onstrated that these patterns were due merely to the electrostatic repulsion of the ions in the beam by the charge which accumulated on the crystal and the crystal holder. By applying an electric field across the beam to remove the ions, the fan-shaped patterns disappeared, the crystal remained clear, and its high reflecting power persisted for a long time.

With the discovery of this effect of ion bombardment on the reflecting power of LiF it became of interest to make a reinvestigation of the reflecting power of NaCl and KCl with the ions removed from the beam. The reflection from these crystals, however, appeared to be unaffected by the ion concentrations present.

The fact that the electrostatic charging of an insulated surface can deflect a beam of ions into irregular patterns, shows that one must be cautious in interpreting any pattern as the diffraction of de Broglie waves when ions or electrons are reflected from insulated crystals.

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February 19, 1930.

Multiple Coincidences of Geiger-Müller Tube-Counters

The ordinary method of coincidences [e.g. Bothe and Kolhörster, Zeits. f. Physik **56**, 751 (1929)] does not make possible the performance of experiments upon the individual very high energy β-particles which presumably give rise to the coincidences between Geiger-Müller tube-counters (*elektronenzahlröhre*), chiefly because suitable collimation by slits is nearly impossible in the interesting region of very high energies (10^8 to 10^9 volts) which this new instrument has opened to analytical experimental attack. It occurred to the writer some weeks ago that the observation of the coincidences between *three* tube-counters would make such a study possible. The first two counters would serve as a slit-system, defining a beam and "picking out" individual particles to be observed while the third movable counter would serve to detect these particles after being scattered, deflected by a magnetic field, or otherwise subjected to experimental conditions. Experiments are under way here for obtaining information on the probability of deflection of such extremely fast β-particles in various (small) angles in passing through a scattering block. The theory of multiple scattering indicates that the deflections may be below the practical limits of angular resolution, but even an upper limit, experimentally determined, for such extremely fast particles will be of interest. Other applications are readily devised.

This arrangement has another advantage which may be immediately appreciated—that of increased "resolving power" against accidental coincidences. If the resolving power of the means for determining coincidences between two tube-counters is such that say one out of 200 (residual) counts (a practical figure) in each individual tube-counter will be accidentally "coincident" within the specified range of resolution, the probability of such an accidental coincidence of *three* tube-counters within the same range of resolution is 1 out of 40,000. The idea of the *multiple*-coincidence method using a series of counters is an obvious extrapolation. Theoretically, any desired degree of freedom from accidental coincidence can readily be obtained, provided, of course, that the efficiency of counting is 100 per cent, as has been shown to be approximately true for β-particles. We do not yet have sufficient data to say how nearly true this is for the very fast particles with which we are dealing. Scattering deflections of the primary particle at the walls of the counters or in the air between counters will set an ultimate limit on the resolution which can be reached in practice even with perfect counting. Secondary effects may also be of importance. The actual resolving power will be less than that calculated on a probability basis also by reason of true coincidences produced only in part of the series of tube-counters by particles not capable of passing through the whole series. There is no doubt, however, that enormously increased resolving power can be obtained by the requirement of multiple instead of paired coincidences. The attainment of very great freedom from accidental coincidences is of greatest importance when it is desired to reduce the solid angle subtended by the tube-counters for true coincidences to a small figure, because of the large number of residual counts in comparison to those due to the very small intensity of the penetrating radiation. The possibility of using the multiple-coincidence method as the basis of a "gamma-ray telescope" for exploring small areas of the sky is being investigated. The intensity of the penetrating radiation is very low for such a purpose if the definition of really small areas is desired unless, of course, later observations show the penetrating radiation to come from particular small areas of the sky rather than uniformly from all directions. An estimate hazarded on the basis of present data, assuming uniform intensity per unit solid angle, gives as the order of magnitude one true coincidence per 1,000 minutes for counters of cross-section 50 cm^2, subtending one square degree in the sky. Automatic recording of the amount of the penetrating radiation coming from particular areas of the sky, using two tube-counters and a special "coincidence circuit" somewhat similar to that recently published by Bothe [Zeits. f. Physik, **59**, 1 (1929)] was begun here early last November. The resolving power (for our circuit between 0.005 and 0.001 second) of such an arrangement without *multiple* coincidences constitutes a severe limitation on the smallness of the area which can be observed.

A few practical notes on a brief oscillographic study of the recovery-time of a tube-counter and associated amplifier-circuits under various conditions may be of interest to others who are using the instrument. The high resistances (5×10^9 ohms) used by Geiger and Müller and others require the tube-counter to operate at a variable voltage, since the time-constant of the circuit is even larger than the average time between counts, whereas lower resistances restrict the range of voltages which give satisfactory counting. By connecting the central wire of the tube-counter directly to the grid of the amplifier-tube, the recovery-time of the tube-counter may be observed. Oscillograms have been taken using this circuit with resistances from 1 to 5,000 megohms. The recovery-time increases rapidly as the voltage is raised above the minimum critical voltage at which counts begin (which is the same for all values of R), and varies by a factor of perhaps five for different single counts at any given voltage. The average recovery-time (to within five volts of the initial potential on the central wire) varies from perhaps 0.002 second at a voltage midway in the working range (of only a few volts) for $R=1$ megohm, to two seconds or more for $R=5{,}000$ megohms, where the true working range (actual voltage between central wire and tube) is considerably more than 100 volts. In spite of this very long recovery time of the tube-counter itself, however, a $0.00004\mu f$ blocking condenser between the tube-counter and the amplifier-grid, and a grid-resistance of 10 megohms, as used by Bothe, gives satisfactory counts on the first amplifier-tube up to several hundred per minute, and the recovery-time of this amplifier-tube is of the order of 0.001 second. The oscillograms using this arrangement show that of two counts 0.01 second apart the second one will be usually missed, but counts 0.1 second apart give ample impulses (UX201A tubes were used). These results could have been safely inferred, but perhaps some interest may be attached to their demonstration by oscillograms.

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Temperature Shift of Spectral Lines and Pole Effect in Vacuum Arc

The work of many investigators has shown that the wave-length of most emission lines is a linear function of the total pressure acting when the vapor is in an arc, a furnace, or an absorption tube. It has been considered that the pressure shift per atmosphere is independent of the temperature. This implies that the experimental wave-length of a line from a source operating at constant pressure is independent of temperature. The chief purpose of this note is to report experimental evidence indicating that this view may be incorrect.

Two conclusions may be drawn from previous work: (1) that the wave-length of a line under given conditions of temperature and pressure is, at least for low values, independent of the partial pressure of the vapor, and (2) that ionic density plays a small part, if any, in the phenomenon of pressure shift. The first is justified by the conclusion of Babcock[1] that pressure shift is independent of changes in vapor density. The second may be justified by consideration of the results of King[2] and of Füchtbauer, Joos, and Dinkelacker.[3] King found a larger pressure shift per

[1] Babcock, Astrophys. J. **67**, 240 (1928).
[2] King, Astrophys. J. **35**, 183 (1912).
[3] Füchtbauer, Joos, and Dinkelacker, Ann. d. Physik **71**, 204 (1923).