SOME REGULARITIES IN THE FORWARD ANGLE YIELDS OF ISOTOPES WITH 4<Z<20 IN THE REACTION OF ^{40}Ar(36.5 A MeV) WITH ^{9}Be.

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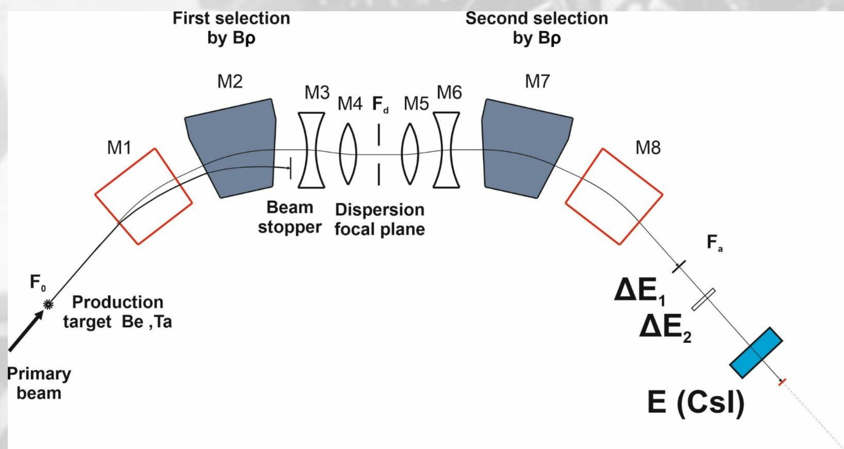
Introduction

Systematic study of forward-angle inclusive yields of nuclei with atomic numbers 4<Z<20 produced in nucleus-nucleus collisions of the ^{40}Ar projectile on the ^{9}Be target in the Fermi energy domain (40 A MeV) was carried out. The reaction products were measured by using the double achromatic fragment-separator COMBAS in the spectrometry mode at FLNR, JINR (Dubna). The inclusive velocity, isotopic and element distributions were obtained. There is no unique mechanism to explain the total set of the results obtained from the experiment. Two main contributions of dissipative low energy reaction mechanisms and of fragmentation mode were observed. The simple exponential approximation realized by the Qgg - systematics satisfactorily describes the total yield of the isotopes produced in stripping nucleon reactions with large negative Qgg values especially for neutron-rich isotopes. The Qgg – systematic can be used to predict correctly the yields of unknown drip-line nuclei. The production rates of neutron-rich isotopes of elements with 4 < Z < 20 were determined.

The experimental details

The study of nuclear reactions induced by secondary beams requires magnetic separation and particle identification (PID) for fragments of interest. In our experiment, a primary ^{40}Ar beam was accelerated to around 40 A MeV by the U-400M cyclotron of the Flerov Laboratory of Nuclear Reactions, JINR, and sent to a ^{9}Be target of 89 mg/cm^2 thickness. A secondary beam cocktail consisting of particles He, Li, Be and B isotopes was produced and transported by the COMBAS fragment separator system (Fig.1) to the detector system . The secondary beams were partially purified by 200 μm Al wedge. The energy dispersion was limited to less than 1% FWHM by analyzing slits. COMBAS separator $M_1M_2M_3M_4F_dM_5M_6M_7M_8F_a$ magneto-optic configuration is realized on the rigid focusing principle. Three parameters are important for particle separation and trajectory analysis by COMBAS setup: magnetic rigidity (Bρ), energy loss difference in the degrader (ΔE/Δx) and time of flight (TOF).



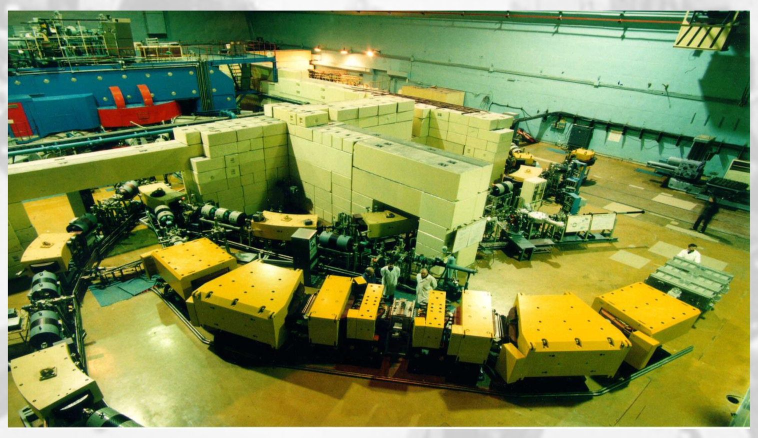


Fig.1. Magneto-optical scheme of the separator COMBAS

The detection sytems

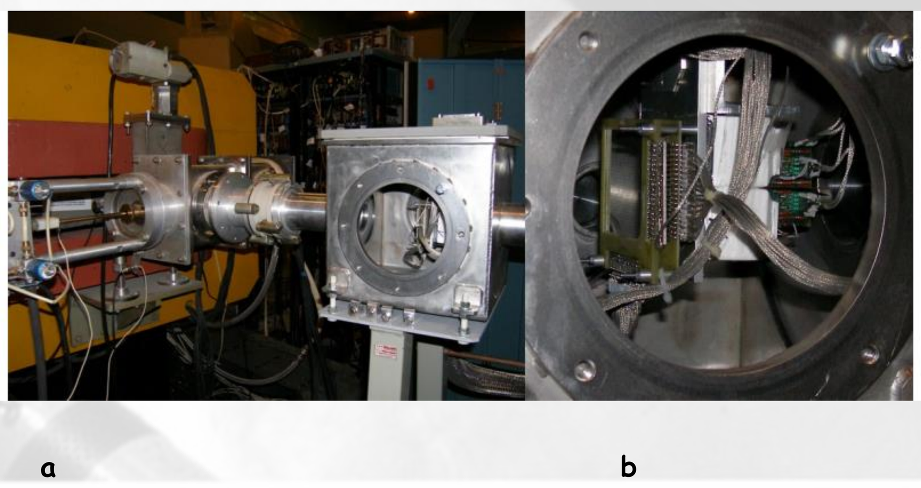


Fig.2. Detection system: a) layout of the detection chamber installed for the measurements with ^{40}Ar beam b) Telescope of two double sided 16-strips silicon detectors and a wall (3 × 3) of four mono-crystals CsI(Tl) inside the detection chamber.

The telescope consists of three detectors (ΔE1, ΔE2, and E). The ΔE1 detector is a 32-strip silicon X detector 380 μm in thickness and 64 × 64 mm2 in area for measuring the particle coordinate along the horizontal direction. The ΔE2 detector is a 32- strip silicon Y detector 1000 μm in thickness and 64 × 64 mm^2 in area for measuring the particle coordinate along the vertical direction. The E detector is a granular assembly of nine full-absorption scintillation detectors 20 mm thick, the total area of the assembly being 64 × 64 mm^2. The strip structure of the penetrate ΔE1 and ΔE2 detectors also played an important role in tuning beam products to the exit focus Fa with minimal losses in the telescope aperture. In the course of the exposure, the monitoring functions of the strip detectors made it possible to correct the fragment-beam axis in X and Y toward the Fa focus.

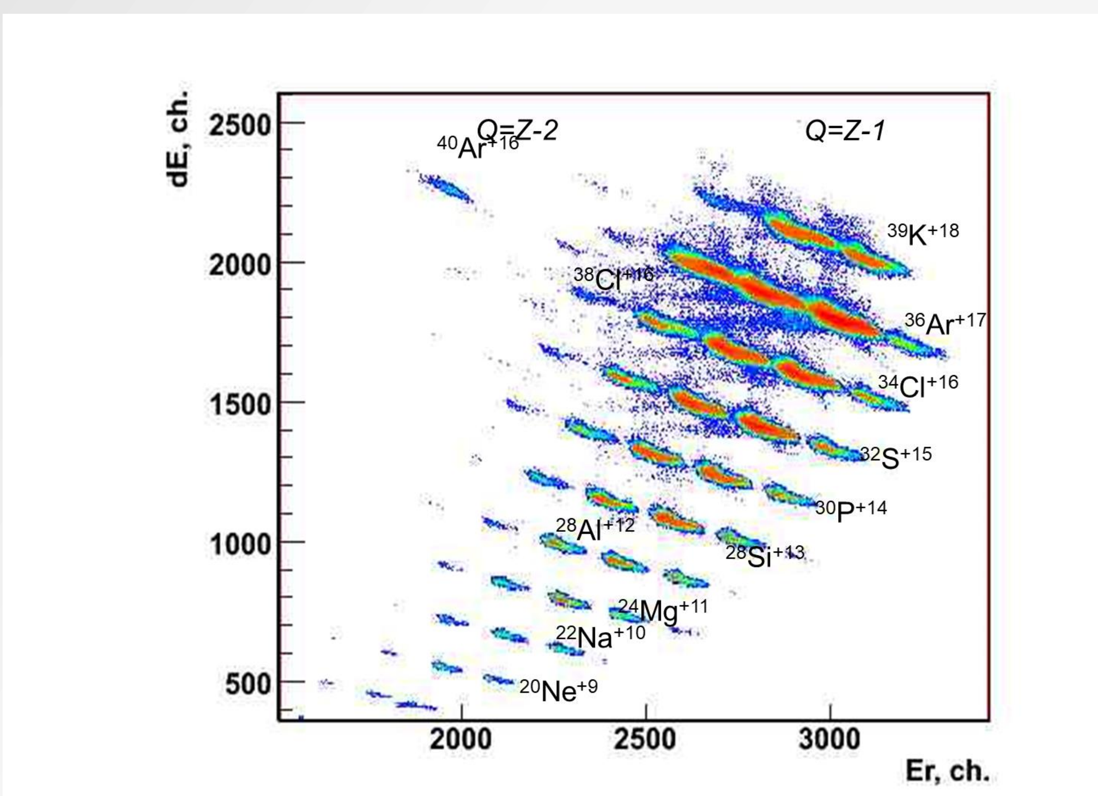


Fig.3 Particle identification in the dE–E plane at $B\rho$ = 1.8 Tm with the Be target

Velocity distributions

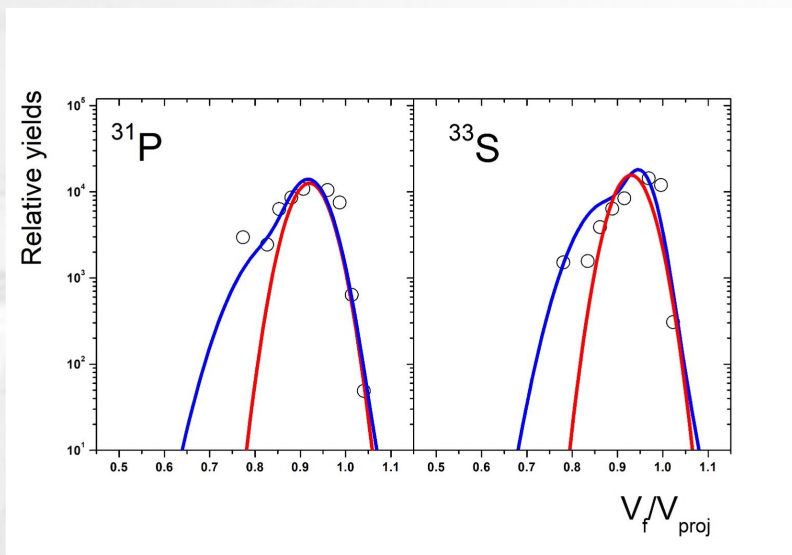


Fig 4 Fragment velocity distributions of ^{31}P (a) and ^{33}S (b) produced in the ^{40}Ar + ^{9}Be reaction. The solid curves are the fit results by using a two-component expression

The velocity distributions of the projectile-like fragments produced in fragmentation reactions can give more detailed information about the reaction mechanism than the isotope distributions. From these one can learn about different modes involved in the process. In this work we have systematically parameterized this behaviour by a two-component expression with a direct breakup Gaussian component at beam velocity as in the Goldhaber model, and a dissipative component at lower velocity also of Gaussian shape, and have determined the relative strength, positions and width of these contributions from a fit to the data.

As discussed above we parameterize these velocity distributions with a two-component form, a Gaussian peak centred at beam velocity plus a dissipative contribution at a lower velocity.

$$\frac{d\sigma}{dv} = \begin{cases} s_0 \exp[-(v-v_0)^2/2\sigma_0^2] + s_1 \exp[-(v-v_1)^2/2\sigma_1^2] & v < v_0 \\ s_0 \exp[-(v-v_0)^2/2\sigma_0^2] & v \geq v_0 \end{cases}$$

Here s_0, v_0 and σ_0 are the height, position and width of the direct contribution, and s_1, v_1 and σ_1 the corresponding quantities for the dissipative contribution.

Isotope distributions

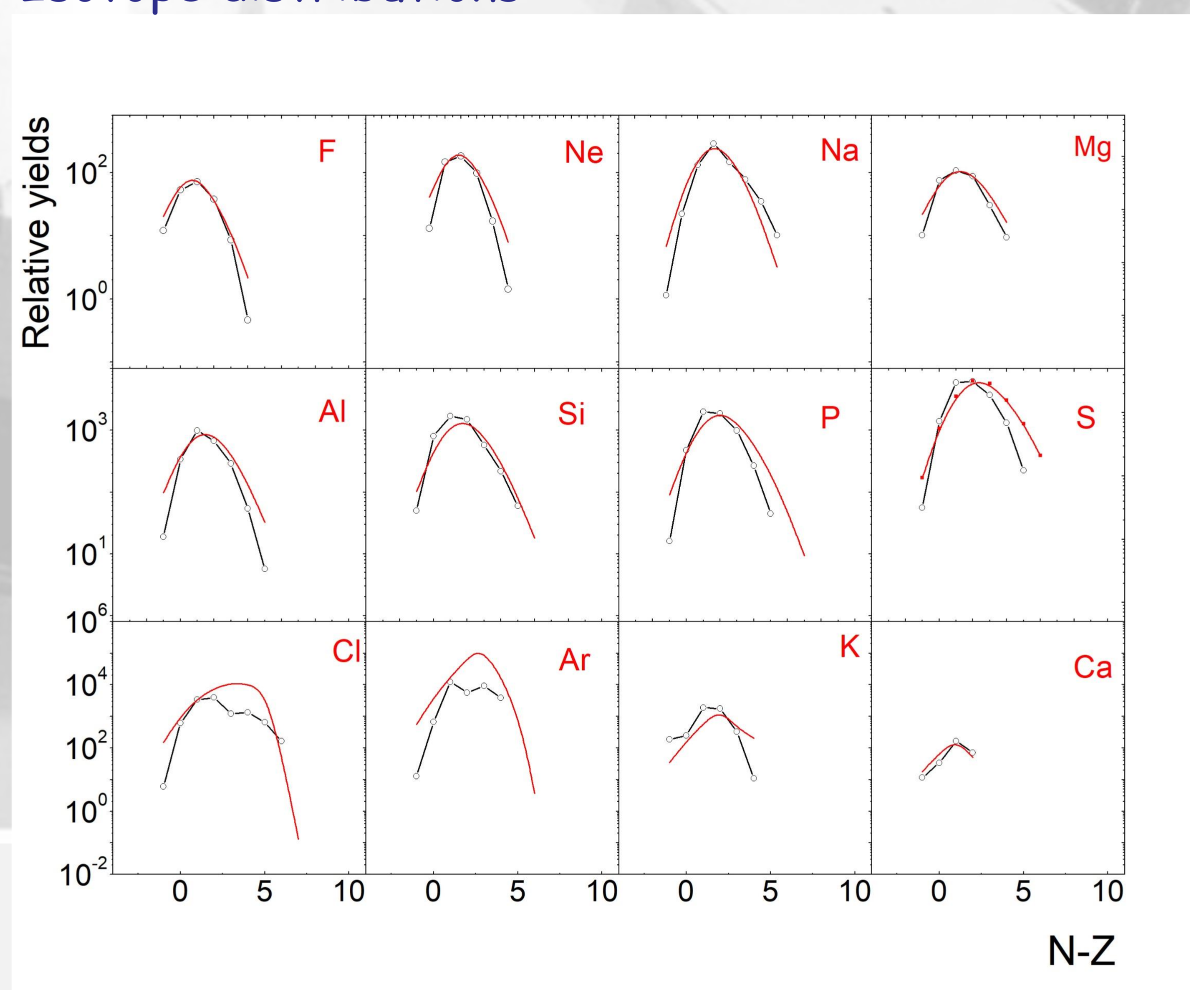


Fig 5 Production cross sections or relative yields for fragments in the 40Ar + 9Be reaction. Open circles show the experimental data and solid red lines show the calculation by the EPAX-2,

Conclusions

The projectile fragmentation reactions of a 36.5 MeV/nucleon ^{40}Ar beam on $_9$Be targets have been studied by fragment-separator COMBAS in the spectrometry mode at FLNR, JINR (Dubna).

By measuring the velocity distribution of the fragments, we have seen clearly the competition between projectile fragmentation and other mechanisms in the production of fragments. The high-momentum-side widths of the fragments are in good agreement with the Goldhaber model, which shows that the projectile fragmentation reaction is dominant. The low-momentum-side widths are much broader, which may come from the nucleon transfer between the projectile and target nuclei during the reaction process. For the fragments close to the projectile, the contribution from the nucleon transfer process is nearly the same as the projectile fragmentation process but, for light fragments, the production is dominated by the multifragmentation process.

The production cross sections of the fragments have been studied with the EPAX2 . The calculations show that the nucleon transfer process in the abrasion stage has an important influence on the isotope distributions of prefragments, and the calculated excitation energies of the prefragments can explain well the measured momentum-peak shifts.

We have shown that the study of the velocity distributions is a promising way to understand the mechanism of fragment production in heavy-ion collisions. The empirical parameterization and the interpretation with phenomenological and microscopic model help to gain insight and should be further developed.