Correlation in the Direction and Polarization of Two Successive Quanta for Rh^{106}, Co^{60}, and Cs^{134}

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DEUTSCH and Metzger[1] have reported their observation of the correlation between the polarization of one quantum and the direction of emission of the other for the two successive gamma-rays of Rh^{106}. We have used a polarimeter of a type similar to that described by Deutsch and have verified their results. In assuming that the two excited states have J-values 020, the angular correlation function $W(\theta)$ can be reasonably well duplicated if one uses half the values of the coefficients α_2 and α_4 as given by Hamilton.[2]

By this same device it is possible also for the data to be in agreement with the theoretical curve in the case of the polarization correlation. Spiers,[3] however, has pointed out that by assuming one of the excited levels to consist of two levels which are close together in energy but which have different spins, then it is possible to account for $W(\theta)$. The expression I_θ/I_ϕ for the polarization correlation, which has been developed by Hamilton[4] can also be accounted for by the assumption of the additional level.

The three spin values ($J_1'=1$, 2, 3) and the two types of transitions (electric dipole and magnetic dipole) suggested by Spiers allow six combinations to be tried for this additional level. Our data, as shown in Fig. 1, indicate that the most likely transitions are $J_1'=3$ (magnetic dipole) or $J_1'=1$ (magnetic dipole or electric dipole). These choices with the resulting parities are shown in Fig. 2.

The experimental curve for Co^{60} is shown in Fig. 1. The directional correlation experiments have shown that both transitions are quadrupole. The polarization correlation experiment indicates that both transitions are electric. The parities of the two excited states are then the same as that of the ground state.

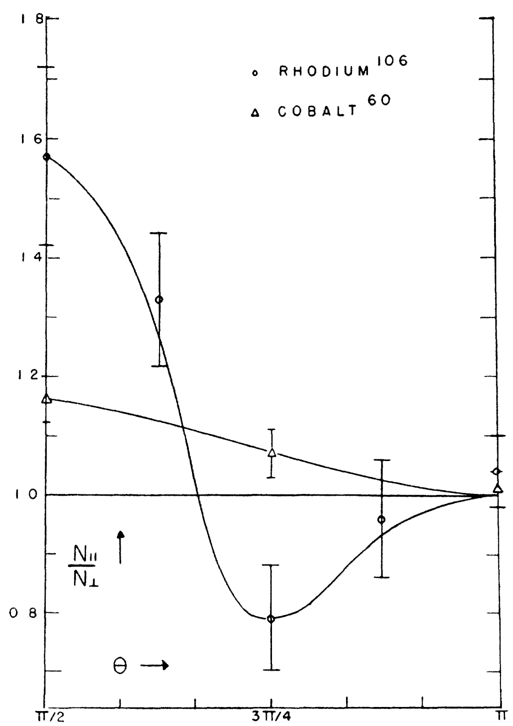

FIG. 1. Polarization of Rh^{106} and Co^{60} gamma-rays.

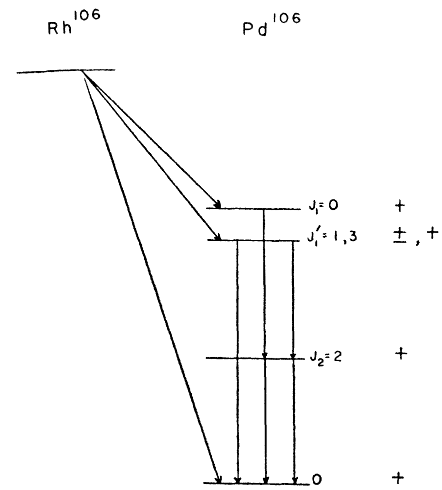

FIG. 2. Energy level scheme for Rh^{106}. The parity for $J'_1=1$ is even or odd, that for $J_1'=3$ is even.

In the case of Cs^{134}, no polarization correlation was observed. According to the theory a correlation should be found for two quadrupole transitions, one of which is magnetic and the other electric, only if the experimental arrangement is such that one can distinguish between which of the two quanta goes to the polarimeter or to the individual counter. In our case this discrimination was not possible. If both transitions are electric or both magnetic, this discrimination is not necessary in order to observe a correlation. If one assumes then that both transitions are quadrupole, the conclusion is that one is electric and the other magnetic.

[1] M. Deutsch and F. Metzger, Phys. Rev. **74**, 1542 (1948).
[2] D. R. Hamilton, Phys. Rev. **58**, 122 (1940).
[3] J. A. Spiers, Phys. Rev. **78**, 75 (1950).
[4] D. R. Hamilton, Phys. Rev. **74**, 782 (1948).

Double Beta-Decay of Te^{130}

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IN a previous letter[1] the authors described the preliminary results of a study of the double beta-transition $Te^{130}\rightarrow Xe^{130}$ by the method of isotopic analysis of xenon extracted from geologically old tellurium ores. The ore on which that work was based was blasted from an outcrop at Mångfallberget, Sweden, and it contained 12 percent by weight of the mineral Bi_2Te_3. Although the age of the telluride minerals in Mångfallberget and in Boliden, Sweden is known to be 1500±500 million years, there exists an uncertainty in the "xenon age" of the Mångfallberget material owing to the possibility of comparatively recent crystal alteration by percolating surface waters.

As a result of the generous cooperation of Dr. Erland Grip of the Boliden Mining Company, we have recently obtained some excellent samples of 70 percent rich Bi_2Te_3 from the 240-meter level of the Boliden mine. According to geologists, it is improbable that the crystals of this Bi_2Te_3 have been affected by a recent alteration. A 371-g sample of this material, containing 124 g of tellurium, was broken up to pea size and vacuum roasted at temperatures high enough to decompose the mineral and produce vigorous boiling of the molten bismuth and tellurium. The rare gases evolved were purified as before,[1] and were found to consist of 2.4×10^{-2} cc S.T.P. argon plus 2.6×10^{-7} cc S.T.P. xenon. The results of an isotopic analysis of this xenon are presented in Table I. The percentage composition of the excess or radiogenic

TABLE I. Isotopic composition of xenon extracted from 371 g of a 1.5×10^9 year old mineral containing 70 percent Bi_2Te_3. The total xenon content was 2.6×10^{-7} cc S.T.P.

Mass	Bi_2Te No. 4	Normal	Diff.	Difference normalized
124	<0.004	0.0005	<0.0035	<0.29 —
126	<0.005	0.0005	<0.0045	<0.38 —
128	<0.014	0.011	<0.003	<0.25 —
129	≡1.000	0.1525	0.8475	71.66±0.7
130	0.0652	0.0236	0.0416	3.52±0.17
131	0.4088	0.1235	0.2853	24.12±0.3
132	0.1566	≡0.1566	≡0.0000	≡0.00 —
134	0.0651	0.0611	0.0040	0.34±0.25
136	0.0562	0.0519	0.0043	0.36±0.16

xenon has been given in the last row of the table. These percentages were calculated by assuming that all of the Xe^{132} present was normal (atmospheric), and by subtracting corresponding amounts at the other mass positions. It is evident from the table that, aside from the somewhat questionable excess xenon at mass 134 and 136 (possibly due to uranium fission), the excess xenon is distributed among the isotopes Xe^{129}, Xe^{130}, and Xe^{131}.

The excess Xe^{129} and Xe^{131} is probably caused by (n,γ) reactions on Te^{128} and Te^{130}. To account for the neutron "flux" required to produce this much xenon in 1.5×10^9 years, it is necessary to assume that there was considerable uranium in the immediate neighborhood of the tellurium mineral. Dr. Grip informs us that unusually large amounts of the uranium mineral thucholite have been found in the stope from which the Bi_2Te_3 was taken. Thus we ascribe the excess Xe^{129} and Xe^{131} to the proximity of such a deposit.

An interesting discrepancy appears in the ratio of Xe^{129} to Xe^{131} found in the sample. The present measurements show this to be 3.0, whereas one would expect a ratio of 0.6 from Seren's values[2] for the tellurium cross sections. One possible explanation is that Xe^{129} was also produced by the decay of small amounts of $I^{129}(\sim3\times10^7$ yr.) present in the mineral. This nuclide, as yet undetected in nature, may have been formed originally in amounts comparable to that of I^{127}.

The excess Xe^{130} is attributed to double beta-decay of Te^{130}. There appears to be no other explanation for its formation. Assuming an age of 1.5×10^9 years for the Bi_2Te_3, the excess Xe^{130} present corresponds to double beta-decay of Te^{130} with a half-life of 1.4×10^{21} years. This result is to be compared with theoretical half-lives of 6×10^{14} years and 10^{24} years. the former computed from the Majorana theory of the neutrino, and the latter from the Dirac theory. Both calculations are for allowed transitions with 1.6 Mev of available energy.

[1] M. G. Inghram and J. H. Reynolds, Phys. Rev. **76**, 1265 (1949).
[2] Seren, Friedlander, and Turkel, Phys. Rev. **72**, 888 (1947).

The Effect of the Compressibility of the Earth on Its Magnetic Field

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IN his recent review of geomagnetism associated with the earth's interior Elsasser[1] has noted that the equation for the magnetic induction **B** in a fluid moving with velocity **v** reduces to

$$D\mathbf{B}/Dt=\mathbf{B}\cdot\mathbf{grad}\mathbf{v}-\mathbf{B}\ \mathrm{div}\mathbf{v}, \quad (1)$$

provided displacement currents and decay may be neglected. He remarks that "we may safely drop the last term, considering the fluid as incompressible," so that (1) reduces to a form "analogous to the well-known Helmholtz equations for the conservation of vorticity . . . ," whence results analogous to the Helmholtz theorems follow.

While the neglect of volume changes is doubtless justified for motions at uniform depth, the great pressure gradients conjectured to exist in the earth's interior make it rather unlikely that Elsasser's approximation is justified if there be any considerable vertical motion. In some of the models suggested by Bullard[2] a part of the flow is nearly vertical. The neglect of compressibility effects is quite unnecessary, however, to obtain the conservation theorems. Equation (1) as it stands is a youthful discovery of Lagrange,[3] and Nanson[4] observed that by using Euler's continuity equation

$$\mathrm{div}\mathbf{v}=-D\log\rho/Dt, \quad (2)$$

where ρ is the density, one can reduce it to the form

$$D(\mathbf{B}/\rho)/Dt=(\mathbf{B}/\rho)\cdot\mathbf{grad}\mathbf{v}. \quad (3)$$

Hence the analogs of the Helmholtz theorems for the present instance may be stated in the following form: (a) the lines of induction are material lines, (b) the flux of induction,[5] $\int_S\mathbf{B}\cdot d\mathbf{S}$, is constant in time for a material surface S.

Among the finest proofs of these results are those of Kirchhoff,[6] who derived them directly from Cauchy's formula[7]

$$\mathbf{B}/\rho=\mathbf{B}_0/\rho_0\cdot\mathbf{GRAD}\ \mathbf{r}, \quad (4)$$

where $\mathbf{B}_0$ and ρ_0 are the values of **B** and ρ at some arbitrary initial instant $t=0$, and **GRAD r** is the gradient of the present position field **r** with respect to the initial position field **R**. It is easy to see that (4) is the general solution of (3).

In fact, however, Zorawski[8] showed directly that a condition of the form (a) is both necessary and sufficient for the validity of theorems of the Helmholtzian type for the field **B**, irrespective of its physical significance.

Equivalent to (b) is the conservation of the circulation of the magnetic vector potential around a material circuit.

For motions in the earth's interior the case when the flow is rotationally symmetric and the field **B** is perpendicular to the axial planes might be relevant for part of the motion. Equation (4) then reduces to a result analogous to the vorticity convection theorem of Svanberg:[9]

$$B/r\rho=\mathrm{const.} \quad (5)$$

for each particle, r being the distance from the axis of symmetry. In motions of this type the effect of density changes appears in a particularly lucid way, tending to counteract the increase in B incident upon approaching the axis of symmetry.

[1] W. M. Elsasser, Rev. Mod. Phys. **22**, 1 (1950). See p. 30.
[2] E. C. Bullard, Proc. Roy. Soc. **A197**, 433 (1949). See Section 8.
[3] J. L. Lagrange, Misc. Taur. **2**[2] (1760-1761), 196-298 (1762) =Oeuvres **1**, 365-468. See Chapter XLII.
[4] E. J. Nanson, Mess. Math. **3**, 120-121 (1874).
[5] This result was discovered by Cowling. See W. M. Elsasser, Phys. Rev. **72**, 821 (1947), see p. 827.
[6] G. Kirchhoff, *Vorlesungen über mathematische Physik: Mechanik* (Leipzig, 1876); second edition (1877); third edition (1883). See Vorlesung 15, §3.
[7] A.-L. Cauchy, *Théorie de la propagation des ondes à la surface d'un fluide pesant d'une profondeur indéfinie* (1815), Mem. Divers Savants (2) **1** (1816), 3-312 =Oeuvres (1) **1**, 5-318. See part I, Section 1, §4.
[8] K. Zorawski, Bull. Acad. Sci. Cracovie, Comptes Rendus 335-342 (1900). See R. Prim and C. Truesdell, Proc. Am. Math. Soc. **1**, 32-34 (1950).
[9] A. F. Svanberg, *On fluides rörelse*, K. Vetenskaps-Acad. Handlingar (1839), pp. 139-154 (1841)—trans. "Sur le mouvement des fluides," J. Reine Angew. Math. **24**, 153-163 (1842).

The Production of π^+-Mesons by Protons on Protons in the Direction of the Beam*

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A SIMPLE method[1] has recently been developed for measuring the differential production cross sections of positive and negative π-mesons when various nuclei are struck by high energy charged particles from the 184-in. synchrocyclotron. In this