Gases evolving from the brass walls of the container resulted in gradually decreasing charging, which could be returned to the original value by pumping for several hours at 1×10^{-5} mm of mercury. These results indicate that this type of tribo-electric charging strongly depends on the gas layers adhering to the surfaces involved. The amorphous quartz particles might be expected, because of the differences in structure, to acquire charge in friction with crystalline quartz. Actually, however, there was greater charging when the amorphous quartz particles struck the amorphous quartz receiving bucket, which further substantiates the belief that so-called "tribo-electric" series have little meaning.

Since the piezo-electric contribution to the charging of the sand amounted to less than 20 percent of its total charge, when the crystal was strained by a force of nearly 5×10^6 dynes, it seems evident that the piezo-electric effect is not an important factor in tribo-electrification.

* This work was supported by ONR funds.
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The *K*-Shell Internal Conversion Coefficients*

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THE purpose of this letter is to report the fact that numerical calculation of the K-shell internal conversion coefficients has been carried out and to describe the results briefly. These calculations were carried out using relativistic (Dirac) wave functions for the Coulomb field, for the following parameters: $10\leq Z\leq96$ (comprising 23 values of Z); $0.3\leq k\leq5.0$ (for $Z\leq78$, 16 values of k) and $0.5\leq k\leq5.0$ (for $Z>78$, 14 values of k), where $k\,mc^2$ is the gamma-ray energy, and for both electric and magnetic multipoles of order 2^l with $1\leq l\leq5$. The domain of computation in the $Z-k$ plane is indicated in Fig. 1. A total of 680 values of the conversion coefficient have been obtained on the automatic sequence relay calculator (Mark I) at Harvard University (for 12 values of Z and 5 to 6 values of k) and 2560 additional values were obtained by interpolation. The values obtained on the Mark I are given to four significant figures and the interpolated values are given to three. While extensive tables have been prepared, space limitations prevent their inclusion here.[1] It is planned to present these results in a subsequent publication in which they would appear in the form of families of curves to be given for essentially all values of Z throughout the periodic table. In addition, internal conversion coefficients for all three sub-shells of the L-shell will then be presented for $10k$ values, 10 multipoles and all Z values. These results which include the effect of screening will be supplemented by low energy K-shell coefficients computed in the same manner, i.e., with screening.

In Fig. 1 the contour lines for the electric dipole and 2^5 pole (α_1 and α_5)[2] give an indication of the numerical results. Comparison with the approximate calculations of Hebb and Uhlenbeck[3] (non-relativistic, electric multipoles), of Drell[4] ("non-relativistic," magnetic multipoles) and of Dancoff and Morrison[5] (Born approximation) shows that these approximations give reliable results in a much more restricted range of Z and k than had been previously thought to be applicable. Their application, even in the range $Z<50$, can lead to an error of a factor 3 or more (especially in the case of higher order multipoles and magnetic conversion) and in many cases the error is such as to lead to an incorrect assignment of multipole order.[6]

Comparison was also made with the relativistic calculations of Hulme[7] (α_1; $Z=84$), Taylor and Mott[8] (α_2; $Z=84$), Fisk and Taylor[9] (β_1, β_2, β_3; $Z=84$) and Griffith and Stanley[10] (α_1; $Z=69$

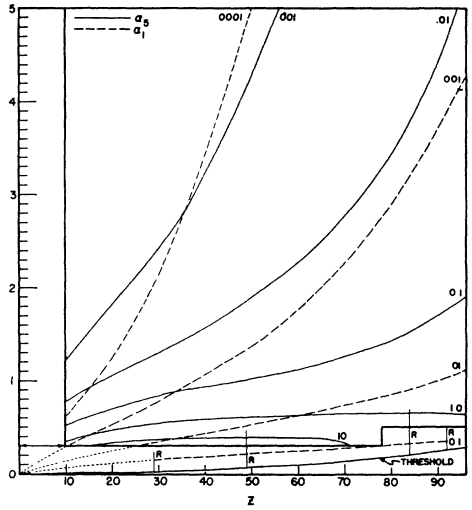

FIG. 1. The heavy lines ($Z\geq10$, $k\geq0.3$, 0.5) show the domain of calculation. Contour lines for electric dipole (α_1) and electric 2^5 pole (α_5) are also shown with values of the internal conversion coefficients affixed to the curves and α_1 has been extrapolated to low k. The lines marked R show where Reitz's calculations were made.

(5) 89). In all cases, except for α_2 where the results of Taylor and Mott differ slightly, there was agreement within the mutual precision of the calculations (of order 3 percent). The neglect of screening, which is the only significant effect omitted in these calculations, is *a posteriori* justified by comparison with the results of Reitz[11] who has computed the low energy K-shell coefficients, taking screening into account with a Thomas-Fermi-Dirac field, in the cases α_1, α_2, and β_1 for $Z=29$, 49, 84, and 92. In the region of k for which our calculations overlap those of Reitz the screened results exceed our unscreened values by at most 10 percent (where screening would be expected to be most serious) and in the large majority of cases by an amount which is less than 3 percent. The $Z-k$ values for which Reitz's calculations were made are shown in Fig. 1 by the vertical lines marked R. The dashed curves for $k<0.3$ are rough extrapolations for α_1 using Reitz's results and the approximation values for $Z<10$.

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The Disintegration of In^{114}

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THE 50-day activity of In^{114} was investigated some years ago by Lawson and Cork[1] who found that the 50-day isomer decays to a 72-second isomeric state, under the emission of a highly internally converted gamma-ray of energy 0.192 Mev. The state of In^{114} of 72-sec. half-life then decays to the ground state of Sn^{114} with the emission of a beta-ray whose end point

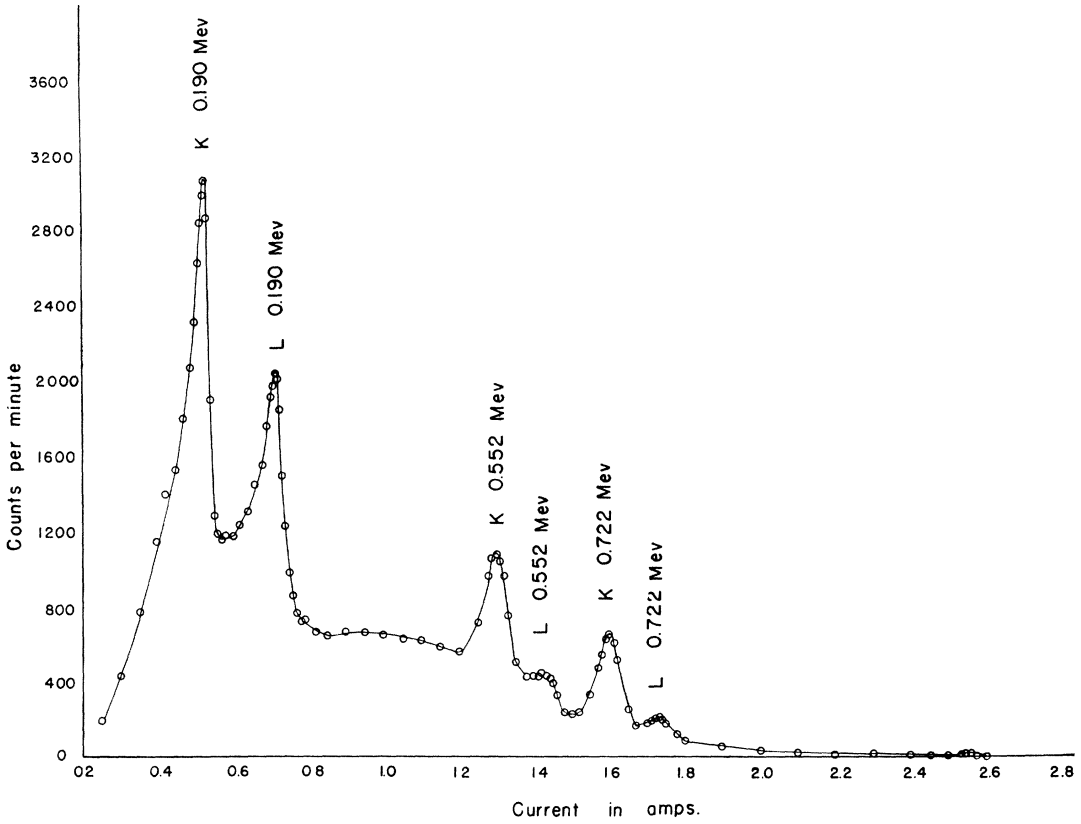

FIG. 1. Gamma-rays from indium 114. Photoelectrons from lead radiator.

energy is 1.98 Mev. Recently Cork, Shreffler, and Fowler[2] reported that In^{114} also emits a gamma-ray of energy approximately 0.8 Mev. This result was found by lead absorption. In view of the fact that the beta-ray spectrum of the 72-second In^{114} has been usually considered to be simple and allowed, it was decided to investigate the gamma-rays both by coincidence counting and spectroscopic techniques. The results of the coincidence studies have been published by Maienschein and Meem.[3] While the spectroscopic work was in progress, experiments of a similar nature were reported by Boehm and Preiswerk[4] with results substantially in agreement with ours. We have, however, found an additional gamma-ray not reported by them.

Metallic indium was irradiated by neutrons in the Oak Ridge Pile. Both unpurified and chemically purified sources were measured in a magnetic lens spectrograph. It was established by chemical experiments that all the gamma-rays belong to indium.

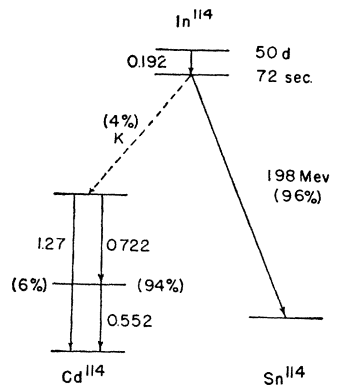

FIG. 2. Disintegration scheme of indium 114.

The energies of the several gamma-rays were determined from the energies of photoelectrons ejected from a lead or uranium radiator. Figure 1 shows the distribution of the photoelectrons from a lead radiator. K and L lines from gamma-rays at 0.190 $\pm$0.004; 0.552$\pm$0.005; and 0.722$\pm$0.005 Mev are shown on the figure. In addition, a very weak gamma-ray of energy 1.27$\pm$0.01 Mev was found with both lead and uranium radiators. The relative intensities of the several gamma-rays were obtained with the help of Gray's[5] formula for the photoelectric efficiency as a function of the energy of the gamma-ray. The results are shown in Table I.

TABLE I. Relative intensity of gamma-rays.

Energy (Mev)	Relative intensity arbitrary units
0.190	257
0.552	47.9
0.722	47.7
1.27	3.2

The energy of the gamma-ray at 1.27 Mev is the sum of the energies of those at 0.552 and 0.722 Mev. Since the two lines at 0.552 and 0.722 Mev are of equal intensity, it is assumed that they are in cascade. This assumption is borne out by the fact that gamma-gamma-coincidences are found.[3] The line at 1.27 Mev connects the higher excited state of the cascade process with the ground state and occurs in about 6 percent of the transitions. This line was also found in the coincidence experiments. Since there are no beta-ray groups in the beta-ray spectrum of the 72-sec. In^{114} which correspond to these gamma-rays and since characteristic x-rays of Cd have been found,[3,4] it is assumed that the three higher energy gamma-rays arise as a result of K-electron capture. In order to calculate the percentage of transitions which go by K-electron capture, it is necessary to know the ratio

$N_e^-/(N_e+N_\gamma)$ for the internally converted 0.190-Mev line. This has been given by Lawson and Cork as 1.00±0.30, by Boehm and Preiswerk as 0.80±0.05, and Langer and Price[6] as 0.80±0.10. Taking the value of 0.80 as correct the percentage K-capture is found to be 4.0 percent in good agreement with Boehm and Preiswerk. The disintegration scheme is shown in Fig. 2.

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Penetration and Diffusion of Hard X-Rays through Thick Barriers. IV. Multiply Scattered γ-Rays: Angular Distribution*

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August 22, 1949

In order to gain some insight into the angular distribution of γ-rays which are scattered many times within a barrier, the following quite schematic problem has been studied theoretically: A source of monochromatic γ-rays of energy E_0 is distributed uniformly throughout an isotropic medium. Each γ-ray is emitted in exactly the same direction. What will be the distribution in angle, $N(E,\theta)$, of those photons which are degraded by Compton scattering to the energy E? (θ is measured from the initial direction.)

This might be said to be a study of the manner in which photons "forget" their original direction as they lose their energy through Compton scattering.

Under the conditions of this problem, $N(E,\theta)$ obeys the following integral equation:

$$\mu(E)N(E,\theta)=\int_E^{E_0}k(E',E)dE'\int_{4\pi}(1/2\pi)\delta \times(\boldsymbol{\omega}\cdot\boldsymbol{\omega}'-1+mc^2/E-mc^2/E')\times N(E',\theta')d\boldsymbol{\omega}'+k(E_0,E)\delta \times(\cos\theta-1+mc^2/E-mc^2/E_0) \quad (1)$$

where $\mu(E)$ is the probability, per unit path length, that a photon of energy E will undergo scattering, photoelectric absorption, or pair formation; $k(E',E)$ is the probability, per unit path length, that a photon of energy E' will attain the energy E through a scattering process; δ is the Dirac function and $\boldsymbol{\omega}$ represents a unit vector with direction coordinates (θ,ϕ). The first term in (1) gives the rate of disappearance of photons having energy E and inclination θ. This must be balanced (under steady state conditions) by contributions coming from the source in a single scattering, represented by the third term, plus those contributions coming from the source in two or more scatterings, represented by the second term.

Using an expansion in Legendre polynomials,[1] that is,

$$N(E,\theta)=\sum_{l=0}^{\infty}[(2l+1)/4\pi]N_l(E)P_l(\cos\theta) \quad (2)$$

$$\delta(\boldsymbol{\omega}\cdot\boldsymbol{\omega}'-1+mc^2/E-mc^2/E') =\sum_{l=0}^{\infty}[(2l+1)/2]P_l(1-mc^2/E+mc^2/E')P_l(\boldsymbol{\omega}\cdot\boldsymbol{\omega}') \quad (3)$$

we can carry out the integral over $\boldsymbol{\omega}'$. Introducing (2) and (3) into (1) we find that the coefficients $N_l(E)$ must fulfill the integral equation

$$\mu(E)N_l(E)=\int_E^{E_0}k(E',E)P_l(1-mc^2/E+mc^2/E')N_l(E')dE' +k(E_0,E)P_l(1-mc^2/E+mc^2/E_0). \quad (4)$$

For $l=0$, this equation coincides with Eq. (1) in the accompanying paper.[2]

We solve Eq. (1) in the following manner: We obtain the contributions to $N(E,\theta)$ which are scattered only one time or only two times through iteration of (1). We subtract these same contributions from Eqs. (4), likewise through iteration. Orders of scattering higher than the second can contain at most a discontinuity in the derivative $dN/d\theta$; consequently the part of the sum (2) representing these higher orders of scattering will converge reasonably well. Actually, we found that using values of l up to four we obtain sufficiently good convergence at all except the highest energies.

We did some numerical work for purposes of orientation choosing $E_0=10$ mc²; and for materials we used aluminum and lead as representative light and heavy elements. Figures 1 and 2 show the results of our calculations for various values of E in the case of aluminum. In Fig. 1, the vertical straight lines indicate the portion of the radiation of each energy which arises from single scattering and whose angular distribution is peaked like a δ-function. The dotted rectangles give a measure of the intensity of this component. The other discontinuity in each curve is at the maximum angle obtainable by a photon going from E_0 to E in two scatterings. These last appear also in Fig. 2.

The high orders of scattering become increasingly effective as the energy decreases, as evidenced by the increase in the number of photons at larger angles than the "two-scattering" cut-off. It will be noticed that at $E=0.476$ mc², which corresponds to a single scattering through 180°, this multiply scattered beam tends to ∞ at the backward pole. This is because those photons attaining 0.476 mc² in two scatterings can reach this direction no matter what the intermediate energy is. At still lower energies than

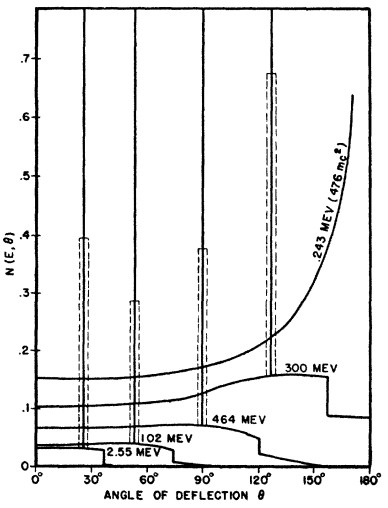

FIG. 1. Angular distribution of secondary photons for various energies of degradation. Initial energy $E_0=5.1$ Mev (10 mc²). The dotted rectangles represent the strength of the corresponding sharp lines.

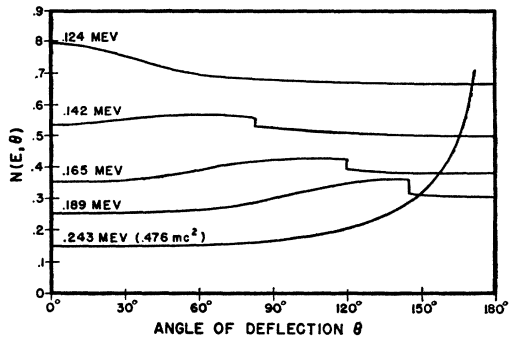

FIG. 2. Angular distribution of secondary photons for various energies of degradation. Initial energy $E_0=5.1$ Mev (10 mc²).