

Some New Mass Comparisons Involving Si, Fe, Ni, Cu, Zn, W, and Pt*

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A number of mass comparisons have been made using a large Dempster-type mass spectrograph with a spark source. Packing fraction differences have been obtained for the doublets $\text{Si}^{28}-\text{Fe}^{56}$, $\text{Si}^{29}-\text{Ni}^{58}$, $\text{Si}^{30}-\text{Ni}^{60}$, $\text{W}^{183}-\text{Ni}^{61}$, $\text{W}^{186}-\text{Ni}^{62}$, $\text{Pt}^{192}-\text{Zn}^{64}$, $\text{Pt}^{196}-\text{Cu}^{65}$, $\text{Pt}^{198}-\text{Zn}^{66}$.

1. INTRODUCTION

THE divergence of the masses of atoms from whole numbers first suggested by Aston¹ in 1923, and first measured by Costa² in 1925, has become increasingly important with the growth of nuclear physics. The interest in this subject led in the middle 1930's to the construction of double-focusing mass spectrographs by Dempster,³ Bainbridge and Jordan,⁴ and Mattauch.⁵ These instruments of high resolving power were used to measure isotopic masses precisely, the divergence from integral values being expressed usually in terms of a packing fraction.⁶ As a result of these measurements, Aston's original packing fraction curve,⁷ drawn in 1927, was superseded by Dempster's more accurate one in 1938.⁸

Recent mass measurements suggest that there are large fluctuations in the packing fraction curve,⁹ and also indicate that the minimum, which occurs in the neigh-

borhood of mass 60, is lower than given by Dempster's curve.⁹⁻¹² However, there have been several inconsistencies among recent measurements, and these two features have yet to be unequivocally demonstrated. Also, there is the recent suggestion by Feenberg¹³ that a plateau in the packing fraction curve may exist in the region $108 \leq A \leq 124$. It is hoped that the present measurements, and others in progress, will help to establish the true shape and position of the curve.

2. APPARATUS

The measurements reported in this paper have been made using the method devised by Dempster.¹⁴ In this method, a double-focusing mass spectrograph, equipped with a "hot-spark" ion source, is used to photograph doublets consisting of almost coincident singly and multiply charged ions. The electrodes between which the spark occurs consist, wholly or in part, of the elements desired in the comparison. Thus, for example, Dempster has photographed the doublet formed by singly charged Cu^{65} and triply charged Pt^{195} and, from measurements thereon, has calculated the packing fraction difference (Δf) between these two nuclides. For this comparison, one electrode was a copper-beryllium alloy and the other a platinum-iridium alloy.

The mass spectrograph used in the present work, a large Dempster-type instrument, has recently been constructed at Wesleyan University.¹⁵ Its resolution, with a principal slit of 0.001", is 7000 which is sufficient to resolve completely a large number of interesting doublets.

3. SECURING MATCHED DOUBLET LINES

It is difficult to make reliable measurements of a doublet spacing if the two lines are not fairly well matched in intensity. If the two lines of the doublet are being photographed simultaneously, as has been the usual practice, the electrodes between which the spark occurs and which vaporize to form the positive ion beam must contain the desired nuclides in appropriate proportions. These electrodes are often hard to prepare, especially if one is dealing with two elements whose

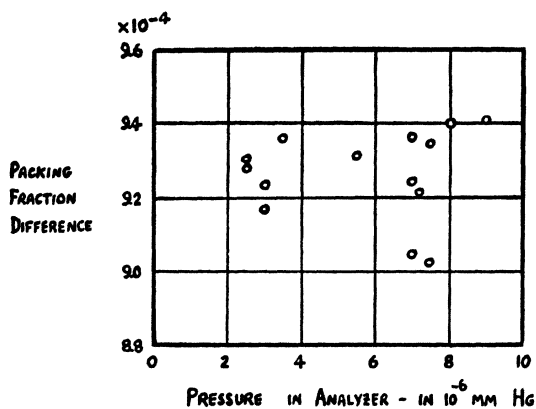


FIG. 1. Values of the $\text{Pt}^{195}-\text{Cu}^{65}$ packing fraction difference plotted against the pressure in the analyzing section of the mass spectrograph.

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¹ F. W. Aston, *Phil. Mag.* **45**, 941 (1923).

² J. L. Costa, *Ann. de physique* **4**, 425 (1925).

³ A. J. Dempster, *Proc. Am. Phil. Soc.* **75**, 755 (1935).

⁴ K. T. Bainbridge and E. B. Jordan, *Phys. Rev.* **50**, 282 (1936).

⁵ Josef Mattauch, *Phys. Rev.* **50**, 617 (1936).

⁶ The term "packing fraction," introduced by Aston, is defined as $f = (A - I)/I$, where A is the mass of the atom in question, and I is the nearest integer.

⁷ F. W. Aston, *Mass Spectra and Isotopes* (Edward Arnold and Company, London, England, 1942), p. 81.

⁸ A. J. Dempster, *Phys. Rev.* **53**, 869 (1938).

⁹ K. Ogata, *Phys. Rev.* **75**, 200 (1949).

¹⁰ H. E. Duckworth, *Phys. Rev.* **62**, 19 (1942).

¹¹ A. J. Dempster, *Phys. Rev.* **74**, 1225 (1948).

¹² A. E. Shaw, *Phys. Rev.* **75**, 1011 (1949).

¹³ E. Feenberg, *Rev. Mod. Phys.* **19**, 239 (1947).

¹⁴ A. J. Dempster, *Phys. Rev.* **53**, 64 (1938).

¹⁵ H. E. Duckworth, *Rev. Sci. Inst.* **21**, 54 (1950).

boiling points are widely different. As an example of this sort, suppose one is attempting to photograph the doublet consisting of singly charged Zn^{66} and triply charged Pt^{198} . One cannot simply make an alloy of these two elements. If one uses platinum as one electrode and an alloy of zinc as the other, the zinc alloy, generally possessing a low boiling point, vaporizes rapidly and appears to limit the temperature of the spark, with the result that few platinum ions are created. Furthermore, some of the vaporized zinc will condense on the platinum, thereby protecting it still further. It is sometimes possible to salvage from such an unsuccessful experiment, platinum electrodes which have been contaminated by zinc to just the proper degree that when a spark occurs between two of them the zinc and platinum ions are released in the desired ratio for a limited period of time. In more favorable comparisons, where the temperature of the spark is hot enough to vaporize both electrodes readily, there is still the general problem of fabricating electrodes of the desired composition.

An alternative method, which avoids these difficulties, is to photograph the two lines in a doublet consecutively. This requires an arrangement for changing electrodes so that the line intensities may be matched by running the spark between different pairs of electrodes for different times. In this way the $Zn^{66}-Pt^{198}$ doublet mentioned above has been photographed by using one brass and one platinum electrode for the first minute, two platinum electrodes for the following fifteen minutes, and brass and platinum electrodes again for the final minute. Of course, such a method can only be used if the fields of the mass spectrograph are very constant. By bracketing the Pt-Pt spark with two brass-Pt sparks, it was hoped to detect any change in the fields during the exposure, by a broadening of the zinc lines. It has been discovered that this test for constancy is not sensitive enough when the field changes are very small. Consequently, accurate absolute measurements have not been made on doublets photographed in this manner. However, useful comparative measurements which have been made will be described later in this paper in the nickel-tungsten and zinc-platinum comparisons. Except for these, the present measurements have been made from doublets photographed simultaneously in the conventional manner. When the necessary field stabilities have been achieved, the consecutive method should greatly simplify the problem of securing matched doublet lines.

 TABLE I. Packing fraction of Fe^{56} .

	Doublet	Packing Fraction
Present work	$Si^{28}-Fe^{56}$	-8.52 ± 0.05
A. J. Dempster*	$Ni^{61}-Fe^{56}$	-7.1 ± 0.4
K. Ogata**	$C_4^{12}H_3^1-Fe^{56}$	-8.32 ± 0.05

* See reference 14.

** See reference 9.

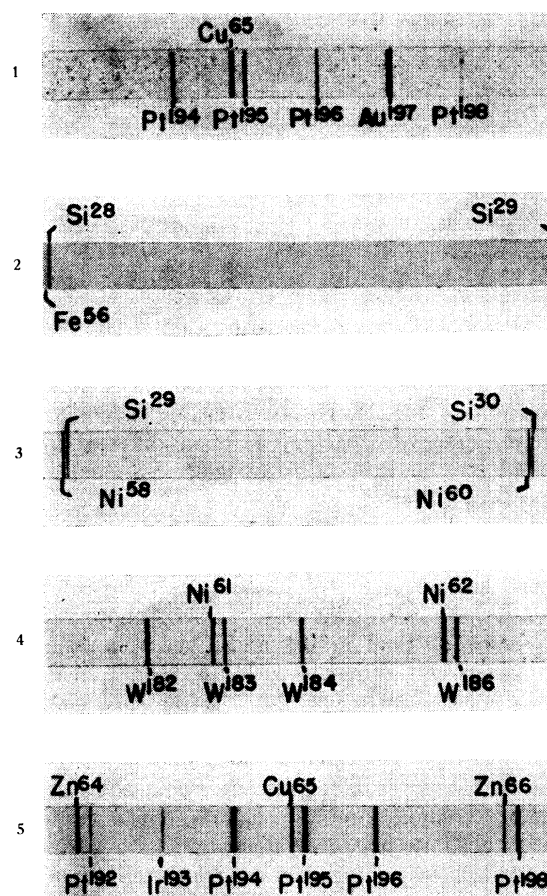


FIG. 2. Spectrum 1: A typical $Cu^{65}-Pt^{195}$ doublet used in studying the effect of pressure on doublet spacing. Spectrum 2: A typical $Si^{28}-Fe^{56}$ doublet used in the silicon-iron comparison. Spectrum 3: Representative $Si^{29}-Ni^{58}$ and $Si^{30}-Ni^{60}$ doublets used in the silicon-nickel comparison. Spectrum 4: Sample $Ni^{61}-W^{183}$ and $Ni^{62}-W^{186}$ doublets. Spectrum 5: Representative $Zn^{64}-Pt^{192}$, $Cu^{65}-Pt^{195}$, and $Zn^{66}-Pt^{198}$ doublets used in the zinc-platinum comparison. Magnification $8\times$.

4. $Cu^{65}-Pt^{195}$ COMPARISON AND THE EFFECT OF PRESSURE ON THE DOUBLET SPACING

Dempster and Shaw have recently observed¹⁶ that the spacing of doublets consisting of triply charged samarium atoms and hydrocarbons of the corresponding mass is dependent upon the pressure in their mass spectrograph. This effect is attributed to a differential slowing down of the ions by residual gas.

The $Cu^{65}-Pt^{195}$ doublet has been used to study this effect in the Wesleyan mass spectrograph. With a spark between a platinum electrode and a gold electrode containing two percent copper, doublets at mass 65 formed by singly charged Cu^{65} and triply charged Pt^{195} were photographed with exposure times ranging from three to ten minutes. Exposures were taken at various pressures in the range 2.5×10^{-6} to 9×10^{-6} mm Hg. The results of this experiment are shown in Fig. 1, where the pack-

¹⁶ A. J. Dempster and A. E. Shaw, *Phys. Rev.* **77**, 746 (1950).

TABLE II. Packing fraction of Ni⁵⁸.

	Doublet	Packing Fraction
Present work	Si ²⁹ —Ni ⁵⁸	-8.09±0.05
Aston*		-8.5 ±0.35
T. Okuda <i>et al.</i> **	C ₄ ¹² H ₁₀ —Ni ⁵⁸	-6.97±0.07
A. E. Shaw†	C ₂ ¹² H ₅ —Ni ⁵⁸	-8.29±0.07

* F. W. Aston, *Mass Spectra and Isotopes* (Edward Arnold and Company, London, England, 1942), p. 151.

** See reference 21.

† See reference 12.

ing fraction difference between Pt¹⁹⁵ and Cu⁶⁵ is plotted against the pressure in the analyzing region of the mass spectrograph. A typical exposure is shown in spectrum 1 of Fig. 2. The mass scale needed for the computation of the packing fraction differences was provided by the Pt¹⁹⁴—Pt¹⁹⁵ spacing, assumed to be integral.

It will be seen from Fig. 1 that the dependence of the doublet spacing on the gas pressure is small in this pressure range. The doublets used in the other comparisons described in this paper have been photographed at pressures less than 5×10^{-6} and it has been assumed, on the basis of the results with Cu⁶⁵—Pt¹⁹⁵, that the pressure effects are negligible. The pressure readings have been made with a Distillation Products VG-1A ionization gauge calibrated for air. Since much of the residual gas comes from the silicone used in the diffusion pumps and from vacuum wax, there is some uncertainty as to the absolute pressure values.

In addition to the fourteen exposures represented in Fig. 1, nineteen additional photographs of the Cu⁶⁵—Pt¹⁹⁵ doublets have been taken without noting the corresponding pressures. It is known, however, that the pressures were less than 6×10^{-6} mm. The mean packing fraction difference for these latter nineteen exposures¹⁷ is 9.20 ± 0.02 , compared with a mean of 9.26 ± 0.02 for the former eleven. The average of the 33 exposures is 9.23 ± 0.015 . The extreme values for the entire group are 9.03 and 9.42. This doublet had been studied with the Wesleyan mass spectrograph a few months ago. At that time measurements on six exposures¹⁸ inferior to the present ones gave $\Delta f = 9.26 \pm 0.06$. Dempster¹⁴ obtained for this doublet $\Delta f = 8.93 \pm 0.1$.

The errors included in the present measurements are probable errors in all cases, based on the internal consistency of the data. No attempt has been made to allow for possible systematic error or to allow a comfortable margin of safety.

5. SILICON-IRON COMPARISON

With a spark between a silicon electrode and an electrode of stainless steel containing 10 percent nickel, close doublets were photographed at mass 28, formed by singly charged Si²⁸ and doubly charged Fe⁵⁶. Ex-

¹⁷ Throughout the paper the factor $\times 10^{-4}$ will be understood and not written in expressing the numerical value of the packing fraction.

¹⁸ H. E. Duckworth, *Phys. Rev.* **76**, 690 (1949).

TABLE III. Packing fraction of Ni⁶⁰.

	Doublet	Packing Fraction
Present work	Si ³⁰ —Ni ⁶⁰	-8.54±0.02
T. Okuda <i>et al.</i> *	C ₅ ¹² —Ni ⁶⁰	-8.37±0.06
A. E. Shaw†	C ₅ ¹² —Ni ⁶⁰	-8.69±0.08

* See reference 21.

† See reference 12.

posure times ranged from 30 to 40 seconds. A typical photograph, shown in spectrum 2 of Fig. 2 is seen to be poorly matched in intensity. However, measurements of five such exposures were quite consistent and yielded an average packing fraction difference of 3.32 ± 0.02 . The Si²⁸—Si²⁹ separation, assumed to be integral, served as the mass scale. Mattauch and Flammersfeld¹⁹ have recently given the packing fraction of Si²⁸ as -5.20 ± 0.04 , based on both mass spectrographic and disintegration evidence. This value combined with the present packing fraction difference, gives the packing fraction of Fe⁵⁶ as -8.52 ± 0.05 . In Table I this value is compared to previously measured values.

6. SILICON-NICKEL COMPARISON

Using the same electrodes as in the Si—Fe comparison, Si²⁹—Ni⁵⁸ and Si³⁰—Ni⁶⁰ doublets were photographed at masses 29 and 30, with exposure times ranging from 3 to 5 minutes. A typical photograph of these close doublets is shown in spectrum 3 of Fig. 2. From five photographs of the Si²⁹—Ni⁵⁸ doublet, the packing fraction difference is $\Delta f = 3.07 \pm 0.02$, while from eight photographs of the Si³⁰—Ni⁶⁰ doublet $\Delta f = 2.90 \pm 0.01$. The Si²⁸—Si²⁹ and Si²⁹—Si³⁰ separations provided suitable mass scales. Mattauch and Flammersfeld list the packing fractions of Si²⁹ and Si³⁰ as -5.02 ± 0.04 and -5.64 ± 0.02 , respectively. The present results, combined with these, give values of -8.09 ± 0.05 for Ni⁵⁸ and -8.54 ± 0.02 for Ni⁶⁰. A comparison between the present values for Ni⁵⁸ and Ni⁶⁰ and those obtained elsewhere is given in Tables II and III.

7. NICKEL-TUNGSTEN COMPARISON

When a tungsten electrode was used with the strainless steel electrode mentioned above, W¹⁸³—Ni⁶¹ and W¹⁸⁶—Ni⁶² doublets were formed at mass numbers 61 and 62. The doublets shown in spectrum 4 of Fig. 2, were photographed with an exposure time of 15 minutes. The W¹⁸²—W¹⁸³ and W¹⁸⁴—W¹⁸⁶ separations were used as mass scales. From three such W¹⁸³—Ni⁶¹ exposures, $\Delta f = 8.49 \pm 0.02$, while from four W¹⁸⁶—Ni⁶² exposures, $\Delta f = 9.03 \pm 0.02$.

These doublets were first photographed consecutively, using the scheme described above. Although only those

¹⁹ J. Mattauch and A. Flammersfeld, "Isotopic Report—1948," Verlag d. Zeits. f. Natur., Tübingen, Germany, 1949. Professor K. T. Bainbridge has kindly communicated the Mattauch and Flammersfeld values to the authors.

photographs whose constituent lines appeared to be sharp were selected for measurement, the values of Δf obtained therefrom scattered widely. For example, the four best $W^{183}-Ni^{61}$ exposures gave Δf values ranging from 8.41 to 9.03, compared to a spread of 8.46 to 8.53 for the three best simultaneous exposures. However, although the nickel and tungsten lines were not photographed simultaneously in these earlier plates, the Ni^{61} and Ni^{62} lines were, as were those for W^{183} and W^{186} . Thus, it was possible to compute the *difference* between the Δf 's for the two doublets. This difference was found on the four best exposures to be 0.52 ± 0.07 , in splendid agreement with the value of 0.54 ± 0.03 ($9.03 - 8.49$) obtained from the simultaneous photographs.

8. ZINC-PLATINUM COMPARISON

It was hoped to photograph both the $Zn^{64}-Pt^{192}$ and $Zn^{66}-Pt^{198}$ doublets. Some of the difficulties encountered have been described above, and the exposure time for consecutive photographing of the $Zn^{66}-Pt^{198}$ doublet has been given. Use of the brass as a source of zinc resulted in the appearance of the $Cu^{65}-Pt^{195}$ doublet, the copper lines being photographed simultaneously with the zinc. Thus, although no absolute measurements could be made from these plates, it was possible, as in the case of the Ni-W comparison, to obtain the difference in Δf 's between the $Zn^{66}-Pt^{198}$ and $Cu^{65}-Pt^{195}$ doublets. This difference is found on 25 photographs to be 0.20 ± 0.03 , and when combined with the present results for the Cu-Pt doublet gives for $Pt^{198}-Zn^{66}$ the value $\Delta f = 9.43 \pm 0.04$. In the course of other work zinc-contaminated platinum electrodes were used, and two fair simultaneous photographs of the $Zn^{66}-Pt^{198}$ doublet were taken. The packing fraction differences measured from these are 9.58 and 9.64.

To photograph the $Zn^{64}-Pt^{192}$ doublet a brass and a platinum electrode were used for the first 20 seconds, two platinum electrodes were used for the following hour, and brass and platinum electrodes used for an additional 20 seconds. A typical exposure is shown in spectrum 5 of Fig. 2. On five exposures the difference between the $Pt^{192}-Zn^{64}$ and $Pt^{195}-Cu^{65}$ packing fraction differences is found to be 0.01 ± 0.02 . This leads to a value for the $Pt^{192}-Zn^{64}$ separation of $\Delta f = 9.24 \pm 0.03$. The five consecutive exposures yield values between 9.20 and 9.53, with a mean of 9.40 ± 0.04 .

For these Zn-Pt comparisons the $Pt^{192}-Pt^{194}$ and $Pt^{196}-Pt^{198}$ spacings served as mass scales.

9. MASSES OF THE ISOBARS Zn^{64} AND Ni^{64}

Professor Dempster²⁰ has recently measured the mass of Zn^{64} , obtaining a packing fraction of -7.68 , using the $O^{16}-Zn^{64}$ doublet. K. Ogata,⁹ using the $C_5^{12}H_4^1-Zn^{64}$ doublet has obtained a value of -7.24 ± 0.10 . Shaw,¹² in measuring the mass of the isobar, Ni^{64} , using the $C_4^{12}C^{13}H_3-Ni^{64}$ doublet, has found $f = -8.62 \pm 0.08$,

while T. Okuda *et al.*,²¹ using the $C_5^{12}H_4-Ni^{64}$ doublet, have obtained -8.22 ± 0.09 . These results suggest that the packing fraction of Ni^{64} is about one unit smaller than Zn^{64} .

Three poor $O^{16}-Zn^{64}$ doublets have been photographed in this laboratory and give packing fractions for Zn^{64} of -8.00 , -7.85 and -7.98 . These doublets are poor in the respect that the Zn lines were faint; $Zn^{64}-Zn^{66}$ served as the mass scale. It is planned to improve these doublets, but it is interesting to note that these preliminary attempts suggest a lower packing fraction than either Dempster or Ogata found. Some other local work bears on the mass difference between these isobars. The $Ni^{64}-Pt^{192}$ doublet was photographed consecutively before the limitations of that method were fully realized. The measurements are thought to be reliable enough to indicate that Δf for the $Ni^{64}-Pt^{192}$ doublet is not much different than for the $Zn^{64}-Pt^{192}$ doublet. They are probably within 0.25 of one another.

It is pertinent to note, as Flügge and Mattauch²² have pointed out, that there are disintegration data available which may be used to check the $Zn^{64}-Ni^{64}$ mass difference. Cu^{64} emits electrons to form Zn^{64} and, at the same time, emits positrons to form Ni^{64} . Since both these activities have the same half-life, they are assumed to start from the same state of Cu^{64} . Assuming the negatron and positron energies to be 0.571 Mev and 0.657 Mev respectively, as given by Cook and Langer,²³ one can compute the packing fraction of Ni^{64} to be 0.19 smaller than that of Zn^{64} . It is hoped that it may soon be possible to reconcile mass spectrographic values with this accurately determined mass difference.

It is most desirable that further disintegration experiments be done in the Ni-Cu-Zn region with a view to determining accurate mass differences between adjacent or nearly adjacent isotopes and elements. Such fine structure data would be invaluable as a check on certain mass spectrographic conclusions, viz. the $Ni^{64}-Zn^{64}$ case, and would provide additional springboards for mass comparisons involving singly and multiply charged ions.

10. DISCUSSION OF RESULTS

It is gratifying to note that the present packing fractions for Ni^{58} and Ni^{60} of -8.09 ± 0.05 and -8.54 ± 0.02 are in substantial agreement with Shaw's recent values of -8.29 ± 0.07 and -8.69 ± 0.08 . It is, perhaps, significant that they are not as low. This agreement, plus the present value of -8.52 ± 0.05 for Fe^{56} , supports the view that the minimum in the packing fraction curve has a value of approximately -8.5 , or possibly lower. This lowering of the minimum results, through the Ni-W, Cu-Pt and Zn-Pt comparisons, in a lowering and steepening of the upper end of the curve in the W-Pt region. This steepening may be inter-

²¹ Okuda, Ogata, Kuroda, Sima, and Shindo, Phys. Rev. **59**, 104 (1941).

²² S. Flügge and J. Mattauch, Physik. Zeits. **44**, 181 (1943).

²³ C. S. Cook and L. M. Langer, Phys. Rev. **73**, 601 (1948).

²⁰ A. J. Dempster, Phys. Rev. **74**, 1225 (1948).

preted as supporting Feenberg's suggestion that the plateau which Dempster had drawn in the region 180-210 should be shifted to the region 108-124.

A detailed discussion of the effect on the packing fraction curve of the present measurements and others in progress will be given in a later paper.

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Spectroscopic Isotope Shift and Nuclear Polarization*

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Staggering of term values of odd isotopes with respect to those of the even ones is discussed. The validity of the static picture of nuclei as applied to their interaction with electrons is examined. It is found that the partial excitation of nuclei by atomic electrons results in polarization effects which lower the energy by amounts comparable to the observed irregularities and staggering. Correlations of observed shifts with the formation of stable shells are also discussed in a tentative way.

NOTATION

Ψ = wave function of nucleus and atomic electrons or electron.
 N_i = nuclear functions; N_0 = nuclear ground state; N_1 = nuclear perturbing state.
 $H = H^N + H^e + H'$ = Hamiltonian of the whole system.
 E_i^N = energy of nuclear level.
 E = total energy.
 $E_i = E - E_i^N$.
 $(r, s) \dots$ Cartesian and spin coordinates of electrons taken collectively.
 φ_i defined by $\Psi = \sum_i N_i \varphi_i(r, s)$.
 $\psi = \varphi_0, \varphi = \varphi_1, H_{ij} = (N_i, H' N_j)$.
 Operators: $H_0 = H^e + H_{00}'$, $H_1 = H^e + H_{11}'$.
 (f, g) = radial functions for ψ .
 (f_φ, g_φ) = radial functions for φ .
 $G = rg, G_\varphi = rg_\varphi, \chi = \left(\frac{G}{G_\varphi}\right)$.
 $-U$ = potential energy of electron inside the nucleus (approximated by a constant).
 $\hat{E}_0 = E_0 + U, \hat{E}_1 = E_1 + U; a$ = nuclear radius.
 $\gamma = f/g, \gamma_\varphi = g_\varphi/g_\varphi$.
 $V = H_{01}'$ (approximated by a constant).
 θ defined by $-2V/[(E_0 - E_1)^2 + 4V^2]^{\frac{1}{2}} = \sin\theta$.
 k_1, k_2 = the two possible values of $2\pi \times$ wave number for χ inside nucleus; values of k_1, k_2 are obtainable from Eq. (3.6).
 $z_1 = k_1 a$.
 $z_2 = k_2 a$.
 ξ_1, ξ_2 are defined by Eq. (3.2).
 $a' = amc/\hbar, \gamma = Z\alpha^2/\hbar c$.
 $\rho = (1 - \gamma^2)^{\frac{1}{2}}$.
 $\Delta(\delta y) = y_{a+\delta a}(a + \delta a) - y_a(a + \delta a)$.
 A = mass number.
 $\delta_e E$ = change in the electron's energy $\delta_e E$ caused by $A \rightarrow A + \delta A$.
 $s = \delta_e E / \delta U$.
 \mathfrak{N} defined by Eq. (6.5).
 κ_0 defined by Eq. (6.7); κ_0 = value of k_1 for $V=0$.
 κ defined by Eq. (7).
 n = principal quantum number.
 δ = quantum defect.
 F = relativistic correction factor for electron density at nucleus.
 \mathcal{R} = ratio of electron density at nucleus to that for a free electron.

p = momentum of electron in units mc .

$C(E)$ coefficient of lowest power of r in formula for linear density of s electron for unit linear density at $r = \infty$.

$S(r)$ = wave function of s nucleon in ground state.

z_N = charge of nuclear particle interacting with electron.

I. INTRODUCTION

It is usually supposed that the hyperfine structure of spectroscopic terms can be understood sufficiently well by considering only the static features of the nucleus. A marked exception has been pointed out by A. Bohr who found that the deuteron has to be considered in terms of its constituent parts rather than as a static system. Conditions in the deuteron are somewhat exceptional because the whole nuclear charge is carried by the proton, while in heavier nuclei the charge on any one of the nuclear protons is a small fraction of the whole. The centering of the electronic wave function on a proton is not likely to be as important in these cases. It appears, nevertheless, that the static picture is not necessarily a good one and may be inadequate in discussions of isotopic displacements of spectroscopic terms. In the usual theory¹ of these displacements the change in nuclear radius which is held responsible for the effect is only a small fraction ($\sim 1/600$) of the whole radius. The change in potential energy between the electron and the nucleus is correspondingly small in comparison with the whole deviation from Coulomb energy which is expected from customary nuclear models. It would not be too surprising, therefore, if other effects than changes in the nuclear radius were found to be important. One such effect has been suggested by Brix and Kopfermann² in connection with

¹ G. Racah, *Nature* **129**, 723 (1932); J. E. Rosenthal and G. Breit, *Phys. Rev.* **41**, 459 (1932); G. Breit, *Phys. Rev.* **42**, 348 (1932).

² P. Brix and H. Kopfermann, *Zeits. f. Physik* **126**, 344 (1949).

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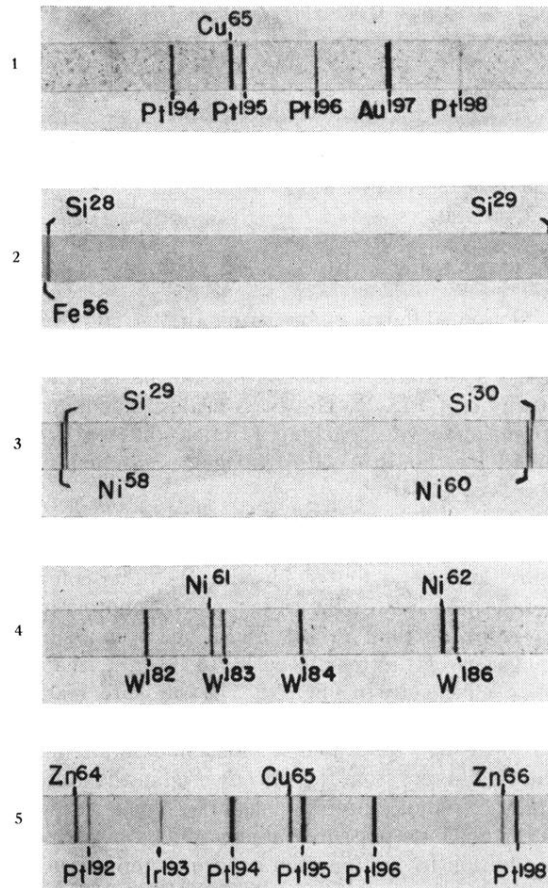


FIG. 2. Spectrum 1: A typical Cu^{65} - Pt^{195} doublet used in studying the effect of pressure on doublet spacing. Spectrum 2: A typical Si^{28} - Fe^{56} doublet used in the silicon-iron comparison. Spectrum 3: Representative Si^{29} - Ni^{58} and Si^{30} - Ni^{60} doublets used in the silicon-nickel comparison. Spectrum 4: Sample Ni^{61} - W^{183} and Ni^{62} - W^{186} doublets. Spectrum 5: Representative Zn^{64} - Pt^{192} , Cu^{65} - Pt^{195} , and Zn^{66} - Pt^{198} doublets used in the zinc-platinum comparison. Magnification $8\times$.