TABLE I. Measured lines of the $J=1\rightarrow 2$ pure rotational transition of NaCl.

Isotopic species	Vibrational state	Frequency in megacycles/sec
$NaCl^{35}$	$v=0$	26051.1 ±0.75
	1	25857.6
	2	25666.5
	3	25473.9
$NaCl^{37}$	$v=0$	25493.9
	1	25307.5
	2	25120.3

A measurement of the ratio of intensities of the $NaCl^{37}$ $v=0$ and $NaCl^{35}$ $v=3$ lines gives a value for the vibrational frequency $\omega_e(35)=378\ cm^{-1}$, if the dipole moment is assumed independent of vibrational state. Including a reasonable variation of the dipole moment, this measurement may be in error ±15 percent. It agrees well, however, with a value of 380 cm^{-1} obtained by Levi.[3]

At approximately 715°C, the $J=5\rightarrow 6$ transition of CsCl was observed, and lines listed in Table II were measured. These give

TABLE II. Measured lines of the $J=5\rightarrow 6$ pure rotational transition of CsCl.

Isotopic species	Vibrational state	Frequency in megacycles/sec
$CsCl^{35}$	$v=5$	25300.0 ±1.5
	6	25180.1
	7	25061.0
	8	24941.2
$CsCl^{37}$	$v=0$	24798.2
	1	24685.7
	2	24571.4
	4	24337.9

values $B_e(Cl^{35})=2163.8\pm 0.2$ Mc, $\alpha_e(Cl^{35})=10.06\pm 0.06$ Mc, and the internuclear distance $r_e=2.9041\pm 0.0003$A.

The observed spectrum of KCl gave molecular constants in agreement with those found by measurement of rotational transitions in molecular beams.[4] A rich spectrum of lines between 25,000 Mc and 23,500 Mc was observed[2] in TlCl vapor at approximately 305°C. This spectrum showed no obvious regularities, and cannot be produced by a diatomic molecule, so that the vapor of TlCl must contain a considerable amount of dimers or some other combination of Tl and Cl.

It may be noted that the r_e value of CsCl is 4 percent less than the value of 3.02±0.03A obtained from electron diffraction measurements of the average over-all vibrational states at 1200°C, but falls within the experimental error of molecular beam measurements,[5] which is 2.88±0.03A. Likewise, the r_e value for NaCl is 5 percent less than the value of 2.48±0.03A given by electron diffraction measurements.[6] This discrepancy is unexplained.

The value of α for $CsCl^{35}$ obtained from molecular beam measurements of the product of the dipole moment and the moment of inertia[5] is 15.6±1.5. The large discrepancy between this result and the directly measured value given here may be due to an incorrect assumption about the variation of the dipole moment with vibration state.

We are very grateful to Mr. C. O. Dechert, foreman of the Columbia Radiation Laboratory machine shop, for considerable aid in the design and construction of the apparatus, as well as to Mr. A. P. Marshall and others of the machine shop staff. We also appreciate the help of Mr. A. Javan and Mr. W. A. Hardy with several of the experimental measurements.

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μ-Meson Decay and β-Radioactivity*

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THE decay $\mu^{\pm}\rightarrow\epsilon^{\pm}+2\nu$ cannot be consistently explained by indirect interaction through any known virtual particles. Thus we are led to suppose a direct interaction between the four fermions μ, ϵ, ν, ν.

If we restrict ourselves to the kind of interaction terms used in β-radioactivity [no derivatives of the wave functions; however, the use of imaginary and/or pseudoscalar coupling constants would not modify formula (1)], the theoretically predicted possible energy spectra[1] for the secondary electrons are (with the normalization $\tau\int_1^W P(E)dE=1$, where τ is the μ-meson mean life and E is the electron energy):

$$\tau P(E)=(4E^2/W^4)[3(W-E)+\tfrac{2}{3}\rho(4E-3W)], \qquad (1)$$

where ρ is a parameter satisfying $0\leq\rho\leq 1$. The agreement with experimental results is very satisfactory and ρ may be obtained from experiments.[2]

Direct interaction[3].—With four Dirac wave functions ψ or ψ^* (I shall write ψ^K for both types of functions), we can form only five linearly independent scalars J_i, and the most general interaction Hamiltonian density is

$$H=\Sigma g_i J_i+\text{Hermitian conjugate}. \qquad (2)$$

A set of five linearly independent J_i is usually constructed as follows: with two ψ^K in a given order one can form five Lorentz covariants S, V, T, A, P; each J_i is then a scalar product of one of these covariants by corresponding covariant made with the two other ψ^K (also in a given order).

If the order of the ψ^K in J_i is changed, the new J_i is a linear combination of the old ones. This corresponds in H to a change of reference system for the five-dimensional vector space of the g_i. The only vector g invariant for all permutations corresponds to the Critichfield and Wigner interaction.[4]

If two ψ^K are identical (this occurs for instance when there are two indistinguishable particles), there are only three linearly independent J_i and this corresponds to a projection on three dimensions of the five-dimensional g space. Therefore we have to consider two cases:

(1) The two emitted neutrinos are experimentally distinguishable (for example, by the sign of their magnetic moment). This case can occur if the neutrinos are described by Dirac's hole theory and the two emitted neutrinos are particle and antiparticle, respectively. Then $0\leq\rho\leq 1$.

(2) The two emitted neutrinos are identical particles. This may occur if the emitted neutrinos are both particles or both antiparticles in Dirac's hole theory, or if they are described by Majorana's theory[5] according to which all neutrinos are identical. Then $0\leq\rho\leq 3/4$.

The triangle of interactions.—Several authors[6] have shown that direct interactions with the same magnitude for coupling constants can explain β-radioactivity, μ-meson decay and μ-meson capture by heavy nuclei. It is then natural to test first the simplest hypothesis that the "same" interaction is responsible for these three phenomena.

But it is clear that the direct interaction of one set of four fermions can be compared to the direct interaction of another set of four fermions only if a one-to-one correspondence between the particles of the two sets is agreed on. It can be shown that except for minor questions of signs (immaterial for β-radioactivity) it is sufficient to have a correspondence between pairs of particles. The "triangle" suggests such a correspondence

$$(n, p)\leftrightarrow(\epsilon, \nu)\leftrightarrow(\mu, \nu).$$

If one refers to the usual notations of β-radioactivity, calling f_1 the five coupling constants (f_1 for the "scalar" interaction, f_2 for the "vector" interaction, and so on $\cdots$), ρ is given by

(1) different neutrinos:

$$0\leq\rho=\frac{3}{4}\frac{(f_1-f_3)^2+(f_3+f_5)^2+2(f_2+f_4)^2}{f_1^2+4f_2^2+6f_3^2+4f_4^2+f_5^2}\leq 1;$$

(2) identical neutrinos:

$$0\leq\rho=\frac{3}{2}\frac{[f_1+f_5-2(f_2+f_4)]^2}{(f_1+6f_3-f_5)^2+16(f_2-f_4)^2+2[f_1+f_5-2(f_2+f_4)]^2}\leq\frac{3}{4}.$$

Another quadratic relation [different for (1) and (2)] between f_i is given[7] by the ratio

(neutron mean life)/(μ-meson mean life).

A better knowledge of the nature of the direct interaction responsible for β-radioactivity, of the neutron mean life and of the energy spectrum of the secondary electrons from μ-meson decay will allow one to answer the following questions:

(a) Can a "same" direct interaction explain β-radioactivity and μ-meson decay?

(b) Are the two neutrinos emitted in μ-meson decay identical or not?

From the present experimental data it can already be concluded that question (a) cannot be answered separately.

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