TABLE I. π^+ to π^- ratio as a function of the laboratory meson energy.

E_π, Mev	π^+/π^- ratio
42	5.8 ± 2.5
51	7.4 ± 1.7
60	21.6 ± 8.9
70	22.1 ± 3.5
79	20.8 ± 7.1
88	36.5 ± 6.2
98	$34\ \ \pm14$
108	—
126	—

indicated a less than 5 percent contamination of particles with ranges greater than the expected meson ranges.

The target used was a high pressure gas target 24 in. long, which contained deuterium at 1400 psi at liquid nitrogen temperature. This placed 3.3 grams per square centimeter of deuterium in the beam, and since the end windows of the target contained only 1.7 grams per square centimeter of stainless steel, the production from the deuterium was greater than that from the target windows. Magnetic shielding was placed around the target to prevent the fringe fields of the first magnet from effecting the paths of the mesons produced in the far end of the target.

The ratios observed were obtained by measuring the meson production from the container plus gas at a series of energies, reversing the fields in both magnets, and measuring the mesons produced at the same energies. The gas was then removed from the container and similar measurements were made for the production from the end windows of the target. The values of the field strengths corresponding to various meson energies were obtained by using a current carrying wire to give the trajectories of the mesons of various energies. The fields were adjusted so the trajectory for each energy was the same. Use of the wire showed that reversing the magnetic fields delivered particles of the same energy but of opposite sign to the same position on the rear counters.

Checks of the counter efficiency were made using a Co^{60} source, and reversal of the magnetic fields was found to effect the counting rate in counters 1 and 3 by less than one percent. Counters 2 and 4 could not be tested in this manner, but the measured magnetic field at these counters was less than that at the position of counters 1 and 3.

The values of the π^+ to π^- ratio obtained for deuterium are given in Table I. Errors shown are standard deviations. Values are not shown for 108 and 126 Mev because no negative mesons were found at these energies. The ratios shown are those obtained by simply reversing the magnetic fields at a particular meson energy. The production curves are being corrected at the present time for the energy resolution of the apparatus, and any changes in the results will be published in a forthcoming article which will also include the results obtained for He, Be, C, and Pb.

The results that were obtained agree with the previous work on deuterium[1] in that they show a value higher than expected. Previous theoretical work[2] indicated that a ratio of about 8 might be expected. Some theoretical implication of these results are discussed in the following letter.

[1] Passman, Block, and Havens, Phys. Rev. 85, 370 (1952).
[2] H. P. Noyes, Phys. Rev. 81, 924 (1951).

The π^+ to π^- Ratio from Proton Bombardment of Deuterium*

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NOYES[1] has calculated the expected ratio of negative to positive π-mesons in the forward direction when deuterium is bombarded by 345-Mev protons. Most of the mesons in collisions with free target nucleons have 60-Mev to 70-Mev energy in the laboratory system. To obtain π-mesons in this energy range from $p-d$ collisions, the production must come mostly when the internal momentum of the deuteron is small. For these cases, when the proton and neutron are far apart, the uncertainties in the deuteron wave function are minimized and Noyes' assumptions are most likely to be valid. He finds a π^+ to π^- ratio of 8.2 ± 0.8 at 60 Mev if the $p+p\rightarrow\pi^+$ cross section differs from $p+n\rightarrow\pi^-$ only in a factor of two for the two protons and in the different interactions between the final nucleons. The final proton and neutron after π^+ production are taken to be in a ^3S state. Any admixture of singlet lessens the ratio. The matrix elements are assumed to be energy independent. If they vary like the square root of the meson center of mass kinetic energy, the ratio is a few percent smaller.

The experimental[2] value of the forward π^+ to π^- ratio at 60 Mev is about three times larger than predicted, implying that the $p+n\rightarrow\pi^-$ matrix element is suppressed relative to $p+p\rightarrow\pi^+$. This also seems to be true at 90°.[3]

If isotopic spin is conserved in meson production and the π^- meson is emitted predominantly into a p-state, the initial $p-n$ system is ^3S or ^3D and therefore has isotopic spin zero. Then in the final state of a π^- meson and two protons, the π^- and either proton must be in a state of isotopic spin one-half. To the extent that the interaction is strong only when leading to π^--proton states of isotopic spin $\frac{3}{2}$, the π^- production will be forbidden.[4] It is interesting to note that while isotopic spin does not contribute a selection rule for $p+p\rightarrow\pi^+$, the angular distribution indicates that the final state is one in which the π^+ and either nucleon have angular momentum $\frac{3}{2}$.[5]

* This work was performed under the auspices of the AEC.
† Now at Columbia University, New York, New York.
[1] H. P. Noyes, Phys. Rev. 81, 924 (1951).
[2] J. Carothers and C. G. André, preceding Letter [Phys. Rev. 88, 1426 (1952)].
[3] Passman, Block and Havens, Phys. Rev. 85, 370 (1952).
[4] This would not necessarily imply that, at these energies, the scattering of π-mesons in hydrogen should be strong only in isotopic spin 3/2 states, since the scattering could involve matrix elements which cannot contribute to single meson production, viz., a meson pair coupling [J. V. Lepore, Phys. Rev. 88, 750 (1952); G. Wentzel, Phys. Rev. 86, 802 (1952)].
[5] K. Brueckner and K. M. Watson, Phys. Rev. 86, 923 (1952).

Optical and Infrared Reflectivity of Metals at Low Temperatures

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THE theory of the anomalous skin effect in metals was developed by Reuter and Sondheimer[1] to cover the case, often encountered at low temperatures, in which the electron mean free path is comparable to, or larger than the skin depth, as computed from the conventional theory.[2] Under such conditions explicit account must be taken of the motion of electrons in a spatially inhomogeneous electric field, with the result that the standard relation,[3]

$$\mathbf{j}(\mathbf{r})=\sigma(\omega)\mathbf{E}(\mathbf{r})=(ne^2\tau/m)(1+i\omega\tau)^{-1}\mathbf{E}(\mathbf{r}), \tag{1}$$

between the current density and electric field must be replaced by a more general expression of the form:

$$\mathbf{j}(\mathbf{r})=\int G(\mathbf{r},\mathbf{r}')\mathbf{E}(\mathbf{r}')dV'. \tag{2}$$

With regard to the "relaxation" region $\omega\gg1/\tau$ with which we are primarily concerned here, Reuter and Sondheimer make the plausible statement that, when the skin depth

$$\delta\gg v/\omega, \tag{3}$$

i.e., when the skin depth is large compared to the distance traversed by an electron in a period of electromagnetic oscillation, the conventional theory based upon (1) should apply. Nevertheless, their results (reference 1, Fig. 4) on metallic absorptivity in the optical and near infrared regions, in which (3) is valid, are generally in disagreement with the prediction of this theory. In the present note, we explain the disagreement in terms of a mechanism of electromagnetic loss which operates even when the relaxation time τ is infinite.

In our treatment, we assume that the validity of Eq. (3) permits us to consider the electromagnetic field to be essentially that associated with a stationary but otherwise free electron gas—the model provided by Eq. (1) with $\tau=\infty$. For the case of normal incidence of a plane electromagnetic wave upon a plane-parallel metallic surface, one readily obtains

$$E=E_s{}^{-x/\delta_f}\cos(\omega t+\alpha), \tag{4}$$

where

$$\delta_f=(4\pi ne^2/mc^2)^{-\frac{1}{2}} \tag{5}$$

and

$$E_s=(2i\omega\delta_f/c)E_i. \tag{6}$$

(E_i is the amplitude of the incident field, α an arbitrary phase angle, and x the coordinate perpendicular to the surface.)

In the approximation of a stationary free-electron gas there is no loss of electromagnetic energy. However, when account is taken of the motion of the electrons to and from the metallic surface, one obtains a finite transfer of energy from the electromagnetic field to the electrons. The computation of this transfer will now be sketched briefly.

For the case in which an electron is specularly reflected, its terminal velocity $\mathbf{v}_t$ which it possesses upon leaving the boundary region in which the field is effectively contained is given by

$$\mathbf{v}_t=\mathbf{v}_i+(e/m)\int_{-\infty}^{+\infty}\boldsymbol{\varepsilon}(t)dt,$$

where $\boldsymbol{\varepsilon}(t)$, the field seen by the electron, is obtained from Eq. (4) by substituting[4] $x=v_i|t|\cos\theta$. The energy ΔE_{sp} transferred to the electron is then readily seen to be

$$\Delta E_{sp}=\left\langle\left[(e/m)\int_{-\infty}^{+\infty}\boldsymbol{\varepsilon}(t)dt\right]^2\right\rangle_{\text{Av}}, \tag{7}$$

the average[5] being taken with respect to the arbitrary phase angle α.

In the case of diffuse reflection at the metallic surface, the electron velocity is "randomized" at $t=0$; as a result, the energy gain ΔE_d turns out to be

$$\Delta E_d=\left\langle(e/m)^2\left[\left(\int_{-\infty}^{0}\boldsymbol{\varepsilon}(t)dt\right)^2+\left(\int_{0}^{\infty}\boldsymbol{\varepsilon}(t)dt\right)^2\right]\right\rangle_{\text{Av}}. \tag{8}$$

One obtains the rate of energy transfer per unit surface by multiplying (7) or (8) by the differential current,[6]

$$dI=nv(\sin\theta\cos\theta d\theta/2)(3v^2dv/v_0{}^3), \tag{9}$$

and integrating over all angles of incidence and all velocities from zero to v_0. Upon dividing the result by the incident flux per unit surface $cE_i{}^2/8\pi$, one obtains the absorptivity, which may be written in the general form

$$A=p\frac{2\pi ne^2}{m\omega^2}\cdot\frac{v_0{}^3}{c^3}+(1-p)\frac{3}{4}\frac{v_0}{c}, \tag{10}$$

where p is the fraction of electrons incident on the metallic surface which are specularly reflected, the remainder being diffusely reflected.

In the case of specular reflection ($p=1$), Eq. (10) gives

$$A_{sp}=(2\pi ne^2/m\omega^2)(v_0{}^3/c^3),$$

which agrees substantially with the graphical result of Reuter and Sondheimer in the optical and near infrared regions (reference 1, Fig. 4). However, the diffuse absorptivity $A_d=\frac{3}{4}v_0/c$, in contrast to the other cases treated by Reuter and Sondheimer, ($\omega\gtrsim 1/\tau$), may exceed A_{sp} by orders of magnitude. Namely, from Eqs. (5) and (3), we have

$$\frac{A_d}{A_{sp}}=\frac{3}{2}\frac{m\omega^2}{4\pi ne^2}\frac{c^2}{v_0{}^2}=\frac{3}{2}\left(\frac{\omega\delta_f}{v_0}\right)^2\gg 1.$$

We may finally report an observation of Pippard[7] that in the case of copper; if we assume one free electron per atom, we have $v_0\sim 1.5\times 10^8$ cm/sec, which gives $A_d\sim 0.4$ percent, in order of magnitude agreement with the experimental result, 0.62 percent, obtained by Ramanathan.[8]

A more complete report of this work will be presented at a later date.

[1] G. E. H. Reuter and E. H. Sondheimer, Proc. Roy. Soc. (London) **A195**, 336 (1948).
[2] See, e.g., A. H. Wilson, *The Theory of Metals* (Cambridge University Press, Cambridge, 1936), Chap. V, Sec. 4.1.
[3] In Eq. (3), ω is the circular frequency of the incident field and τ the relaxation time for attainment of thermal equilibrium between electrons and lattice.
[4] Here $\mathbf{v}_i$ is the initial random velocity and θ the angle of incidence (and reflection). We may without loss of generality take the origin of time to be the instant the electron strikes the surface.
[5] In this averaging operation, the cross term in the square of the right-hand side of (7) vanishes.
[6] We assume isotropically directed velocities with magnitudes varying from 0 to $v_0\equiv(h/m)(3n/8\pi)^{\frac{1}{3}}$ according to the Fermi distribution at absolute zero.
[7] A. B. Pippard, private communication.
[8] K. G. Ramanathan, Proc. Phys. Soc. (London) **A65**, 532 (1952).

Dependence of Gamma-Radiation Lifetimes on Nucleon Configurations

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It has been pointed out[1] that the gamma-radiation lifetimes of $M4$ transitions deviate by less than 30 percent from the mean lifetime τ_γ, given by a simple empirical formula of the Weisskopf type.[2] For other multipole radiations there is no such good agreement with empirical formulas. In particular, it has been observed[1] for $E3$ transitions that the squares of the matrix element, $|M|^2$, defined as τ_γ(theoretical)/τ_γ(experimental), vary by as much as $10^{\pm 2}$ from a median value.

In connection with an investigation of a 14-hour isomeric decay of Os^{191}, an extremely slow $E3$ transition has recently been observed.[3] Since one of the states involved in this transition was identified as having a complex nucleon configuration, it seemed of interest to investigate whether there existed other evidence of a

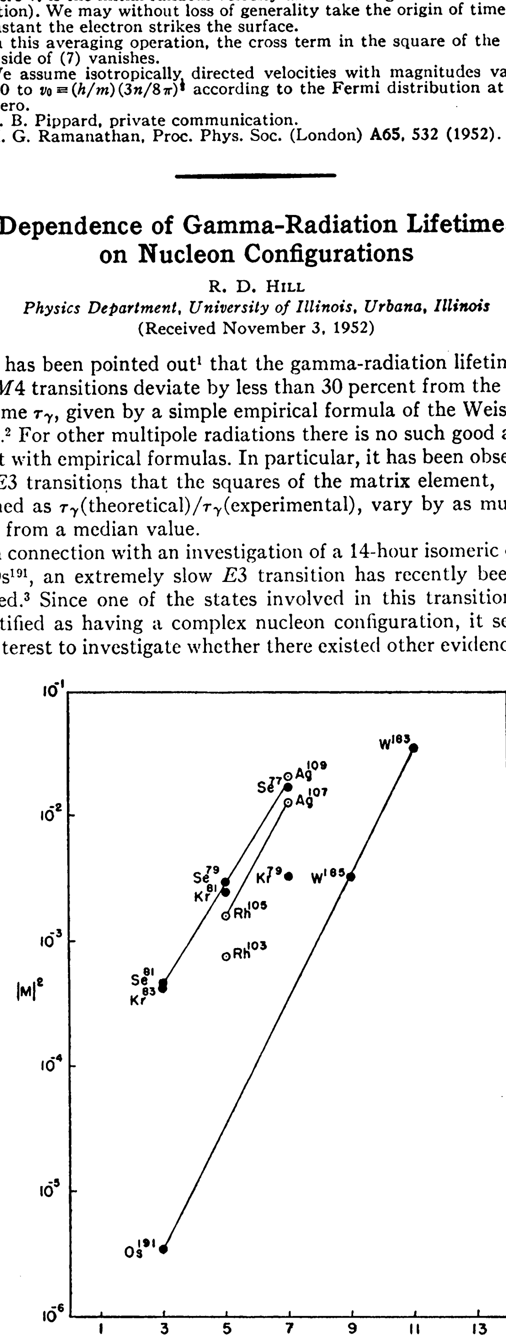

FIG. 1. Variation of the matrix element, $|M|^2$, for $E3$ transitions of the $7/2+\rightleftarrows p_{\frac{1}{2}}$ type, with complexity n of the $7/2+$nucleon configuration. Full circle points refer to even Z-odd N isomeric transitions. Open circle points refer to odd Z-even N isomeric transitions.