The half-thickness values found for the x-ray components of the absorption curves are given in Table III.

TABLE III. Half-thickness values for absorption of x-rays from Ba^{131} and Cs^{131}.

Absorbers	Ba^{131} x-rays	Cs^{131} x-rays
Sn	34 mg/cm²	30 mg/cm²
Sb	30	63
Te	144	95

The K_α x-ray of Xe, which arises after the Cs^{131} captures a K electron, should be strongly absorbed by Sn but not by Sb and Te. This general condition is met. However, the half-thicknesses given for Te absorbers are too high. This may be due to insufficiently uniform distribution of the Te powder in the beeswax. Although it can be concluded from these data that the x-rays from Cs^{131} are the K radiations of Xe, the data are inconclusive with respect to Ba^{131}. But since the latter decays to Cs^{131}, the observed x-rays are very probably the K radiations of Cs.

This paper is based on work performed at the Metallurgical Laboratory of the University of Chicago under Contract W-7401-eng-37 for the Manhattan Project, and the information contained therein will appear in Division IV of the Manhattan Project Technical Series.

* This work was originally reported in Manhattan Project Report CC-3148 (June 1, 1945); see also Plutonium Project Record IX B, 12.1.2.
** Now at University of California at Los Angeles.

[1] S. Katcoff, Phys. Rev. 72, 1160 (1947).

The Conductivity of Metals at Microwave Frequencies*

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IT is the purpose of this note to point out that the application of the free electron theory to the problem of metallic conductivity at microwave frequencies leads to conclusions about the temperature dependence of r-f conductivity which seem to have been overlooked.

We consider an electromagnetic wave of frequency ν with the electric vector polarized in the x direction incident in the z direction on a metal whose surface lies in x-y plane, so that inside the metal the electric field equals $E(z,t)=Re\{E_{0x}e^{2\pi i\nu(t-Mz/c)}\}$, where E_{0x} = amplitude of the electric vector, t = time, M = complex index of refraction of the metal, and c = velocity of light in vacuum. In the presence of this field, the distribution function, $f(\mathbf{k},\mathbf{r})$, giving the number of electrons per unit volume at the point $\mathbf{r}$ having momentum $\mathbf{k}$, is a solution of the Boltzmann equation[1],

$$\frac{\partial f}{\partial t}-\frac{e}{\hbar}E(z,t)\frac{\partial f}{\partial k_x}+v_z\frac{\partial f}{\partial z}=-\left(\frac{f-f_0}{\tau}\right),$$

where e = electronic charge, $\hbar$ = Planck's constant/2π,

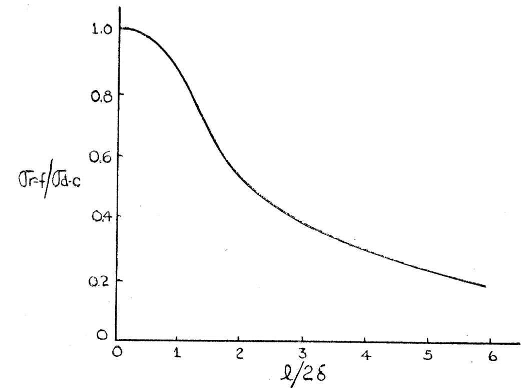

FIG. 1. The ratio of the r-f conductivity to the d.c. conductivity is shown plotted *versus* the ratio of the mean free path to twice the skin depth.

$k_x = x$ component of the electron momentum, $v_z = z$ component of the electron velocity, f_0 = distribution function in the absence of the field, and τ = relaxation time for the collision of an electron with the metal lattice.

In view of the dependence of the field on z and t, we have attempted to find a solution of this equation without neglecting any of the terms. For the case where the distribution function f differs only slightly from the equilibrium Fermi-Dirac function f_0, the differential equation has a particular solution

$$f=f_0+\frac{e}{\hbar}\frac{\partial f_0}{\partial k_x}\tau\ Re\left\{\frac{E(z,t)}{1+2\pi i\nu\tau-2\pi i\nu M v_z\tau/c}\right\}.$$

This solution reduces to the usual solution in the limit $\nu=0$.

The current density is found by multiplying f by v_x and averaging over momentum space. If this is carried out for the case of free electrons and the conduction current is separated from the displacement current, it is found that the ratio of the r-f conductivity ($\sigma_{r\text{-}f}$) to the d.c. conductivity ($\sigma_{d.c.}$) in the microwave region is a function only of

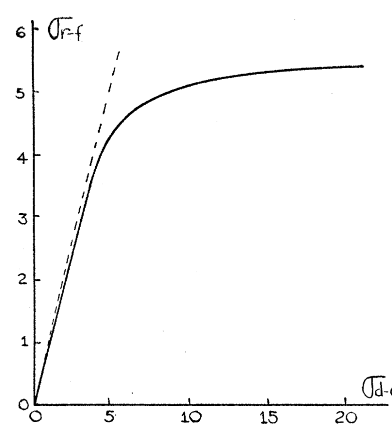

FIG. 2. The theoretical curve of the r-f conductivity *versus* the d.c. conductivity is shown for the metal silver. The r-f frequency was assumed to be 10^4 mc/sec. The σ's are in units of the value at 0°C.

the quantity $l/2\delta$, where l = electron mean free path and δ = skin depth. This function is shown in Fig. 1.

The calculation of $\sigma_{r\text{-}f}/\sigma_{d.c.}$ for any given l (i.e., for a $\sigma_{d.c.}$) must be carried out self-consistently since δ depends on $\sigma_{r\text{-}f}$. The theoretical curve of $\sigma_{r\text{-}f}$ at 10^4 megacycle/sec. *versus* $\sigma_{d.c.}$ for the metal silver is shown in Fig. 2. It is to be noted that $\sigma_{r\text{-}f}/\sigma_{d.c.}$ decreases rapidly with increasing $\sigma_{d.c.}$. $\sigma_{d.c.}$ may be increased by decreasing the temperature.

The above results are in qualitative agreement with recent experiments performed on lead[2,3] at M.I.T.

At infra-red frequencies, the effect of skin depth is again small and one obtains the usual expression[4] for the r-f conductivity.

The author wishes to thank Dr. H. C. Torrey for suggesting this problem to him.

* This work was supported in part by funds provided by the Research Corporation, F. G. Cottrell Grant, and by the Rutgers University Research Fund.

[1] A. H. Wilson, *The Theory of Metals* (Cambridge University Press, 1936), pp. 3, 158.

[2] J. C. Slater, private communication.

[3] J. G. Daunt has recently informed the author that A. B. Pippard of the Royal Society Mond Laboratory, England, has several papers in press in the Proc. Roy. Soc. on both the experimental and theoretical aspects of this subject.

[4] See reference 1, p. 123ff.

Abnormality in Cosmic-Ray Absorption in Lead in Low Latitudes*

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THE apparatus used comprised two cosmic-ray telescopes in parallel, each supplied with five counter trays. Lead could be placed between trays 3 and 4 and between trays 4 and 5. Triple coincidences were observed between trays 3, 4, and 5.[1] Six centimeters of lead were placed above the apparatus to shield out electrons and a shield was also placed around the top tray.

In taking the aforementioned observations, and in order to allow for possible variations of the cosmic-ray intensity throughout those observations which extended over about ten days, the plan was not to complete the observations for any one lead thickness, a, and then pass on to another

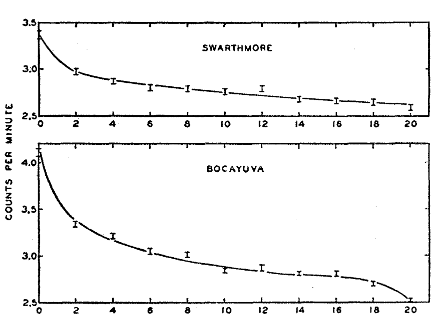

FIG. 1. Coincidence rate *vs.* lead-absorber thickness.

thickness, b, but to take a few observations for all thicknesses ranging from the smallest to the largest, then another few observations with thicknesses ranging from the largest to the smallest, then another set ranging from the smallest to the largest, and so on. In this manner, each thickness of lead was tested with rays which, on the average, were of exactly the same kind. Also the procedure was to make observations without lead, with 1 cm of lead between trays 3 and 4 and another between trays 4 and 5, then with two 1-cm slabs between trays 3 and 4 and two between trays 4 and 5, proceeding in this way until a totality of 20 cm of lead had been reached. Observations were made with each of the two telescopic units, and the results were combined.

Figure 1 shows the data obtained at Bocayuva (magnetic latitude 7°S) and at Swarthmore (magnetic latitude 51.5°N). The Bocayuva curve shows an approximately 10 percent drop at a total lead thickness of 22 cm. Experiments performed by S. V. Chandrashekhar Aiya at Bangalore show a 5 percent drop at 21 cm of lead. On the other hand, the Swarthmore curve shows no appreciable drop. These facts seem to invite the belief that the phenomenon resulting from a component of the radiation which is present in low latitudes is absent in high latitudes. This aspect is being developed in detail by one of us elsewhere.

One element rather difficult to reconcile is the fact that the altitude at Bocayuva is 2300 feet while that at Bangalore is 3100 feet. The difference in lead absorption is the equivalent of about 7 cm of lead. It is rather surprising, therefore, that the phenomenon seems to take place at approximately the same lead thickness at Bocayuva as at Bangalore, suggesting that it is concerned purely with something happening in the lead as distinct from something depending upon the energy of the rays.

* Supported by funds from Navy Contract N6ori-144 and from the National Geographic Society, also by airplane services from the U. S. Army Air Force.

[1] The other trays were for another purpose.

Microwave Spectra: Methyl Cyanide and Methyl Isocyanide*

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November 7, 1947

THE first and second rotational transitions of CH_3CN and of CH_3NC have been studied in the microwave region.

Nuclear Effects. The spectrum of CH_3CN shows a definite hyperfine structure which can be attributed to the quadrupole moment effects of the nitrogen nucleus. Figure 1 shows the $J=0$ to $J=1$ transition, which is split into only three components by the nuclear effects. Accurate measurement of the separation of the components was made by a method evolved in this laboratory.[1] The bars give the theoretically predicted hyperfine structure. The magnitude of the coupling coefficient, $eQ(\partial^2 V/\partial z^2)$, thus deter-