Case A. When $r_1^2a^2$ is small compared with br_1^2 we have the full space-charge condition and (13) reduces to

$$V|_1^2 = b^{\frac{1}{2}} \int_{r_1}^{r_2} \frac{(r^2 - r_1^2)^{\frac{1}{2}}}{r} dr. \quad (15)$$

Peirce[2] Eq. (131) gives

$$V|_1^2 = b^{\frac{1}{2}}([r_2^2 - r_1^2]^{\frac{1}{2}} - r_1 \cos^{-1}[r_1/r_2]). \quad (16)$$

Case B. When $r_1^2a^2$ is large compared with br_1^2 we have a transition equation from the full space-charge condition to no space charge. Here (13) reduces to

$$V|_1^2 = b^{\frac{1}{2}} \int_{r_1}^{r_2} \frac{(r^2 + r_1^2 a/b)^{\frac{1}{2}}}{r} dr. \quad (17)$$

Peirce[2] Eq. (130) gives

$$V|_1^2 = (r_1^2a^2 + br_2^2)^{\frac{1}{2}} - (r_1^2a^2 + br_1^2)^{\frac{1}{2}} + r_1 a \log_\epsilon \frac{r_2}{r_1} \frac{r_1 a + (r_1^2a^2 + br_1^2)^{\frac{1}{2}}}{r_1 a + (r_1^2a^2 + br_2^2)^{\frac{1}{2}}}. \quad (18)$$

Case C. When $r_1^2a^2$ is large compared with both br_1^2 and br_2^2. In this case the current is limited by back diffusion only and Eq. (18) reduces to

$$V|_1^2 = r_1 a \log_\epsilon r_2/r_1. \quad (19)$$

As previously stated, the above equations are all in c.g.s. electrostatic units. For calculation we will want to use cm, gram, second, volts, amperes per cm, length, and mobility in cm/sec./volt/cm. In that case a remains

$$a = \frac{c}{(6\pi)^{\frac{1}{2}}\mu}\left(\frac{i}{I-i}\right), \quad (20)$$

and b becomes

$$b = 0.903 \times 10^{12}\, 2i/\mu. \quad (21)$$

It was interesting to find experimentally that these equations which are based on a constant mobility gave a good fit to the experimental volt-ampere characteristics, under a wide variety of conditions, for both electron and lithium positive ion emitters in air at atmospheric pressure.

[1] J. J. Thomson, *Conduction of Electricity through Gases* (The Cambridge University Press, New York), second edition, p. 267.
[2] B. O. Peirce, *A Short Table of Integrals* (Ginn and Company, New York).

Note on Thickness of Quartz Wafers for Observed Surface Phenomena

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The writer and his co-workers have reported some effects occurring on thin crystals.[1–3] In this work the critical thickness has been given as 25–30 microns. These figures for thickness do not take into account the depth of the etch pits developed on the surface. Examination of the cross sections of some of the plates, and more recent work with smoother surfaces indicate that the thickness is ~10 microns.

[1] D. D'Eustachio and S. B. Brody, Phys. Rev. **69**, 256 (1946).
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Spontaneous Emission of Neutrons from Uranium*

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Flerov and Petrzhak[1] have established the existence of spontaneous fission in uranium by recording the heavy fission fragments with a uranium-coated ionization chamber. The partial decay constant of the "average uranium atom" calculated from their data lies between 2×10^{-25} and 2×10^{-24} sec.$^{-1}$ for this process. It seemed possible that the mechanism of spontaneous fission might be different from that of induced fission, in particular that no neutrons might be split off in the former process. Libby[2] had previously made an unsuccessful attempt to find spontaneous fission neutrons with the help of a boron counter. His results indicated an upper limit for the partial disintegration constant of 2×10^{-22} sec.$^{-1}$ for spontaneous fission with neutron emission. We have now carried out an experiment with a more sensitive calibrated arrangement, using a hydrogen-filled ionization chamber which allowed us to record neutrons of an energy higher than about 100 kev.[3] Spontaneous emission of neutrons from uranium was observed. Several sources of error were excluded by check experiments and simple considerations. From the number of counts obtained we estimate the partial decay constant for spontaneous fission for the "average uranium atom" to be of the order of 7×10^{-24} sec.$^{-1}$ under the assumption that one neutron is emitted per fission. Neutrons with energies up to 800 kev have been observed.

* This paper was received for publication on the date indicated, but was voluntarily withheld from publication until the end of the war.
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On the Production of Penetrating Ionizing Particles by the Non-Ionizing Component of Cosmic Radiation

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Experiments of the type using a vertical coincidence set of two or more counter tubes, in which an absorber is placed either above the whole system, or between the two top counters, have been reported by various authors.[1–6] All these experiments are in agreement in that they give an increased coincidence rate with the absorber in the first position as compared to that with the absorber in between the counters.

In all these experiments, except those of Froman and Stearns,[5] the material shifted during the experiment was either iron or lead, and the increase in counting rate was found to be relatively small. Rossi *et al.*,[7] using the anti-coincidence method, have shown conclusively that the

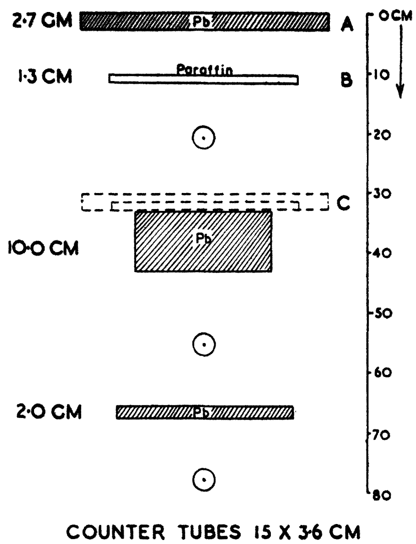

FIG. 1. Threefold coincidence set-up showing the arrangement of lead and paraffin absorbers. Drawn to scale.

increase in counting rate caused by shifting lead absorber relative to the coincidence set is not to any appreciable extent caused by the production of ionizing particles (penetrating or soft) by the non-ionizing component of cosmic radiation, but can be accounted for by spurious effects such as knock-on showers, scattering and side-showers. This holds for experiments made at low altitudes. The large increase found by Schein and Wilson at 25,000 feet seems to be real enough.

Froman and Stearns used paraffin in their experiments and found the very interesting result that paraffin, in relatively thin layers, caused a larger increase in counting rate when so shifted, than a layer of lead of approximately the same thickness.

In order to try to confirm this result a series of coincidence measurements were made in the Merensky Physics Institute at Stellenbosch, i.e., practically at sea level. The experimental set-up was as shown in Fig. 1, which has been drawn to scale. Threefold coincidences were recorded with (a) lead in position *A* and paraffin in *B* or *C* and (b) paraffin kept in position *B* and lead placed alternately in positions *A* and *C*. The results obtained are collected in Table I.

The Geiger-Müller counters used in this experiment were made according to a technique previously described,[8] and the set has now given eighteen months' continuous service without one becoming defective. The resolving time of the recording circuit was reduced to a minimum by using very small coupling condensers (50 micromicrofarads) between the tubes and their amplifiers, as well as relatively small leak resistors.

As Table I shows, shifting the lead scatterer from *A* to *C* makes very little difference to the threefold coincidence counting rate. The fact that the rates are equal must be regarded as accidental as can be seen from the probable mean error, but the results show that the effect, if any, is very small.

TABLE I. Threefold coincidence rate or various positions of lead and paraffin scatterers

Series	Lead position	Paraffin position	Counts	Time in hours	counts/hour
(a)1	*A*	*B*	25503	821.9	31.0±0.2
2	*A*	*C*	24773	821.2	30.2±0.2
(b)1	*A*	*B*	35701	1147.4	31.1±0.2
2	*C*	*B*	31103	999.4	31.1±0.2

Shifting the layer of paraffin scatterer however, causes a change in counting rate substantially greater than the probable mean error. If spurious effects were responsible for the change in counting rate between (a) 1 and (a) 2, it is to be expected that these same effects would also cause a change between (b) 1 and (b) 2, for one would expect lead to be a better scatterer and producer of knock-on showers than the far less dense paraffin. We therefore come to the same conclusion as that reached by Froman and Stearns, that the effect is real.

The fact that a light substance like paraffin is so effective in producing this effect gives ground for the hypothesis that the neutral component of cosmic radiation responsible for the phenomenon might be fast neutrons, and the penetrating secondaries might be mesotrons, or even protons. It may be remarked in this connection that Jánossy and Rochester[9] have already come to the conclusion that cosmic-ray neutrons might be responsible for an appreciable part of the penetrating showers observed at sea level. Anti-coincidence experiments are now under way at Potchefstroom to measure the penetrating power of the primary neutral radiation, and of the secondary ionizing particles.

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Successive Multiple Production of Penetrating Particles

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THE production of mesotrons by protons in successive nuclear collisions has been predicted by Hamilton, Heitler, and Peng[1] but Janossy subsequently showed[2] that one would expect a multiple process in the case of collision with a nucleus containing many protons and neutrons. Several observers[2,3] have reported some 90 penetrating particle showers in some of which mesotrons are identifiable. There has, however, been no previous direct observation of successive production centers for penetrating particles, with the possible exception of a photograph by Shutt,[3] in which heavily ionizing particles are ejected from a plate that was traversed by a penetrating particle shower.