phonon mean free path throughout this range of temperatures.

At 8°K, the electron-phonon mean free path is about 0.08 cm as determined by the experiments of MacDonald and Mendelssohn.[7] If we extrapolate this result by means of the Bloch-Gruneisen T^5 law, we find that at 4°K, the electron-phonon and electron-electron free paths are comparable. The concept of an electron-phonon free path is used here for purposes of comparison of the importance of the two effects. 4°K is a temperature at which the lattice scattering is negligible compared to the residual resistance. These remarks tend to show that electron-electron scattering effects are less important that lattice or impurity scattering throughout all temperatures.

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Two Types of Band Emission Curves of Copper in the Soft X-Ray Region

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EXPERIMENTAL curves showing the energy distribution of the higher electronic levels in solid metals may be obtained from the soft x-ray emission spectra of metals. The methods which have been used may be described as follows: (a) the voltages applied to the anticathode are kept constant and the generally soft x-rays emitted are analyzed by means of a diffraction grating, and (b) the voltages applied to the anticathode are varied gradually, the soft x-rays thus emitted are detected with a photoelectric device, and the resulting voltage *vs* photocurrent curves are differentiated graphically.

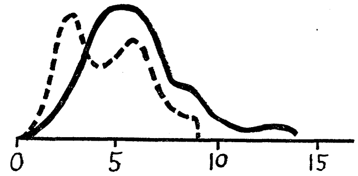


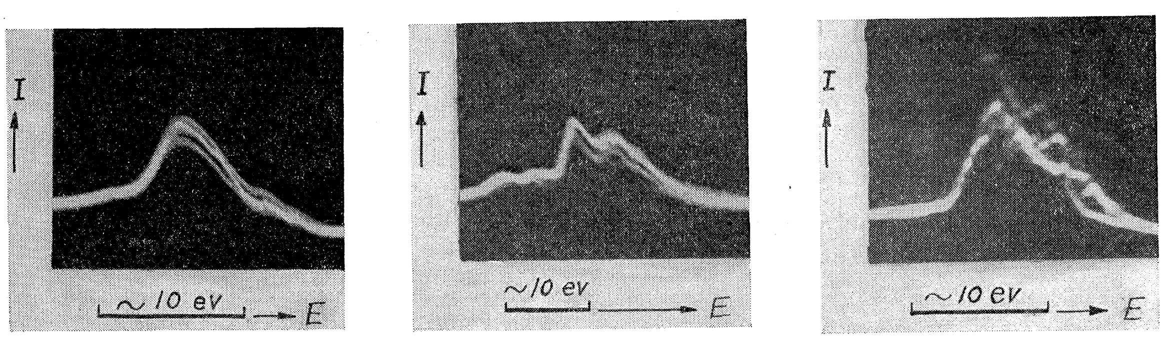
Fig. 2. The full curve shows the typical result obtained by previous investigators and the dotted one shows the theoretical curve of Rudberg and Slater (reference 6).

The former method has recently been improved and used by several investigators,[1] while the latter method has not been used for nearly thirty years.

We have improved this latter method. In our method electronic differentiation devices are used instead of an inaccurate graphical one, and the voltages applied to the anticathode are supplied from the saw-tooth wave oscillator of 100 cps. In this way spectral intensity curves of the soft x-ray may be shown directly on a cathode-ray oscillograph.[2,3] As the period of the repetition of the saw-tooth wave is fairly short, occasional changes due to adhesion and liberation of gas molecules do not cause any harmful effects.

Some of the results obtained for $M_{\mathrm{II,III}}$ emission curves of pure copper are shown in Fig. 1. Two types of spectrograms were found. The one shown in (a) resembles those of a number of workers,[4,5] while the one shown in (b) has not been hitherto found. The full curve in Fig. 2 shows the typical result obtained by previous investigators and the dotted one shows the result obtained by Rudberg and Slater[6] theoretically; the latter curve is quite similar to our curve (b).

Usually, a curve like that shown in (a) was observed on the oscillogram. However, the curve frequently changes its shape and after a short transient stage, as



(a) (b) (c)

Fig. 1. Two types of the $M_{\mathrm{II,III}}$ band emission curves of pure copper. The curve (a) resembles those of previous investigators, and (b) resembles Rudberg and Slater's theoretical curve. The transient time from (a) to (b) or (b) to (a) was very short. These two curves were observed simultaneously in photograph (c). Exposure: 1/25 sec.

shown in (c), transforms to the type (b). The curve (b) does not persist for a long time and eventually it returns to the curve (a). Therefore, if we take a photograph with long exposure, we will have an oscillogram of type (a). This will be true in the case of diffraction grating spectroscopy. Thus, the curve (b) would not have been found by previous investigators. Perhaps the curve (b) which was predicted by Rudberg and Slater represents the correct energy distribution in a clean metal surface and the type (a) corresponds to a somewhat disturbed state.

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Evaporated Multiple Layers with Semiconductor Properties

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THIN multiple-layer films were deposited on Pyrex in a high vacuum (10^{-6} mm Hg) by alternate evaporations of two metals not likely to form intermetallic compounds or alloys. Successive layers were deposited at intervals of 15 seconds giving about equal increments of conductance with average thicknesses of approximately 2 A. Such films had negative temperature coefficients of resistivity.

Figure 1 refers to a film comprising 210 layers each of iron and lead. The pressure was maintained at 10^{-6} mm Hg for 42 days while measurements *S*1, *S*2, *S*3, and *S*4 were made. The slight increase in conductance and decrease of slope with aging is accentuated by heating indicating some recrystallization.

Thin films of single metals are known to possess negative temperature coefficients[1] which can be interpreted as due to gaps between deposited islands requiring some activation energy to be bridged.[2] This corresponds to a stage of film formation when the increase of conductance is more than proportional to the metal deposited. The multiple layers were at a stage where the conductance increased proportionally with time, indicating a continuous conducting layer.

Films of only iron or lead obtained under conditions similar to those for the composite layers and of similar conductance gave negligibly small or positive temperature coefficients showing that the large negative temperature coefficients of the composite films were not due to impurities or to gross oxidation.

Figure 2 gives the conductance to temperature relation in modified experiments which favored the formation of larger metal agglomerates. At temperatures below that of formation (330°K) the change of conductance with temperature given in Figs. 1 and 2 was

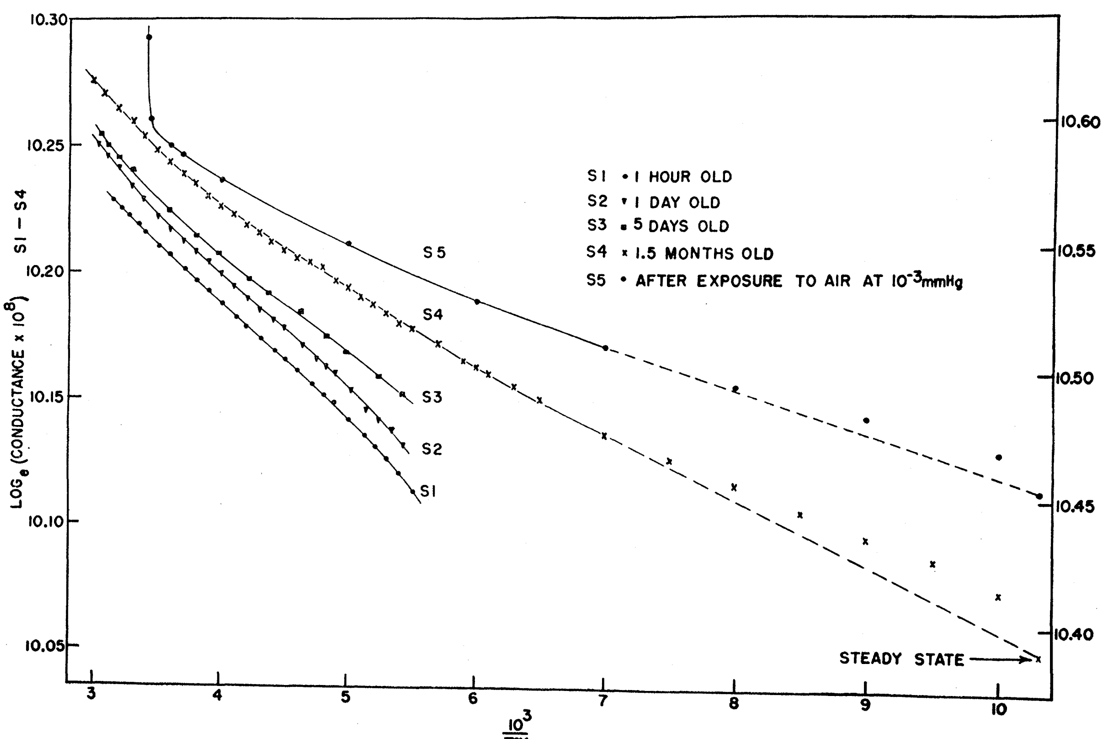
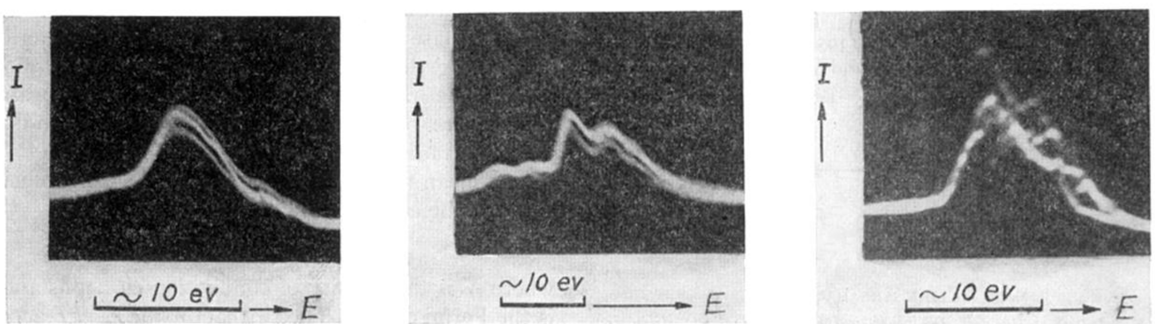


FIG. 1. Log$_e$ conductance *vs* $1/T$ for an alternately evaporated deposit of 210 layers each of iron and lead.



(a) (b) (c)

FIG. 1. Two types of the $M_{\mathrm{II,III}}$ band emission curves of pure copper. The curve (a) resembles those of previous investigators, and (b) resembles Rudberg and Slater's theoretical curve. The transient time from (a) to (b) or (b) to (a) was very short. These two curves were observed simultaneously in photograph (c). Exposure: 1/25 sec.