plications by introducing only two kinds of transverse and one kind of scalar photon, instead of the four kinds of photon variables of the Fermi electrodynamics.

Starting from the interaction representation, the states of free transverse photons can be described in a relativistic way by means of the 6-vector solutions $F_{\mu\nu}^{(1)}$ of the vacuum maxwell equations:

$$\begin{aligned}\partial_\mu F_{\mu\nu}^{(1)}&=0,\\ \partial_\kappa F_{\mu\nu}^{(1)}+\partial_\nu F_{\kappa\mu}^{(1)}+\partial_\mu F_{\nu\kappa}^{(1)}&=0.\end{aligned}\tag{1}$$

These equations insure that $F_{\mu\nu}^{(1)}$ represents transverse waves in any reference system. Quantization gives for the operators $F_{\mu\nu}^{(1)}$ the well-known covariant commutation relations of the field strengths. Using hyperplanes σ perpendicular to a timelike direction n_μ, the interaction between the transverse photon field and the current j_μ of the electrons can be introduced by means of an interaction hamiltonian

$$H_1^{(1)}=-\int_\sigma d\sigma' j_\mu(x')A_\mu^{(1)}(x'),\tag{2}$$

where the potential $A_\mu^{(1)}$ is defined with respect to the direction n_μ by means of the field $F_{\mu\nu}^{(1)}$, as

$$A_\mu^{(1)}=-\partial^{-1}F_{\mu\nu}^{(1)}n_\nu.\tag{3}$$

$\partial=n_\kappa\partial_\kappa$, and ∂^{-1} is a suitably defined inverse operator.[3] From Eqs. (1) and (3) and from the commutation relations for the $F_{\mu\nu}^{(1)}$, $A_\mu^{(1)}$ satisfies the equations $A_\mu^{(1)}n_\mu=0$, $\partial_\mu A_\mu^{(1)}=0$, $\Box A_\mu^{(1)}=0$, and the commutation relations of the transverse potential of the Fermi electrodynamics. A different choice of n_μ means only a different choice of the gauge of the potential $A_\mu^{(1)}$. Adding to Eq. (2) the covariant expression of the coulomb interaction energy, we have the usual form of quantum electrodynamics with the coulomb interaction treated separately. The present formulation has, however, the advantage of a relativistic description of the states of light quanta.

In order to describe the coulomb interaction as transmitted by a field, we introduce besides $F_{\mu\nu}^{(1)}$ another field, characterized by the four-vector B_μ, which satisfies in vacuum equations analogous to (1),

$$\begin{aligned}\partial_\mu B_\mu&=0,\\ \partial_\nu B_\kappa-\partial_\kappa B_\nu&=0.\end{aligned}\tag{4}$$

According to Eq. (4), $B_\mu=\partial_\mu Q$ can be deduced from a single scalar function $Q(x)$. The canonical formalism and the quantization of Eq. (4) can be worked out easily and correspond to the theory of a scalar meson with zero rest mass. In characterizing the states of scalar photons with the solutions of Eq. (4), we can introduce an interaction with the electrons by means of an interaction hamiltonian $H_1^{(2)}$ of the form (2), with a potential

$$A_\mu^{(2)}=-\partial^{-1}B_\mu=-\partial_\mu\partial^{-1}Q\tag{5}$$

instead of $A_\mu^{(1)}$.

The potentials $A_\mu=A_\mu^{(1)}+A_\mu^{(2)}$ satisfy the commutation relations

$$\begin{aligned}[A_\mu(x),A_\nu(x')]&=id_{\mu\nu}D(x-x'),\\ d_{\mu\nu}&=\delta_{\mu\nu}-2\partial_\mu\partial_\nu\partial^{-2}-n_\mu\partial_\nu\partial^{-1}-n_\nu\partial_\mu\partial^{-1}.\end{aligned}\tag{6}$$

The interaction hamiltonian $H_1=H_1^{(1)}+H_1^{(2)}$ together with the commutation relations (6) describes correctly the interactions between electrons and the electromagnetic field.

By means of a canonical transformation, very similar to that used in the Fermi electrodynamics, the scalar photon variables can be eliminated. A wave equation is obtained in which the interaction energy $H_1^{(2)}$ is replaced by the direct coulomb interaction energy. In order to obtain the correct sign of the coulomb interaction one has to choose in the commutation relation for the scalar field $Q(x)$ the sign corresponding to the time-component photons of the Fermi electrodynamics. The scalar field and quanta do not represent measurable quantities, but are related to the gauge of the potentials. This corresponds to the fact that also in classical theory the retarded transmission of the coulomb interaction corresponds to potential waves only.

In calculating the S-matrix in the unseparated treatment, the commutation relations, Eq. (6), may be replaced, as can be shown, by the simpler relations of the Fermi electrodynamics. The additional terms of Eq. (6) do not give any contribution.

In transforming the equations to the Heisenberg representation, the potentials $\mathbf{A}_\mu$ do not satisfy the Lorentz condition, but $\partial_\mu\mathbf{A}_\mu$ depends on the currents and on n_μ which plays the role of a gauge vector. The fields $\mathbf{F}_{\mu\nu}=\partial_\mu\mathbf{A}_\nu-\partial_\nu\mathbf{A}_\mu$ satisfy, however, the maxwell equations,

$$\partial_\mu\mathbf{F}_{\mu\nu}=-\mathbf{j}_\nu.\tag{7}$$

$\mathbf{F}_{\mu\nu}$ is independent on the scalar field variables.

As shown by Professor C. Møller, one can build up the theory also by starting directly from the Heisenberg representation and introducing suitable energy-momentum expressions and the corresponding commutation rules.

Details will be published in the *Proceedings of the Copenhagen Academy.*

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Molecular Constants of $Cs^{133}Cl^{35}$

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(Received June 18, 1951)

THE radiofrequency spectra of cesium chloride were studied by means of the electric resonance method of molecular beam spectroscopy.[1,2] Lines were observed arising from the $J,m_J\rightarrow J,m_J'$ transitions 2,0→2,1; 3,0→3,1; 4,0→4,1; 4,1→4,2; and 5,1→5,2. Lines arising from molecules in six different vibrational states were resolved. Evidence for the quadrupole interaction of Cs and Cl was seen in the broad lines observed at low frequencies, but no fine structure due to these interactions could be resolved. Cs has but one isotope; however, Cl has two with an abundance ratio of 3:1. The spectrum of the less abundant specie could be discerned superimposed on the spectrum of the more abundant one in the predicted position.

It was possible to observe the 2,0→2,1; 3,0→3,1; and 4,1→4,2 transitions in electric fields of sufficient magnitude to obtain values of the permanent dipole moment, μ, and the moment of inertia, A. Consistent results were obtained for the three transitions and the weighted average $A=384\pm7\times10^{-40}$ cgs unit and $\mu=10.5\pm0.25$ Debyes for the zeroth vibrational state. The rotational constant B_e is, then, 0.0736 ± 0.0015 cm^{-1}. The constant α_e was calculated using the separation of the observed lines corresponding to different vibrational states and a theoretical value[3] of $\omega_e=299$ cm^{-1}. We found $\alpha_e=0.52\pm0.05\times10^{-3}$ cm^{-1}.

The internuclear distance, r_v, of vibrational state v may be calculated from the moment of inertia, and a value $r_0=2.88\pm0.03$A was obtained. The internuclear distance has been measured by Maxwell, Hendricks, and Mosley[4] using the electron diffraction method, with a resulting value of $r=3.06\pm0.03$A. This result, however, is an average over the vibrational states present, and for their observation temperature $v=3$ is the median vibrational state. Using our value of α_e, we get $r_0=3.02\pm0.03$A as the number to be compared with the electric resonance value above. It is seen that the discrepancy of 5 percent between the two values is well outside the limits of estimated experimental errors for both methods.

It is to be expected that both nuclei contribute to the quadrupole interaction present. If the interaction for one of the nuclei is predominant, the resolving power of the spectrometer was such that some fine structure lines should have been resolved. If, however, the interaction of the two nuclei are of the same order, the large number of lines present would make any resolution impossible. As no structure was observed, this latter condition is concluded

to prevail. If calculations are made assuming the entire interaction to be due to one nucleus alone, it is possible to place maximum values on the interactions present from the separate nuclei. This leads to values of 3 Mc and 4 Mc as the maximum possible values of the interaction constant, $|eqQ/h|$, for Cl and Cs, respectively.

* Supported in part by the ONR.
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The Positron to γ-Ray Ratio in Zn^{65}

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(Received June 27, 1951)

IN connection with the calibration of Zn^{65} and Co^{60} sources, the following measurements were made which indicate a ratio of 1 positron to 65±5 γ-rays for 250-day Zn^{65}.

Two scintillation counters were placed at equal distances from, and on opposite sides of, a small zinc source, and coincidence and single channel counting rates were obtained. The source was surrounded by aluminum foil, so that for each positron there were two annihilation quanta emitted in very nearly opposite directions. If the source produced N_+ positrons and N_γ γ-rays per unit time and the plane angles subtended by the counters at the source were large compared with the small departure from collinearity of the annihilation quanta,[1] then the positron to γ-ray ratio is approximately given by

$$N_+/N_\gamma = N_c{}^+\epsilon_1{}^\gamma/2\epsilon_1{}^+\epsilon_2{}^+(N_1{}^\gamma+N_1{}^+) = N_c{}^+\epsilon_2{}^\gamma/2\epsilon_1{}^+\epsilon_2{}^+(N_2{}^\gamma+N_2{}^+),$$

where N is a counting rate, ϵ a counter efficiency, superscripts + and γ refer to annihilation radiation and nuclear γ-rays, respectively, and subscripts 1, 2, and c refer to counters 1, 2 and the coincidence counter, respectively. This approximate formula holds for the case when the ratio N_+/N_γ is small, as it is for Zn^{65}. Note that the solid angle factor does not appear. Thus, with the above-mentioned measurements, corrected for background, dead time, and accidental coincidences, we require only the counter efficiencies[2] at 0.51 and 1.11 Mev in order to calculate N_+/N_γ.

The efficiency for the Zn^{65} γ-ray (1.11 Mev) was assumed to be the same as that for the Co^{60} γ-rays (1.17 and 1.33 Mev). By means of a standard coincidence method (applicable for a source giving cascaded radiations of about the same energy) the efficiency for Co^{60} γ-rays was found to be 17 percent when the quanta traversed one inch of a clear anthracene block ($1''\times1''\times\frac{1}{2}''$) mounted on the end of an RCA 5819 photomultiplier. Within experimental errors this is equal to the efficiency as calculated using the Klein-Nishina formula. When the geometry was such that 180° backscattered quanta (0.2 Mev) from one counter could enter the second counter, the coincidence rate increased because of single quanta producing pulses in both counters. From the amount of the increase we calculated that the counter efficiencies for the 0.2-Mev backscattered quanta were about 30 percent, close to the theoretically expected value of 38 percent. The experimental value is low, owing to absorption of some of the backscattered quanta in the scattering crystal and to the smaller number of photons excited in the crystal by the low energy quanta. Since these measurements agree reasonably well with the theory, we assumed that the efficiency for the annihilation radiation was 25 percent as given by the Klein-Nishina formula.

Owing to the small departure from collinearity of annihilation quanta, the ratio N_+/N_γ increased as the counters were moved closer to the source, and angular correlation curves at the larger distances showed the characteristic tails.[1] These effects were not detectable with the counters closer than 40 cm to the source. The result of 1 positron in 65±5 γ-rays is the average of 4 measurements with the counters 35 cm from the source (the ±5 includes an estimate of the error involved in the efficiency figures). This result is not in agreement with the decay scheme presented in *Nuclear Data*[3] but is in rough agreement with the results in the *Trilinear Chart of Nuclear Species*.[4] The data for Zn^{65} in the latter publication was based primarily on unpublished work of Dr. W. C. Peacock.[5] Taking his value of 50 percent K-capture to the 1.11-Mev level of Cu^{65}, one finds that 0.8 percent of the Zn^{65} disintegrations are by positron emission.

I wish to express my thanks to Dr. K. C. Mann for providing the Zn^{65} and to the Ontario Research Council for a scholarship.

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Paramagnetic Resonance Absorption in Three Chlorides of Copper

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WE have measured the microwave paramagnetic resonance absorption in single crystals[1] of $CuCl_2\cdot2H_2O$, $K_2CuCl_4\cdot2H_2O$, and $(NH_4)_2CuCl_4\cdot2H_2O$ at 3100 Mc/sec and at

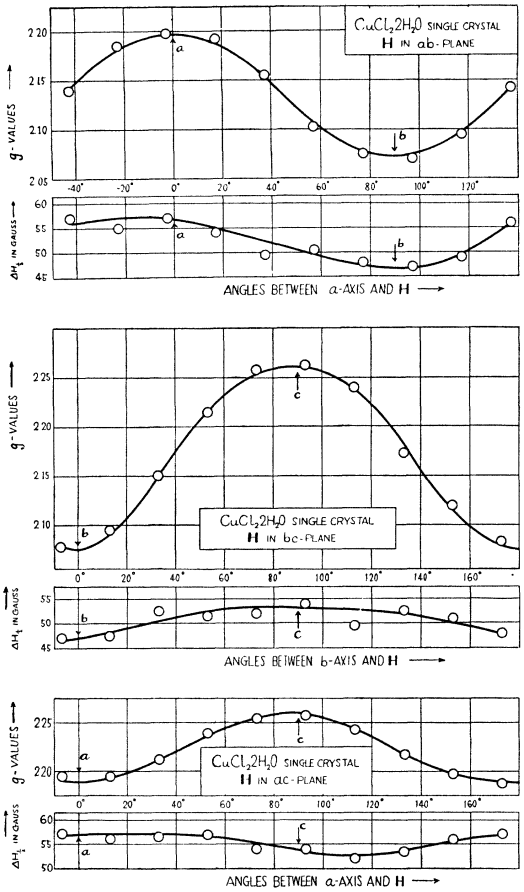

FIG. 1. Variation of g-values and half-widths ($\Delta H_{\frac{1}{2}}$) with angle between the static field **H** and the crystal axis in $CuCl_4\cdot2H_2O$, at 3100 Mc/sec. The figures indicate these angular dependences for the cases in which **H** rotates about the c axis, the a axis, and the l axis, respectively.