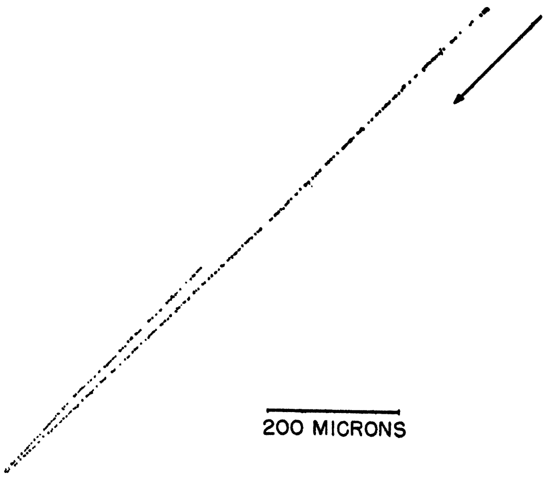

FIG. 2. Large angle meson scattering. The length of the incoming meson track is 8000 microns. The angle of scattering is 177 degrees. Observed by Leon Lederman.

In order to compute the relative numbers of π^-- and μ^--mesons, the ratio of σ- to ρ-mesons[1,2] stopping in another group of plates placed after an additional absorber was determined. After making a small correction for the nuclear absorption of π^--mesons in this last absorber, a total of 900 cm of π^--track was obtained in the 30- to 50-Mev energy range. This length was further reduced to 780 cm by the correction for the condition on the minimum length of tracks. In this way a mean free path of 29 cm of emulsion was obtained. The geometric mean free path is 25 cm.

A similar study is in progress to determine the interaction in emulsions of the directly incident mesons (energy about 95 Mev). Up to the present, 13 stars, 3 inelastic scatterings, and one elastic scattering have been observed. Further reports on both experiments will be made when better statistics are available.

The authors wish to thank Dr. Hugh Bradner, Berkeley, California, for privately communicating to us his results on an experiment of a similar nature. They also wish to thank Mr. S. Lindenbaum for assisting with the computations of the meson orbits, and Messrs. R. Durbin, W. Goodell, and H. Loar for performing counter experiments for locating the meson beam.

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† Now at the University of Rochester, Rochester, New York.
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Secondary Electron Emission and Atomic Shell Structure*

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A SIMPLE correlation has been found between the maximum value of the true secondary electron yield (Δ_m) and the atomic shell structure of the elements. The values of Δ_m, defined as the number of low energy ($\lesssim$50 ev) electrons leaving the surface per incident primary electron, were obtained by subtracting the fraction of high energy back-scattered electrons (η) from the maximum total yield coefficient δ_m reported in the literature.

Table I lists the data used in this investigation. The data obtained by Bruining and DeBoer and Warnecke have been used wherever possible in view of the careful experimental techniques used by these workers, which insured a maximum degree of freedom from surface impurities and uncertainties due to multiple scattering between target and collector. For the remaining elements, the results of other authors were used whose measurements on "standard" materials such as Ni, Cu, and Au agreed to better than 10 percent with the values found by Bruining and DeBoer and Warnecke. The values of δ_m listed in Table I agree to better than 5 percent with those given by McKay,[1] except in the cases of Pt, K, Be, and Fe, where they differ by about 10 percent because the work of different authors was chosen for reasons mentioned above.

TABLE I. Values of maximum total yield δ_m.

Element	δ_m	±%	Element	δ_m	±%	Element	δ_m	±%
Ni*	1.24;[a] 1.28[b,†,d]	5	Zr	1.10[a]	5	K	0.78[e]	10
Cu*	1.28;[a] 1.29;[b] 1.40;[c,†,f]	5	Ag	1.53[a]	5	Rb	0.90[e]	10
Au*	1.58;[b] 1.50;[c] 1.56;[e] 1.44[g]	5	Cs	0.76[a]	5	Co	1.16[d]	5
Li	0.47[a]	5	Ba	0.83[a]	5	Cd	1.13[e]	10
Be	0.51[a]	5	Cb	1.17[b]	5	Fe	1.11[f]	10
Mg	0.93[a]	5	Mo	1.25[b]	5	Pt	1.79[g]	10
Al	0.97[a]	5	Ta	1.28[b]	5	Si‡	1.1[h]	>10
Ti	0.92[a]	5	W	1.36[b]	5	Ge‡	1.2[h]	>10

* Standard values for comparison.
† Data do not extend as far as the maximum yield.
‡ Tentative, pending more detailed investigations.
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Experimental values of η from nine elements ranging from $Z=6$ to $Z=79$ at primary energies from 2 to 16 kv have recently been obtained by Palluel.[2] His results indicate that η is very nearly independent of the energy for all except the heaviest elements, where back-scattering appears to increase somewhat with increasing primary energy. Using these data, as well as those of Schonland[3] at higher energies, the following empirical equations for η as a function of Z were found to hold:

$$\eta=0.01Z \quad (\pm 5 \text{ percent}) \quad \text{for } Z<30;$$
$$\eta=0.18+0.004Z (\pm 10 \text{ percent}) \quad \text{for } Z>30.$$

The values of Δ_m obtained for 24 elements are plotted against Z in Fig. 1.

It is seen that a surprisingly regular pattern emerges when elements of neighboring atomic numbers are grouped together (heavy

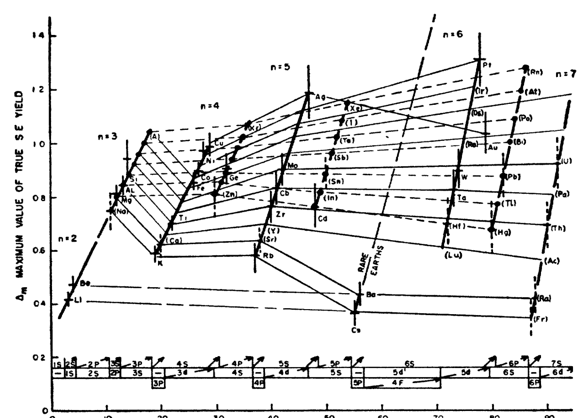

FIG. 1. Plot of the maximum value of the true yield *versus* the atomic number. Solid vertical bars—experimental points; dotted vertical bars—sample predicted values.

slanting lines), and when elements of similar outer shell configuration are connected (light horizontal lines). Δ_m increases steadily as long as successive shells are filled without leaving an inner shell vacant. Whenever a new shell is begun outside of one that is subsequently filled, as for $Z=19$, 37, 55, and 87, Δ_m drops discontinuously. Likewise, when an inner shell is completed and a new sub-shell is begun, as for $Z=30$, 48, 71, and 80, Δ_m drops to a lower value, thereby giving rise to two parallel sets of lines for complete and incomplete inner shell structures. Δ_m varies as the number of outer shell electrons, so that it appears to be a true atomic property much like the x-ray emission characteristics of the elements.

The regularity of the plot is such that it is possible to complete it as indicated in Fig. 1 for values of Z where no data are at present available.[4] This makes it possible to predict the values of Δ_m to better than 10 percent for nearly all metals in the atomic table. The basic pattern as it appears in Fig. 1 is not materially affected by relatively large errors in η or δ_m, and it is even apparent when δ_m is plotted against Z.

Present theories of secondary emission are based on the Fermi gas[5,6] or Bloch model[7,8] of a metal. These theories predict a dependence of the yield on the lattice spacing, Fermi energy level, and work-function, but not on the atomic shell structure. The simple correlation of Δ_m with position in the periodic system would seem to indicate that a satisfactory theory of secondary emission must take into account atomic electrons more firmly bound than the valence or conduction electrons of a metal.

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* Preliminary results were reported at the April 1949 meeting of the American Physical Society (see Phys. Rev. **76**, 189 (1949)). A detailed account is being prepared for publication.

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