The only other quantum theory of x-ray line intensities that we have seen is the oldest of them all, that of Davis,[7] who assumed the collisions to be equivalent to those of hard spheres. This theory predicted a deviation from our data in the direction opposite to that of the inverse-square theories.

To explain these deviations, several ideas present themselves. One is that the inverse-square law ought to be the best basic hypothesis, but that the deviations of these inverse-square theories from the data are caused by relativity effects, which might well be large at these voltages. Another idea is that the inverse-square law may fail between electrons at distances less than 10^{-11} cm, such as are demanded by these theories for the transfer of the large amounts of energy carried by our cathode rays. Still another idea is that the inverse-square law may fail for some other reason, connected with the dynamics of electrons within an atom, rather than with high energy. This last idea is the only one of these three, at least, that will explain observations on the inert gases by Hughes and Klein,[8] Compton and Van Voorhis,[9] and Smith.[10] Their data cover argon, neon and helium, and in all cases show the same sort of departure from the inverse-square theories that we find here. Helium may perhaps be the best for comparison with our data, since it contains only K electrons; and Smith's data show most clearly a very flat maximum around 4.5 V_K, remarkably like that given by our silver K electrons. Here at least, at 110 volts, there is no relativity or high energy problem.

[7] B. Davis, Phys. Rev. **11**, 433 (1918).
[8] A. L. Hughes and E. Klein, Phys. Rev. **23**, 450 (1924).
[9] K. T. Compton and C. C. Van Voorhis, *ibid.* **26**, 436 (1925) and **27**, 724 (1926).
[10] P. T. Smith, *ibid.* **36**, 1293 (1930).

To test the possibilities of laws other than the inverse-square, therefore, we have tried an interpolation between it and Davis's inverse-infinity power. For this purpose we made all other assumptions exactly like those of Rosseland's theory, the simplest of the inverse-square theories, but substituted an inverse-cube law for the inverse-square. The result is the equation

$$j(U)=\frac{6}{U\left\{\left(\dfrac{\pi}{2\cos^{-1}U^{-1/2}}\right)^2-1\right\}}$$

This equation fits our present experimental values of $j(U)$ to within ± 0.01 for all values of U up to 3, though it is low by 0.04 at $U=5$ and by 0.08 at $U=7$. Altogether, it fits far better than any of the other theories, unless possibly the changes with U in the parameters of Bethe's theory may make it fit better than it appears to.

We must recognize, of course, that any theory such as this, based on the classical concept of force, with the introduction of quanta as extraneously imposed prohibitions, is at least antiquated. We must also remember that there is no basis for an inverse-cube hypothesis other than *ad hoc.* We therefore offer this hypothesis, not as one to be taken literally, but as a suggestion on the direction in which it may prove worth while to change the potential energy functions used in better theories.

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Concerning the Production of Groups of Secondaries by the Cosmic Radiation

The experiments with counters and cloud chambers have shown that the ionization attributed to the cosmic radiation is produced by ionizing corpuscular rays (capable of discharging a counter or of producing a cloud track) of energies ranging from 10^6 to 10^{10} electron volts. At least some of these corpuscular rays are secondaries originating within the surrounding matter, but whether the primary radiation which ejects these secondaries itself consists of ionizing corpuscles or is of a non-ionizing gamma-ray or neutron character has been an unanswered question.

Experiments by Rossi[1] and by the writers[2] have shown that there are frequent groups consisting of two or more divergent ionizing rays which emerge simultaneously from a

[1] B. Rossi, Phys. Zeits. **33**, 304 (1932); Rend. Lincei XV, 734 (1932).
[2] Johnson and Street, Phys. Rev. **40**, 638 (1932).

block of lead, and a similar grouping phenomenon has been observed by those who have worked with cloud chambers. These observations could be explained by any one, or all of three postulates. I. The primary may be an ionizing ray which in passing through matter produces other ionizing rays by close collisions with electrons or nuclei. II. The primary may be a non-ionizing ray whose energy is at once transferred by a single nuclear collision to a group of secondary ionizing rays.

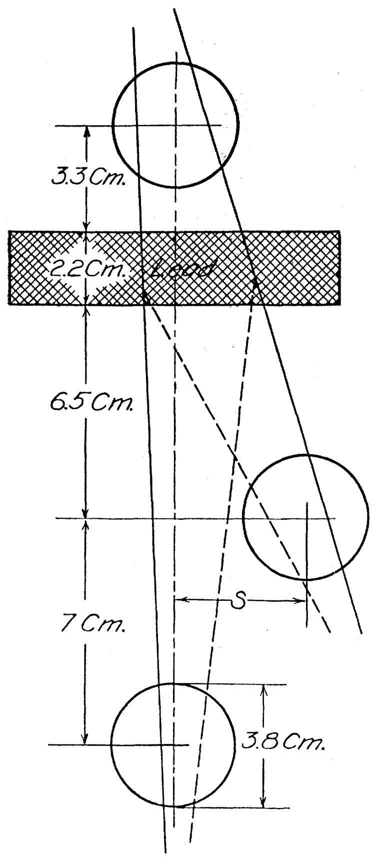

Fig. 1. Effective length of counter 9 cm.

III. The primary may be a non-ionizing ray whose energy is degraded by the formation of a succession of ionizing rays along an extended path.

To distinguish between these postulates we have made some experiments with the arrangement of three counters and the lead block shown in Fig. 1. If II is the correct hypothesis the presence of the lead block in the position indicated should have only an absorbing effect on the triple coincidence counting rate whereas an increase due to the lead should be noticed if I or III is right. The results in Table I show an increase due to the lead which is well above the statistical probable error, proving that at least a part of the grouping phenomenon must be accounted for either by postulate I or by III or perhaps by both.

To determine which of these two postulates applies, some experiments with the arrange-

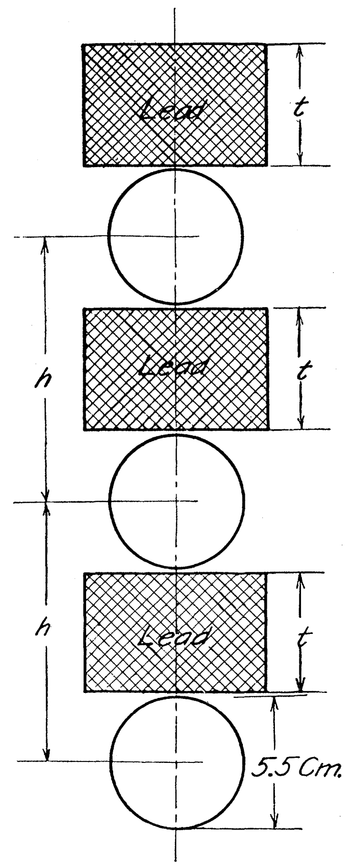

Fig. 2. Effective length of counter 12 cm.

ment of counters and lead blocks shown in Fig. 2 have been carried out. In this case the circuits were arranged for counting the double coincidences between counters 1 and 3 simultaneously with the triple coincidences. Counts were made both with the three lead blocks in position and with all of the lead removed. An explanation[3] of the transition effects dis-

[3] T. H. Johnson, Phys. Rev. **41**, 545 (1932).

covered by Schindler[4] and by Rossi[1] requires that, whether I or III is correct, the secondaries which enter any one of the lead blocks from above shall, for the most part, be absorbed in the thickness of lead used so that the probability that a primary be accompanied by a secondary below a lead block is independent of the condition above. However, most of the secondaries are sufficiently penetrating to pass through all three counters in the absence of the lead. If E is the efficiency of counter 2, the ratio T/D of triple to double counts without the lead is E whereas, with the lead in place, this ratio is EP, where P is the probability of any element of the path of the primary in lead being traversed by at least one ionizing ray (whether it be the primary itself or one of its secondaries). The results obtained are shown in Table II, from which it appears that there is no change in the ratio T/D due to the lead within the limits of error. Hence P is equal to unity. We must conclude, therefore, that the primary ray is either itself an ionizing ray or, if it is a non-ionizing ray, it is always accompanied by at least one of its secondary ionizing rays. This latter possibility must be excluded on other grounds. In the first place, the groups observed in the cloud chamber seldom contain more than two ionizing rays, and in the second place, a comparison of ionization measurements with counter data indicates an average of only two to three ionizing rays per group. These considerations necessitate the conclusion that if the primary is a non-ionizing ray it would be unaccompanied by ionizing secondaries over such a large fraction of its path that P would be less than unity by an easily detectable amount. (If three were the average density of independently formed secondaries 20 percent of the path of the primary should be non-ionizing.) We are, therefore, left with the conclusion that all of the groups observed in the first experiment arise from an ionizing primary. This ray, of course, may itself have been produced by a non-ionizing gamma-ray or neutron and, furthermore, it is still possible that a part of the groups observed by other arrangements of counters or in the cloud chamber may arise according to postulate II.

TABLE I.

Distance s		Total counting period	Total counts	Counts per minute	Difference due to lead
4 cm	with lead	2484 min.	136	0.055 ± 0.003	0.015 ± 0.004
	without lead	3971	159	0.040 ± 0.002	
5 cm	with lead	3069	132	0.043 ± 0.002	0.014 ± 0.003
	without lead	2512	73	0.029 ± 0.002	
7 cm	with lead	5795	194	0.034 ± 0.002	0.018 ± 0.002
	without lead	3886	63	0.016 ± 0.001	

TABLE II.

Spacing between counters (h)	Thickness of lead (t)	Total counting period	Total double counts (D)	Total triple counts (T)	T/D
13 cm	5 cm	1228 min.	2289	1913	0.84 ± 0.01 with lead
		1072	2389	1954	0.82 ± 0.01 without lead
18 cm	10 cm	1993	2074	1731	0.84 ± 0.01 with lead
		1497	2014	1615	0.81 ± 0.01 without lead

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The Bartol Research Foundation of The Franklin Institute, Swarthmore, Pa.,
August 29, 1932.

[4] H. Schindler, Zeits. f. Physik **72**, 625 **(1931)**.