Review Of Research
ISSN 2249-894X
Impact Factor : 3.1402(UIF)
Volume - 4 | Issue - 12 | Sept - 2015

NUCLEAR REACTION MECHANISM IN HEAVY FOR INDUCED REACTION

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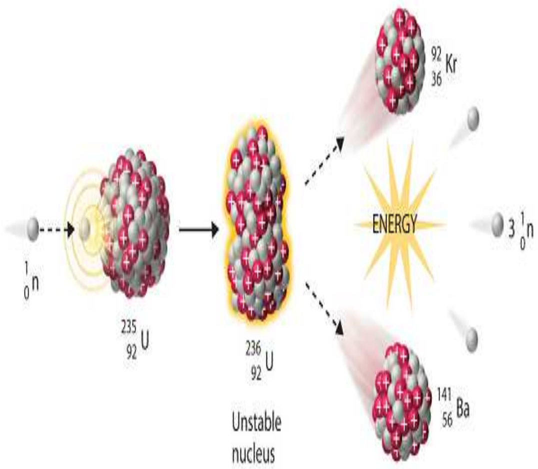
ABSTRACT:

A process that occurs as a result of interactions between atomic nuclei when the interacting particles approach each other to within distances of the order of nuclear dimensions (≃10-12 cm). While nuclear reactions occur in nature, understanding of them and use of them as tools have taken place primarily in the controlled laboratory environment. In the usual experimental situation, nuclear reactions are initiated by bombarding one of the interacting particles, the stationary target nucleus, with nuclear projectiles of some type, and the reaction products and their behaviors are studied.

KEYWORDS : nuclear dimensions , Nuclear Reaction Mechanism , controlled laboratory environment.

INTRODUCTION:-



The study of nuclear reactions is important for a number of reasons. Progress In the understanding of nuclear reactions has occurred at a faster pace and generally a higher level of sophistication has been achieved Compared to similar studies of chemical reactions. The approaches used There are certain nuclear reactions that play a preeminent role in the affairs of man and our understanding of then at ural world in which we live. For example, life on earth would not be possible without then energy provided to us by the sun. That energy The energy released in the nuclear reactions that drive the sun and other stars. For Better or worse, then unclear reactions, fission and fusion, are the basis for nuclear Weapons ,which have shaped much of the geopolitical dialog for the last 50 years. A part from the intrinsically interesting nature of these dynamic processes, their practical importance would been ough to justify their study.

To discuss nuclear reactions effectively we must understand the notation or jargon that is widely used to describe them. Let us begin by considering the nuclear reaction

$^{4}He+^{14}N \rightarrow ^{17}O+^{2}H$.

Most nuclear reactions are studied by inducing a collision between two nuclei where one of the reacting nuclei is at rest (the target nucleus) while the other nucleus(the projectile nucleus)is in motion.(Exceptions to this occur both in nature and in the laboratory in studies where both the colliding nuclei are in motion relative to one another).But let us stick to the scenario of a moving projectile and a stationary target nucleus. Such nuclear reaction scan be described generically as

Projectile P+ target T→ emitted particle X and residual nucleus R

For example ,the first reaction discussed above might occur by bombarding ^{14}N with alpha particles to generate an emitted particle, the proton and a residual nucleus ^{17}O.A shorthand way to denote such reactions is, for the general case,

$$T(P,x)R \text{ or}$$

for the specific example ,

$$14N(\alpha,p)\ 17O.$$

In a nuclear reaction, there is conservation of the number of protonsand neutrons (and thus the number of nucleons). Thus the tot al number of neutrons (protons)on the left and right sides of the equations must be equal.

Sample Problem. Consider the reaction $^{59}Co(p, n)$.What is the product of the reaction?

$$^{1}_{1}H+^{59}_{27}Co \rightarrow ^{1}_{0}n+^{Y}_{X}Z$$

On the left side of the equation we have 27+1 protons. On the right side we have 0+X protons where X is atomic number of the product. Obviously X=28 (Ni).On the left hand side, we have 59+1 nucleons and on the right side, we must have1+Ynucleonswhere Y=59. So the product is ^{59}Ni There is also conservation of energy, momentum, angular momentum and parity, which will be discussed.

Nuclear reactions involving heavy ions.

Nuclear reactions involving heavy ions. For heavy ions ($Z > 2$) as the incident particles, the potential Coulomb barrier E_0 is Z times greater than for protons, and therefore it is necessary that the ion energy corresponding to one nucleon of the nucleus exceed a few MeV (the more so the greater the Z of the target). The effective cross section of nuclear reactions involving heavy protons, with an energy $\mathcal{E} > 1.2E_0$, is given by the expression $\sigma = \pi R2\ (1 - E_0/\mathcal{E})$, where

$$R \approx 1.4(A1^{⅓+\ A2⅓})$$

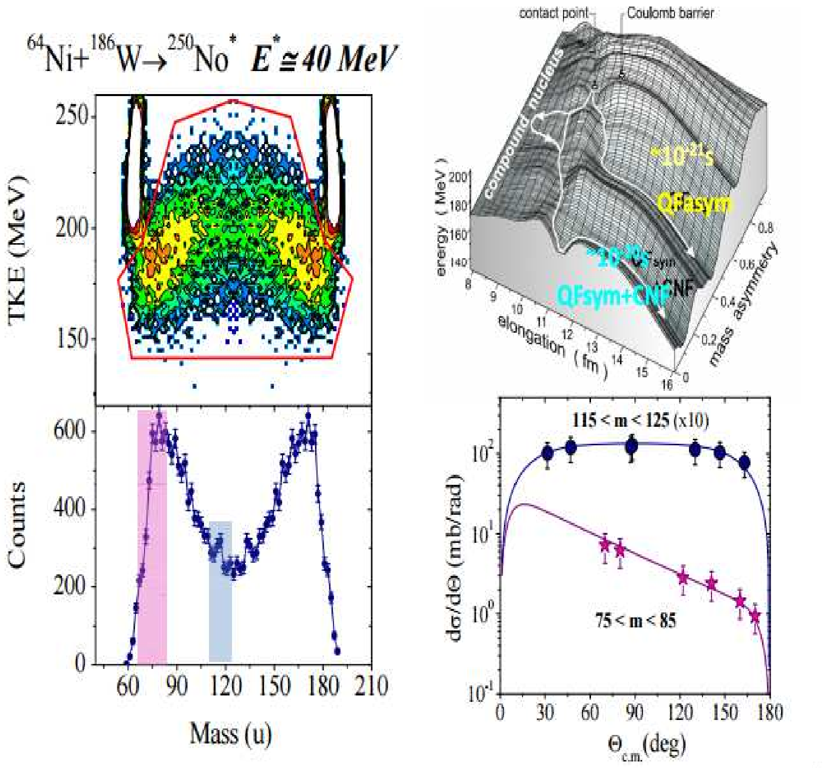
This corresponds to classical representations of the collision of two charged black spheres of radius R. At energies $\mathcal{E} < \mathcal{E}0$, the nuclear reaction proceeds by tunnel infiltration through the barrier (seeTUNNEL EFFECT). In this case, $\sigma R = (R0/^{2}2)(\hbar\omega 0/\mathcal{E})\ In\ [1 + exp\{2\pi(\mathcal{E} - \mathcal{E}0)/$

$\hbar\omega 0\}]$, where R0 is the sum of the radii of the interacting nuclei and ω0 is the curvature of the barrier. The incident ions may not cause a nuclear reaction but may undergo elastic scattering in the field of Coulomb and nuclear forces. The angular distribution of ions upon elastic scattering (when the ƛ of the ion is of the order of the distance of maximum approach to the nucleus) exhibits diffraction characteristics. At smaller ƛ, the diffraction structure disappears. As a rule, the energy dependence of effective cross sections for nuclear reactions by heavy ions are nonresonant in nature. Elastic scattering is an exception. Resonances with widths of the order of a few MeV are observed, along with a finer structure, in the energy dependence of the effective cross sections of elastic scattering of $6_{Li}\ by\ 6_{Li}$, $12_C\ by\ 12_C, l4N\ by\ 14_N, 16_O\ by\ 14_N$, and so on in the energy range of $\varepsilon_0 \sim 5- 35\ MeV$.

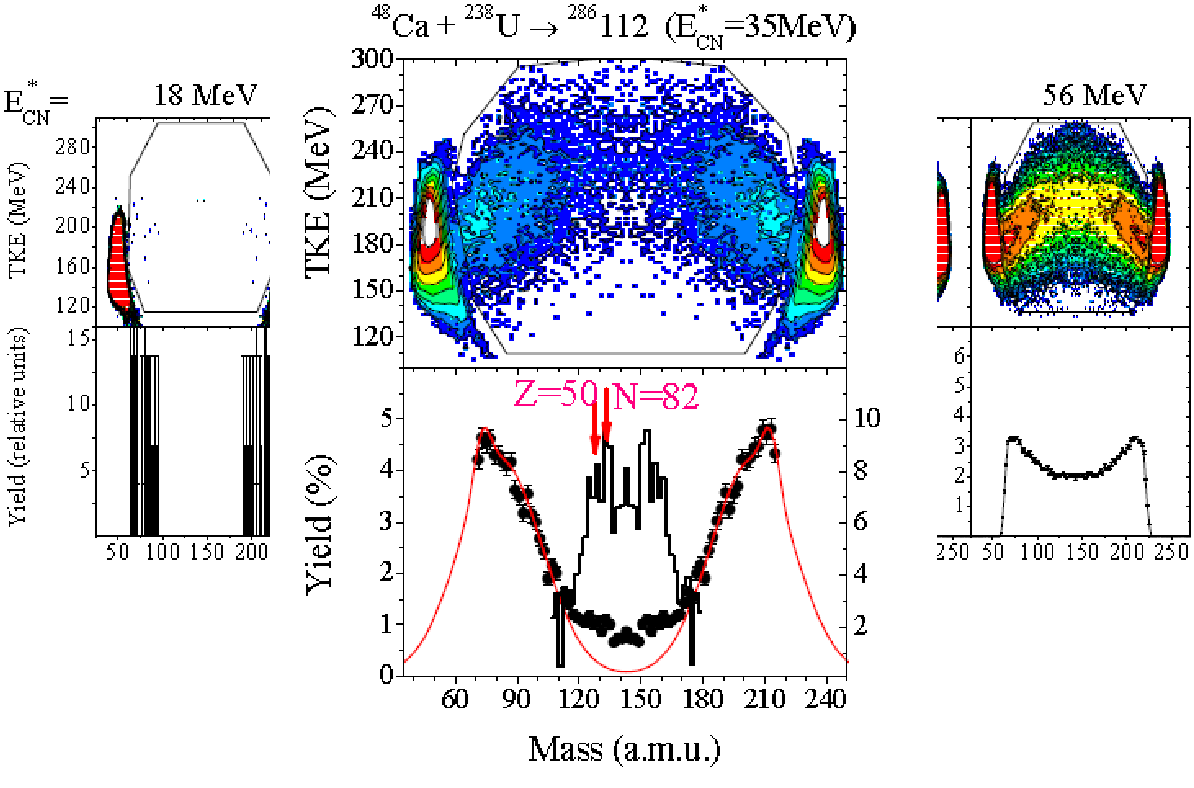
Nuclear reactions involving heavy ions are characterized by a large number of exit channels. For example, nuclei of Ca, Ar, S, Si, Mg, and Ne are formed upon the bombardment of ^{232}Th with ^{40}Ar ions having energies of ^{379}MeV.

The following distinctions are made among nuclear reactions involving heavy ions: reactions of nucleon transfer, reactions of the transfer of more complex particles, and merging reactions (formation of a compound nucleus). Nuclear reactions involving the transfer of a small number of particles or a small portion of energy are called soft collisions. The theory of such collisions has a great deal in common with the theory of direct reactions. Nuclear reactions involving the transfer of considerable mass or energy are called hard collisions, or deeply inelastic transfers. The angular distributions of the products of these nuclear reactions are sharply asymmetric; light products are emitted chiefly at stríall angles with respect to the ion beam. The energy distribution of the reaction products has a broad maximum. The kinetic energy of the reaction products is close to the height of the exit Coulomb barriers and is virtually independent of the ion energy.

A short-lived intermediate system is formed upon deeply inelastic collisions of nuclei. Despite the exchange of mass and energy, the nuclei of the intermediate system retain individuality as a result of tightly bound cores. Many new nuclides are formed as a result of hard collisions. In such reactions, compound nuclei with high excitation energies (~100 MeV) and angular momenta (~50) may arise. Nuclear reactions that involve the formation of compound nuclei are used in the synthesis of transuranium elements (the combining of Pb and Bi target nuclei with ions of ^{40}Ar, ^{50}Ti, ^{54}Cr, ^{55}Mn, and ^{58}Fe). For example, fermium was synthesized by the nuclear reaction.



Heavy ion-induced induced reactions: binary channel channel



Reactions with 48Ca-ions

Mechanisms of nuclear reactions.

An incident particle, such as a nucleon, may enter and leave the nucleus at differentangles, but with the same energy (elastic scattering). The nucleon may collide directly with a nucleon of the nucleus; in thiscase, if either or both of the nucleons have an energy greater than that required to leave the nucleus, they may leave withoutinteracting with any of its other nucleons (direct process). There also exist more complex direct reactions, in which the energyof the incident particle is transferred directly to one nucleon or a small group of nucleons in the nucleus (*see*DIRECT NUCLEARREACTION). If the energy introduced by the incoming particle is gradually distributed among many nucleons of the nucleus,the nuclear states will become increasingly more complex. However, after a certain time, dynamic equilibrium will bereached: different nuclear configurations will arise and decay in the resultant system, called a compound nucleus(*see*COMPOUND NUCLEUS). The compound nucleus is unstable and rapidly decays into the final products of the nuclearreaction. If the energy of one of the nucleons in some configurations is sufficient for ejection from the nucleus, the compoundnucleus decays with the emission of a nucleon. On the other hand, if the energy is concentrated in a few groups of particles,existing for a short time in the compound nucleus, then there may be the emission of alpha particles, tritons, deuterons, andthe like. At excitation energies of the compound nucleus that are lower than the energy for the ejection of particles, the onlyreaction path is the emission of gamma quanta (*see*RADIATIVE CAPTURE OF NEUTRONS). Sometimes particles are ejectedbefore equilibrium is reached, that is, before the formation of a compound nucleus (the mechanism of preequilibrium decay).

The different mechanisms of nuclear reactions vary with respect to duration. The direct nuclear reaction has the shortesttime.This is the time it takes for the particle to pass through the region of space occupied by the nucleus ($\sim 10^{-22}$sec). Theaverage lifetime of a compound nucleus is considerably longer (10^{-15} to 10^{-16} sec).

At low energies of the incident particles,the major mechanism of nuclear reactions, as a rule, is the formation of a compound nucleus, with the exception of nuclearreactions with deuterons. Direct processes predominate at high energies.

The nature of the dependence of the effective cross sections σ of nuclear reactions on the energy $\mathcal{E}$ of the incident particles $\sigma(\mathcal{E})$ differs for different mechanisms of nuclear reactions. For direct processes, the dependence $\sigma(\mathcal{E})$ exhibits monotonic behavior. In the case of nuclear reactions resulting in the formation of compound nuclei, maxima are observed in $\sigma(\mathcal{E})$ at low particle energies; these maxima correspond to the energy levels of the compound nucleus. In the high-energy region ($\mathcal{E} \geq 15$ MeV for intermediate-mass and heavy nuclei), the energy levels of the compound nucleus overlap, and the cross section depends mono-tonically on energy. Against this background, broader maxima are distinguished corresponding to the excitation of the isobaric analog states (states of the nucleus in which the isotopic spin is greater than in the ground state), and giant resonances are observed. These broader maxima correspond to the levels of the nucleus that are formed when a nucleus combines with the incident particle and have a simpler structure than the levels of the compound nucleus. The lifetime τ of the excited nucleus is related to the total width Γ of the observed maxima by the expression $\Gamma = \hbar/\tau$, where $\hbar$ is Planck's constant.

Upon the decay of a compound nucleus, the residual nucleus may be formed both in the ground state and in any one of several excited states. The energy spectrum of the decay products of a compound nucleus in the region of higher energies consists of separate lines, and in the low-energy region the emitted particles have a broad maximum. The angular distribution of the final products (in the center of mass system) in the resonance energy region is symmetric with respect to the direction that forms a 90° angle with the direction of the incident particles. In the energy region where the energy levels of the compound nucleus overlap, the quantum characteristics of different levels of the compound nucleus are averaged, and the angular distribution of the emitted particles is spherically symmetric as a rule.

The particles produced in the course of a nuclear reaction are usually polarized. Polarization arises in the case where the beam of bombarding particles is not polarized. On the other hand, if the incident beam is polarized, azimuthal asymmetry of the nuclear reaction products is observed (seePOLARIZED NEUTRONS and ORIENTED NUCLEI).

Reactions induced by high-energy particles

Particles with energies of about 100 MeV correspond to $\lambdabar = 0.43$ fermi, which is small compared to the average internuclear distance in the nucleus (1.9 fermi). This makes possible "probing" of the nucleus: in a first approximation, it can be assumed that the nucleon entering the nucleus interacts at each instant with only one nucleon as if it were free. An important feature of nuclear reactions induced by high-energy particles is the feasibility of transferring an excitation of about 100 MeV even to a light nucleus.

Upon the interaction of a fast nucleon with a nucleus, the nucleon may be elastically scattered, causing a nuclear reaction. The elastic scattering cross section σel depends evenly on the energy of the incident particles. The total cross section of the interaction of fast nucleons σtot varies from $2\pi R^2\ to\ \pi R^2$. At a nucleon energy of greater than 150 MeV, σel = ⅓ σ_{tot}, and the cross section of the nuclear reaction σr = ⅔σ_{tot}. Thus, the nucleus does not behave as an absolutely absorbing medium (in this case, $\sigma_{el} = e_l$). The angular distributions of elastically scattered particles are similar to a diffraction pattern, and a pronounced forward peaking is observed.

The high energy of an incident particle may be distributed among many nucleons of a nucleus. In this case, some nucleons may acquire an energy sufficient to escape from the nucleus. Upon the interaction of high-energy particles with a nucleus, an intranuclear cascade may develop, resulting in the emission of several high-energy particles and leaving a strongly excited compound nucleus that emits low-energy particles as it decays. The average number of emitted particles increases with increasing energy of the primary particle. Heavier nuclear fragments, such as deuterons, tritons, and alpha particles, may be emitted (with lower probability) along with the nucleons in the nuclear reaction. A nuclear reaction in which various numerous charged particles are emitted forms a multipointed star in a nuclear photographic emulsion. In such reactions, a large number of diverse radioactive products are formed, which are studied by the methods of radiochemistry.

Simpler nuclear reactions are also observed under the effect of fast particles, for example, inelastic scattering (p, p’), the charge-exchange reaction (p, n), the pickup reaction (p, d), and the knock-out reaction (p, 2 p). The contribution of these processes to the total cross section of the nuclear reaction is low (about 10–20 percent). The knock-out proton reaction (p, 2p) has proved to be very convenient for studying the structure of nuclei. The energy loss in a nuclear reaction and the binding energy of a knock-out proton can be determined by measuring the energy of the emitted protons. The distribution of the residual nuclei according to energy shows maxima corresponding to the excited levels of a residual nucleus. The excitation energy of these levels reaches 50–70 MeV, corresponding to hole excitation of deep shells.

CONCLUSION:

While the relative contribution of QF to the capture cross section mainly depends on the reaction entrance channel properties, the features of asymmetric QF are determined essentially by the driving potential of a composite system.

The fragment yield increases when the both formed fragments are close to nuclear shells as in the case of QF (asymmetric QF), as well as in the case of fusion-fission (bimodal fission, asymmetric fission, superasymmetric fission) .

At the transition from Ca to Ni projectiles the contribution of QF process rises sharply and Ni ions is not suitable for the synthesis of element Z=120 in the complete fusion reactions. An alternative way for further progress in SHE can be achieved using the deep-inelastic or QF reactions. To estimate the formation probabilities of SHE in these reactions the additional investigations are needed.

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