values of α and R for which, according to Lin, the flow should be unstable.

It was suggested three or four years ago by J. von Neumann, C. C. Lin, and C. L. Pekeris, that this question could be settled by numerical work and an attempt was then made which was successful in finding c only up to $R=1600$. We have now found it possible to integrate the equation successfully for larger values of R and have obtained the results for c given in Table I, which

TABLE I. Characteristic values of c.

α \ R	1600	2500	6400	10,000	35,000
0.9		0.2857+0.0211i	0.2444+0.0012i	0.2261−0.0040i	
1.0	0.3231+0.0262i	0.3011+0.0142i	0.2569 −0.0009i	0.2375−0.0037i	0.1886+0.0009i
1.1	0.3384+0.0206i	0.3148+0.0108i	0.2677+0.0007i	0.2470+0.0003i	0.1911+0.0116i
1.2		0.3267+0.0107i	0.2763+0.0056i	0.2535+0.0075i	

For $\alpha=1.05$, $R=8000$, $c=0.2524-0.0017i$

are believed accurate to 0.5 in the last place. Interpolation gives a critical Reynolds number $R=5780$ for $\alpha=1.02$, which has been checked by integrations. These numbers confirm Lin's results closely, and it may now be regarded as proved that plane Poiseuille flow becomes unstable at about $R=5800$. It may be noted that for a given value of α the flow is unstable only for a finite range of Reynolds numbers as was also found by Lin.

This latest work was done on International Business Machines Corporation's Selective Sequence Electronic Calculator by Donald A. Quarles, Jr. and Phyllis K. Brown. The numerical work was done to 13 digits using a step of 0.01 in y with an integration formula having an error per step proportional to the 8th derivative. The problem took about 150 hours of operating time, equivalent to about 100 years of hand computing.

[1] C. C. Lin, Quart. Appl. Math. 3, 288 (1946).
[2] C. L. Pekeris, Phys. Rev. 74, 191 (1948).

Radiations from Nb^{97}†

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THE properties of the 17-hr Zr^{97} and of its daughter element, the 70-minute Nb^{97}, have been the subject of considerable investigation.[1–5] Spectrometric measurements[5] have yielded beta-ray energies of 1.91±0.02 Mev and 1.267±0.02 Mev, and gamma-ray energies of 0.747±0.005 Mev for Zr^{97} and 0.665±0.005 Mev for Nb^{97}. The gamma-ray at 0.747±0.005 Mev was shown to be emitted from an isomeric level in Nb^{97} of half-period 60 sec.

In the present investigation $Zr^{96}O_2$ (isotopic concentration 90 percent in Zr^{96}), obtained from the Y-12 plant, Carbide and Carbon Chemicals Division, Union Carbide and Carbon Corporation, Oak Ridge, Tennessee, was irradiated by slow neutrons in the Oak Ridge pile. The radioactive materials were received within twenty-four hours after cessation of irradiation and chemical separations were immediately commenced. The slow neutron irradiated zirconium dioxide was dissolved by potassium pyrosulfate fusion, and the separation of the niobium daughter activity from zirconium was effected by the use of Steinberg's "oxalate" procedure.[6]

The decay of Nb^{97}, freshly separated from its parent element, was followed for ten half-periods, and the half-period, taken from the slope of the decay curve was found to be 72.1±0.7 minutes. This value is to be compared with previously reported values of 68 minutes[7] and 75 minutes.[2] The decay of Zr^{97} was followed for 200 hours, and the resulting half-period was calculated to be 17.0±0.2 hours, in agreement with the earlier measurements.

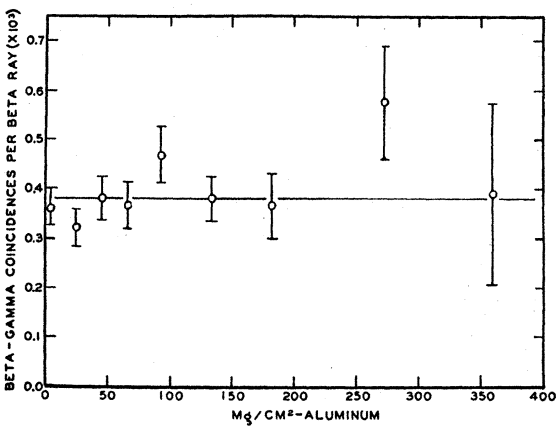

FIG. 1. Beta-gamma coincidence rate of Nb^{97} as a function of the surface density of aluminum placed before the beta-ray counter.

The beta-rays of Nb^{97}, freshly separated from its parent element, were absorbed in aluminum, and a Feather[8] plot of the data gave a maximum beta-ray energy of 1.40 Mev.

The beta-gamma coincidence rate of the 72-minute Nb^{97} is shown as a function of absorber thickness before the beta-ray counter in Fig. 1. It is seen to be constant, independent of the beta-ray energy, suggesting that the beta-ray spectrum of Nb^{97} is simple. Calibration of the beta-gamma coincidence counting arrangement by the beta-gamma coincidence rate of Sc^{46} showed that each beta-ray of Nb^{97} is followed, on the average, by 0.7 Mev of gamma-ray energy. Each point of Fig. 1 was, of course, properly corrected for decay of the source.

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* Frankford Arsenal, Philadelphia, Pennsylvania.
[1] Sagane, Kojima, Mijamoto, and Ikawa, Phys. Rev. 57, 1179 (1940).
[2] A. V. Grosse and E. T. Booth, Phys. Rev. 57, 664 (1940).
[3] S. Katcoff and B. Finkle, *Radiochemical Studies: The Fission Products* (McGraw-Hill Book Company, Inc., New York, 1951), Paper No. 83, National Nuclear Energy Series, Plutonium Project Record, Vol. 9, Div. IV.
[4] O. Hahn and F. Strassman, Naturwiss. 29, 285 (1941).
[5] Burgus, Knight, and Prestwood, Phys. Rev. 79, 104 (1950).
[6] E. P. Steinberg, *Radiochemical Studies: The Fission Products* (McGraw-Hill Book Company, Inc., New York, 1951), Paper No. 243, National Nuclear Energy Series, Plutonium Project Record, Vol. 9, Div. IV.
[7] G. E. Boyd, communication to G. T. Seaborg and I. Perlman, Revs. Modern Phys. 20, 585 (1948).
[8] N. Feather, Proc. Cambridge Phil. Soc. 30, 599 (1938).

Microwave Spectroscopy at High Temperature-Spectra of CsCl and NaCl*

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A SPECTROMETER for measurement of microwave absorption by gases at high temperature has been constructed,[1,2] and with it spectra of gaseous NaCl, KCl, CsCl, and TlCl have been obtained. Microwaves pass through a 5-foot absorption cell which can be held at temperatures at least as high as 875°C. Absorption lines are modulated by Stark effect to give sensitive detection.

At approximately 775°C the pure rotational transition $J=1\rightarrow2$ of NaCl was observed. Frequencies for the two Cl isotopes and various vibrational states are listed in Table I. These give $B_e(Cl^{35})=6536.9\pm0.3$ Mc, $\alpha_e(Cl^{35})=48.1\pm0.1$ Mc, and the internuclear distance $r_e=2.3606\pm0.0003$A. Frequency measurements of the absorption lines were made with a frequency standard. However, experimental conditions gave lines several megacycles broad, which limited the precision of measurements which could be easily obtained to that indicated in Table I.

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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[1] M. L. Stitch and C. H. Townes, Quarterly Report, Columbia Radiation Laboratory, December 31, 1950 and subsequent CRL reports.
[2] Stitch, Honig, and Townes, Bull. Am. Phys. Soc. **27**, No. 1, 32 (1952).
[3] H. Levi, dissertation, Berlin, (1934).
[4] Fabricand, Carlson, Lee, and Rabi, Bull. Am. Phys. Soc. **27**, No. 1, 32 (1952).
[5] R. G. Luce and J. W. Trischka, Phys. Rev. **83**, 851 (1951).
[6] Maxwell, Henderson, and Mosely, Phys. Rev. **52**, 968 (1937).

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