Using (4), it is readily shown that

$$\frac{d\delta_l(\epsilon)}{d\epsilon}=-\int_0^\infty\left(\frac{dv_\epsilon}{d\epsilon}\right)(G_{l\epsilon}{}^2+F_{l\epsilon}{}^2)dx. \tag{8}$$

But

$$\frac{dv_\epsilon}{d\epsilon}=\frac{\gamma}{\epsilon^2}\int_{x/\epsilon}^\infty \rho x dx. \tag{9}$$

Therefore

$$\delta_l<0, \tag{10}$$

providing ρ is positive everywhere. Rewriting (8) with the aid of (9),

$$\frac{d\delta_l(\epsilon)}{d\epsilon}=-(\gamma/\epsilon^2)\int_0^\infty \rho(x')x'\left\{\int_0^{x'}\left[G_{l\epsilon}{}^2(x)+F_{l\epsilon}{}^2(x)\right]dx\right\}dx'. \tag{11}$$

From this it seems plausible that the phase shifts tend monotonically toward zero with increasing l, since the inner integral probably decreases with increasing l (fixed x').

In conclusion, we should point out the actual source of error in Elton's paper. He estimates the phase shifts (for large l) by the approximation

$$\delta_l\cong-\int_0^\infty (V_l/\alpha)G_l{}^2dx, \tag{12}$$

where

$$\begin{aligned}V_l=&(v_E-v_P)(2-v_E-v_P)+x^{-1}(l+1)[(\alpha_P'/\alpha_P)-(\alpha_E'/\alpha_E)]\\&+\tfrac{3}{4}[(\alpha_E'/\alpha_E)^2-(\alpha_P'/\alpha_P)^2]-\tfrac{1}{2}[(\alpha_E''/\alpha_E)-(\alpha_P''/\alpha_P)],\end{aligned} \tag{13}$$

$$\alpha=1-v.$$

The subscript P refers to the point charge and E to the extended charge. Elton considers the term in $(l+1)$ to be dominant for large l, leading to $\delta_l\rightarrow+0$. The fallacy in the argument lies in neglecting the fact that G_l depends on l. This can be seen by carrying out an integration by parts in the term involving the second derivatives of α_E and α_P. The result is a contribution which cancels the term which Elton considered to be dominant.

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* Supported in part by the Office of Scientific Research, Air Research and Development Command.

[1] L. R. B. Elton, Proc. Phys. Soc. (London) **A65**, 481 (1952). In a private communication, Dr. Elton concurs that his paper is in error.

[2] L. R. B. Elton, Proc. Phys. Soc. (London) **A66**, 806 (1953). In deriving (4), Elton takes one of the two potentials to be the Coulomb potential, but the proof is also valid for any two potentials so long as the integral converges.

Further Production of Transcurium Nuclides by Neutron Irradiation

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IN a continuation of the work previously reported,[1] we have succeeded in producing and chemically identifying an isotope of the element with atomic number 100 through neutron irradiation of the heavy californium isotopes in the Materials Testing Reactor. The method of chemical isolation consisted of precipitation and ion exchange procedures,[1] and the atomic number identification depends on the position in the elution sequence in the ion exchange adsorption-elution method of separation of the actinide elements.[2]

Alpha particles of roughly 7.2-Mev energy and about 3-hour half-life were found in the ion exchange column fraction corresponding to the eka-erbium position immediately preceding the 6.6-Mev alpha particles[1] due to element 99 which eluted in the eka-holmium position immediately preceding the californium alpha activity.[1] Although the amount of activity was small, the identification of atomic number is regarded as definite.

The isotope of element 100 emitting the approximately 7.2-Mev alpha particles is tentatively assigned[3] as 100^{254}, and a possible reaction sequence leading to its production might be the following:

$$\mathrm{Cf}^{252}(n,\gamma)\,\mathrm{Cf}^{253}\xrightarrow{\beta^-}99^{253}(n,\gamma)99^{254}\xrightarrow{\beta^-}100^{254}.$$

Because of the existence of unpublished information on element 100 the question of its first preparation should not be prejudged on the basis of this paper.

It is a pleasure to acknowledge that this work was accomplished with the helpful guidance of Professor Glenn T. Seaborg. Special thanks are due Almon E. Larsh for his valuable assistance with some of the measurements. We wish to acknowledge the help of Dr. W. B. Lewis and the entire Phillips MTR staff for aid in the irradiation of the sample. The continued interest and encouragement of Professor Ernest O. Lawrence and the support of the U. S. Atomic Energy Commission are gratefully acknowledged.

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[1] Thompson, Ghiorso, Harvey, and Choppin, Phys. Rev. (to be published).

[2] See, e.g., G. T. Seaborg, *Transuranium Elements: Survey*, edited by G. T. Seaborg and J. J. Katz (McGraw-Hill Book Company, Inc., New York, 1954), National Nuclear Energy Series, Plutonium Project Record, Vol. 14A, Div. IV, Chap. 17 (to be published).

[3] G. T. Seaborg, University of California Radiation Laboratory Report UCRL-1942, March, 1952 (unpublished). (Ohio State University Third Annual Phi Lambda Upsilon Lecture Series.)

Total Cross Sections of 135-Mev to 250-Mev Negative Pions in Hydrogen*

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TRANSMISSION measurements yielding the total cross section for the interaction of negative pions with protons have been reported by Anderson *et al.*[1] at Chicago and by Yuan and Lindenbaum[2] at Brookhaven. The Chicago measurements showed a rapid increase of the cross section above 80 Mev with a leveling off or perhaps a maximum at 66±6 millibarns in the region of 150 to 200 Mev. The Brookhaven measurements above 265 Mev gave values well below the maximum Chicago value, thus confirming the existence of a maximum in the cross section in the energy range of the Chicago experiments. The work reported here with the 450-Mev Carnegie Institute of Technology cyclotron covers the energy range from below to above the maximum with the same technique and with somewhat better accuracy than before. This permits the location of the maximum of the cross section within rather narrow limits.

Up to 220 Mev, the experiments have been made with quite intense and well-collimated beams of negative pions with intensities from 300 to 500 particles/cm² sec. At the highest energy, 260 Mev, the beam is reduced to about 3 particles/cm² sec, but this is readily usable for transmission measurements. The pions emerge from channels in the 8-foot magnetite concrete shielding, pass through a double-focusing deflecting magnet which bends them through 45°, and enter a monitoring telescope which determines the number of particles incident. The monitor telescope consists of three stilbene crystals, 4 cm in diameter and ½ cm thick, with a total separation of 115 cm. The beam next traverses the absorber, a

TABLE I. Total cross sections of negative pions in hydrogen.

Energy Mev	Cross section 10^{-27} cm²	Error (10^{-27} cm²)	
		Statistical	Total
133±7	46.9	±1.3	±2.4
157±8	62.9	±1.0	±2.4
179±8	65.9	±1.2	±2.5
194±7	64.6	±1.2	±2.5
195±7	63.1	±1.3	±2.5
215±8	55.5	±1.0	±2.2
236±7	46.1	±1.7	±2.4
240±7	43.5	±1.6	±2.3
258±9	38.2	±3.0	±3.4

column of liquid hydrogen, 4.7 inches long in the beam direction, contained in a styrofoam box.[3,4] The mesons that are not absorbed are detected by a 4-inch diameter liquid scintillation counter in coincidence with the monitor, with mid-plane 22 cm from the center of the hydrogen and 42 cm from the third monitor counter. A dummy target with total thickness of 6 inches of styrofoam in the beam direction was used to obtain the effect of the styrofoam on the transmission. From the ratio of the transmissions (fourfold to threefold coincidences) with and without hydrogen, one obtains directly the total cross section.

In Table I, we have listed the cross sections obtained after the necessary corrections have been applied. Corrections have been made for the following effects:

(1) The incident beam is diluted by the presence of muons to the extent of 5 to 10 percent. The muons are assumed to traverse the hydrogen with no absorption. The percentage of muon contamination is estimated from the range curve for the incident beam (taken with copper absorber) and is probably uncertain to ±2 or 3 percent. The electron contamination of the beam was shown to be unimportant.

(2) Accidental coincidences in the last detecting counter give an occasional apparent transmission when the meson is really absorbed. These accidentals range from 1 to 3 percent and are considered uncertain to ±0.5 or ±1 percent.

(3) Mesons scattered forward into the solid angle defined by the last counter are not recorded as scattered. In addition, a meson scattered sufficiently backward gives a recoil proton which may be detected and thus give a false transmission. Corrections for these events were made on the basis of the Chicago angular distributions of negative pion scattering in hydrogen.[5] They amount to about 3 millibarns with an uncertainty of perhaps ±1 millibarn.

(4) Effects caused by the angular spread of the beam. From the geometry used and from the measured divergence of the beam, the divergence effects can be shown to be negligible.

The last two columns of Table I contain estimates of the errors in the results. Since we feel that a systematic error which varies strongly with the meson energy is unlikely in view of the fact that all measurements were taken with the same equipment, we have given the error due to counting statistics alone as a measure of the relative error in the measurements. The last column contains an estimate of the total error, taking account of the uncertainties already mentioned. The first column gives the mean meson energy in the center of the hydrogen and the combined energy spread due to the beam inhomogeneity and the energy loss in the hydrogen.

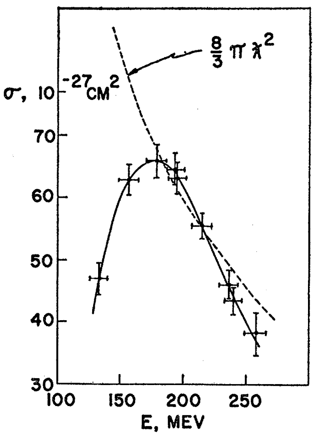

FIG. 1. Total cross sections of negative pions in hydrogen.

The total cross sections are also shown graphically in Fig. 1 with a smooth curve drawn through the points. It is of some theoretical interest[6] to compare the measured values with $(8/3)\pi ƛ^2$, the maximum possible negative meson cross section for the $P_{\frac{3}{2}}$ state of isotopic spin $\frac{3}{2}$. If there is a resonance in this state, the data would indicate that it lies somewhere near 200 Mev and that in this region the other states of angular momentum and isotopic spin contribute surprisingly little to the total cross section. From the total cross section measurements alone it is not possible to decide whether the resonance is real. Measurements of the angular distribution of the scattered mesons in this energy range have been performed at Chicago, but the analysis is so far not complete.[7]

It is a pleasure to express our thanks to S. Friedberg and J. Zimmerman of the Carnegie Institute of Technology Low Temperature Laboratory for expert advice in the production and handling of liquid hydrogen.

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[1] Anderson, Fermi, Long, and Nagle, Phys. Rev. **85**, 934 (1952).

[2] L. Yuan and S. J. Lindenbaum, Bull. Am. Phys. Soc. **28**, No. 6, 13 (1953); Phys. Rev. **92**, 1578 (1953).

[3] We wish to thank L. Marshall for information about the styrofoam target for liquid hydrogen which was used in connection with the proton-proton scattering experiments at Chicago.

[4] The styrofoam box containing the hydrogen was lined with a one-mil copper form to keep the hydrogen from having direct contact with the plastic and to better define the geometrical volume occupied by the hydrogen. Nevertheless, we consider that we do not know the thickness of hydrogen in the beam direction to better than ±2 percent. This is taken into account in the final error quoted on the cross sections, but should not affect the relative values at different energies.

[5] Fermi, Glicksman, Martin, and Nagle, Phys. Rev. **92**, 161 (1953).

[6] K. A. Brueckner, Phys. Rev. **86**, 106 (1952).

[7] See, however, R. L. Martin, Bull. Am. Phys. Soc. **29**, No. 1, 28 (1954), where a phase shift analysis showing a resonance is reported.