siderations have led to the constants (the c's are in Mev)

$$c_1=26.00,\ c_2=9.560,\ c_3=0.00780,\ c_4=22.5,\ c_5=33.5,\ \gamma=0.400 \text{ and } B=200.$$

Together with Eq. (1) these simple key functions characterize an empirical energy surface which does not deviate significantly from the Weizsäcker surface for the great range of mass numbers and which lies significantly closer to the true nuclear surface for very heavy nuclei. Furthermore, Eq. (4) is now exact.

Apart from systematizing nuclear data, it is thought that this empirical surface will be very useful as a base surface for investigating the irregularities of the actual surface. Thus if $E_{sh}(A, D)$ is the deviation of the true surface from the empirical surface at the A, D point then any discrepancy between an experimental Q value and the calculated Q value is given by

$$Q_{\text{exp}}-Q_{\text{calc}}=E_{sh}(A, D)-E_{sh}(A', D'). \tag{15}$$

I would like to thank the many students who have assisted in this study, in particular Mr. Robert Minogue who determined the values of c_1, c_2, and c_3 quoted above. Mr. Minogue has also carried out a survey of experimental and calculated neutron binding energies and alpha-decay energies as well as a study of the shell correction in the neighborhood of mass number 208. These results will be reported in a detailed communication.

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On the Spin and Quadrupole Moment of Cl^{36}

C. M. Johnson and Walter Gordy
*Department of Physics, Duke University, Durham, North Carolina**
and
Ralph Livingston,
Oak Ridge National Laboratory, Oak Ridge, Tennessee†

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From observation of the hyperfine structure of the $J=0\rightarrow1$ transition of CH_3Cl^{36} we have confirmed the assignment of 2 for the nuclear spin of Cl^{36} by Townes and Aamodt.[1] This is the only known nuclear spin value of 2.

The hyperfine structure of a $0\rightarrow1$ transition is particularly simple, consisting of only three lines for any spin value. The ratios of the frequency intervals differ widely for different spin value, so that an unquestionable assignment of a spin can be made by a precise measurement of these ratios. Table I lists the frequency ratios for spin values 1 to 4, together with the measured value for CH_3Cl^{36}. It is seen that all theoretical values except those for $I=2$ are considerably outside the range of limits of error.

TABLE I. Frequency ratios of hyperfine components for different spin values.

Spin	Theoretical ratio	Observed ratio
1	1.500	
2	0.556	0.547 ±0.017
3	0.350	
4	0.257	

Tables II and III list the various constants which were evaluated. The quadrupole moment is determined from the coupling ratio, using the Cl^{35} moment -0.07894×10^{-24} cm², as revised by Jaccarino and King.[2] The value agrees with that of Townes and Aamodt,[1] $-0.0172\pm0.0004\times10^{-24}$ cm²,[3] within the limits of error of the two observations.

TABLE II. Measured frequencies of CH_3Cl^{36}.

Transition	Observed frequency Mc/sec	B_0 Mc/sec
$J=0\rightarrow1,\quad F=2\rightarrow2$	26,372.42 ±0.05	
$2\rightarrow3$	26,376.01	13,187.66[a]
$2\rightarrow1$	26,377.97	

[a] D_J is assumed to be 26.5 kc/sec.

TABLE III. Cl^{36} constants.

Spin	Coupling Mc/sec	Quadrupole moment cm²
2	−15.87 ±0.09[a]	$-0.0168\pm0.0001\times10^{-24}$

[a] The accuracy of relative frequency measurements is ±0.03 Mc/sec.

Figure 1 shows a cathode-ray presentation of the spectrum, with bars to indicate the theoretical spectrum for $I=2$. One of the lines of CH_3Cl^{35} in an excited vibrational state falls among the Cl^{36} group. Although this could not be completely "frozen out," it was easily identified and resolved from the Cl^{36} lines. The observations were made at dry ice temperature with a 20-foot Stark cell. A 100-kc square wave Stark modulating voltage was employed, with the field adjusted so as to remove the Stark components completely from the undisplaced group (zero field components). The methyl chloride was synthesized by reacting NaCl with H_2SO_4 and CH_3OH. The Cl^{36} was made by neutron capture in Cl^{35} in a reactor. Its concentration was less than 1 percent.

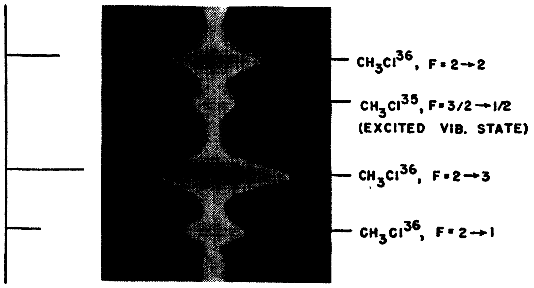

FIG. 1. Oscilloscope picture of $J=0\rightarrow1$ hyperfine pattern for CH_3Cl^{36}, with the calculated pattern below.

Since the hyperfine structure lines of an excited vibrational state of CH_3Cl^{35} occur so near the Cl^{36} group, the frequencies of these lines were also measured during this experiment in order to determine whether or not the quadrupole coupling remained the same as in the ground state. The coupling was found to be −74.70 Mc/sec, which is not significantly different from the latest value,[4] −74.77 Mc/sec, given for the ground state.

We wish to thank Ralph Trambarulo, J. Q. Williams and C. F. Luck for assisting with the measurements.

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[*] The research at this institution was sponsored by the Geophysical Research Directorate of Air Force Cambridge Research Laboratories.
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[2] V. Jaccarino and J. G. King, private communication.
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The Specific Alpha-Radioactivity of Pu^{240}

Edgar F. Westrum, Jr.*
Argonne National Laboratory, Chicago, Illinois†

(Received July 26, 1951)‡

The small concentrations of Pu^{240} produced by the reaction $Pu^{239}(n, \gamma)Pu^{240}$ during irradiation of uranium or plutonium samples in thermal neutron reactors make possible the calculation of the half-life of Pu^{240} from a determination of the relative specific alpha-activities and the isotopic compositions of the plutonium fractions of such samples.

The plutonium fractions of several samples subjected to different neutron fluxes were separated and carefully purified to spectrochemical freedom from foreign cations, to the absence of uranium (detected by a sensitive fluorescence test), and to radioactive purity. Duplicate portions of each plutonium fraction were converted to PuF_3 and reduced to high purity metal by microscale methods.[1]

Milligram globules of plutonium metal were massed against calibrated weights and dissolved in weighed quantities of solution. Aliquots were plated on platinum by a very precise gravimetric technique,[2] and counted on a parallel plate nitrogen counter (N-4) by methods previously described.[3] The isotopic compositions of the samples were available from the mass spectrometric examinations of Bartlett and Swinehart.[4] A minor change in the isotopic composition of sample C indicated by a recent determination has been incorporated into the present calculation after correcting for the accumulated radioactive disintegration.[5]

Appropriate corrections for Pu^{239} and the small amounts of Pu^{238} and Pu^{241} present were made in calculating the half-life of Pu^{240} from the observed[3] specific activity of the samples relative to that of Pu^{239}.

The Pu^{240} half-life calculated from three such plutonium fractions in order of increasing Pu^{240} content were sample A, 6180±360 years; sample B, 6100±200 years; and sample C, 6310±130 years; with a best value of 6240±120 years. The indicated probable errors in these measurments includes consideration of the uncertainties in the mass spectrometry and weighing, limitation of spectrochemical sensitivity, observed standard deviations in the counting, and the probable error in the half-life of Pu^{239}.

It is noted that this half-life value is in accord with an estimate of about 6000 years by James *et al.*[6]

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* Present address: Department of Chemistry, University of Michigan, Ann Arbor, Michigan.

† Formerly the Metallurgical Laboratory.

‡ Based on Manhattan Project Document CC-3894 (1946).

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Half-Life of Plutonium-240 by Determination of Its Uranium-236 Daughter

M. G. Inghram, D. C. Hess, P. R. Fields, and G. L. Pyle
Argonne National Laboratory, Chicago, Illinois

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A new measurement of the Pu^{240} half-life has been made using a technique which depends on the growth of the uranium daughters from a plutonium sample of known isotopic composition. The decays involved in this experiment are

$$Pu^{239} \xrightarrow[\alpha]{24{,}410\ \text{yr}^1} U^{235} \xrightarrow[\alpha]{7\times 10^8\ \text{yr}}, \qquad (1)$$

$$Pu^{240} \xrightarrow[\alpha]{\sim 6000\ \text{yr}^2} U^{236} \xrightarrow[\alpha]{\sim 2\times 10^7\ \text{yr}^3}. \qquad (2)$$

Since the time necessary to complete the experiment was short in comparison to the half-lives involved, the following simplified analytical expression can be obtained for the Pu^{240} half-life:

$$T_{\frac{1}{2}}(Pu^{240}) = \frac{\text{moles of } U^{235}}{\text{moles of } U^{236}} \times \frac{\text{moles of } Pu^{240}}{\text{moles of } Pu^{239}} \times T_{\frac{1}{2}}(Pu^{239}).$$

The half-life thus obtained depends on the isotopic ratios of the uranium daughters and of the plutonium parents as determined by the mass spectrometer, and on the known half-life of Pu^{239}. Previous measurements of the Pu^{240} half-life have been dependent on the Pu^{239} half-life and on the ratio of the plutonium isotopes, but have also been subject to the errors inherent in specific activity measurements.

The plutonium used for this experiment was chosen because it contained a relatively large amount of Pu^{240} and because it had been purified several years earlier with respect to the other heavy elements. After a chemical separation of the uranium daughters and subsequent purifications, an analysis on the alpha-differential pulse analyzer indicated that the final uranium fraction was sufficiently free of plutonium for mass spectrometric determinations.

The calculation of the half-life of Pu^{240} involved two experimental errors: (1) The error in the half-life of Pu^{239}, which is given by Westrum as ±0.3 percent;[1] (2) the error in the mass spectrometric measurements of the isotopic ratios, which is about ±0.3 percent. It should be noted that the usual mass discriminations inherent in a mass spectrometer cancel in the present case. Substituting in the analytical expression, the values obtained on the mass spectrometer for the isotopic ratios of Pu^{240}/Pu^{239} and U^{235}/U^{236} and the value $T_{\frac{1}{2}}{}^{239} = 24{,}410$ years,[1] gives the half-life of Pu^{240} as 6580±40 years. This value and its limits of error is to be compared with those of 6240±120 yr,[4] 6850±150 yr,[5] and 6650±150 yr,[5] as determined by specific activity measurements.

The authors wish to express their appreciation to Dr. W. M. Manning for his helpful discussions of this problem.

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Low Excited States of Nuclei and the Quasi-Atomic Model*

L. J. Koester,† H. L. Jackson,‡ and R. K. Adair
University of Wisconsin, Madison, Wisconsin

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The independent particle, or quasi-atomic model of the nucleus, has been used to discuss the ground states of nuclei[1,2] and the doublet splitting in light nuclei.[3] Recent experiments[4] on the elastic scattering of protons by He^4, C^{12}, O^{16}, and of neutrons by He^4 have been analyzed,[4,5] and assignments of angular momentum and parity have been made to the excited states observed. These quantum numbers have also been determined for some of the low states of Al^{25} by an analysis of the scattering[6] of protons by Mg^{24}. Although these assignments are not all quite conclusive, we shall assume them to be correct for the purpose of discussion. The resulting series of energy levels, which are about 4 Mev in extent and lie near the ground states, show an interesting correlation with the predictions of an independent particle model with strong spin-orbit coupling.

One assumes that the nucleons of the target nucleus form a core of zero resultant angular momentum and that the influence of this core on the extra nucleon can be represented by an average potential. As a first approximation, this potential might be considered similar to that of a three-dimensional harmonic oscillator.