helium (or neon) when an excited atom of helium encounters an argon atom. In the process the argon atom is ionized and a pair of ions collected in the chamber. Thus for helium, we have

$$He^*+A \rightarrow He+A^++e^-.$$

Any additional energy imparted by the metastable helium atom He* to the argon atom A, above that energy to produce an ion pair, is carried off as kinetic energy in the ejected electron e^-. The above reaction has already been studied[3,4] under quite different experimental conditions in connection with metastable atoms.

Krypton and carbon dioxide as contaminants in helium have been found to yield results, in general, similar to argon. However, no significant increase in ionization is observed when neon is added to helium. This is in accord with the explanation above, since the energy available in the metastable state for helium (19.8 ev) is insufficient to ionize the neon atom with an ionization potential of 21.5 ev.

[1] Jesse, Forstat, and Sadauskis, Phys. Rev. **77**, 782 (1950).
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The Reaction $Li^6(\gamma,d)He^4$ at 2.76 Mev

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A SEARCH has been made for the $Li^6(\gamma,d)He^4$ reaction using 2.76-Mev γ-rays from Na^{24}. Ilford C2 nuclear emulsions loaded with enriched Li^6 were used. Using fused NaF irradiated in the Argonne heavy water pile, the Li^6 plates were exposed to approximately 10 r using $\frac{1}{8}$ in. of Al to filter out the beta-rays from Na^{24}. Using the accepted mass values[1] for Li^6, He^4, and H^2, the reaction threshold is found to be 1.48 Mev and there is 1.28 Mev available for the reaction products. From the kinetics of the problem, neglecting γ-ray momentum, the alpha-particle receives $\frac{1}{3}$ and the deuteron receives $\frac{2}{3}$ of this energy. These correspond to ranges of 2 and 8 microns, respectively, in the emulsions used.

During preliminary investigations, one example of the reaction was found. Searching was continued on a plate which had the maximum exposure, but with a tolerable gamma-background. In 7500 fields of view, corresponding to $\frac{3}{4}$ cm^2, only two possible events were found. Figure 1 shows the first example to be found. The ranges for the alpha and the deuteron tracks are 2 and 8 microns, respectively, as predicted, and the track density shows the two-body nature of the event. The photograph does not show the two tracks and the point of disintegration as clearly as they appear under the microscope.

On the basis of this evidence, an upper limit for the cross section for the reaction can be placed at

$$\sigma[Li^6(\gamma,d)He^4]_{2.76\ Mev}=(4\pm4)\times10^{-30}\ cm^2.$$

The only other work reported[2] on this reaction was done using a mixture of 14.8-Mev and 17.6-Mev γ-rays from the $Li^7(p,\gamma)$ reaction.

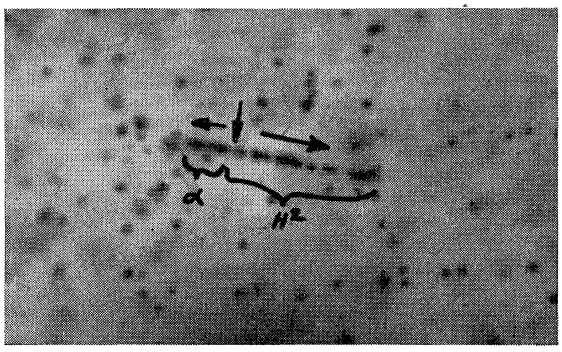

FIG. 1. Example of the reaction $Li^6(\gamma,d)He^4$.

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Mean Free Paths of Electrons in Evaporated Metal Films

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RECENT work on the evaporation of metals, particularly Cu and Ag, has made available thin films of these metals, in the thickness range from about 100–2000 angstroms, which have resistivities and resistance-temperature coefficients predictable from existing theories. These results suggest approximate values for the mean free paths l of the conduction electrons in these metals at room temperatures.

It is well known that the resistivity ρ' of a thin metallic film is greater than ρ for the bulk metal, and that the ratio ρ'/ρ increases with decrease in film thickness t. Thomson[1] was the first to suggest a theory of this effect involving the mean free path and the film thickness. Subsequently, this theory has been modified and extended by others, including Fuchs[2] and Dingle.[3] A comprehensive review of this subject has been given recently by Sondheimer.[4] Andrew,[5] working with Sn and Hg using relatively thick layers $>3\mu$ and wires $>6\mu$ in diameter, has obtained experimental confirmation of this theory at low temperatures. Similar results appear lacking in the literature for thinner layers and for higher temperatures. In general, thin metallic films exhibit wide variations in properties with method of preparation and have much larger resistivities than would be predicted from theory. Our recent work has been successful in minimizing these variations by selection and control of the rate of evaporation and residual gas pressure. Optimum conductivity is obtained by using fast rates of evaporation, for example, 500–1000 angstroms per second, and low residual gas pressure, for example, 10^{-5} mm. At these rates and pressures satisfactory films can be obtained in the thickness range previously mentioned. Films deposited at much slower rates and/or higher pressures show considerable departure from calculated values.

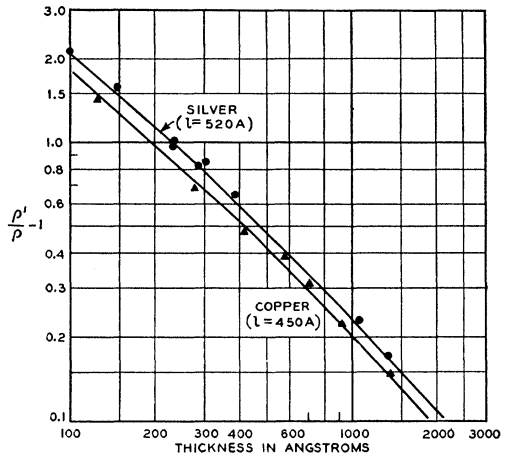

FIG. 1. Experimental points involving resistivity measurements of Cu and Ag films at room temperature, shown with curves calculated from theory to obtain approximate values of mean free paths.

Methods of film preparation other than evaporation have been tried, such as chemical deposition and electrolysis. The films thus obtained had much higher resistivities, in some cases by factors as large as fivefold, and in this respect were comparable to films evaporated under adverse conditions.

Evaporated Cu films have been examined in greatest detail. These films, formed under optimum conditions, show large aging effects immediately after evaporation. Their resistance drops rapidly during the first few minutes, reaching an approximate equilibrium in about 1–2 hours in vacuum. These films, stored in dry air, remain essentially constant in resistance over a period of many months. Fast evaporated Cu films are highly crystallized.

Figure 1 is a plot of $(\rho'/\rho)-1$ *versus* film thickness in angstroms. The solid lines are computed from Dingle's tabulations for the case of inelastic scattering at the film boundaries using values of mean free paths l of 520 and 450 angstroms for Ag and Cu, respectively, to approximate the experimental data. This value of l for Ag is in good agreement with that calculated from Sommerfield's theory assuming N_e/N_a, the number of free electrons per atom, is unity. The experimental value of l for Cu is about 15 percent higher than calculated. It may be of practical interest to note that since these plots are nearly straight lines, Planck's[6] empirical equation, $\rho'/\rho=1+cl/t$, agrees within about five percent with the more exact theory down to thicknesses of $t=l/10$ where c is assigned an arbitrary value of 0.4.

Resistance-temperature coefficients α' have been determined for these fast evaporated films. Results for Cu and Ag are given in Fig. 2. The solid lines are calculated, and the circles represent

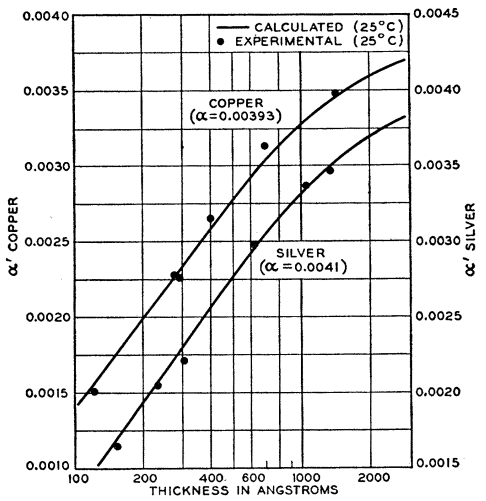

FIG. 2. Comparison of measured and calculated resistance-temperature coefficients.

experimental points. These calculations are based on the assumption that $\rho'\alpha'=\rho\alpha$, where ρ, α are the bulk values, and ρ', α' are the corresponding film quantities. Films not deposited under optimum conditions have smaller values of α' than indicated by these curves. Such films have larger values of ρ' than normal, but the product $\rho'\alpha'$ remains essentially constant for a given metal, indicating that Matthiessen's rule is followed.

The following bulk metal values at 25°C have been used in the calculations:

	ρ(Microhm-cm)	α(deg C^{-1})
Ag	1.623	0.0041
Cu	1.705	0.00393

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The Geometrical Correction in Angular Correlation Measurements*

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THE presence of the effects of mixtures of multipole radiations and disturbing extra-nuclear fields in angular correlation studies necessitates an accurate evaluation of the correlation function. The largest correction that must be applied to the experimental data before an appropriate analysis can be made is that due to finite instrumental angular resolution. The problem of accounting for such effects has been discussed by Walter *et al.*,[1] Frankel,[2] and Frauenfelder.[3] The object of the present note is to present a simple procedure for correcting the data directly in terms of the experimental resolution curve and to indicate that the corrections so introduced are greater than has heretofore been assumed. The method outlined, an extension of the procedure of Frankel, is applied to a particular case and verified at two different geometries. The corrections are found to be large and sensitively dependent on the shape of the resolution curve.

The directional correlation function for a $\gamma-\gamma$ cascade may be written in the form

$$W(\theta)\equiv N(\theta)/N(\tfrac{1}{2}\pi)=\Sigma_M A_{2M}P_{2M}(\cos\theta), \tag{1}$$

where the coefficients A are functions of the cascade parameters. The resolution curve $f(\delta)$, corresponding to a particular geometry, is determined using annihilation radiation and is conveniently expanded as

$$f(\delta)=N(\pi-\theta)=\Sigma_m B_m P_m(\cos\delta). \tag{2}$$

Assuming the counters to be individually symmetric, the observed correlation function $W'(\theta)$ may be compounded out of (1) and (2) as

$$W'(\theta)=\int W(\theta')f(\delta')d\Omega', \tag{3}$$

where θ,θ', and δ' are the three sides of a triangle on the surface of the unit sphere. The integral (3) can be evaluated by an application of the addition theorem for spherical harmonics as shown by Frankel.[2] One finds

$$W'(\theta)=\sum_M\left[\left(\frac{4\pi}{2M+1}\right)B_{2M}\right]A_{2M}P_{2M}(\cos\theta)\equiv\sum_M A_{2M}'P_{2M}(\cos\theta). \tag{4}$$

The effect of finite counter geometry is therefore one of altering the original coefficients by a simple factor.

The coefficients B_{2M} are obtained by direct numerical integration over the experimental resolution curve as shown below. To within an arbitrary factor which cancels in the subsequent normalization of $W(\theta)$,

$$\left(\frac{4\pi}{1}B_0\right)=\int f(\mu)P_0(\mu)d\mu,\ \left(\frac{4\pi}{5}B_2\right)=\int f(\mu)P_2(\mu)d\mu,\ \left(\frac{4\pi}{9}B_4\right)=\int f(\mu)P_4(\mu)d\mu, \tag{5}$$

where $\mu\equiv\cos\delta$.

If the resolution curve can be approximated by a triangular or Gaussian distribution, these coefficients can be estimated by means of the expansions[4]

$$\begin{aligned}\left(\frac{4\pi}{1}B_0\right)&=1-\frac{6.092}{7.325}(-5)\delta_0^2+\ldots,\\ \left(\frac{4\pi}{5}B_2\right)&=1-\frac{6.092}{7.325}(-4)\delta_0^2+\frac{1.609}{2.930}(-7)\delta_0^4-\ldots,\\ \left(\frac{4\pi}{9}B_4\right)&=1-\frac{1.889}{2.271}(-3)\delta_0^2+\frac{1.460}{2.659}(-6)\delta_0^4\\ &\quad-\frac{0.631}{2.133}(-9)\delta_0^6+\ldots,\end{aligned} \tag{6}$$

where δ_0 is the half-width at half-maximum of the resolution curve expressed in degrees. The upper coefficients refer to a triangular, and the lower to a Gaussian distribution.