B to B′ in the strain field below the plane of Fig. 1. If μb is quite small, this difference in excitation of A′ and B′ will be little changed at the exit surface. The dislocation image will be asymmetric, being stronger on the side above the plane of Fig. 1 than on the side below.

In practice, the images of pure screw dislocations normal to the BRAGG planes in f.c.c. structures, seen under the conditions $\boldsymbol{g} \cdot \boldsymbol{b} = 2n$, show double peaks. This helps to make asymmetry visible. Asymmetry just as expected has been observed in an array of pure screw dislocations forming one sector of a FRANK–READ "spiral" already described [12]. Fig. 3 shows segments of five screw dislocations, in the 220 reflection, above, and in the $\overline{2}\overline{2}0$ reflection, below. In this field b is constant at about 0.4 mm, and a increases from about 0.7 mm in the top left to just over 1 mm in the bottom right. The microdensitometer trace across the $\overline{2}\overline{2}0$ field shows the transition from the symmetrical case [$(a-b)$ small] to the asymmetrical case [$(a-b)$ large] quite clearly, despite some instrumental broadening in the trace. It follows that these screws are right-handed.

With these and other pure screw dislocations it is observed, in accord with prediction, that if a and b differ little, even if $(a+b)$ is large, no difference in the $h\,k\,l$ and $\bar{h}\,\bar{k}\,\bar{l}$ images is apparent. With $b > a$ the asymmetry would be expected to reverse, for a given sense of BURGERS vector, but the images of dislocation with $b > 1$ mm cannot be measured accurately. It has been observed that the apparent diameter of hexagonal loops, measured between the centres of gravity of the images of the screw segments, differs in the expected way on the 220 and $\overline{2}\overline{2}0$ topographs when a exceeds b sufficiently. This brief analysis neglects Pendellösung oscillations, but in the thickness range covered in Fig. 3 these oscillations are quite weak.

The author has pleasure in thanking Dr. M. WILKENS for valuable discussion.

[12] A. AUTHIER and A. R. LANG, J. Appl. Phys. **35**, 1956 [1964].

Test of Cabibbo's Theory of CP-Violation in Neutrino Reactions

R. R. SILBAR *

Physics Department, The Johns Hopkins University, Baltimore, Maryland

and H. ÜBERALL

Physics Department, The Catholic University of America, Washington, D. C.

(Z. Naturforschg. **20 a**, 638—640 [1965]; received 15 March 1965)

In the wake of the observation of a 2π decay mode of the long-lived neutral kaon [1], which indicates that the weak interactions violate CP-invariance, several suggestions have been made as to how CP-violation can be incorporated in a weak interaction theory [2, 3]. In this letter we consider a consequence of CABIBBO's scheme [3] for elastic neutrino reactions.

CABIBBO assumes that the strongly interacting weak current J_λ transforms as a member of an SU_3 octet. Then, if the non-leptonic weak Lagrangian violates CP, J_λ must contain both regular and irregular parts with respect to behavior under CP. The latter give rise to second class currents [4] of a special kind, viz., being 90° out of phase with the first class currents deriving from the regular parts, thus leading to a maximal violation of CP and, through the CPT theorem, of T.

It is the interference between the two types of currents that gives T- and CP-violating effects. Since these contributions are of a forbidden type, they should be most easily observed in high-momentum-transfer reactions and would have escaped detection in β-decay [5].

Using CABIBBO's theory, we have calculated transverse muon polarizations resulting from time reversal violation in the elastic reactions

$$\nu + A_z \rightarrow A_{z+1}{}^* + \mu^-, \qquad (1\,\text{a})$$

$$\bar{\nu} + A_z \rightarrow A_{z-1}{}^* + \mu^+ \qquad (1\,\text{b})$$

the nucleus being described by a FERMI gas model; A^* represents the residual nucleus with one directly ejected nucleon. Reaction (1 a) on a single free neutron has previously been considered in this context by BERMAN and VELTMAN [6].

We use the weak interaction HAMILTONIAN with CP-violating terms suggested by CABIBBO [3, 6]:

$$H = (G_V/\sqrt{2})\; l_\alpha J_\alpha\,, \qquad (2\,\text{a})$$

$$l_\alpha = \overline{\psi}_{q'}\, \gamma_\alpha (1+\gamma_5)\, \psi_q \qquad (2\,\text{b})$$

$$J_\alpha = F(Q^2)\, \bar{u}_{p'} \Big(\gamma_\alpha + \frac{\mu}{2M} \sigma_{\alpha\beta} Q_\beta + \frac{A}{m} Q_\alpha + \lambda\, \gamma_\alpha \gamma_5 + i\,\frac{b}{m} Q_\alpha \gamma_5 + i\,\frac{B}{2M} \sigma_{\alpha\beta} Q_\beta \gamma_5 \Big) u_p \qquad (2\,\text{c})$$

* Work supported by the National Science Foundation.

[1] J. H. CHRISTENSON, J. W. CRONIN, V. L. FITCH, and R. TURLAY, Phys. Rev. Letters **13**, 138 [1964]. — A. ABASHIAN, R. J. ABRAMS, D. W. CARPENTER, G. P. FISHER, B. M. K. NEFKENS, and J. H. SMITH, Phys. Rev. Letters **13**, 243 [1964].

[2] R. SACHS, Phys. Rev. Letters **13**, 286 [1964]. — T. N. TRUONG, Phys. Rev. Letters **13**, 258 a [1964]. — T. T. WU and C. N. YANG, Phys. Rev. Letters **13**, 380 [1964]. — L. WOLFENSTEIN, Phys. Rev. Letters **13**, 562 [1964].

[3] N. CABIBBO, Phys. Letters **12**, 137 [1964].

[4] S. WEINBERG, Phys. Rev. **112**, 1375 [1958].

[5] N. T. BURGY, V. P. KROHN, T. B. NOVEY, G. R. RINGO, and V. L. TELEGDI, Phys. Rev. Letters **1**, 324 [1958].

[6] S. M. BERMAN and M. VELTMAN, Phys. Letters **12**, 275 [1964].

with M the nucleon and m the muon mass, q and q' the initial and final lepton four-momenta, p and p' the initial and final nucleon four-momenta, and $Q=p-p'=q'-q$ the four-momentum transfer. We take the same form factor for all currents,

$$F(Q^2)=(1+Q^2/M_1^2)^{-2} \tag{3}$$

with $M_1=840$ MeV, corresponding to a proton radius of 0.8×10^{-13} cm. The coupling constants are

$$G_V=10^{-5}\,M^{-2},\quad \mu=3.71,\quad \lambda=1.21,\quad b=8\,\lambda,$$

and the second class couplings A and B are unknown.

The squared matrix element $|M|^2$ can be written as $L_{\alpha\beta}\,N_{\alpha\beta}$, where the lepton trace $l_\alpha\,l_\beta^*$ leads to

$$L_{\alpha\beta}=4[q_\alpha\,q_\beta'+q_\alpha'\,q_\beta-\delta_{\alpha\beta}\,q\cdot q'+\varepsilon_{\alpha\beta\varkappa\lambda}\,q_\varkappa\,q_\lambda'\mp m(q_\alpha\,s_\beta+s_\alpha\,q_\beta-\delta_{\alpha\beta}\,q\cdot s+\varepsilon_{\alpha\beta\varkappa\lambda}\,q_\varkappa\,s_\lambda)] \tag{4}$$

with $-$, $+$ referring to reactions (1 a), (1 b) respectively; s_α is the conventional four-polarization vector [7]. The nucleon trace $J_\alpha\,J_\beta^*$ gives

$$N_{\alpha\beta}=A_1\,\delta_{\alpha\beta}+A_2\,p_\alpha\,p_\beta+A_3\,Q_\alpha\,Q_\beta+A_4(p_\alpha\,Q_\beta+Q_\alpha\,p_\beta)\pm A_5\,\varepsilon_{\alpha\beta\varrho\sigma}\,p_\varrho\,Q_\sigma\pm i\,A_6(p_\alpha\,Q_\beta-Q_\alpha\,p_\beta) \tag{5}$$

where [8]

$$\begin{aligned}
&A_1=8\,M^2\,\lambda^2+2\,Q^2[\lambda^2+(1+\mu)^2]\,,\qquad A_2=8(1+\lambda^2)+2\,Q^2(B^2+\mu^2)\,M^{-2}\,,\\
&A_3=-2\,\mu^2-4\,\mu+8\,A^2\,M^2\,m^{-2}-8\,\lambda\,b\,M\,m^{-1}+\tfrac{1}{2}Q^2[(B^2+\mu^2)\,M^{-2}+4(A^2+b^2)\,m^{-2}]\,,\\
&A_4=-\tfrac{1}{2}A_2\,,\qquad A_5=-8\,\lambda(1+\mu)\,,\\
&A_6=-4\,B\,\lambda-8\,A\,M\,m^{-1}+2\,Q^2(B\,b+A\,\mu)\,M^{-1}\,m^{-1}.
\end{aligned} \tag{6}$$

The squared matrix element is evaluated for an initial nucleon moving in a FERMI gas for which we assume an equal number $A/2$ of neutrons and protons. We obtain a differential cross section per initial reacting nucleon

$$\frac{2}{A}\,\frac{\mathrm{d}^2\sigma}{\mathrm{d}q_0'\,\mathrm{d}w}=G_V^2\,\frac{r_0^3}{3(2\,\pi)^2}\,|F(Q^2)|^2\,\frac{|\boldsymbol{q}'|}{\Delta}\,I_0 \tag{7 a}$$

and a transverse muon polarization (in the direction of $\boldsymbol{q}\times\boldsymbol{q}'$)

$$P_\perp=I_\perp/I_0 \tag{7 b}$$

where

$$I_0=\int p_0\,\mathrm{d}p_\parallel[2\,A_2\,\alpha-Q^2\,A_2+2\,m^2\,A_4\mp2\,Q^2\,A_5-q\cdot q'(2\,A_1-M^2\,A_2+m^2\,A_3\pm Q^2\,A_5)(\alpha^2-\beta^2)^{-1/2}], \tag{8 a}$$

$$I_\perp=2\,m\,A_6\int p_0\,\mathrm{d}p_\parallel\{\xi(\alpha^2-\beta^2)^{-1/2}-\eta\,\beta^{-1}[1-\alpha(\alpha^2-\beta^2)^{-1/2}]\}\,, \tag{8 b}$$

$$\alpha=p_0\,q_0-p_\parallel\,|\boldsymbol{q}|\cos\psi\,, \tag{9 a}$$

$$\beta=-p_\perp\,|\boldsymbol{q}|\sin\psi\,, \tag{9 b}$$

$$\xi=p_0\,|\boldsymbol{q}|\,|\boldsymbol{q}'|\sin\vartheta+p_\parallel\,|\boldsymbol{q}|\,q_0'\sin\psi-p_\parallel\,q_0\,|\boldsymbol{q}'|\sin\chi\,, \tag{9 c}$$

$$\eta=p_\perp(|\boldsymbol{q}|\,q_0'\cos\psi+q_0\,|\boldsymbol{q}'|\cos\chi) \tag{9 d}$$

and

$$\vartheta=\sphericalangle(\boldsymbol{q},\boldsymbol{q}'),\quad \psi=\sphericalangle(\boldsymbol{q},-\boldsymbol{Q}),\quad \chi=\sphericalangle(\boldsymbol{q}',\boldsymbol{Q}),$$

$$w=\cos\vartheta\,,\quad \Delta=q_0-q_0',\quad \text{and}\quad r_0=1.2\times10^{-13}\ \text{cm}.$$

Here, the initial nucleon three-momentum $\boldsymbol{p}$ has been decomposed into two components $p_\parallel$ and $p_\perp$, parallel and perpendicular to $-\boldsymbol{Q}$; we have

$$p_\perp=(p_\parallel\,Q^2+p_\parallel|\boldsymbol{Q}|\,Q^2+\tfrac{1}{4}Q^4-M^2\,\Delta^2)/\Delta^2. \tag{10}$$

The limits of integration are determined by energy-momentum conservation and by the condition that $\boldsymbol{p}$ lie inside the FERMI sphere of the initial nucleons (radius $P=250$ MeV/c), and $\boldsymbol{p}'$ lie outside the FERMI sphere of final nucleons, so as to satisfy the PAULI exclusion principle [9].

The differential cross sections and transverse muon polarizations have been evaluated numerically for $q_0=1$ GeV and for [6] $A=0$, $B=3.71$, and are shown in Fig. 1, plotted vs. the energy of the outgoing muon, for two values of $w=\cos\vartheta$. The transverse polarizations are found to be quite large and fairly constant over the muon energy range; they turn out to be considerably larger for the antineutrino reaction (1 b) than for the neutrino reaction (1 a), due to the smaller cross section of the former [10]. Fig. 2 shows the muon transverse polarization plotted vs. the cosine of the emission angle (Fig. 1 and 2 on p. 640).

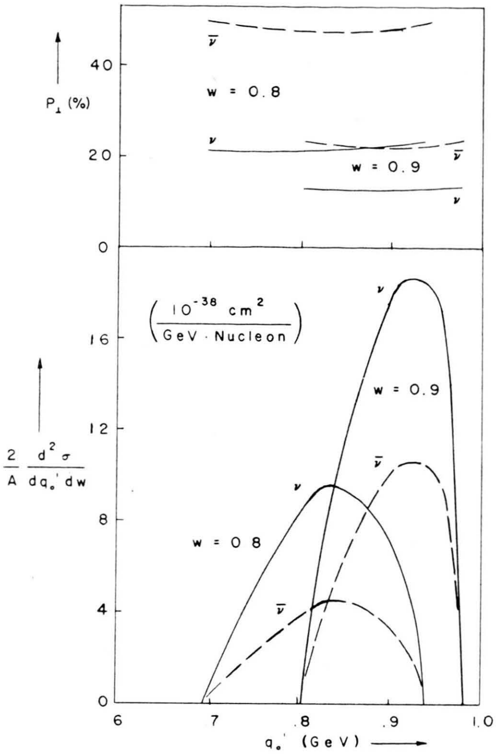
We wish to thank Professor K. EISEMANN for making the facilities of the Computing Center of The Catholic University of America available for this work.

[7] C. FRONSDAL and H. ÜBERALL, Phys. Rev. **111**, 580 [1958].

[8] In A_6 of reference [6], all signs except that of the last term should be changed. Also, the sign in front of the term with μ in their expression for J_α should be $+$.

[9] For details, see similar calculations by H. ÜBERALL, Phys. Rev. **126**, 1572 [1962] and Nuovo Cim. **26**, 533 [1957]. — J. TIOMNO and J. A. WHEELER, Rev. Mod. Phys. **21**, 153 [1949].

[10] T. D. LEE and C. N. YANG, Phys. Rev. Letters **4**, 307 [1960]. — Y. YAMAGUCHI, Prog. Theor. Phys. **23**, 1117 [1960].



← Fig. 1. Transverse muon polarization $P_\perp$ and differential cross section vs. outgoing muon energy q_0'; for initial energy $q_0 = 1$ GeV and two values of $w = \cos\vartheta = 0.8$, 0.9. The second class couplings A and B have been taken as 0 and 3.71, respectively. ——— refers to the neutrino reaction (1 a) and - - - - - to the antineutrino reaction (1 b). $P_\perp$ is given in per cent and the differential cross section is in units of 10^{-38} cm²/GeV/nucleon.

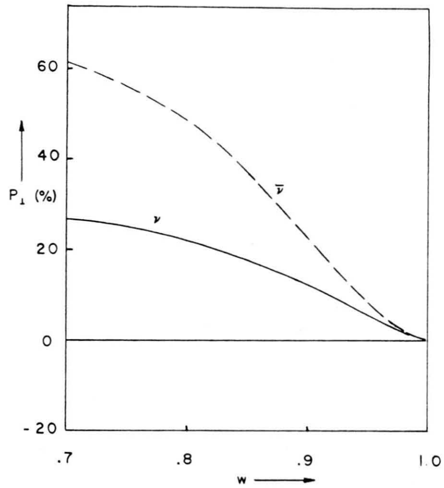


Fig. 2. Transverse muon polarization vs. the cosine of the muon emission angle w. Parameters are the same as in Fig. 1.

Zum Hall-Effekt dünner polykristalliner Wismut-Aufdampfschichten

LOTHAR FRITSCHE, KLAUS MARQUARD und FRANZ WOLF

Institut für Theoretische Physik der Technischen Hochschule Karlsruhe

(Z. Naturforschg. **20 a**, 640—642 [1965]; eingegangen am 19. März 1965)

Nach orientierenden Versuchen von WOLBER [1] läßt sich der HALL-Effekt von im Ultrahochvakuum aufgedampften dünnen Wismut-Schichten nach Vorzeichen und Betrag in weiten Grenzen willkürlich und reproduzierbar variieren. Einzelheiten werden verständlich, wenn man den Leitungscharakter von Bi und die Struktur der dünnen Schichten beachtet. Man darf bei Bi gleich viele n- und p-Träger, Elektronen und Löcher annehmen. Der beobachtete HALL-Effekt muß immer als Summe zweier entsprechender Leitungsvorgänge angesehen werden. Vom (rhomboedrischen) Einkristall weiß man [2], daß die Löcher nur parallel zur (111)-Ebene, d. h. senkrecht zur Hauptachse, eine wesentliche, übrigens wenig temperaturabhängige Beweglichkeit haben. Dagegen ist diejenige der Elektronen isotrop und wächst mit abnehmender Temperatur. Bei nicht epitaktisch aufgedampften Schichten handelt es sich um ein Haufwerk von Kristalliten, deren Hauptachsen bevorzugt senkrecht auf der Unterlage stehen, deren (111)-Ebenen also der Unterlage parallel liegen [3]. Wir haben uns selbst durch Elektronenbeugungsaufnahmen vom Vorhandensein dieser Einfachorientierung überzeugt. Bei unseren Messungen steht auch das Magnetfeld senkrecht auf der Unterlage, die HALL-Spannung wird in der Ebene der Unterlage abgenommen. Sie wird deshalb stark davon abhängen, wie gut die Teilordnung der Kristallite mit der (111)-Ebene parallel der Unterlage ausgebildet, wie sehr also die Löcherleitung am Gesamtvorgang beteiligt ist.

Selbstverständlich wird diese Teilorientierung zunächst schon durch Art und Temperatur der Unterlage beim Aufdampfen, ebenso durch die Dicke der Schicht beeinflußt. Beispielsweise ergab sich unter sonst gleichen Bedingungen bei einer auf sehr oberflächenglatter, homogener und nachgewiesen amorpher Bi_2O_3-Unterlage aufgedampften Bi-Schicht die (positive) HALL-Konstante größer als auf Duranglas als Träger. Sie wuchs auch mit der beim Herstellungsvorgang eingehaltenen

[1] W. WOLBER, Diplomarbeit, Karlsruhe 1964.

[2] H. JONES, Proc. Roy. Soc., Lond. A **155**, 653 [1936]. — D. V. GITSU u. G. A. IVANOV, Soviet Phys.—Solid State **2**, 1323, 1330 [1960].

[3] C. T. LANE, Phys. Rev. **48**, 193 [1935].