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MEASUREMENTS OF THE MAXIMUM α-PARTICLE ENERGY AT FORWARD ANGLES IN THE REACTION $^{22}Ne + ^{197}Au$

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Герлик Э. и др. **E7 - 12922**

Измерение максимальной энергии альфа-частиц в реакции $^{22}Ne + ^{197}Au$ под передними углами

Измерялся энергетический спектр α-частиц, испускаемых в реакции $^{22}Ne + ^{197}Au$ при $E_{лаб}$= 178 МэВ. Продукты реакции, вылетающие под углом 0° к оси пучка, анализировались магнитным спектрометром и регистрировались полупроводниковым ΔE–E телескопом. Измеренный спектр α-частиц сильно отличался от ожидаемого по модели испарения частиц из составного ядра. Экспериментально измеренное максимальное значение энергии α-частиц в пределах точности эксперимента близко к максимально возможному по энергетическому балансу реакции. Полученный результат обсуждается с точки зрения механизма образования высокоэнергичных α-частиц.

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Gierlik E. et al. **E7 - 12922**

Measurements of the Maximum α-Particle Energy at Forward Angles in the Reaction $^{22}Ne + ^{197}Au$

The energy spectrum of α-particle has been measured for the system $^{22}Ne + ^{197}Au$ at E_{lab}= 178 MeV. The reaction products emitted at 0° relative to the beam direction are analysed using a magnetic spectrometer and detected by means of a semiconductor ΔE–E telescope. The measured α-particle spectrum strongly differs from the one expected from evaporation. The experimentally measured maximum α-particle energy almost amounts to the maximum possible value calculated from the reaction energy balance. The obtained results are discussed from the point of view of the mechanism of formation of high-energy α-particles.

The investigation has been performed at the Laboratory of Nuclear Reactions, JINR.

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Recently, great interest has been shown in studies of the emission of light charged particles in reactions between two complex nuclei [1,2]. This process is characterized by a rather large cross section [3] and an unusual shape of the energy spectrum [4], which is difficult to explain within the framework of the generally accepted concepts. One of the possible and well studied reaction channels is the complete fusion of two colliding nuclei, which leads to the formation of a compound nucleus whose lifetime is well known to significantly exceed the characteristic nuclear interaction time. In this case, a practically total energy dissipation occurs and the mechanism of nucleon emission from the compound nucleus is well describable in terms of thermodynamics.

All this is valid for complete fusion, where the initial state of the compound nucleus is determined unambiguously. However, the emission of one or several particles, preceding compound nucleus formation, may notably change the kinematics of the process and the characteristics of final products. It has been experimentally shown that in such direct processes the light-particle production cross section, especially that for α-particles, strongly increases with the energy of the bombarding ions and, at $E_p > 8$ MeV/nucleon, comprises a significant part of the total cross section [3]. In such reactions, α-particles make up a major fraction of light particles (ref. [1]). The characteristics of the processes accompanied by α-particle emission have in a great detail been investigated in the reactions induced by the ^{16}O , ^{12}C , ^{9}Be ions (refs. [5,6,7]) in connection with the possibility of explaining the mechanism of α-particle emission by projectile break-up reactions in the nuclear field. Within the framework of such an interpretation, the most probable velocity of the α-particles should be close to the projectile velocity before the collision.

Also, α-particle emission, with great probability, occurs in reactions induced by even heavier incident ions ($A_i \geq 20$) having energies up to $E_{HI} \approx$ 20 MeV/nucleon [8].

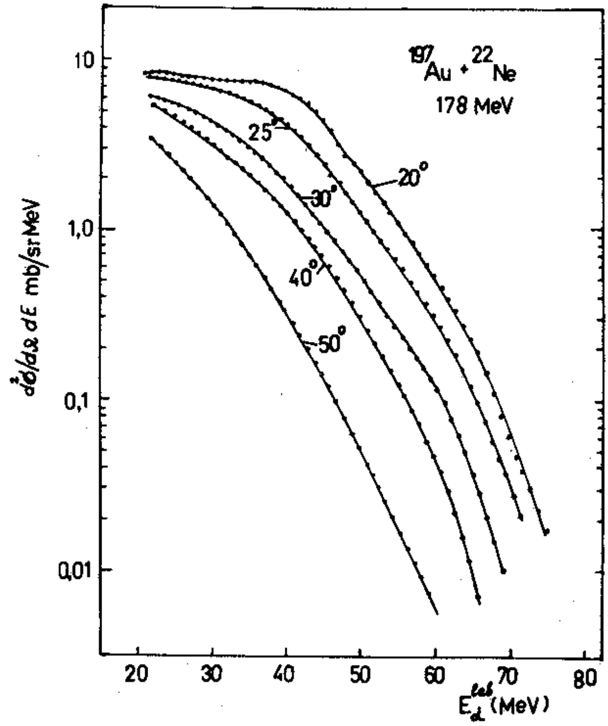

Fig. 1. Experimental α-particle energy spectra measured at different angles to the beam direction, in the reaction $^{22}Ne + ^{197}Au$ at a bombarding energy of 178 MeV.

As an example, in fig. 1 are shown the α-particle spectra measured at different angles in the reaction $^{22}Ne + ^{197}Au$ (ref.[9]). These spectra exponentially fall as the energy of the α-particles increases. The high energy portion of the spectra, however, changes noticeably more slowly than is expected from calculations of compound-nucleus statistical emission spectra. This may be indicative of the pre-equilibrium mechanism of α-particle production[11]. It is noteworthy that the high-energy component depends on the α-particle emission angle: as this angle decreases, the α-particle energy strongly increases. In most measurements carried out so far, the minimum angle of registration has been around 20°; investigations at angles $\theta < 20°$ are connected with great technical difficulties because of the high background due to the scattered ions. On the other hand, from the observed trends it follows that the most energetic α-particles should be emitted in the direction of the incident ion ($\theta = 0°$). In this case it seems interesting to determine the end-point α-particle energy which may be connected with the mechanism of this complex process. In order to obtain such a kind of data, in the present work we measured the energy spectrum of α-particles emitted at 0° in the reaction $^{22}Ne + ^{197}Au$ with 8.1 MeV/nucleon beams.

The experiments were carried out at the 300 cm cyclotron of the JINR Laboratory of Nuclear Reactions. The ^{22}Ne ion beam with an energy of 178 MeV bombarded a self-supporting 250 $\mu g/cm^2$ thick gold target. The energy dispersion of the ion beam at the target exit did not exceed 1.8 MeV.

The reaction products emitted in the angular range $0° \pm 2°$ entered a magnetic spectrometer of the type MSP-144, whose resolution was $dp/p = 2 \times 10^{-4}$ over the whole interval of measurements, $1.0 \le B\rho \le 1.6$.[10] In the spectrometer focal plane, a telescope was placed consisting of two semiconduc-

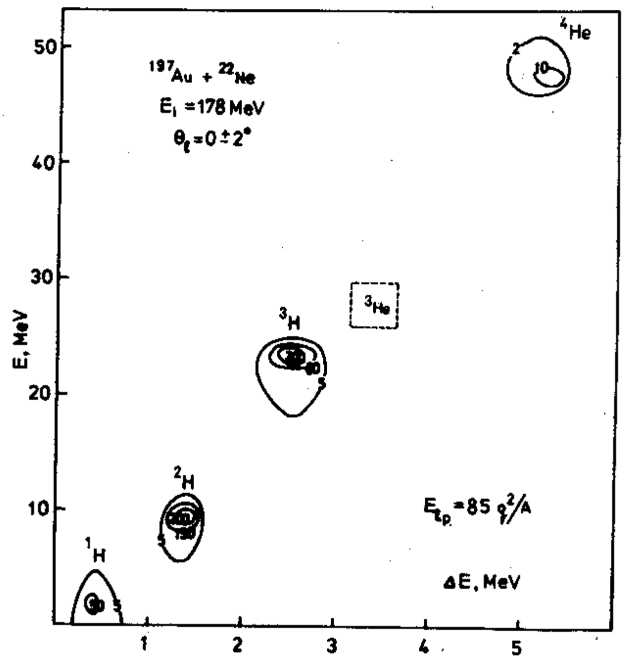

Fig. 2. The $\Delta E \times E$ experimental spectrum for different light particles at a fixed value of $B\rho$.

tor detectors - a surface-barrier Si(Au) detector 300 μm thick and a drift Si(Li) detector 2 mm thick. The energy resolutions of the detectors were 30 and 60 keV, respectively. This system allowed one to perform α-particle measurements in the energy range 25-120 MeV.

Figure 2 shows a two-dimensional spectrum of charged particles with $A \leq 4$, which was measured using the $\Delta E - E$ telescope at a value of $B\rho = 1.34$. It can be seen that by using the given technique a clear separation of particles of different mass numbers can be carried out at all fixed values of $B\rho$ of the separator magnet. The energy spectra were actually measured by changing the magnetic rigidity of the spectrometer. The maximum energy that the ions can gain in the magnetic spectrometer MSP-144 corresponds to

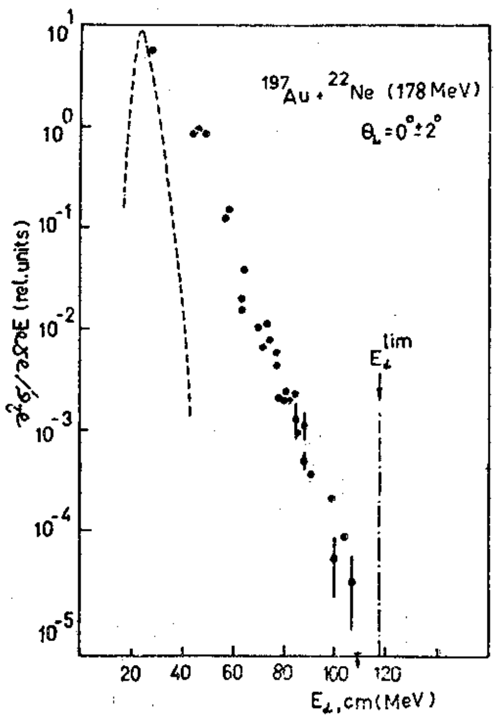

Fig. 3. The centre-of-mass experimental energy spectrum for α-particles emitted at 0° in the reaction ^{22}Ne (178 MeV)+ + ^{197}Au. The broken line is the calculated evaporation spectrum. E_α^{lim} is the maximum possible α-particle energy calculated from reaction kinematics.

the value $E_{magn} = 120 z_i^2 / A_i$ (for α-particles, $E_{magn} = 120$ MeV). In order to register particle energies greater than E_{magn}, a gold absorber 300 μm thick was used ($\Delta E \geq 20$ MeV). With all the necessary corrections taken into account, the resulting energy spectrum of α-particles emitted in the reaction $^{22}Ne + {}^{197}Au$ is shown in fig. 3.

The last measured point in the spectrum is close to the kinematic limit. In the same figure, one can also see the α-particle spectrum calculated on the basis of the evaporation model for the compound nucleus ^{219}Ac. The experimental and calculated spectra strongly differ at energies $E_\alpha > 40$ MeV. On the assumption of the evaporation character of the emission of α-particles by the excited nucleus, the value of the nuclear temperature can be estimated from the exponential part of the spectrum by using the relation $\sigma \sim E_\alpha \exp(-E_\alpha/T)$. The value thus obtained is 5.8 MeV. This is approximately three times the temperature of the compound nucleus ^{219}Ac, whose excitation energy is equal to 109 MeV ($T = 2.1$ MeV). Hence, it seems that the α-particles emitted in the interaction of ^{22}Ne with ^{197}Au can be attributed to evaporation from a region having an increased temperature. Naturally, other models are possible, too. However, the observation, in the given reaction, of α-particles with an energy close to their maximum possible one, suggests that such a situation can occur solely in the case of a two-body exit channel, in which the outgoing α-particle carries a significant part of the incident ^{22}Ne ion momentum. Such a mechanism can bring forth the formation of a weakly excited nucleus.

Moreover, if the interaction takes place at impact parameters others than zero, the residual nucleus, in spite of its low excitation energy, will have a relatively large angular momentum as the outgoing α-particles even with high energy will not be able to take away the whole initial momentum. In the extreme case, the remaining excitation energy of the nucleus will manifest itself as rotational energy. It is quite possible that in the given reaction the difference $\Delta E_\alpha = E_\alpha^{lim} - E_{max}$ is first of all rotational energy of the residual nucleus ^{215}Fr. If this is true the transition of such a nucleus to the ground state should be accompanied by the emission of a great number of γ-rays as in the case of the deexcitation of a compound nucleus with high angular momentum. It is also possible that as the nucleus is strongly rotating,nucleons will be emitted,while in the region of the highly fissile nuclei the major decay channel may be fission as a consequence of the influence of the rotational energy on the fission barrier height/12/. On the other hand,if the given process is not connected with peripheral collisions,it can prove to be a method of obtaining "cool" nuclei with relatively low spin and this fact can be used to synthesize heavy nuclei in the ground state. In order to give answers to all these questions, it is necessary to measure the characteristics of α-particles emitted in different projectile-target combinations by means of the techniques based on the registration not only of the α-particles, but also of the decay channels of the residual nucleus. Such experiments are in preparation to be carried out at the U-400 cyclotron.

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