tion of all electron lines can be made only when it is possible to obtain enriched isotopes of masses 151 and 153.

Since the sum of 336.4 and 778 kev is the observed 1115-kev line, this is arbitrarily shown as associated with Gd 152. The known sequence of 123- and 344-kev lines are shown together as arising from Gd 154. This will, of course, be much more complicated when the identification of all electron energies is complete.

* This investigation has been supported jointly by the AEC and ONR.
[1] A. W. Tyler, Phys. Rev. **66**, 125 (1939); M. G. Inghram and R. J. Hayden, Phys. Rev. **71**, 130 (1947); Cork, Schreffler, and Fowler, Phys. Rev. **72**, 1209 (1947); F. B. Shull, Phys. Rev. **74**, 917 (1948); and Hayden, Inghram, and Reynolds, Phys. Rev. **75**, 1500 (1949).
[2] C. Muehlhause, Manhattan Project Report CP-3750 (1947).

Cloud-Chamber Study of Cosmic Rays Underground*

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February 6, 1950

A COUNTER-CONTROLLED Wilson cloud chamber has been operated in a salt mine at a depth of 860 mwe (8.6×10^4 g/cm^2) from the top of the atmosphere. The primary aims of the experiment were two: First, to determine the character of the penetrating rays present at great depths and second, to investigate the properties of the secondaries that the penetrating rays produce in the salt roof above the cloud chamber and in lead, aluminum, and brass absorbers in the cloud chamber.

In order to determine whether or not the penetrating rays were ionizing, four one-inch lead plates were placed in the chamber with one tray of counters in the center of the chamber and the other tray below the chamber. A twofold coincidence between trays expanded the chamber and stereoscopic pictures were taken. With this arrangement, the pictures (aside from accidental coincidences) could be due to a single penetrating ionizing particle, to an electronic shower, or to a penetrating non-ionizing particle that produced two or more ionizing secondaries in the neighborhoods of the counters. Examination of the tracks in 175 pictures taken with this arrangement showed that 153 of the pictures were caused by single ionizing particles capable of traversing four inches of lead without unusual interactions. Eleven of the remaining pictures showed electronic showers, one of which was within the allowed region of the counter telescope, the remainder being side showers. Six accidentals were expected, leaving an upper limit of 5/153, or 3 percent, which might be caused by non-ionizing penetrating particles.

In order to investigate the electronic secondaries produced by the penetrating particles in the salt roof above the chamber, counter trays were placed above and in the center of the cloud chamber. The amount and nature of the absorber between the counters were then varied and the ratio of the number of soft particles with particular ranges to the number of penetrating particles was obtained. The results are summarized in Table I.

The penetrating particles were occasionally accompanied by secondary electrons upon emerging from the plates of lead, aluminum, or brass (center counter box). The ratios of accompanying secondary electrons to the producing penetrating particles are given in Table II. It is to be noted that these secondary electrons are more numerous than the knock-on electrons accompanying the penetrating component in lead at sea level. Nassar and Hazen[1] found about 6 percent for electrons of comparable energy range at sea level. The difference between the relative intensities of secondary electrons to penetrating particles in the mine and at sea level is most readily interpreted in terms of the expected difference in mean energies of the penetrating particles.

TABLE I. Absorption of electrons accompanying penetrating particles from salt roof.

Absorber	Penetrating particles	Electrons	Ratio electrons pen. part.
9 g/cm^2 Al+brass	108	75	70%
22 g/cm^2 Al+brass	100	16	16
66 g/cm^2 Pb (some Al+brass)	224	9	4

TABLE II. Secondary electrons produced in the chamber.

Absorber	Traversals		Electrons	Ratio-elec./p.p.
Pb	776	forward	162	
	808	backward	8	22 percent
Al	561		128	23
brass	420		73	17

If the penetrating particles traverse the entire layer of earth above the point of observation, we expect that a fraction $dI/I=2.9dh/h$ would be stopped in the absorber below the counters. Of a total of 454 penetrating particles, two were stopped while the expected number was about one. Thus it is unlikely that a significant number of the penetrating ionizing particles are produced in the earth.

Occasional large electron showers from the roof of the mine were detected in the chamber. Two very large showers were initiated in the chamber by single penetrating rays.

The pictures show that the majority of the penetrating particles at 860 mwe that are capable of producing twofold coincidences in a counter telescope are ionizing. These ionizing penetrating rays interact with matter in a manner that demonstrates qualitative resemblance with the penetrating rays at sea level. Since the average number of secondary electrons is higher and showers of electrons occur more frequently than at sea level, the average energy is apparently much higher.

We wish to express our appreciation for the assistance of the administration and personnel of the Detroit mine of the International Salt Company.

* This work has been assisted by the Joint Program of the ONR and the AEC.
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S-Matrix in Non-Local Field Theory

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January 26, 1950

RECENTLY the present author discussed certain types of quantized non-local fields, which were supposed to correspond to assemblies of elementary particles with finite radii.[1] In order to deal with the system consisting of two non-local fields, or a local field and a non-local field, which interact with each other, one must first find the substitute for the Schrödinger equation for the total system. However, it is naturally anticipated that the *S*-matrix in local field theory, which was obtained as the result of integration of the Schrödinger equation by successive approximations, may well find a counterpart in non-local field theory, whereas the physical interpretation of the Schrödinger wave functional itself, if it exists in non-local field theory, may be quite different from that in local field theory.

In fact, the *S*-matrix in non-local field theory can be obtained by a straightforward extension of the usual formalism. An arbitrary non-local operator A can be represented by a matrix $(\mathbf{n}', x'|A|\mathbf{n}'', x'')$, with rows and columns characterized by $\mathbf{n}'$, x' and $\mathbf{n}''$, x'' respectively, where each of the symbols $\mathbf{n}'$, $\mathbf{n}''$ stands for the distribution in numbers of particles in all possible quantum states while x' and x'' stand for a set of eigenvalues of four space-time operators x_μ. Further, we define $\langle A\rangle$ for an arbitrary operator A by

$$(\mathbf{n}'|\langle A\rangle|\mathbf{n}'')=\int\cdots\int(\mathbf{n}', x'|A|\mathbf{n}'', x'')(dx')^4(dx'')^4. \quad (1)$$

The *S*-matrix with matrix elements $(\mathbf{n}'|S|\mathbf{n}'')$ can now be written symbolically in the form

$$S=1+(i/\hbar)\{L'\}+(i/\hbar)^2\{L'D_+L'\}+(i/\hbar)^3\{L'D_+L'D_+L'\}+\cdots \quad (2)$$

in non-local field theory as well as in local field theory, where L' is an invariant operator characterizing the interaction which can be expressed as a sum of products of non-local and local field quantities. In the particular case of the interaction between local fields, the matrix elements of L' reduce to the form

$$(n', x'|L'|n'', x'')=(n'|L'(x')|n'')\prod_{\mu=1}^{4}\delta(x_\mu'-x_\mu''), \quad (3)$$

where $(n'|L'(x')|n'')$ is the matrix element for the Lagrangian density for the interaction in the usual theory. D_+ is an invariant displacement operator with the matrix elements

$$(n', x'|D_+|n'', x'')=1, \tfrac{1}{2}, \text{ and } 0, \quad (4)$$

according as $x'-x''$ is a future-like vector, a space-like vector, and a past-like vector respectively. We can show very generally that the matrix S as defined by (2) fulfills all requirements for the S-matrix. Firstly, it is obviously relativistically invariant. Secondly, one can prove that it is unitary. Thirdly, the matrix element $(n'|S|n'')$ is different from zero only if the final and initial states, which are characterized by n' and n'' respectively, have the same total energy and momentum.[2]

As for the finiteness of the matrix S, it is not easy to draw a general conclusion. However, we can show that, for example, the self-energy of a spinor particle interacting with the non-local scalar field is finite due to the appearance of the form factor, as far as the third term of S in (2) is concerned. Further investigations are needed in order to settle the question of convergence in non-local field theory.

Detailed accounts will be published at a later date.

* On leave of absence from Kyoto University, Kyoto, Japan.

[1] H. Yukawa, Phys. Rev. **76**, 300 (1949); **76**, 1731 (1949); **77**, 219 (1950).

[2] We mean by the total energy and momentum the sums of energies and momenta respectively of the translational motion of the existing particles.

Photon Pulses from Point-to-Plane Corona

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February 6, 1950

An RCA 5819 photo-multiplier and a millimicrosecond oscilloscope have been used to study the photon pulses occurring at corona onset in air at atmospheric pressure, by use of a point-to-plane gap. Pulses of more than ten volts amplitude are obtained directly from the photo-multiplier, from single corona events which cannot be individually observed either visually or photographically. The method should be valuable for other gas discharge processes that have a similar low average, but high intrinsic, light output. It has already been used to study discharges of high average brightness such as long sparks[1] and pulsed discharges.[2]

Figure 1 shows the photon pulses obtained with 1-mm radius of curvature point and 5-cm gap. Pulses from the photo-multiplier were passed through an amplifier with pass band 100 kc to 100 Mc per second and through a coaxial line which delayed them relative to the triggering of the sweep. The photographs are a superposition of several sweeps, as can be seen in the lower picture where all the pulses do not coincide. Single sweeps were observed visually.

Studies of the induced pulses produced at the plane electrode by the corona[3] have indicated that these are due to electron motion near the point. This motion is quite slow compared to the rate of propagation of the corona, so that little of the corona process is revealed. The photon pulses do not suffer from this limitation, and give quite distinct and characteristic pulses for positive and negative point polarity.

The *positive* pre-onset streamer pulse shows a slow initial rise which may be due to the multiplication process that builds up the initial space charge necessary for the streamer to propagate. On about every tenth pulse this slow rise is replaced by a slight "bump," and the main rise of the pulse is delayed about two trace-widths. Each pulse shows a well-defined plateau, which gives the impression of two overlapping peaks. Pulse duration at 30 percent maximum amplitude is about 6×10^{-8} second. Observations with test pulses of from 3 to 8×10^{-8} second duration, inserted at the photo-multiplier anode, indicate that the plateau does not arise in the amplifier. It may be due to the nature of the decay of excitation in a single streamer channel, or again, perhaps it is possible for two successive pulses of excitation to occur in the same channel, even with a time separation as short as 3×10^{-8} second.

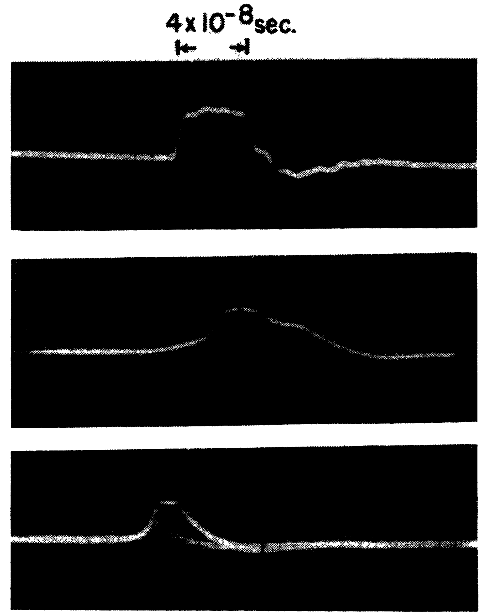

Fig. 1. Upper: Test pulse from discharge of 0.02 microsecond delay line. Middle: Photon pulse from positive point pre-onset streamer. Lower: Photon pulse from negative point "Trichel" pulse. All pulses traversed the same amplifier system.

The *negative* "Trichel" pulse shows only a slight indication of the initial multiplication process mentioned above. It rises abruptly at a rate about the same as the fast rise of the positive pulse, and decays smoothly after a duration at 30 percent maximum amplitude of about 3.5×10^{-8} second. Such a short simple pulse is surprising. The negative point corona in air has the appearance of a complete miniature glow discharge, and one might expect the process of building up the space charge formations needed to account for this structure[4] to give rise to a longer and more complex pulse.

In preliminary interpretation of the present results, it has been assumed that excitation of the gas is proportional to ionization, and that the decay of the excited states is rapid compared to the duration of the photon pulse. Further experiments with different gases, pressures, and electrode arrangements should make possible an explanation of the pulse shapes observed, and give new information of the corona processes involved.

The writer is grateful to Dr. C. Hendee of Northwestern University for suggesting the use of a photo-multiplier in the present problem. He is indebted to the Electronics Branch, Chalk River Laboratory, and especially to Mr. G. J. R. MacLusky, for loan of the oscilloscope, amplifiers and pulse generator, and for helpful advice.

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[2] W. S. Huxford and H. N. Olsen, Pittsburg Conference on Gaseous Electronics (November, 1949).
[3] W. N. English and A. W. Love (to be published).
[4] L. B. Loeb, J. App. Phys. **19**, 882 (1948); Phys. Rev. **71**, 712 (1947).