result proves to be also true for the mica, it may enable us to investigate the nature of the surface distribution apart from the bulk distribution.

A more detailed account of the work to date will be published later.

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[2] J. Joly and E. Rutherford, Phil. Mag. **25**, 644 (1913).
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Infra-Red Color Center Bands in the Alkali Halides

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NEW color center bands in the near infra-red have been observed in alkali halides irradiated with x-rays from a beryllium window tube with a tungsten target[1] and subsequently irradiated with white light. In agreement with the results of earlier investigators, the F- and M-bands formed by relatively small x-ray exposures (10^6 roentgens/cm^2) are completely bleached without appreciable R-band formation. However, after greater x-ray exposures (10^8 roentgens/cm^2) the F- and M-bands are only partially bleached by irradiation with white light. Under these conditions there is appreciable R-band formation and, in addition, new bands are observed in the near infra-red beyond the M-bands. Additional prolonged irradiation with white light produced relatively little effect on the appearance of the various bands. Visual examination of the partially bleached specimens showed that the residual color was located in a thin section at the surface of the crystal entered by the x-rays. At liquid nitrogen temperatures the various bands narrowed, shifted to shorter wave-lengths, and showed additional structure. The various color center bands are shown in Fig. 1 for KCl after a dosage of 600×10^6 roentgens/cm^2 and subsequently irradiation with white light. Preliminary measurements on additively colored crystals of KCl which were exposed to white light revealed that the new bands are also present in these crystals. Similar results were obtained for KBr and NaCl.[2]

The nature of the new near infra-red bands ("N-bands") and the factors leading to their formation are being investigated further. At present, it may be supposed that the N-bands correspond either to electrons trapped at specific clusters of vacancies in a manner analogous to that suggested by Seitz for the R- and M-bands[3] or to two-dimensional aggregates of F-centers as suggested by Mitchell for the color center bands in the silver halides.[4] The inability to bleach the color center bands indicates that the positive holes formed during irradiation have diffused away from the surface regions of the crystal. A loss of atomic halogen from the surface of the crystal during x-irradiation is highly probable and may, in fact, account for part of the decrease in density observed in KCl on prolonged x-irradiation.[5] Regardless of the exact mechanism for the decrease in density, it is reasonable to assume that the x-irradiated crystal contains a larger concentration of vacancies than is normally present. Partial bleaching increases the concentration of negative ion vacancies still further so that conditions are favorable for the aggregation of vacancies or F-centers. Measurements are being carried out on the changes in ionic conductivity and dielectric loss to obtain further information about the mechanism of vacancy formation during x-irradiation.

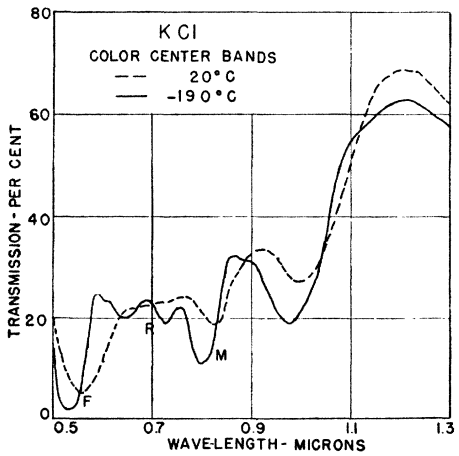

FIG. 1. Various color center bands for KCl after a dosage of 600×10^6 roentgens/cm^2.

[1] A Machlett AEG-50A tube operated at 50 kv and 20 ma was used in this work.
[2] A color center band in NaCl corresponding to the N-band was reported by Molnar in his thesis (M.I.T. 1942).
[3] F. Seitz, Rev. Mod. Phys. **18**, 348 (1946).
[4] J. W. Mitchell, Phil. Mag. **40**, 249 (1949). We are grateful to Dr Mitchell, who pointed out this possibility to us.
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The S-Matrix for Meson-Nucleon Interactions

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DYSON[1] has given a set of simple rules for writing down the integrals for the matrix elements for transitions in electrodynamics. These rules have since been extended to cover the more general meson-nucleon interactions which may include differentials.[2] With the use of his rules Dyson[3] has proved that the consistant renormalization of mass and charge will remove all the divergences from the S-matrix for scattering processes in electrodynamics. Dyson starts by proving that there are only four types of primitive divergents in the theory. One of these—the scattering of light by light, to be referred to as a "square" part—is then shown by arguments of gauge invariance to introduce, in fact, no new divergences. For (pseudo-)scalar meson scalar-interactions with nucleons the primitive divergents are the same as in electrodynamics, but the attempt to obtain a finite S-matrix fails because genuine divergences arise from square parts.[4] In all the other meson-nucleon interactions the occurrence of extra differentials allows for an infinite number of primitive divergents and Dyson's method appears to fail completely. However, the (pseudo-)vector meson vector-interactions are peculiar in that the differentials occur in the commutation relations, not in the interactions. It will be shown below that in the single case of the neutral vector meson vector-interaction the differentials do not contribute to the matrix elements and a finite S-matrix can be obtained by Dyson's method.

The vector meson field $\varphi_\mu(x)$ with positive definite energy can be expressed in terms of two subsidiary fields,[5] a vector field $A_\mu(x)$ and a scalar field $B(x)$, where

$$\varphi_\mu(x)=A_\mu(x)+(1/\kappa)(\partial B/\partial x_\mu). \tag{1}$$

The wave function satisfies the subsidiary condition

$$(\partial A_\mu/\partial x_\mu+\kappa B)\Psi=0. \tag{2}$$

The Hamiltonian for the vector-interaction in the interaction representation is[6]

$$H(x)=(1/c)j_\mu(x)(A_\mu(x)+(1/\kappa)\partial B/\partial x_\mu)+(1/2c^2\kappa^2)(j_\mu(x)n_\mu)^2, \tag{3}$$

where n_μ is the normal to the general space-like surface. The components of $A_\mu(x)$ and $B(x)$ commute like independent scalar fields so that the differentials in the commutation relations of $\phi_\mu(x)$ arise from the differential of $B(x)$ in the definition of $\phi_\mu(x)$.

Now $B(x)$ occurs in $H(x)$ as a scalar meson vector-interaction. If we perform the transformation[7]

$$\Psi = e^{-iS}\Psi', \tag{4}$$

where

$$S = (1/\hbar c\kappa)\int j_\mu(x)B(x)d\sigma_\mu, \tag{5}$$

on the generalized Schrödinger equation in the Schrödinger representation,[8] the total Hamiltonian is unaltered except for the removal of the last two terms in (3). In this form the free field Hamiltonians can be removed by a transformation to the interaction representation to give the Hamiltonian

$$H(x) = (1/c)j_\mu(x)A_\mu(x) = ig\psi(x)\gamma_\mu\psi(x)A_\mu(x) \tag{6}$$

from which differentials of Δ_F-functions will not arise in the S-matrix. Since (5) commutes with the operator in (2), the subsidiary condition will not be altered by the transformation. Just as in electrodynamics, the suffix μ can take all four values in virtual effects but for real mesons it is restricted by the supplementary condition. This restriction will be automatically satisfied if the free meson lines are made to correspond to factors $\phi_\mu(x)$ in the integrals. Thus the Hamiltonian can be taken to be

$$H_1(x) = (1/c)j_\mu(x)\phi_\mu(x) - \hbar c\delta\kappa_0\psi(x)\psi(x) - \tfrac{1}{2}\delta\kappa^2\phi_\mu^2(x) \tag{7}$$

in the calculation of the S-matrix provided internal meson lines correspond to factors

$$\langle P(A_\mu(x), A_\nu(y))\rangle_0 = \tfrac{1}{2}\hbar c\delta_{\mu\nu}\Delta_F(x-y). \tag{8}$$

The extra terms in $H_1(x)$ allow for the renormalisation of both nucleon and meson masses. The possible primitive divergents are the same as in electrodynamics. The integrals from square parts are also the same and thus introduce no new divergences. Hence a finite S-matrix can be obtained. If the mesons are charged there is an extra term in (6)[7] which cannot be treated by these methods.

A similar treatment is not possible for the pseudo-vector meson because the corresponding transformation does not remove the subsidiary pseudo-scalar field, but introduces a complicated interaction involving the subsidiary field in the power of an exponential.[7]

It is hoped to publish elsewhere a more detailed discussion of the derivation of (7) and the failure of Dyson's method in the other cases.

[1] F. J. Dyson, Phys. Rev. **75**, 486 (1949).
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[3] F. J. Dyson, Phys. Rev. **75**, 1736 (1949).
[4] I am indebted to Mr. F. J. Dyson for pointing out a fundamental error in my original (unpublished) deduction on this point.
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Electric Quadrupole Moments of Nuclei

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THE rule, given by Gordy[1] in order to estimate the electric quadrupole moments Q for isotopic pairs having the same spin may be extended to isotopic pairs having different spin and to nuclei with Z values nearly equal.

The magnetic moment is a function of atomic number, spin, and quadrupole electric moment, other things being equal: (1) the spin decreases with a decrease of the magnetic moment; (2) the magnetic moment increases with Z; (3) if the quadrupole moment becomes more positive (or less negative for flattened nuclei), the magnetic moment appears to decrease.

With these rules, we can obtain further Q-values, absolute or relative. All the quadrupole electric moments as estimated by Gordy are in good agreement with these rules, which are cumulative. For instance, going from Ga^{71} to As^{75}, Z grows by two units, the spins remain the same, and the magnetic moment gets smaller. Therefore, we expect the nuclear quadrupole moment of As^{75} to be more positive, which turns out to be true.

According to these rules, the following Q-values can be expected:

Zn^{67} nucleus is less flattened than Cu^{65} and $Q(Zn^{67}) \sim = 0$,
Co^{59} nucleus is less flattened than Mn^{55} and $Q(Co) > Q(Mn)$,
Rb^{85} nucleus is less flattened than Rb^{87} and $Q(Rb^{85}) \sim = +30 \times 10^{-26}$ cm^2,
Sb^{123} nucleus is less flattened than Sb^{121} and $Q(Sb^{123}) \sim = -60 \times 10^{-26}$ cm^2.

[1] W. Gordy, Phys. Rev. **76**, 139 (1949).

On the Delayed Neutron Emitter $_7N^{17}$ *

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IT has been found by E. O. Lawrence and his associates[1] at California that when O and the elements immediately above it in atomic number are bombarded with 195-Mev deuterons, a delayed neutron emitter with a 4.14 ± 0.04 sec. half-life is formed. Alvarez[2] identified this delayed neutron emitter as N^{17} and Alvarez[3] and Hayward[4] determined the energy relationships in the β–n decay process. The production of N^{17} by bombarding elements of higher atomic number than fluorine with 195-Mev deuterons probably takes place by a spallation process. It is known that the yield of the delayed neutron emitter decreases with increasing atomic number of the target material.[5] The same nuclide was also produced by the $C^{14}(\alpha,p)N^{17}$ process by Sun, Jennings, Shoupp, and Allen[6] who found an upper limit of the (α,p) threshold of 16 Mev in agreement with Alvarez's measurements.

We may calculate the Q-values of the possible simple nuclear reactions by which N^{17} may be formed. Using Bethe's[7] value for the mass of O^{17} and Alvarez's value[3] for the $(N^{17}-O^{17})$ mass difference one obtains the mass of N^{17} to be 17.01385 a.m.u. Using Bethe's values for the other atomic masses, the Q-values for these reactions are given in Table I.

Because of the short half-lives of N^{16} and F^{20}, it is reasonable to consider the stable, although rare, nuclides O^{17} and O^{18} as the starting elements for the production of N^{17}. The following experiment was performed to determine whether N^{17} can be made by the $O^{17}(n,p)N^{17}$ process. Neutrons of known maximum energy were produced by bombarding a thick LiF or C target with a 14-Mev 2μa external deuteron beam from the University of Pittsburgh cyclotron. (Q-values are 15.0 Mev for Li^7, 10.7 Mev for F and -0.28 Mev for C.) Our previous measurements of neutron fluxes from various targets in this cyclotron indicate that the total number of neutrons produced per μa by the LiF and C targets is about the same and that only the energy of the neutrons, as inferred from the Q-values, is different. Thus it follows that the number of neutrons with energy above 8 Mev is greater for LiF than C targets. Neutrons from these sources were used to bombard 500 g of water containing O^{17} in its natural isotopic proportion.

TABLE I. Q-values of various reactions by which N^{17} is formed.

Reaction	Q-value
$N^{16}(n,\gamma)N^{17}$	5.9 Mev[a]
$O^{17}(n,p)N^{17}$	−7.9 Mev
$O^{18}(n,d)N^{17}$	−13.7 Mev
$N^{16}(d,p)N^{17}$	3.7 Mev
$O^{18}(\gamma,p)N^{17}$	−15.9 Mev
$F^{20}(n,d)N^{17}$	> -4.3 Mev and < 0.4 Mev

[a] The mass of N^{16} is taken as 16.01121 after L. D. Wyly, Phys. Rev. **76**, 462 (1949).