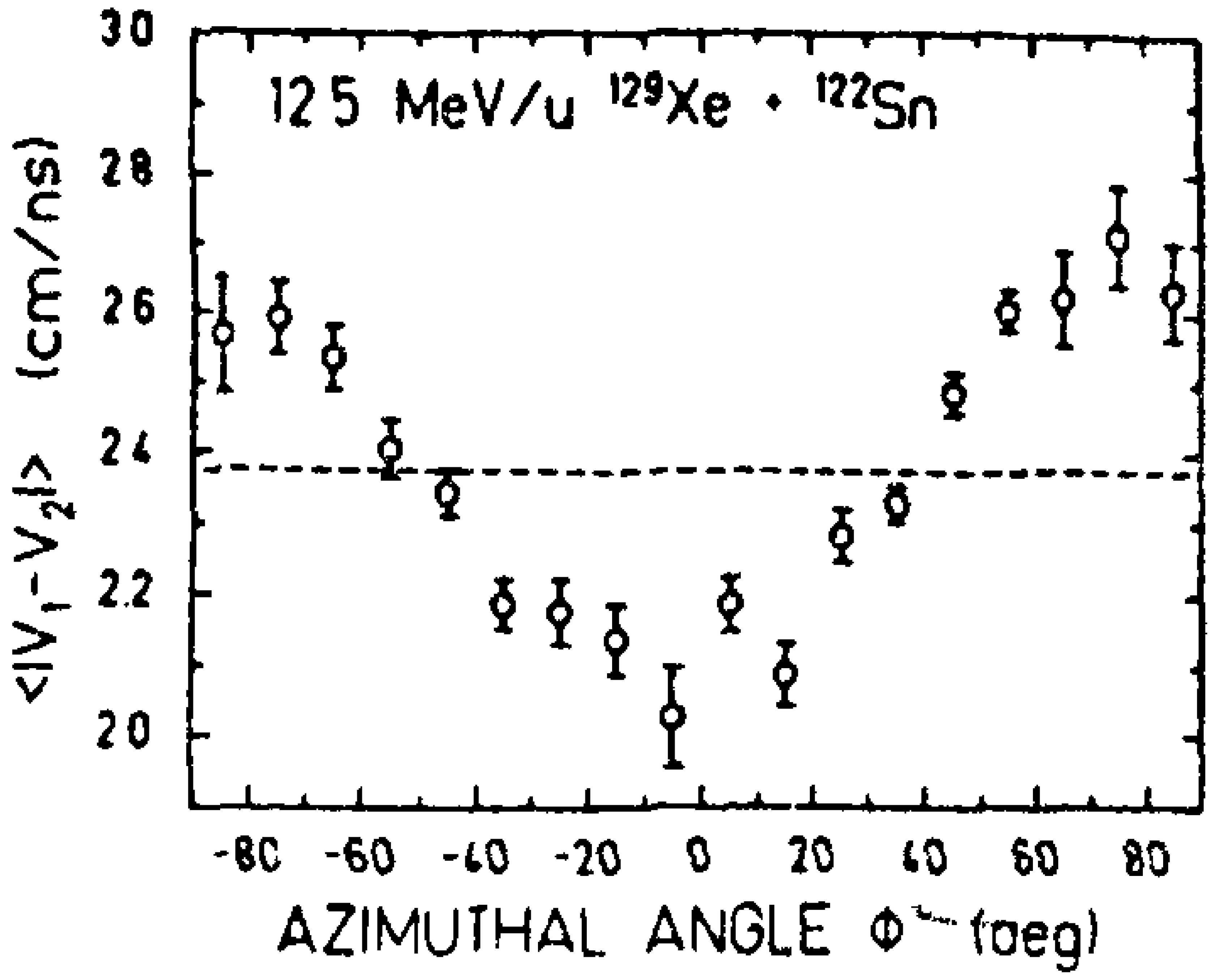

Figure 5. Average relative velocity $\langle V_{12}\rangle = \langle V_1 - V_2\rangle$ of fragment pair (1, 2) *vs* the azimuthel angle The data are integrated overall polar angles, but represent a selection in TKE (350–450 Mev), m_{12} (110–130) and θ_{cm}(10–40°). The dashed line is the ϕ averaged value of. $\langle V_{12}\rangle$ (ref. 31)

60–70 ħ and the liquid drop model barrier reduced to 80%. In the final three-body state of the Xe-Sn reaction, strong proximity effects were observed, which established a scission-to scission time of 1×10^{-21} S. These proximity effects can be seen from figure 3, where the average relative velocity $\langle V_{12}\rangle = \langle|v_1 - v_2|\rangle$ of forward going fragment pair (1,2) is plotted versus the orientation of the fission axis relative to c.m velocity direction of the third particle. (Here, $\phi = 0$ describes an asymptotically collinear final state, and positive angles are towards the beam direction.) The sole existence of a modulation of order Mega-electron volt in the fragment kinetic energies E_k ($E_k = 1/2\mu\langle V_{12}\rangle$) suggests the influence of a final-state Coulomb interaction between the fission pair and third particle operating on distances of the order of 20–200 fm, equivalent to times of the order of 10^{-21} — 10^{-20} S. This is the first time in heavy-ion physics that a direct clock for the reaction dynamics has been found out. Further detailed analysis[32] of the $^{129}Xe + ^{122}Sn$ system has brought out that the angular distribution of the fission axis in the reaction plane is approximately collinear with the axis of the first scission, and the mass distributions of the fission is asymmetric with the heavier mass preferentially emitted opposite to the direction of the third particle. The proximity effect, short time scale of fission and the large fission probabilities, and the anisotropic fragment angular distributions in the reaction plane are thus all indicative of the fission of the intermediate nucleus by further elongation of the deformation axis acquired in the exit channel of the DIC. The above experiments have thus unfolded a new phenomenon of non-equilibrium fission induced through the process of deep inelastic collisions.

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50 YEARS OF CURRENT SCIENCE—GLEANINGS

THE NEED FOR BIOPHYSICAL RESEARCH†

THE main trend of scientific research in the present century has been the progressive intermingling of various branches, which were formerly considered as independent. Thus, physical chemistry and mathematical physics were the earliest to be recognized as distinct fields of study, while biochemistry has now been in existence for a considerable period as a separate discipline. But the application of physical and mathematical methods on a large scale to biological problems is a recent development, resulting in the emergence of 'biophysics' and 'biometry'. It is obvious that major developments are likely to occur in these comparatively virgin fields, which serve as common grounds for different well-established disciplines.

In the past, a few biologists have been interested in the physical aspects of their subject, and physicists have applied their methods to the study of living organisms. Unfortunately, however, there has been no uniformity in the approach to biophysics, nor even a clear conception of its scope and potentialities. The problems concerning the development of biophysics as a separate field of endeavour have been ably treated in an article by R. W. Stacey and his views have been discussed by a number of workers in another issue of *Science.**

The term 'biophysics' may be used to cover broadly three types of studies: the physics of biological systems, the biological effects of physical agents and the use of physical methods in the study of biological problems. It is thus clear that biophysics covers a very large domain of knowledge, and that no logical and well-defined demarcation can be laid down between it on the one hand and the allied branches of physics and biology on the other. But there is no doubt that there exists at present a large area of no-man's-land between physics and biology, which would yield interesting results on exploration. For instance, there is an impressive volume of work waiting to be done on living matter at the microscopic, sub-microscopic and molecular levels. The worker interested in this phase would study tissue ultrastructure with the aid of physical instruments like the X-ray camera, the centrifuge and the electron-microscope. He would investigate the various properties of protoplasm like viscosity, elasticity, optical activity and so on. The thermodynamics of living matter constitute another fundamental field of research, rich in exciting biophysical problems. Spectrophotometric analysis of biological materials may constitute a real contribution to our knowledge of the molecular patterns in the protoplasm and to an understanding of the real nature of life. The measurement of bioelectric phenomena may lead to a proper understanding of neural and mental processes.

Man now travels faster and farther, higher in the air and deeper in the ocean, than ever before. He is exposed to new physical influences by virtue of the invention of new weapons and machines. We must learn the effects of these physical agents on living matter and the biophysicist has a large part to play in such studies. The rapid advances in nuclear physics have led to new and important aspects of biophysical research, such as the tracer isotope techniques and the effects of nuclear radiations on living matter. Again, physical instrumentation forms a major portion of the projected activity of the biophysicist.

Perhaps the reason why many of these subjects have not been investigated in detail in the past is that one needs a background both of biology and physics for a proper appreciation of the problems. Whether we like it or not, there is a difference in the approaches of physicists and biologists in tackling their problems, and it is difficult for one trained in only one of these disciplines to acquire the way of thinking of the other. There is obviously therefore, a need for the development of a special curriculum for training students who wish to take up biophysical research.

Researches in biophysics have been going on in other countries mostly through collaboration between workers in the two fields to which it is related. In some, as in France, regular courses of study are available in the subject. It is time that we in India too considered the possibility of affording courses, at the post-graduate level, to those who wish to take up research in this fascinating field. As a first step, summer courses may be given in the premier laboratories, to acquaint the biologists with the physical techniques that could be profitably used in their studies as also to familiarise the physicists with the basic concepts and ideas behind biological research. Workers in our country could expect to make significant contributions to this field, for it is still in the exploratory stage and not much spadework needs to be done in catching up with workers elsewhere as far as technique is concerned.

Let us therefore earnestly hope that active collaboration between workers in physics, chemistry and biology will soon be forthcoming from our universities and research institutions, to enable us to contribute our share to the field of biophysical research.

* "The Status and Development of Biophysics," *Science*, 1951, **113**, 169, 617.

† Published in *Current Science*, 1951, Vol. 20, p. 197.