which we reported in an earlier communication in connection with the discovery of several ferro-electric columbates and tantalates.[2]

The crystals as grown from very pure tungstic acid vary in color from dark yellow to green. They are triclinic and show a marked domain structure very similar to that of ferro-electrics in the perovskite crystal system.

In the case of WO_3, however, the differences of lattice constants in different directions amount to about 5 percent whereas in the perovskite system they are near 1 percent. With a small external pressure the entire domain pattern in WO_3 can be shifted or changed, without damage to the crystal. Consequently the crystals appear to be very soft, nearly plastic.

The electric conductivity of the single crystals at room temperature is extremely high, which may have some connection with the occurrence of coloration in the crystals. It is not clear whether the color is due to slight chemical reduction or Na impurities. Pressed samples fired at much lower temperatures retained their light color and gave comparatively small losses and dielectric constants of the order of 10^3.

Dielectric measurements on the single crystals can be easily made, however, at liquid air temperature. There the losses are small and no longer interfere with the dielectric measurements. Preliminary results indicate a hysteresis loop and a dielectric constant between 100 and 300. This value is high compared to other ferro-electrics at the same temperature.

[1] Pauling and Goldschmidt.
[2] B. T. Matthias, Phys. Rev. **75**, 1771 (1949).

On the $\gamma-\gamma$-Angular Correlation in Pd^{106}

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MEASUREMENTS of $\gamma-\gamma$-correlations in excited states of Ni^{60}, Ti^{46}, Mg^{24}, Ba^{134}, Sr^{88}, and Pd^{106} have been reported by Deutsch and co-workers. Of these, all but Sr^{88} and Pd^{106} can be satisfactorily fitted with theory[2] by assuming that the γ-rays are either pure dipole or quadrupole radiation and by assigning to the nuclear states involved spins consistent with such other information as is available from measurements on internal conversion or β-decay. In general, the angular correlation theory by itself is not sufficient to make any unique assignment of multipole orders or of nuclear quantum numbers.

We have developed[3] the extension of the theory of $\gamma-\gamma$-angular correlations for the case in which one of the transitions is a mixture of magnetic dipole and electric quadrupole radiation and the other either pure dipole or quadrupole radiation. With it one can explain the observed correlation in Sr^{88} which could not be explained by assuming pure multipole transitions. The discussion of this and the interference effects accompanying such mixtures will be given elsewhere.[4] We discuss here some consequences of the application of this theory to the experimental data on the $\gamma-\gamma$-angular correlation in Pd^{106}. These data seem quite reliable having been independently reproduced by Deutsch and Wiedenbeck[5] with and without a strong applied magnetic field.

Pd^{106} being an even-even nucleus, its ground state may be taken as having zero spin. Because of the $\cos^4\theta$-term in the measured correlation function, neither transition can be pure dipole. A mixture of dipole and quadrupole radiation in one or both transitions would still be consistent with this $\cos^4\theta$-dependence. However, such mixtures are allowed only when $\Delta J=0, \pm 1$. Since quadrupole radiation is forbidden for $0\rightarrow 0$ or $0\rightarrow 1$ transitions and we have already ruled out pure dipole transitions, the least possible spin for the intermediate state must be $J=2$, and this choice would force pure quadrupole radiation for the lower transition. Similarly, for the upper (initial to intermediate state) γ-transition, the lowest multipoles possible are either pure quadrupole or a mixture of electric quadrupole and magnetic dipole. Deutsch[1] has already pointed out that the data cannot be fitted when both transitions are pure quadrupole. Since the assumption of a mixed transition made possible good agreement with experiment in the case of Sr^{88}, we attempted to interpret the data for Pd^{106} with a dipole-quadrupole mixture for the upper transition, the lower transition being taken as pure quadrupole. We find that agreement with experiment cannot be obtained. It follows, therefore, subject only to the reasonable assumption that the ground state has spin zero, that at least one of the successive rays must be of octupole or higher order.

A proposed disintegration scheme for Pd^{106} and its parent Ru^{106} has been given by Peacock.[6] Our arguments, while limiting the possible multipole orders of the γ-rays, do not otherwise affect his decay scheme except to exclude $J=1$ for the intermediate state in Pd^{106}.

This example illustrates the value of the angular correlation theory for nuclear spectroscopy, but it also makes clear the need for extending the calculations to higher multipoles

* Supported in part by the joint program of the AEC and ONR at the University of Notre Dame.
[1] E. L. Brady and M. Deutsch, Phys. Rev. **72**, 870 (1947); **74**, 1541 (1948); M. Deutsch and F. Metzger, Phys. Rev. **74**, 1542 (1948).
[2] D. R. Hamilton, Phys. Rev. **58**, 122 (1940).
[3] D. S. Ling and D. L. Falkoff, Phys. Rev. **74**, 1224 (1948).
[4] Phys. Rev. in preparation.
[5] M. Deutsch and M. L. Wiedenbeck, private communication
[6] W. C. Peacock, Phys. Rev. **72**, 1049 (1947).

The Magnetic Susceptibilities of Some Tetravalent Uranium Fluorides*

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THE magnetic susceptibilities of UF_4, KUF_5, K_2UF_6, and Na_3UF_7 have been measured by the Gouy method over a temperature range of approximately 74°K to 300°K.

UF_4 was prepared from UO_2 by treatment with anhydrous HF. The complex salts were prepared by the fusion of UF_4 with stoichiometric quantities of the alkali or alkaline earth fluorides. This was done in a platinum crucible in an HF atmosphere, as described by Zachariasen.[1] Observation through a microscope showed them to be homogeneous. Uranium analyses were carried out on all the salts.

The susceptibility measurements were made over a two-month period on three or more samples of each compound, and during that time remained sensibly constant. If structural changes were taking place in any of the compounds, which might well be the case when one considers the method of preparation, this was not revealed by an effect on the susceptibilities.

With the exception of K_2UF_6, these substances obeyed the Curie-Weiss law $x=C/(T+\theta)$ over the whole temperature range of the investigation. K_2UF_6 followed the Curie-Weiss law down to 198°K, but deviated below this temperature. At 76°K its susceptibility is 8.6 percent smaller than that given by the Curie-Weiss equation. The experimental data are given in Table I.

The tetravalent uranium ion is thought to contain two $5f$ electrons, and so be in a $^3H_4$ state. The theoretical moment for a free ion in this configuration has been calculated by Van Vleck[2] to be 3.58 Bohr magnetons. It is seen from the table that the experimentally calculated moments are reasonably close to this value.

TABLE I. Susceptibilities of tetravalent uranium fluorides.

Compound	C	θ	μ
UF_4†	1.36	147°	3.30β
KUF_5	1.30	122°	3.30
K_2UF_6	1.47	108°	3.45
$CaUF_6$	1.31	101°	3.25
Na_3UF_7	1.45	290°	3.40

The large values found for the Weiss temperature in all these compounds make one hesitate to give the usual interpretation to the Curie constant, however, and experiments are in progress at this laboratory to obtain further information on the nature of the Weiss temperatures observed in these salts.

* Research conducted at Brookhaven National Laboratory under an AEC contract.

[1] W. H. Zachariasen, J. Am. Chem. Soc. **70**, 2147 (1948).

† In a previous letter to the editor the Curie constant for UF_4 was erroneously reported to have the value 1.00 (N. Elliott, Phys. Rev. **74**, 498 (1948)).

[2] J. H. Van Vleck, *Theory of Electric and Magnetic Susceptibilities* (Oxford University Press, New York).

Interaction of Mesons with the Electromagnetic Field

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IN terms of the formalism of Duffin and Kemmer,[1] a Lorentz gauge and charge invariant theory of the interaction of a meson with an electromagnetic field has been formulated. It was found that a possible interaction Hamiltonian is of the form

$$H=-\frac{1}{c}j_\mu A_\mu+\frac{e^2}{mc^2}M_{\mu\nu}A_\mu A_\nu, \tag{1}$$

where

$$j_\mu=(iec/2)(\bar{\psi}\beta^\mu\psi-\bar{\phi}\beta^\mu\phi)$$
$$M_{\mu\nu}=\tfrac{1}{2}[\bar{\psi}\beta^\mu(\beta_N{}^2+1)\beta^\nu\psi+\bar{\phi}\beta^\mu(\beta_N{}^2+1)\beta^\nu\phi]$$
$$\phi=C\bar{\psi};\ \tilde{\beta}^\mu=-C^{-1}\beta^\mu C;\ C^+=C^{-1};\ \tilde{C}=C.$$
$$\beta_N=N_\mu\beta_\mu$$

and N_μ is a unit vector normal to the surface. By means of the method used by Schwinger[2] the longitudinal components of the electromagnetic field were eliminated from the Hamiltonian leaving it in the form

$$H=-(1/c)j_\mu A_\mu+(e^2/mc^2)M_{\mu\nu}A_\mu A_\nu+(\tfrac{1}{2}c)j_N V_N \tag{2}$$

with

$$V_N=N_\mu V_\nu=N_\mu\int\frac{\partial D(x-x')}{\partial x_\mu'}\frac{j_\lambda(x')}{c}d\sigma_\lambda'$$

$(N_\lambda\partial/\partial x_\lambda)^2D(x)=D(x)$; A_μ is the 4-vector of the pure radiation field. The terms linear in A_μ were then removed by means of a unitary transformation and the resulting second-order Hamiltonian analyzed into vacuum, photon, meson self-energy terms and terms representing the coupling of photons with mesons and the interaction between mesons. The explicit dependence on the orientation of the space-like surface present in (1) and (2) is exactly compensated in all these terms by the terms containing the derivatives of the signum function entering into the definition of $\Delta(X)$. The vacuum self-energy was shown to be a constant; the photon self-energy could be taken to vanish, if certain ambiguous integrals were suitably evaluated; the meson self-energy terms when transformed back to the original Kemmer equation could be interpreted as mass correction terms having the values

$$(\delta\kappa/\kappa)=(\alpha/12\pi)[6(P_mP_0/\kappa^2)+11\ln((P_0+P_m)/\kappa)-\tfrac{7}{3}]$$
$$(\delta\kappa/\kappa)=(3\alpha/4\pi)[(P_mP_0/\kappa^2)+\ln((P_0+P_m)/\kappa)-\tfrac{1}{3}]$$

in the representation of rank 10 and 5 respectively, where P_m is the maximum momentum of the virtual quanta and $P_0=(P_m{}^2+\kappa^2)^{\frac{1}{2}}$.

The polarization of the mesic vacuum by a given current distribution was also investigated. For a scalar meson the polarization kernel is of second order in the derivatives. The polarization kernel of the vector meson consists of two terms, separately conserved and gauge invariant. The first is formally identical with the polarization kernel of a spinless particle, the second is of fourth order in the derivatives. As a result, in the first term (and in the case of the scalar meson) the factor multiplying J_μ, and in the second term the factors multiplying J_μ and $\Box^2J_\mu$ are divergent. The physical concept of charge renormalization provides some justification for regarding the terms proportional to J_μ as unobservable and hence the infinities multiplying them as innocuous. It is suggested that because of the high order derivatives present in the second term of the polarization kernel of the vector meson, the formal strategy of dealing with infinities be extended to the term $\Box^2J_\mu$, even though the physical reason for this may not be too clear at present. Thus the current associated specifically with the vector meson would be regarded as observable beginning with derivatives of the external potential of higher order than those appearing in the polarization kernel, the formal procedure being the same as that used in the case of the electron and scalar meson. Explicitly stated, the formulas are:

$$\delta J_\mu=\delta J_\mu{}^{(0)}\quad\text{(for a scalar particle)}$$
$$\delta J_\mu=\delta J_\mu{}^{(0)}+\delta J_\mu{}^{(1)}\quad\text{(for the vector meson)}$$
$$\delta J_\mu{}^{(0)}=-(e^2/\hbar)\int\kappa_{\mu\nu}{}^{(0)}(x-x')A_\nu(x')d\omega'$$
$$\kappa_{\mu\nu}{}^{(0)}(x)=[\Delta^{(1)}(\partial^2\bar{\Delta}/\partial x_\mu\partial x_\nu)+\bar{\Delta}(\partial^2\Delta^{(1)}/\partial x_\mu\partial x_\nu)]$$
$$-[(\partial\Delta^{(1)}/\partial x_\mu)(\partial\bar{\Delta}/\partial x_\nu)+(\partial\Delta^{(1)}/\partial x_\nu)(\partial\bar{\Delta}/\partial x_\mu)]$$
$$+\delta_{\mu\nu}\Delta^{(1)}(x)\delta(x)$$
$$\kappa_{\mu\nu}{}^{(1)}(x)=\kappa^{-2}(\partial^2\Delta^{(1)}(x)/\partial x_\mu\partial x_\nu)\delta(x)$$
$$+\kappa^{-2}[(\partial^2\bar{\Delta}/\partial x_\mu\partial x_\sigma)(\partial^2\Delta^{(1)}/\partial x_\nu\partial x_\sigma)$$
$$+(\partial^2\bar{\Delta}/\partial x_\nu\partial x_\sigma)(\partial^2\Delta^{(1)}/\partial x_\mu\partial x_\sigma)]$$
$$-[(\partial\Delta^{(1)}/\partial x_\mu)(\partial\bar{\Delta}/\partial x_\nu)+(\partial\Delta^{(1)}/\partial x_\nu)(\partial\bar{\Delta}/\partial x_\mu)]$$
$$+\kappa^{-2}\delta_{\mu\nu}[\kappa^4\Delta^{(1)}\bar{\Delta}-(\partial^2\bar{\Delta}/\partial x_\lambda\partial x_\sigma)(\partial^2\Delta^{(1)}/\partial x_\lambda\partial x_\sigma)]$$
$$\langle\delta J_\mu{}^{(0)}\rangle_{\text{vac}}=(-\alpha/6\pi)[\ln((P_0+P_m)/\kappa)-1]J_\mu$$
$$-(\alpha/24\pi)\int F_2(x-x')\kappa^{-2}\Box'^2J_\mu(x')d\omega'$$
$$\langle\delta J_\mu{}^{(1)}\rangle_{\text{vac}}=-(\alpha/6\pi)[(P_0P_m/\kappa^2)-4\log((P_0+P_m)/\kappa)+3]J_\mu$$
$$-(\alpha/6\pi)[\log((P_0+P_m)/\kappa)-(27/20)]\kappa^{-2}\Box^2J_\mu$$
$$-(\alpha/16\pi)\int[F_2(x-x')-\tfrac{1}{3}F_3(x-x')]$$
$$\times(\kappa^{-2}\Box'^2)^2J_\mu(x')d\omega'$$

where $F_n(x)$ is defined by

$$F_n=16\kappa^2\int_0^1 dv\frac{v^{2n}}{(1-v^2)^2}\bar{\Delta}\left[\frac{2x}{(1-v^2)^{\frac{1}{2}}}\right].$$

According to the suggestion made here the second term of $\delta J_\mu{}^{(0)}$ and the third of $\delta J_\mu{}^{(1)}$ would be regarded as physically significant, corresponding to the formal fact that $K^{(0)}$ is of second- and $K^{(1)}$ of fourth order in the derivatives.

[1] N. Kemmer, Proc. Roy. Soc. **173A**, 91 (1939).
[2] J. Schwinger, Phys. Rev. **74**, 1439 (1948); Phys. Rev. **75**, 651 (1949).

Electromagnetic Induction in a Superconductor

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RECENTLY, Houston and Squire[1] reported the results of an experiment in which a Faraday disk of lead, in the form of a flattened spheroid, was investigated above and below the superconductive transition temperature. They found that the induced electromotive force remained practically unchanged as the transition range was traversed. On the basis of the "Meissner effect",[2] however, the electromotive force should have dropped to zero