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[18] There is no apparent reason for expecting the absence of superzone-induced gap effects in β-brass if the Fermi surface is topologically close to that calculated by F. J. Arlinghaus [Phys. Rev. 186, 609 (1969)]. Possible explanations for the anomalous behavior are that (1) the band structure is qualitatively different from that calculated by Arlinghaus, being characterized by a severe paucity of states at $\vec{K}=\vec{Q}$, (2) the electronic factors that weight the correlation function in the most general expression the resistivity are not adequately described by the free-electron approximation utilized in all the theories discussed above, or (3) density fluctuations induced by the concentration fluctuations dominate the critical scattering (see Ref. 1).

Nuclear Reactions of Silver with 300-GeV Protons*

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Cross sections of 27 radionuclides formed by the interaction of 300-GeV protons with silver were determined on the assumption that the cross section of the reaction ^{27}Al(p, $3pn$) remains the same as at 10–30 GeV. The results are compared with the corresponding values obtained at 11.5 GeV. The average value of the ratio $\sigma_{300}/\sigma_{11.5}$ for all products ranging from ^{7}Be to ^{106m}Ag is 0.91 ± 0.07 and is independent of mass number.

The initial investigations of the interaction of 300-GeV protons with complex nuclei are presently being performed. Relative spallation cross sections have been reported for vanadium and cobalt targets,[1] which are representative of the light- to medium-mass region. We have performed similar measurements on a silver target in order to study the interaction of 300-GeV protons with a substantially heavier nuclide. The spallation of silver by 11.5- and 29-GeV protons has been previously investigated[2,3] so that the effect of the increase in bombarding energy can be determined.

Three irradiations were performed in an external 300-GeV proton beam in the Neutrino Hall at the National Accelerator Laboratory for times ranging from 7 to 16 h. The target stacks consisted of three aluminum monitor foils followed by three silver foils. All foils were cut to a 5×5-cm^2 size. The middle Ag and Al foils were assayed while the outer foils served to provide for recoil-loss compensation and to prevent cross contamination. The total thickness of the target stacks was approximately 100 mg/cm^2. In order to determine the presence and possible effect of lower-energy particles arising from the scattering of the incident beam upstream from our target, aluminum and silver foils were simultaneously placed next to the target stack during the bombardment. These foils showed essentially no activity after irradiation, indicating that external sources of secondaries could be neglected.

The radioactive products were detected by γ-ray spectrometry performed on the target foil without chemical separation. The measurements were performed with a calibrated 30-cm^3 Ge(Li) detector connected to a 4096-channel analyzer equipped with punched-paper-tape readout. Measurements commenced approximately 10 h after bombardment. The results reported here are based on data obtained during the first 1–3 months following irradiation. The γ-ray spectra were analyzed by means of a modified BRUTAL computer code[4] followed by decay-curve analysis of individual peaks with the CLSQ code.[5] The assignment of γ rays to specific nuclides was made on the basis of the measured energies and half-lives. In making these assignments we were immensely aided by our previous measurements of the interaction of silver with 11.5-GeV protons.[2]

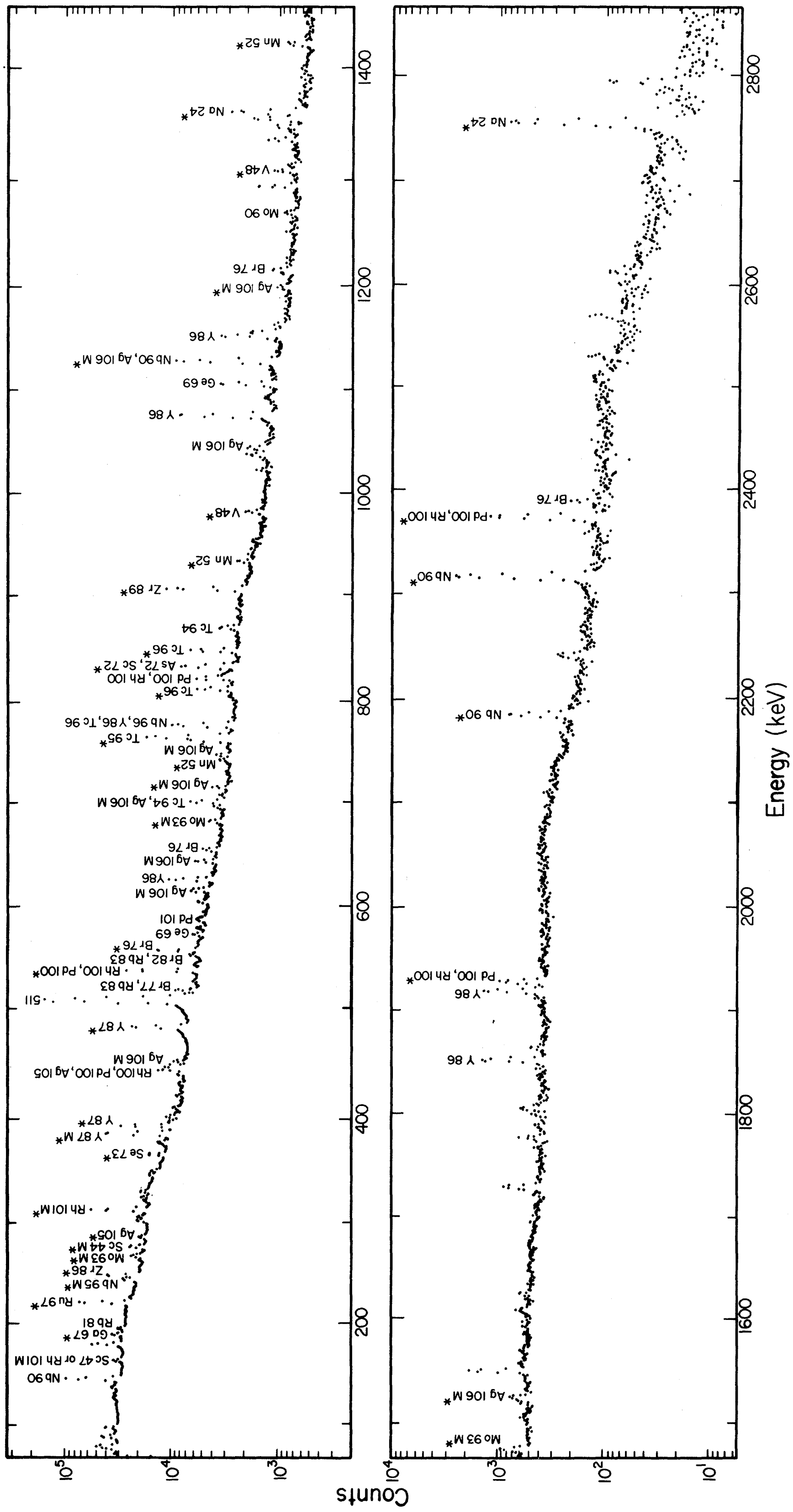

FIG. 1. γ-ray spectrum of silver taken one day after irradiation. Nuclidic assignments are made wherever possible. γ rays useful for cross-section determinations are starred.

In that work considerable effort was devoted to the assignment problem and to possible interference from γ rays of essentially the same energy. We were able to satisfy ourselves in that work that the cross sections for the formation of the nuclides listed below could be determined in a reliable manner. As an example of the quality of the data a γ-ray spectrum recorded approximately one day after irradiation is shown in Fig. 1. The identified peaks are surmounted with their nuclidic assignments, made on the basis of the above considerations. The starred γ rays were judged to be sufficiently well resolved and free from interfering activities, and to have well-enough known abundances, to be useful for cross-section determinations.

The various cross sections were determined on the assumption that the cross section of the monitor reaction ^{27}Al(p, 3pn) was the same at 300 GeV as at 10–30 GeV, 8.6 mb. In determining the saturation disintegration rates corrections were made for the variation of beam intensity during irradiation. The results are summarized in Table I which lists the 27 nuclides for which results have been obtained to date at 300 GeV, the cross sections obtained at 11.5 GeV,[2] and the ratios of the 300- to 11.5-GeV cross sections. The nuclides are labeled by (i) or (c) to denote independent or cumulative yields, respectively. The measurements at 11.5 GeV were performed with the same Ge(Li) spectrometer as those at 300 GeV and the data were analyzed in the same fashion; the cross-section ratios are thus free of systematic errors in counter efficiencies or γ-ray abundances. In those cases where more than one γ ray was determined for a given nuclide the cross-section ratios are based on the average of the ratios obtained for the individual γ rays. The quoted uncertainties in the ratios are based on the reproducibility of the 3–5 separate determinations performed at 11.5 GeV, ~7%, and the agreement of the three determinations at 300 GeV, ~7%.

TABLE I. Comparison of cross sections of products from 300-GeV proton bombardment of Ag, σ_{300}, with similar results at 11.5 GeV, $\sigma_{11.5}$ (Ref. 2). The σ_{300} are based on an 8.6-mb cross section for the monitor reaction ^{27}Al(p, 3pn).

Nuclide	$\sigma_{11.5}$(mb)	$\sigma_{300}/\sigma_{11.5}$
^{106m}Ag(i)	9.4	0.97 ± 0.05
^{103}Ru(c)	1.3	0.98 ± 0.08
^{101m}Rh(c)	21.5	1.04 ± 0.08
^{97}Ru(c)	14.2	0.98 ± 0.06
^{96}Tc(i)	7.1	0.96 ± 0.06
^{95}Tc(c)	15.7	0.92 ± 0.08
^{90}Nb(c)	16.0	0.86 ± 0.08
^{89}Zr(c)	15.7	0.91 ± 0.06
^{86}Zr(c)	5.0	0.89 ± 0.05
^{87m}Y (c)	15.0	0.92 ± 0.11
^{87}Y (c)	18.3	0.80 ± 0.05
^{84}Rb(i)	1.3	0.90 ± 0.10
^{83}Rb(c)	20.6	0.78 ± 0.10
^{77}Br(c)	8.8	0.81 ± 0.10
^{76}Br(c)	8.1	0.84 ± 0.08
^{73}Se(c)	3.8	1.00 ± 0.10
^{74}As(i)	5.9	0.78 ± 0.06
^{69}Ge(c)	5.6	0.94 ± 0.07
^{67}Ga(c)	7.6	0.92 ± 0.10
^{52}Mn(c)	1.8	0.96 ± 0.06
^{48}V (c)	2.5	0.99 ± 0.08
^{48}Sc(i)	0.5	0.91 ± 0.07
^{47}Sc(i)	2.1	0.92 ± 0.07
^{44m}Sc(i)	2.0	0.99 ± 0.12
^{28}Mg(c)	0.7	0.88 ± 0.10
^{24}Na(c)	4.1	1.08 ± 0.16
^{7}Be(c)	19.1	0.90 ± 0.15

It is seen that the cross-section ratios are essentially constant over the entire mass range, which includes the products of relatively simple nuclear reactions, those of more complex spallation, and light fragments. The cross-section ratios are close to unity, the weighted average value of $\sigma_{300}/\sigma_{11.5}$ being 0.91 ± 0.07. The recently reported[1] study of the interaction of vanadium and cobalt with protons of comparable energy indicated that both the spallation cross sections as well as the cross section of the monitor reaction ^{27}Al(p, 3pn) remained constant between 11.5 and 300 GeV. The present results indicate that the spallation yields from a heavier target nucleus are also nearly the same at both these energies. This fact indicates that the spectrum of excitation energies deposited in the struck nucleus does not significantly change between 11.5 and 300 GeV. Although pion production presumably increases markedly in this energy range, the increase is not reflected in the excitation energy of the struck nucleus. This suggests that most pions escape from the nucleus without significant energy loss.

A previously reported[3] comparison of the reactions of silver with 3- and 29-GeV protons indicated that the cross sections for the formation of light-mass products were as much as a factor of 2 higher at 29 GeV, while those for the formation of products in the $A = 70-90$ region were some 20% lower than at 3 GeV. These results showed that reactions which require very high excitation become somewhat more probable at 29 GeV, at the expense of reactions involving more moderate excitation. Evidently, this trend does not continue between 10–30 and 300 GeV, and the excitation energy spectrum for a silver target reaches a point of saturation at bombarding energies of 10–30 GeV.

Although our overall impression is that the interaction of high-energy protons with silver changes very little between 10–30 and 300 GeV, it is well to remember that activation cross sections do not provide a complete picture of this interaction. A more definite conclusion must await the results of recoil studies, energy spectra, and other measurements.

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Subthreshold Fission Induced by Neutrons on ^{238}U†

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Subthreshold fission is observed in ^{238}U(n,f) at 0.720, 1.210, 2.5, 7.5, 11, 15, 27, and 35 keV. Fission widths are obtained for the resonances at 720 and 1210 eV. The average fission cross section is 87 ± 26 μb for $10 \leq E_n \leq 30$ keV and 40 ± 12 μb for $30 \leq E_n \leq 100$ keV. The second potential minimum is deduced to lie ≈2.2 MeV above the first minimum.

A recent lead slowing-down spectrometer measurement of neutron-induced fission in a ^{238}U fission chamber indicated a large fission component near 800 eV, whereas no effect was observed in a blank chamber of identical construction. One plausible interpretation of this measurement was subthreshold fission in ^{238}U, although measurements by Silbert and Bergen[1] seemed to indicate that ^{238}U would have too small a fission cross section in this energy region to account for the large fission counting rate. In order to test for subthreshold fission in ^{238}U, it was decided to carry out a high-resolution time-of-flight beam experiment and see if the large fission component near 800 eV could be resolved into the fine structure characteristic of ^{238}U resonances in the first potential well.

The experiment was conducted at the Rensselaer LINAC laboratory with a 10.1-m flight path, the standard 2.54-cm-thick CH_2 moderator geometry,[2] an accelerator electron pulse width of 66 nsec, a repetition rate of 550 pulses/sec, and an electron beam power of 9 kW. Five fission ionization chambers, each 2.54 cm diam by 12.5 cm long, were coated with a total of 0.66 g of ^{238}U. The only significant impurity in the ^{238}U was 27 ± 6 ppm of ^{235}U, with less than 0.3 ppm of ^{233}U, ^{234}U, and ^{236}U. The ionization chambers were shielded with 0.75-mm-thick Cd, and a 0.75-mm-thick Cd overlap filter was placed in the beam at approximately 5 m; this resulted in a very low-background experiment with the count-