the bombardment of americium and curium samples, and to Nelson B. Garden and the Health Chemistry Group for providing the protective equipment used for the handling of the radioactivity involved. It is a pleasure to acknowledge the valuable assistance by Dr. R. W. Hoff and Mr. A. Chetham-Strode, Jr., in some of the experiments. It is a privilege to acknowledge that this work was accomplished with the helpful guidance of Professor Glenn T. Seaborg.

† This work was performed under the auspices of the U. S. Atomic Energy Commission.

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Disintegration of Bismuth by 2.2-Bev Protons*

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(Received July 23, 1954)

THE irradiation of bismuth with 2.2-Bev protons from the Brookhaven Cosmotron produces a large number of radioactive species. We report here on the cross sections for the formation of some of them.

Foils of bismuth metal were exposed in the circulating proton beam of the Cosmotron. During most of the irradiations, the beam intensity was approximately 10^{10} protons per pulse and the repetition rate was 1 pulse per 5 seconds. The number of protons striking the target was determined from the Na^{24} activity produced in a 0.003-inch aluminum monitor foil adjacent to the bismuth target. The cross section for the production of Na^{24} is approximately 9 millibarns at 2.2 Bev.[1]

Table I lists the products for which cross sections have been determined. After isolation from the target, the radioactivity of each species was measured by a calibrated proportional counter or a NaI scintillation counter. The alpha activity was measured directly in thin target foils.

TABLE I. Formation cross sections from 2.2-Bev protons in bismuth. All values are based on a cross section of 9 mb for the reaction $Al^{27}(p,3pn)Na^{24}$.

Product observed	σ(mb)	Product observed	σ(mb)
Pb^{203}	26	Ba^{129}	1.9
Tl^{202}	3	Ba^{128}	4.3
Tl^{201}	20	Sr^{91}	0.48
Tl^{200}	12	Sr^{89}	1.4
Tl^{199}	27	Br^{82}	0.22
Tl^{198}	15	Br^{80m}	0.67
Tb^{149}	0.95[a]	Ge^{75}	0.53
$Dy^{149-153}$ (19 min)	0.62[a]	Ge^{69}	0.65
$Dy^{149-153}$ (7 min)	1.77[a]	Ge^{66}	0.17
Ba^{131}	5.5		

[a] These nuclei were detected by their alpha activity. The cross sections are for the alpha branch only; the decay branching ratio is not accurately known. For this reason and also because these particular isotopes are highly neutron-deficient, the cross sections given represent only lower limits for the formation cross sections for these mass numbers.

The variation of cross section with mass number is strikingly different from that observed in the hundred-Mev range. Though only a few products have been measured at 2.2 Bev, there appears to be a monotonic decrease of cross section with decreasing Z of the product.[2] This is in contrast to the results obtained in the irradiation of bismuth with 190-Mev deuterons[3] or 340–450 Mev protons.[4] At the lower energies, there is a hump in the cross section curve centered at mass 95–100 with a total cross section of about 200 millibarns. This group of products, attributed to fission, is well separated from the spallation products. The present experiments at the higher energy indicate that, first, spallation with the emission of a large number of nucleons has become more probable, while, second, the division of the target nucleus into two fragments of approximately equal mass has become less probable, so that it is no longer possible to see in the yield *vs* mass curve a sharp division between the two processes. For example, the cross section for the production of Sr^{89} at 2.2 Bev is about 1/5 of that found with 190-Mev deuterons or ~400-Mev protons, while that for the production of mass number 149 is at least 100 times as large at 2.2 Bev as at 190 Mev. The absence, at 2.2 Bev, of a trough in the yield curve between spallation and fission regions has already been reported in preliminary work on reactions with lead.[5] Here a gross rare earth fraction (approximately representing mass numbers 130 to 180) was found to contain about 70 percent of the total x and γ activity of an irradiated lead target, while in a 380-Mev proton bombardment the corresponding fraction was of the order of one percent. The cross section for the formation of Ce^{141} from lead is about 100 times larger at 2.2-Bev than at 380-Mev proton energy.

A few very preliminary experiments have been done to determine the recoil momenta of the radioactive products. It has been found that the ranges in aluminum (mg/cm^2) at 0° to the proton beam of some products are as follows: $Br^{80,82}$, ~3.2; $Sr^{91,92}$, ~3.3; $Ba^{128,129}$, ~1.5; Tb^{149}, ~1. From a thick bismuth target, approximately 5 times as many Tb^{149} recoils were found on a catcher foil in the forward direction as compared to the backward direction to the proton beam. The corresponding ratio in thick targets for $Ba^{128,129}$ was 3.8, and for $Sr^{91,92}$, 1.2. This would appear to mean that the center-of-mass motion accounts for a large part of the range of the Ba and Tb recoils in the forward direction, but does not exclude the possibility that lighter products, such as Sr and Br, result largely from a fission reaction in which only a small portion of the kinetic energy of the incident proton is used for nuclear disintegration.

Finally, a detailed analysis of the results on the barium, strontium, and bromine nuclides at 2.2 Bev shows that the high-yield primary products are more neutron-deficient than those observed in the previously cited work[3,4] at lower energies. The $Tl^{200,201}$ activities in the present experiments, as at lower energy,[6] result primarily from the decay of lead and bismuth predecessors rather than from independent production. This probably accounts for the relatively low yield of Tl^{202}, a shielded nuclide.

We are grateful to many members of the staff of the Brookhaven National Laboratory for cooperation on these experiments, in particular, Dr. G. B. Collins and the operating staff of the Cosmotron.

* Research carried out under the auspices of the U. S. Atomic Energy Commission.

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Errata

New Absorption Lines of Crystals in Submicrowave Region, S. KOJIMA, K. TSUKADA, S. OGAWA, AND A. SHIMAUCHI [Phys. Rev. **92**, 1571 (1953)]. "Rock salt," which appeared three times in the printed text, should read "rock crystal (quartz)."

Reaction Concept in Electromagnetic Theory, V. H. RUMSEY [Phys. Rev. **94**, 1483 (1954)]. Equation (50) of this paper needs some further explanation. The reaction in anisotropic media was given in the form

$$\langle a,b\rangle=\int\int\int[\mathcal{E}(b)\cdot d\mathbf{J}(a)-\mathcal{H}(b)\cdot d\mathbf{K}(a)]. \quad \text{(E-1)}$$

Now the reciprocal relation for this class of fields is

$$\int\int\int[\mathcal{E}(b)\cdot d\mathbf{J}(a)-\mathcal{H}(b)\cdot d\mathbf{K}(a)] =\int\int\int[\mathbf{E}(a)\cdot d\mathbf{J}(b)-\mathbf{H}(a)\cdot d\mathbf{K}(b)], \quad \text{(E-2)}$$

and $\langle a,b\rangle$ is not equal to $\langle b,a\rangle$ in general. However, the methods described in the paper for isotropic media can be carried over to anisotropic media without difficulty. To retain the same notation as for the isotropic case, it seems better to define $\langle a,b\rangle$ by the formula

$$\langle a,b\rangle=\int\int\int[\mathbf{E}(b)\cdot d\mathbf{J}(a)-\mathbf{H}(b)\cdot d\mathbf{K}(a)] \quad \text{(E-3)}$$

instead of (E-1), and use the notation

$$\langle a,b\rangle'=\int\int\int[\mathcal{E}(b)\cdot d\mathbf{J}(a)-\mathcal{H}(b)\cdot d\mathbf{K}(a)] \quad \text{(E-4)}$$

to denote the expression in (E-1). Thus

$$\langle a,b\rangle'=\langle b,a\rangle. \quad \text{(E-5)}$$

The quantity $\langle a,b\rangle$ can still be interpreted as the result of making an observation of the field generated by source b by using a as a test source, and thus the apparatus of the reaction theory still applies. The quantity $\langle a,b\rangle'$ represents the same thing, except that the environment in which the field generated by b exists is obtained from that to which $\langle a,b\rangle$ refers by transposing the tensors $\mu\epsilon$ and σ.

Elastic Scattering of 190-Mev Deuterons by Protons, OWEN CHAMBERLAIN AND MARTIN O. STERN [Phys. Rev. **94**, 666 (1954)]. In this paper, we presented experimental results on the elastic scattering of 190-Mev deuterons by protons, and attempted to compare these results with predictions based on the impulse approximation. Various potentials were used to represent the nucleon-nucleon interaction.

It has been called to our attention that an earlier publication of Daitch and French[1] also considered the relationship between nucleon-nucleon and nucleon-deuteron scattering. In particular, their relations (7) are equivalent to our Eq. (13) and Table V. These relations concern the energies and angles of nucleon-nucleon scattering to be used in calculating the deuteron-proton scattering.

We regret that, due to an oversight, reference to the work of these authors was not made.

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Influence of the Earth's Magnetic Field on the Extensive Air Showers, GIUSEPPE COCCONI [Phys. Rev. **93**, 646 (1954)]. In the discussion of the importance of the displacement D_m of the electrons in an extensive air shower caused by the earth's magnetic field, two mistakes were made which have been pointed out to the author by Professor K. Greisen. (a) The fact that an electron of a certain sign can have had parents of different sign before reaching the detecting apparatus decreases D_m by