resonance. The result is the dashed curve shown in Fig. 5. It can be seen that the experimental yield points suggest that this perhaps overestimates the meson rise in the yield by about a factor of two. In any case, the integrated cross section for the $F^{19}(\gamma,2p)N^{17}$ reaction up to 320 Mev should probably be increased to at least 3.3 ± 0.4 Mev-millibarns. The integral of the $B^{11}(\gamma,2p)Li^{9}$ cross section up to 320 Mev has the value 2.0 ± 0.3 Mev-millibarns. These errors are the rms deviations in the cross sections allowed by the errors in the activation yield points.

The $(\gamma,3p)$ cross section in C^{12} shown in Fig. 9 is in qualitative agreement with the measurements of similar reactions obtained by Halpern *et al.*[1] and Reagan.[2] The cross-section curve indicates that most of the cross section lies above 100 Mev. This is contrary to the assertion of Reagan[3] that the reaction excites like $F^{19}(\gamma,2p)N^{17}$. The source of this discrepancy is not clear. The cross section integrated to 320 Mev has the value 0.31 ± 0.05 Mev-millibarn.

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Atomic Masses from Phosphorus through Manganese*

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Atomic masses of all the stable isotopes of the elements from phosphorus through manganese have been measured with the large double-focusing mass spectrometer at this laboratory.

The comparison with previous mass spectroscopic results presents a varying pattern of agreement and disagreement. The agreement of the present mass measurements with results from microwave spectroscopy is, in general, good. The present masses agree much better with Q-value determinations than do previous masses. The remaining differences appear to be systematic. It would appear to be symptomatic of the discrepancies that in all cases, 10 in number, in which a (p,α) Q-value can be predicted from the present measured masses, the measured Q-value is less than the predicted value.

The present paper includes a tabulation of masses of unstable nuclei. In addition, tables and plots of nucleon separation and total nucleon pairing energies for this mass region are included.

INTRODUCTION

RECENT measurements of atomic masses at this laboratory using a double-focusing mass spectrometer have covered the regions from boron through silicon[1,2] and from iron through zinc.[3] The present work fills in the gap between these previous sets of measurements.

Most of the masses in this region have been determined before, both mass-spectroscopically and by calculations based on Q-values. Certain mass ratios have been determined by microwave spectroscopy. However, the agreement between mass-spectroscopic masses and Q-value masses has not been good in a number of cases. In addition, it would seem that a large block of connected mass data would be of the greatest value in any study of the systematics of nuclear masses as well as in a search for systematic errors in the mass-spectroscopic or Q-value masses. For these reasons it has seemed desirable to undertake the measurements reported in the present paper.

The masses measured include S^{36}, which had been determined previously only by microwave spectroscopy, and Ca^{46}, which had never been measured.

MEASUREMENTS

The mass spectrometer and the method of measurement of the mass doublets have been described in some detail in other reports.[1] The enriched KCl used in the potassium measurements was obtained from the Oak Ridge National Laboratory and had the following isotopic abundances: K^{39}, 63.1%; K^{40}, 7.8%; K^{41}, 29.2%. Enriched argon available at this laboratory was used for the measurements of A^{36} and A^{38}. All other measurements were made using samples having the natural abundances of isotopes.

The Ti^+, V^+, and Cr^+ ions were obtained, respectively, from the vapor of $TiCl_4$, $VOCl_3$, and CrO_2Cl_2. Because of the rather high reactivity of these liquids, a greaseless leak system was required. The adjustable leak used was simply a commercial Monel vacuum

* Research supported by the joint program of the U. S. Atomic Energy Commission and the Office of Naval Research.
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[1] Quisenberry, Scolman, and Nier, Phys. Rev. **102**, 1071 (1956).
[2] Scolman, Quisenberry, and Nier, Phys. Rev. **102**, 1076 (1956).
[3] Quisenberry, Scolman, and Nier, Phys. Rev. **104**, 461 (1956).

valve (Hoke 413). The PH^+ ions were obtained from phosphine gas, PH_3.

The technique for obtaining ions from solids has been changed since the previous measurements were made. The present method uses a small Nichrome box, heated by direct electrical conduction, which encloses the region in which the ions are formed by electron impact. Solid samples placed in the box are vaporized and then ionized by the electron beam. The advantage of this method is that the density of vapor from the solid is nearly uniform within the box, as is the density of the comparison gas. Thus, the spatial distributions of the beams of ions from the solid vapor and from the gas are more nearly the same than was the case previously.[2,3] The present scheme eliminates many of the difficulties experienced in the past in obtaining reproducible measurements using ions from solids. In addition, it provides greater intensity.

It proved to be impossible to get sufficiently reproducible results for the C_3-A^{36} and $C_3H_2-A^{38}$ doublets.[4] The difficulty with the C_3-A^{36} doublet has been mentioned previously.[5] The reason for the difficulty is not understood at present. The masses of A^{36} and A^{38} were finally determined from the doublets $HCl^{35}-A^{36}$ and $HCl^{37}-A^{38}$, which gave good results.

RESULTS

The experimental mass-doublet differences are given in Table I, along with other recent measurements of these doublets. The errors are the square root of the sum of the squares of the errors resulting from the uncertainties in resistance calibration and the standard error of the mean of the runs taken. (Throughout this paper each error listed refers to the last significant figure of the particular result, unless otherwise noted.) For a further discussion of the errors, see Quisenberry *et al.*[5]

The value for $O_2-P^{31}H$ agrees well with the other results. The O_2-S doublet is discussed elsewhere.[5] The values for $C_4H-S^{33}O$ and $C_4H_2-S^{34}O$ disagree with the previous Minnesota values[6] by about two of the previous errors or by 50 of the present errors. It will be seen that the present values agree much better with Q-value measurements.

The present value for $C_3H_4-A^{40}$ is in very good agreement with the more recent previous Minnesota result[1] and with that of Ogata and Matsuda.[7] The early Minnesota result[8] is subject to question because an intense $C_2C^{13}H_3$ satellite necessitated a very large correction to the position of the C_3H_4 peak. In the present measurements, this satellite is completely resolved. Measurement of the mass-40 isobars also was made at Minnesota using a C_2O reference peak[9] but, as Wapstra[10] has pointed out, the C_2O peak is subject to suspicion. Similar comments apply in the case of the disagreement between the present result for $C_3H_4-A^{40}$ and the previous Minnesota result. The present result for $C_3H_4-A^{40}$ also disagrees rather strikingly with the result of Engler and Hintenberger.[11]

TABLE I. Measured mass differences. C, H, and S refer to the isotopes C^{12}, H^1, and S^{32}, respectively.

Doublet	Number of runs	Present results mMU	Other measurements mMU	Reference
$O_2-P^{31}H$	10	8.242 3± 6	8.249 ±30	a
			8.245 ±12	b
O_2-S	15	17.762 3±11	17.716 ±20	a
			17.764 ± 7	c
			17.725 ± 8	d
			17.761 6±24	e
			17.759 9± 9	f
			(17.761 2± 9)	g
$C_4H-S^{33}O$	10	41.460 2±15	41.385 ±46	c
$C_4H_2-S^{34}O$	10	52.988 9±15	52.900 ±40	c
$C_4H_4-S^{36}O$	10	69.317 5±35		
$C_5H_{10}-Cl_2^{35}$	10	140.585 0±34		
$C_6H_2-Cl_2^{37}$	10	83.869 2±23		
$HCl^{35}-A^{36}$	10	9.134 6± 9		
$HCl^{37}-A^{38}$	10	11.000 1±10		
$C_3H_4-A^{40}$	11	68.934 6±11	68.877 ±35	h
			68.937 ±28	d
			69.057 ±41	i
			68.934 4±13	f
$C_3H_3-K^{39}$	10	59.781 9±15	59.905 ±26	c
			59.762 ±20	j
$C_3H_4-K^{40}$	10	67.317 8±21		
$C_3H_5-K^{41}$	10	77.316 7±19	77.361 ±33	c
			77.331 ±20	j
$C_3H_4-Ca^{40}$	12	68.734 1±15	68.539 ±46	h
$C_3H_6-Ca^{42}$	14	88.350 0±22	88.247 ±34	c
$C_3H_7-Ca^{43}$	16	96.018 6±26	96.040 ±52	c
CO_2-Ca^{44}	13	34.344 2±24	34.607 ±59	c
CSH_2-Ca^{46}	6	34.046 2±39		
C_4-Ca^{48}	13	47.496 4±55	47.59 ±10	c
$CSH-Sc^{45}$	15	23.987 3±18		
CSH_2-Ti^{46}	11	35.102 6±14	35.40 ± 4	k
CSH_3-Ti^{47}	12	43.803 5±30	43.83 ± 9	k
$SO-Ti^{48}$	10	19.047 6±12		
C_4H-Ti^{49}	10	59.978 1±15	59.93 ± 5	k
$C_4H_2-Ti^{50}$	10	70.883 9±18	70.892 ±27	k
			70.927 ±27	l
$C_4H_2-V^{50}$	10	68.507 6±15	68.36 ±12	l
$C_4H_3-V^{51}$	10	79.522 3±18	79.28 ± 5	k
$C_4H_2-Cr^{50}$	10	69.621 8±18	69.56 ± 6	k
			69.634 ±46	l
$C_4H_4-Cr^{52}$	12	90.816 5±17	90.88 ± 9	k
$C_4H_5-Cr^{53}$	10	98.506 2±21	98.38 ± 8	k
$C_4H_6-Cr^{54}$	10	108.109 9±23	107.9 ± 2	k
$C_4H_7-Mn^{55}$	12	116.754 7±22	116.58 ±11	k

[a] H. Ewald, Z. Naturforsch. **6a**, 293 (1951).
[b] K. Ogata and H. Matsuda, Phys. Rev. **89**, 333 (1953).
[c] See reference 6.
[d] See reference 7.
[e] L. G. Smith, Third Annual Meeting, Committee E-14, American Society for Testing Materials, 1955 (unpublished).
[f] See reference 1.
[g] Value adopted in reference 5.
[h] See reference 8.
[i] See reference 11.
[j] H. Liebl and H. Ewald, Z. Naturforsch. **11a**, 406 (1956).
[k] Collins, Nier, and Johnson, Phys. Rev. **86**, 408 (1952).
[l] W. H. Johnson, Jr., Phys. Rev. **87**, 166 (1952).

[4] Throughout this paper C, H, S, and O refer to C^{12}, H^1, S^{32}, and O^{16}, respectively.
[5] Quisenberry, Giese, and Benson, Phys. Rev. **107**, 1664 (1957).
[6] Collins, Nier, and Johnson, Phys. Rev. **84**, 717 (1951).
[7] K. Ogata and H. Matsuda, Phys. Rev. **89**, 27 (1953).
[8] A. O. Nier and T. R. Roberts, Phys. Rev. **81**, 507 (1951).
[9] W. H. Johnson, Jr., Phys. Rev. **88**, 1213 (1952).
[10] A. H. Wapstra, Physica **21**, 385 (1955).
[11] A. Engler and H. Hintenberger, Helv. Phys. Acta **26**, 657 (1953).

TABLE II. Atomic masses.

Isotope	Mass[a] amu	Error μMU	Isotope	Mass[a] amu	Error μMU
P^{31}	30.983 612 6	0.6	Ca^{44}	43.969 471 4	2.4
S^{32}	31.982 238 8	0.9	Ca^{46}	45.968 298 4	4.0
S^{33}	32.981 947 3	2.1	Ca^{48}	47.967 776 6	5.7
S^{34}	33.978 663 5	2.1	Sc^{45}	44.970 212 2	2.1
S^{36}	35.978 525 3	3.7	Ti^{46}	45.967 242 0	1.8
Cl^{35}	34.979 972 0	1.9	Ti^{47}	46.966 686 2	3.2
Cl^{37}	36.977 657 3	1.6	Ti^{48}	47.963 191 2	1.6
A^{36}	35.978 982 5	2.1	Ti^{49}	48.963 429 4	2.1
A^{38}	37.974 802 3	1.9	Ti^{50}	49.960 668 7	2.3
A^{40}	39.975 092 6	1.4	V^{50}	49.963 045 0	2.1
K^{39}	38.976 100 2	1.8	V^{51}	50.960 175 4	2.3
K^{40}	39.976 709 4	2.3	Cr^{50}	49.961 930 8	2.3
K^{41}	40.974 855 6	2.1	Cr^{52}	51.957 026 3	2.1
Ca^{40}	39.975 293 1	1.7	Cr^{53}	52.957 481 7	2.5
Ca^{42}	41.971 967 4	2.4	Cr^{54}	53.956 023 1	2.6
Ca^{43}	42.972 443 9	2.8	Mn^{55}	54.955 523 4	2.6

[a] Masses are based on the doublet values of Table I and on $CH_4-O=(36.3961\pm5)$ mMU, $32-S=(17.7612\pm9)$ mMU, and $C-12=(3.8156\pm4)$ mMU. See reference 5.

The agreement of the present results for $C_3H_3-K^{39}$ and $C_3H_5-K^{41}$ with the previous Minnesota values[6] is not very good, but the present results do agree well with the recent measurements of Liebl and Ewald.[12]

As for the remaining doublets, the only direct comparison possible is with previous Minnesota measurements. The agreement is very good in some cases, and rather poor in other cases. It should be pointed out that the doublets involving titanium, vanadium, and chromium have been measured in the present work using mass peaks obtained from gases. In these previous measurements, solid samples were used. Solid samples were employed for the remainder of the present measurements using the improved technique mentioned above.

The final atomic masses are listed in Table II. These are based on the secondary standard masses of

$$H^1=1.008\ 145\ 1\pm2,\quad C^{12}=12.003\ 815\ 6\pm4,$$

and

$$S^{32}=31.982\ 238\ 8\pm9.^5$$

The errors given are the square root of the sum of the squares of the doublet error, Table I, and the error in the mass of the reference peak.

COMPARISON WITH THE RESULTS OBTAINED FROM MICROWAVE SPECTROSCOPY

Certain mass ratios may be measured by using the techniques of microwave spectroscopy. The review article by Geschwind *et al.*[13] gives an excellent summary of the method.

Table III gives comparisons between mass ratios calculated from the present mass measurements and ratios from microwave spectroscopy. The agreement is good except for the case of the present Cl^{35}/Cl^{37} ratio, which disagrees with one microwave value[13] by three times the error quoted on that measurement. That particular disagreement is 70 times the error of the ratio calculated from the present results, however.

The only conclusion drawn from these comparisons is that the generally good agreement suggests that the procedures used in calculating mass ratios from microwave data are correct; the precision of the microwave results is not sufficient to either verify or refute the present mass measurements.

COMPARISON WITH MASSES CALCULATED FROM NUCLEAR REACTION *Q*-VALUES

Most of the calculations of atomic masses from *Q*-values concentrate on the region below mass 36. Two such calculations, however, include enough masses in the region covered in this work to permit useful comparisons. One of these is the extensive study of Wapstra,[10] and the other is a recent analysis by Endt, Buechner, Braams, Paris, and Sperduto.[14]

At the time Wapstra published his results, the nuclear data were too incomplete in the region above mass 33 to permit calculation of an extended mass table using reaction data only. Thus Wapstra was obliged to turn to mass-spectroscopic data or to data from microwave spectroscopy, and in a number of cases he was forced to make choices between sets of experimental data which were inconsistent. Recently, a number of key reactions in this region have been measured precisely, so that it has been possible for Endt *et al.* to calculate a mass table extending from mass 32 to 45 using only nuclear reactions. In addition, Endt *et al.* were able to restrict their analysis to include only reactions having an error of 20 kev or less. This restriction eliminated the less precise range and pulse-height measurements.

Table IV displays the comparison between mass excesses from the present measurements and mass

TABLE III. Mass ratios computed from the present measurements compared with results from microwave spectroscopy.

Ratio	Value computed from present results	Value from microwave measurements	Reference
S^{32}/S^{33}	0.969 689 22± 7	0.969 690 9±32	a
S^{32}/S^{34}	0.941 244 75± 7	0.941 246 2±22	a
Cl^{35}/Cl^{37}	0.945 975 88± 6	0.945 980 1±50	b
		0.945 977 5±40	c
		0.945 978 1±30	d
		0.945 980 3±15	e
K^{39}/K^{41}	0.951 219 95± 6	0.951 225 0±70	f
		0.951 218 9±15	e
$(S^{33}-S^{32})/(S^{34}-S^{32})$	0.500 749 4 ±10	0.500 714 ±30	g
$(S^{36}-S^{32})/(S^{36}-S^{34})$	1.998 281 3 ±50	1.998 320 ±30	h

[a] R. C. Mockler and G. R. Bird, Phys. Rev. **98**, 1317 (1955).
[b] Townes, Merritt, and Wright, Phys. Rev. **73**, 1334 (1948).
[c] Gilbert, Roberts, and Griswold, Phys. Rev. **76**, 1723 (1949).
[d] Honig, Stitch, and Mandel, Phys. Rev. **92**, 901 (1953).
[e] See reference 14.
[f] Honig, Mandel, Stitch, and Townes, Phys. Rev. **96**, 629 (1954).
[g] S. Geschwind and G. R. Gunther-Mohr, Phys. Rev. **81**, 882 (1951).
[h] W. A. Hardy, as quoted in reference 14.

[12] H. Liebl and H. Ewald, Z. Naturforsch. **11a**, 406 (1956).
[13] Geschwind, Gunther-Mohr, and Townes, Revs. Modern Phys. **26**, 444 (1954).
[14] Endt, Buechner, Braams, Paris, and Sperduto, Phys. Rev. **105**, 1002 (1957).

TABLE IV. Mass excesses compared with values from nuclear reaction Q-values.

Isotope	Present results mMU	M.I.T.[a] mMU	Diff. μMU	Wapstra[b] mMU	Diff. μMU
P^{31}	−16.387 4± 6			−16.439± 24	+52± 24
S^{32}	−17.761 2± 9			−17.804± 26	+43± 26
S^{33}	−18.052 7±22	−18.059± 9	+6± 9	−18.111± 30	+58± 30
S^{34}	−21.336 5±22	−21.337±19	0±19	−21.360± 50	+23± 50
S^{36}	−21.474 7±40			−21.560±120	+85±120
Cl^{35}	−20.028 0±22	−20.036± 9	+8± 9	−20.095± 35	+67± 35
Cl^{37}	−22.342 7±17	−22.363±16	+20±16	−22.460± 45	+117± 45
A^{36}	−21.017 5±24	−21.032±21	+14±21	−21.079± 40	+61± 40
A^{38}	−25.197 7±20	−25.209±37	+11±37	−25.210± 50	+12± 50
A^{40}	−24.907 4±19			−24.950± 50	+43± 50
K^{39}	−23.899 8±20	−23.926±23	+26±23	−23.963± 70	+63± 70
K^{40}	−23.290 6±26	−23.312+24	+21±24	−23.347± 60	+56± 60
K^{41}	−25.144 4±25	−25.183±33	+39±33	−25.240± 60	+96± 60
Ca^{40}	−24.706 9±21	−24.728±28	+21±28	−24.770± 60	+63± 60
Ca^{42}	−28.032 6±28	−28.068±24	+35±24	−28.110± 60	+77± 60
Ca^{43}	−27.556 1±32	−27.602+27	+46±27	−27.650± 80	+94± 80
Ca^{44}	−30.528 6±24	−30.585±30	+56±30	−30.660± 80	+131± 80
Ca^{46}	−31.701 6±40				
Ca^{48}	−32.234 0+57			−32.300±200	+66±200
Sc^{45}	−29.787 8±22	−29.837±33	+49±33	−29.925± 80	+137± 80
Ti^{46}	−32.758 0±19			−33.046± 80	+288± 80
Ti^{47}	−33.313 8±33			−33.500± 80	+186± 80
Ti^{48}	−36.808 8±16			−36.880± 80	+71± 80
Ti^{49}	−36.570 6±22			−36.610± 80	+39± 80
Ti^{50}	−39.331 3±24			−39.420± 80	+89± 80
V^{50}	−36.955 0±22			−36.880±180	−75±180
V^{51}	−39.824 6±25			−39.960±120	+135±120
Cr^{50}	−38.069 2±24			−38.360±150	+291±150
Cr^{52}	−42.973 7±25			−43.010±130	+36±130
Cr^{53}	−42.518 3±28			−42.540±130	+22±130
Cr^{54}	−43.976 9±30			−43.980±130	+3±130
Mn^{55}	−44.476 6±31			−44.600±150	+123±150

[a] See reference 14.
[b] See reference 10.

excesses given by Wapstra and by Endt *et al.* We shall first compare the present results with those of Wapstra. We note that although the disagreements are very large in many places, the errors are also large. The agreement is within approximately 1 error in 19 cases, and within about 2 errors in all but two cases. In one such case, Cl^{37}, the difference is $+117\pm45$ μMU, and in the remaining case, Ti^{46}, the difference is $+286\pm80$ μMU. If we regard Wapstra's errors as roughly the equivalent of standard errors, then this is satisfactory agreement. However, because his errors were determined by a judgment based on the spread of individual measurements about the final adopted values, it is difficult to decide their relationship to standard errors. Furthermore, the differences are predominantly of one sign; the present masses are generally greater than those calculated by Wapstra. This suggests the presence of systematic errors somewhere in the sets of measurements being compared. The complexity of the input data to Wapstra's calculation makes a more detailed analysis of the comparison with the present results extremely difficult. For this reason, we turn to the comparison with the results of Endt *et al.*

For convenience, the differences between Endt's Q-value results and the present measurements have been plotted as a function of mass number in Fig. 1. The errors shown on the points are the errors in the Q-value masses. The errors in the present measurements are shown by the shaded area centered on the horizontal axis. Since Endt *et al.* used the previous Minnesota value[1] for the mass of S^{32} as their mass standard, we would expect the masses close to mass 32 to agree fairly well with the present results, and we see that they do. Actually, the presently[5] adopted mass of S^{32} is 1.3 μMU smaller than the previous result. Changing the mass standard to this value would have the effect of lowering all the nuclear reaction points in Fig. 1 by

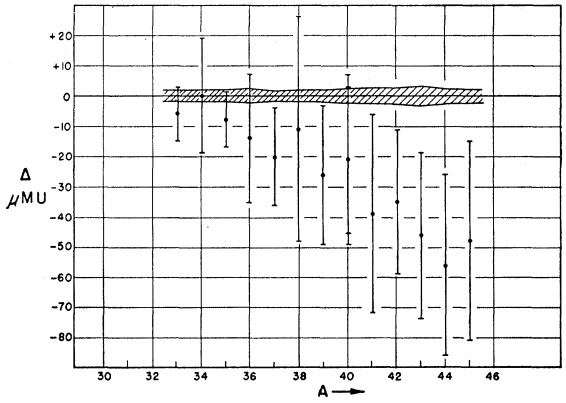

FIG. 1. Differences between Endt's Q-value masses and present mass-spectroscopic results *versus* mass number.

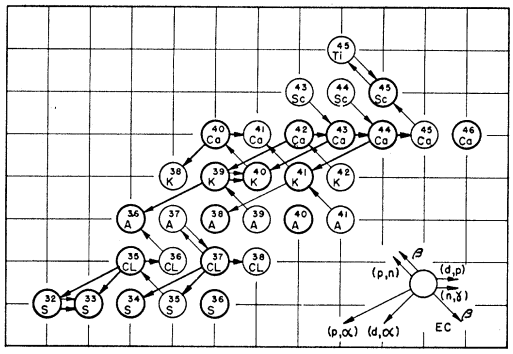

FIG. 2. Reaction scheme used in calculation of Endt's Q-value masses.

1.3 μMU, thus making the agreement somewhat poorer. Looking at the individual points, we see that the maximum difference is 56 μMU with an error of 30 μMU, so the discrepancies are not excessively bad. On the other hand, the points do not scatter symmetrically about zero difference; rather, there seems to be systematic negative trend. This means that the Q-value masses become lower and lower in comparison with the present measurements as one goes further from the standard. This is an effect resembling that which Scolman *et al.*[2] observed in the region from mass 10 to mass 30 in a comparison with the mass values of Wapstra.[15] In their case the standard was O^{16} and a decrease in the Q-value masses relative to the measured masses was observed in both directions from mass 16. The similarity of the two situations may be seen by comparing Fig. 1 of the present paper with Fig. 1 of Scolman *et al.*

In attempting to explain the trend just described, Scolman *et al.* tried two logical adjustments of their data.

(*a*) They tried lowering the mass of the C^{12} secondary standard by 14 μMU to agree with the nuclear value. This improved the agreement in some places but made it worse in other places. It also destroyed the internal consistency of certain data. In the present case, no improvement is noted on trying different values for the C^{12} mass. A change in the mass of H^1 has even poorer results, and furthermore such a change is quite unpalatable because the value used here agrees very well with all recent determinations.[5]

(*b*) They tried changing all mass doublet differences by a constant fractional amount. This also did not result in any general improvement in the agreement. Furthermore, the fractional change required to make an appreciable difference was 50 or 100 times the amount by which one would expect the dispersion to be in error, judging from the accuracy of the hydrogen mass unit doublets (see reference 5). The same conclusion has been reached with the present results.

[15] A. H. Wapstra, Physica **21**, 367 (1955).

No other logical adjustments of the present mass-spectroscopic results suggest themselves at this point, so we will turn to an examination of the Q-value mass calculation. The network of nuclear reactions used in the calculation is shown schematically in Fig. 2.

Almost half of the reaction Q-values in Fig. 2 can be compared directly with values predicted from the present mass-spectroscopic mass values. This comparison is given in Table V, which also includes comparisons with a number of other Q-values not included in the reaction scheme of Fig. 2. The tabulation includes some Q-value results which have become available since Endt *et al.* published their paper. For the calculation of the predicted Q-values, the following

TABLE V. Q-values calculated from present mass values compared with measured Q-values.

Reaction	Calculated value Mev	Measured value Mev	Difference kev	Reference
$P^{31}(p,\alpha)Si^{28}$	1.917±8[a]	1.910± 4	+7± 9	b
$Cl^{35}(p,\alpha)S^{32}$	1.866±3	1.861± 4	+5± 5	c
$Cl^{37}(p,\alpha)S^{34}$	3.040±3	3.026± 5	+14± 6	c
$K^{39}(p,\alpha)A^{36}$	1.293±4	1.283± 8	+10± 9	d
$K^{41}(p,\alpha)A^{38}$	4.027±4	4.002±15	+25±16	e
$Ca^{42}(p,\alpha)K^{39}$	0.129±4	0.118± 7	+11± 8	e
$Ca^{43}(p,\alpha)K^{40}$	0.005±4	−0.014± 8	+19± 9	e
$Ca^{44}(p,\alpha)K^{41}$	−1.036±4	−1.057±10	+21±11	e
$V^{51}(p,\alpha)Ti^{48}$	1.169±3	1.161±10	+8±10	f
$Mn^{55}(p,\alpha)Cr^{52}$	2.578±4	2.568± 8	+10± 9	g
$Cl^{35}(d,\alpha)S^{33}$	8.281±4	8.277±10	+4±11	e
$S^{32}(d,p)S^{33}$	6.415±3	6.415± 6	0± 7	h
$K^{39}(d,p)K^{40}$	5.577±3	5.576±10	+1±10	e
$Ca^{42}(d,p)Ca^{43}$	5.700±4	5.711±10	−11±11	e
$Ca^{43}(d,p)Ca^{44}$	8.912±4	8.913±14	−1±15	e
$S^{32}(n,\gamma)S^{33}$	8.639±3	8.640±20	−1±20	e
$K^{39}(n,\gamma)K^{40}$	7.800±3	7.791± 6	+9± 7	i
$K^{40}(\beta^-)Ca^{40}$	1.319±2	1.323±12	−4±12	e
$Ti^{48}(n,\gamma)Ti^{49}$	8.146±2	8.138± 6	+8± 6	j
$Cr^{53}(n,\gamma)Cr^{54}$	9.726±2	9.716± 7	+10± 7	k
$Cr^{52}(n,\gamma)Cr^{53}$	7.943±2	7.929± 8	+14± 8	k

[a] Si^{28} mass calculated from doublet values reported by Scolman *et al.* (reference 2) and values for C^{12}, H^1, H^2 used in present paper. A check of original data in the above work indicates that the HDO−F^{19} doublet may be in error. This doublet was then omitted from the calculation of the Si^{28} mass. The resulting calculated Q-value for $P^{31}(p,\alpha)Si^{28}$ then becomes 1.917±8 Mev. The value obtained when including the HDO−F^{19} doublet is 1.922±9 Mev.

[b] From a weighted average of 1.909±10 Mev [D. M. Van Patter and W. Whaling, Revs. Modern Phys. **26**, 402 (1954)], 1.911±5 Mev [Van Patter, Swann, Porter, and Mandeville, Phys. Rev. **103**, 656 (1956)], and 1.909±10 Mev [P. M. Endt and C. H. Paris, Phys. Rev. **106**, 764 (1957)].

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[d] From a weighted average of 1.267±20 Mev [Almquist, Clarke and Paul, Phys. Rev. **100**, 1265A (1955)] and 1.286±8 Mev [A. Sperduto and W. W. Buechner, Laboratory of Nuclear Science, Massachusetts Institute of Technology Annual Progress Report MIT-45, 1956] (unpublished), p. 111.

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[i] From a weighted average of 7.789±8 Mev [D. M. Van Patter and W. Whaling, Revs. Modern Phys. **26**, 402 (1954)] and 7.795±10 Mev [Adyasevich, Groschev, Demidov, and Lutsenko, Soviet J. Atomic Energy **1**, 171 (1956); J. Nuclear Energy **3**, 325 (1956)].

[j] From a weighted average of 8.14±2 Mev [Way, King, McGinnis, and Van Lieshout, *Nuclear Level Schemes*, $A=40-A=92$, Atomic Energy Commission Report TID-5300 (U. S. Government Printing Office, Washington, D. C., 1955)], 8.153±10 Mev [Adyasevich, Groschev, and Demidov, Soviet J. Atomic Energy, **1**, 183 (1956); J. Nuclear Energy **3**, 258 (1956)], and 8.132±6 Mev [Manning, Bartholomew, Campion, and Knowles, Bull. Amer. Phys. Soc. Ser. II, **2**, 218 (1957)].

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mass excesses were used:

$$H-1=8.145\,1\pm2 \text{ mMU},^{5}$$
$$n-1=8.986\pm1 \text{ mMU},^{16}$$
$$D-2=14.742\,5\pm5 \text{ mMU},^{17}$$
$$He^{4}-4=3.873\,9\pm26 \text{ mMU}.^{15}$$

One might hope that a comparison such as that in Table V would reveal generally good agreement, with a few outstanding discrepancies. If this were the case, adjustment of these few Q-values would perhaps be justifiable. The comparison shows no such situation. Rather, the calculated Q-values are in generally fair agreement with the measured values. This suggests that the discrepancies of Fig. 1 are caused, not by differences in a few of the Q-values, but rather by the accumulation of differences in many of the Q-values. Further, an analysis of the few closed cycles (sums of Q-values which should add to give zero) shows no closure errors which cast suspicion on any particular Q-values. In short, an adjustment of the Q-value masses of the type done by Scolman *et al.*[2] does not appear to be in order in the present case.

Of the 21 reactions considered in Table V, 10 are of the (p,α) type, and we note that in every case the value calculated from the present results is greater than the measured value. The weighted average of the differences is 10.8 ± 2.5 kev. A comparison between the present mass-spectroscopic results and the seven (p,α) adjusted Q-values used by Endt gives a weighted average difference of 14.9 ± 3.2 kev. Thus, while the inclusion of more recent data lessens the discrepancy, a substantial unexplained difference persists. It is clear from an examination of Fig. 2 that the (p,α) reactions form the "backbone" of a calculation of masses from nuclear reactions in this region. In particular, increasing all (p,α) Q-values by 11 to 15 kev would remove most of the discrepancies shown in Fig. 1, but an adjustment of this sort is not justified. The consistency of the differences between predicted and measured (p,α) Q-values suggests the presence of systematic errors in the mass spectroscopic results or in the Q-value measurements.

The only characteristic which the 10 isotopes appearing on the left sides of the (p,α) reactions in Table V seem to have in common is that they are, respectively, 3 mass units heavier than the isotopes on the right sides. This suggests that if we are to attribute the above discrepancies to the present mass-spectroscopic measurements, we must assume that the mass doublets of Table I have an error which changes roughly by 11 kev as the mass is changed by 3 units. This is quite inconsistent with the results of a number of consistency checks which have been made,[1–3] especially those in which the CH_4-O mass difference was measured at mass 28, 32, and 44.[5]

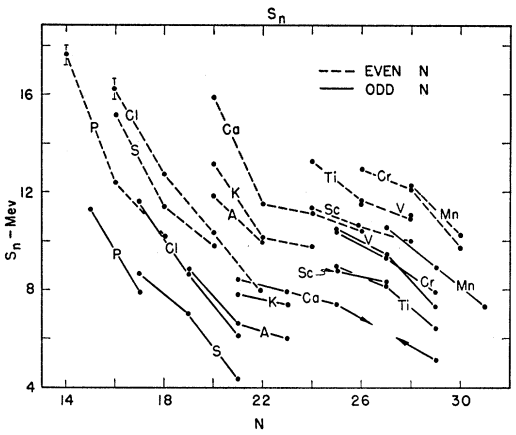

FIG. 3. Separation energy S_n of the last neutron in the nucleus. Data taken from Table VII.

The discrepancies could be caused by the fact that the proton mass or the α-particle mass used was in error by 11 kev, but this seems very unlikely in view of the excellent agreement among recent determinations of these masses.

In conclusion, one may say that the present mass measurements are in fair agreement with the masses from nuclear reaction Q-values. The differences which appear seem to be systematic rather than random. In addition, the (p,α) reaction Q-values seem to be systematically lower than the calculated values in this mass region. No plausible reason for these discrepancies has yet been found.

UNSTABLE ISOTOPE ATOMIC MASSES

A table of unstable-isotope atomic mass excesses in this region, Table VI, has been compiled using the present stable atomic masses as a basis. Table VI gives the mass excesses, in Mev, obtained from the various paths by which the isotope in question can be reached, starting from a stable isotope. The adopted value and its error have been established by a judgment based on the consistency of the separate determinations. A question mark appears in those cases where there are large disagreements and no attempt has been made to make a selection.

NUCLEON INTERACTION ENERGIES

Certain linear combinations of atomic masses are of particular theoretical interest. One of these is the nucleon separation energy, defined as the energy equivalent to that amount of mass which disappears when a nucleon is added to a nucleus of mass $A-1$ to form the nucleus of mass A. These separation energies have been calculated for all nuclei of the elements investigated wherever sufficient mass data exists. The neutron and proton separation energies are listed in Table VII and are plotted in Fig. 3 and Fig. 4, respec-

[16] Computed from the $n-H$ difference of reference 15 and H mass of reference 5.

[17] Computed from the H_2-D doublet of reference 1 and H mass of reference 5.

TABLE VI. Mass excesses of unstable isotopes.

Nuclide	Path	$M-A$ Mev	Reference to Q-value	Adopted $M-A$ Mev
P^{28}	$Si^{28}(p,n)$	+1.0 ± 4	a	+1.0 ± 4
P^{29}	$Si^{28}(d,n)$	−8.13 ± 4	b	−8.348±11
	$(\beta^+)Si^{29}$	−8.348±11	c	
P^{30}	$Al^{27}(\alpha,n)$	$\leqslant$ −11.306± 4	a	−11.305± 9
	$S^{32}(d,\alpha)$	−11.249±13	a	
	$S^{32}(\gamma,d)$	−11.1 ± 2	b	
	$P^{31}(\gamma,n)$	−11.30 ± 5	a	
	$S^{32}(d,\alpha)$	−11.305± 9	d	
	$(\beta^+)Si^{30}$	−11.30 ± 4	e	
P^{32}	$P^{31}(d,p)$	−14.820± 9	b	−14.829± 4
	$P^{31}(n,\gamma)$	−14.83 ± 3	b	
	$(\beta^-)S^{32}$	−14.829± 4	f	
	$Cl^{35}(n,\alpha)$	−14.91 ±11	b	
P^{33}	$(\beta^-)S^{33}$	−16.561± 6	g	−16.561± 6
S^{31}	$(\beta^+)P^{31}$	−9.8 ± 1	g	−9.85 ± 7
	$S^{32}(\gamma,n)$	−9.9 ± 1	b	
S^{35}	$Cl^{35}(n,p)$	−18.39 ± 4	b	−18.482± 3
	$(\beta^-)Cl^{35}$	−18.482± 3	g	
	$Cl^{37}(d,\alpha)$	−18.467±12	b	
	$S^{34}(d,p)$	−18.481±10	h	
S^{37}	$A^{40}(n,\alpha)$	−15.9 ± 1	b	−15.9 ± 1
Cl^{32}	$S^{32}(p,n)$	−3.3 ± 4	b	−3.6 ± 3
	$(\beta^+)S^{32}$	−3.8 ± 4	i	
Cl^{33}	$S^{32}(d,n)$	−11.4	b	−11.239±12
	$(\beta^+)S^{33}$	−11.6 ± 1	g	
	$S^{32}(p,\gamma)$	−11.239±12	a	
Cl^{34}	$P^{31}(\alpha,n)$	−14.3 ± 2	b	−14.5 ± 2
	$(\beta^+)S^{34}$	−14.35 ± 3	g	
	$Cl^{35}(\gamma,n)$	−14.67 ± 4	a	
Cl^{36}	$(\beta^-)A^{36}$	−18.856± 5	g	−18.856± 3
	$(\beta^-)A^{36}$	−18.856± 4	j	
	$Cl^{35}(d,p)$	−18.860± 8	a	
	$Cl^{35}(n,\gamma)$	−18.84 ± 2	a	
	$K^{39}(n,\alpha)$	−18.7 ± 2	a	
Cl^{38}	$Cl^{37}(d,p)$	−18.538± 9	a	−18.538± 9
	$(\beta^-)A^{38}$	−18.65 ± 5	g	
Cl^{39}	$(\beta^-)A^{39}$	−18.26 ± 5	g	−18.24 ± 2
	$(\beta^-)A^{39}$	−18.24 ± 2	k	
	$A^{40}(\gamma,p)$	−20.0 ± 1	b	
A^{35}	$(\beta^+)Cl^{35}$	−13.24 ± 6	g	?
		−12.67 ± 4	l	
A^{37}	$(\epsilon)Cl^{37}$	−19.993± 8	m	−19.990± 2
	$(\epsilon)Cl^{37}$	−19.990± 3	n	
	$Cl^{37}(p,n)$	−19.990± 3	b	
	$A^{36}(d,p)$	−20.01 ± 3	b	
A^{39}	$(\beta^-)K^{39}$	−21.690± 5	g	−21.690± 5
	$A^{40}(\gamma,n)$	−21.71 ±15	a	
A^{41}	$A^{40}(d,p)$	−20.89 ± 3	b	−20.913±12
	$(\beta^-)K^{41}$	−20.81 ± 6	g	
	$(\beta^-)K^{41}$	−20.889±22	o	
	$(\beta^-)K^{41}$	−20.924±10	p	
K^{38}	$Ca^{40}(d,\alpha)$	−17.535±11	a	−17.535±11
	$K^{39}(\gamma,n)$	−17.5 ± 2	b	
	$(\beta^+)A^{38}$	−17.60 ± 3	g	
K^{42}	$K^{41}(d,p)$	−22.39 ±10	b	−22.55 ± 3
	$(\beta^-)Ca^{42}$	−22.54 ± 3	g	
	$(\beta^-)Ca^{42}$	−22.574±28	o	
K^{43}	$(\beta^-)Ca^{43}$	−23.82 ± 1	g	−23.82 ± 1
	$A^{40}(\alpha,p)$	−23.81 ± 3	a	
Ca^{39}	$(\beta^+)K^{39}$	−15.2 ± 2	g	−15.6 ± 1
	$Ca^{40}(\gamma,n)$	−15.6 ± 1	b	
Ca^{41}	$Ca^{40}(d,p)$	−23.003±10	a	−23.003±10
	$K^{41}(p,n)$	−22.97 ± 2	b	
Ca^{45}	$Ca^{44}(d,p)$	−27.471±11	a	−27.480± 3
	$(\beta^-)Sc^{45}$	−27.481± 3	g	
Ca^{49}	$Ca^{48}(d,p)$	−26.778± 8	a	−26.778± 8
Sc^{41}	$Ca^{40}(d,n)$	−17.05 ± 5	a	−17.05 ± 4
	$(\beta^+)Ca^{41}$	−17.04 ± 7	g	
Sc^{43}	$(\beta^+)Ca^{43}$	−23.46 ± 2	g	?
	$Ca^{40}(\alpha,p)$	−27.7 ± 2	b	
Sc^{44}	$(\beta^+)Ca^{44}$	−24.785± 6	o	−24.780± 5
	$(\beta^+)Ca^{44}$	−24.774± 6	q	
	$Sc^{45}(n,2n)$	−25.1 ± 3	b	
Sc^{46}	$(\beta^-)Ti^{46}$	−28.142± 5	g	−28.142± 5
	$Sc^{45}(n,\gamma)$	−28.22 ± 8	b	
	$Sc^{45}(d,p)$	−28.4 ± 3	b	
Sc^{47}	$(\beta^-)Ti^{47}$	−30.420± 4	r	−30.419± 4
	$(\beta^-)Ti^{47}$	−30.410± 6	s	
	$(\beta^-)Ti^{47}$	−30.423± 7	t	
	$(\beta^-)Ti^{47}$	−30.40 ±20	u	
Sc^{48}	$(\beta^-)Ti^{48}$	−30.29 ± 3	g	−30.29 ± 3
Sc^{49}	$(\beta^-)Ti^{49}$	−32.0 ± 1	g	−31.9 ± 1
	$(\beta^-)Ti^{49}$	−32.3 ± 1	v	
	$(\beta^-)Ti^{49}$	−32.00 ± 5	w	
	$Ca^{49}(\beta^-)$	−31.84 ± 6	w	
	$Ca^{49}(\beta^-)$	−31.97 ±12	v	
Ti^{45}	$Sc^{45}(p,n)$	−25.676± 5	a	−25.681± 9
	$(\beta^+)Sc^{45}$	−25.697± 9	o	
	$Ti^{46}(\gamma,n)$	−25.6 ± 2	b	
Ti^{51}	$Ti^{50}(d,p)$	−34.59 ± 7	b	−34.62 ± 3
	$(\beta^-)V^{51}$	−34.63 ± 3	x	
V^{47}	$(\beta^+)Ti^{47}$	−28.14 ± 6	g	−28.11 ± 1
	$(\beta^+)Ti^{47}$	−28.11 ± 1	y	
V^{48}	$(\beta^+)Ti^{48}$	−30.26 ± 2	g	−30.26 ± 2
	$(\beta^+)Ti^{48}$	−30.25 ± 3	z	
V^{49}	$(K)Ti^{49}$	−33.431±11	aa	−33.443± 5
	$Ti^{49}(p,n)$	−33.445± 5	b	
V^{52}	$V^{51}(n,\gamma)$	−36.021± 8	b	−36.017± 8
	$V^{51}(d,p)$	−36.012± 9	b	
Cr^{48}	$(K)V^{48}$	−28.81 ±20	bb	−28.7 ± 2
	$(K)V^{48}$	−28.54 ±20	cc	
Cr^{49}	$(\beta^+)V^{49}$	−30.88 ± 1	g	−30.88 ± 1
	$Cr^{50}(\gamma,n)$	−30.4 ± 2	b	
Cr^{51}	$V^{51}(p,n)$	−36.330± 3	a	−36.329± 3
	$Cr^{52}(\gamma,n)$	−36.58 ±25	b	
	$(K)V^{51}$	−36.326± 6	dd	
	$(K)V^{51}$	−36.35 ± 2	ee	
	$(K)V^{51}$	−36.330±22	ff	
Mn^{51}	$(\beta^+)Cr^{51}$	−33.11 ± 8	g	−33.11 ± 8
Mn^{52}	$(\beta^+)Cr^{52}$	−35.321±18	gg	−35.321±18
Mn^{53}	$Cr^{53}(p,n)$	−38.994± 9	b	−38.994± 9
Mn^{54}	$Cr^{54}(p,n)$	−39.571± 6	a	−39.572± 6
	$Mn^{55}(\gamma,n)$	−39.72 ±14	b	
	$(K)Cr^{54}$	−39.579±21	hh	
Mn^{56}	$Mn^{55}(n,\gamma)$	−40.309± 7	b	−40.315± 4
	$Mn^{55}(d,p)$	−40.37 ±15	b	
	$Mn^{55}(d,p)$	−40.318± 5	ii	

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TABLE VII. Nucleon separation energies for all nuclei where sufficient data enables their calculation.[a]

Isotope	N	S_n [b] (Mev)	S_p [c] (Mev)	Isotope	N	S_n [b] (Mev)	S_p [c] (Mev)
P^{29}	14	17.7 ± 4	2.733±14	Ca^{44}	24	11.135± 4	12.19 ± 1
P^{30}	15	11.324±14	5.579±14	Ca^{45}	25	7.421± 4	
P^{31}	16	12.321± 9	7.282± 7	Ca^{46}	26	10.406± 5	
P^{32}	17	7.937± 4		Ca^{49}	29	5.131±10	
P^{33}	18	8.798± 6		Sc^{41}	20		1.63 ± 4
S^{31}	15		6.16 ± 7	Sc^{44}	23		6.72 ± 1
S^{32}	16	15.06 ± 7	8.865± 2	Sc^{45}	24	11.32 ± 1	6.896± 3
S^{33}	17	8.638± 3	9.565± 5	Sc^{46}	25	8.771± 6	8.246± 6
S^{34}	18	11.425± 3	10.891± 6	Sc^{47}	26	10.644± 6	8.384± 6
S^{35}	19	6.982± 4		Sc^{48}	27	8.24 ± 3	
S^{36}	20	9.882± 5		Sc^{49}	28	10.0 ± 1	9.5 ± 1
S^{37}	21	4.3 ± 1		Ti^{45}	23		8.47 ± 1
Cl^{32}	15		1.3 ± 3	Ti^{46}	24	13.194± 6	10.350± 3
Cl^{33}	16	16.0 ± 3	2.285±12	Ti^{47}	25	8.885± 4	10.464± 6
Cl^{34}	17	11.7 ± 2	5.2 ± 2	Ti^{48}	26	11.622± 4	11.439± 5
Cl^{35}	18	12.5 ± 2	6.366± 3	Ti^{49}	27	8.145± 3	11.35 ± 3
Cl^{36}	19	8.574± 4	7.958± 4	Ti^{50}	28	10.938± 3	12.3 ± 1
Cl^{37}	20	10.316± 4	8.393± 4	Ti^{51}	29	6.36 ± 3	
Cl^{38}	21	6.111± 9	10.2 ± 1	V^{47}	24		5.19 ± 1
Cl^{39}	22	8.07 ± 2		V^{48}	25	10.52 ± 2	6.82 ± 2
A^{36}	18		8.506± 3	V^{49}	26	11.55 ± 2	6.751± 6
A^{37}	19	8.787± 3	8.718± 4	V^{50}	27	9.336± 6	7.942± 3
A^{38}	20	11.840± 3	10.243± 3	V^{51}	28	11.040± 4	8.044± 3
A^{39}	21	6.594± 6	10.731±10	V^{52}	29	7.301± 9	8.98 ± 3
A^{40}	22	9.870± 6	12.53 ± 2	Cr^{48}	24		8.2 ± 2
A^{41}	23	6.088±12		Cr^{49}	25	10.6 ± 2	8.20 ± 2
K^{38}	19		5.129±11	Cr^{50}	26	12.936±10	9.590± 6
K^{39}	20	13.087±11	6.376± 3	Cr^{51}	27	9.248± 4	9.503± 4
K^{40}	21	7.800± 3	7.582± 6	Cr^{52}	28	12.053± 4	10.517± 3
K^{41}	22	10.094± 3	7.805± 3	Cr^{53}	29	7.943± 4	11.159± 9
K^{42}	23	7.50 ± 3	9.22 ± 3	Cr^{54}	30	9.726± 4	
K^{43}	24	9.64 ± 3		Mn^{51}	26		5.25 ± 8
Ca^{39}	19		5.6 ± 1	Mn^{52}	27	10.58 ± 8	6.576±20
Ca^{40}	20	15.8 ± 1	8.336± 3	Mn^{53}	28	12.04 ± 2	6.563± 9
Ca^{41}	21	8.364±10	8.900±10	Mn^{54}	29	8.945±11	7.566± 7
Ca^{42}	22	11.467±10	10.274± 3	Mn^{55}	30	10.209± 7	8.050± 4
Ca^{43}	23	7.924± 4	10.69 ± 3	Mn^{56}	31	7.268± 8	

[a] The calculation is based on the mass excesses of Tables IV and VI, along with a few mass excesses from reference 2, where appropriate.

[b] S_n = neutron separation energy in Mev.
[c] S_p = proton separation energy in Mev.

tively. It is apparent that the variation of separation energy has the same general character as that seen in the iron-zinc region,[3] although the neutron separation energy is seen to be quite large for the lighter elements studied here.

Another concept of interest is that of the total nucleon pairing energy. A neutron added to form a nucleus with even N has a larger separation energy than the previous neutron added to form the nucleus of neutron number $N-1$. This difference in energy is defined as the total neutron pairing energy. The same considerations apply to protons added to give nuclei of

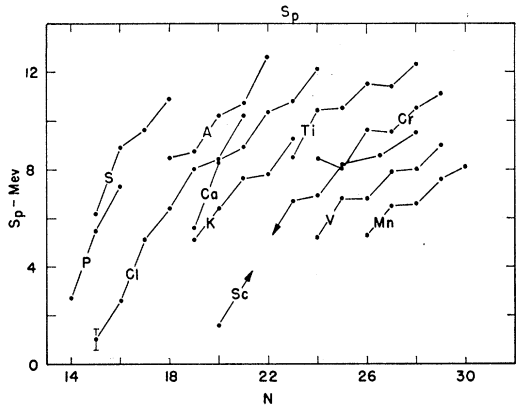

FIG. 4. Separation energy S_p of the last proton in the nucleus. Data taken from Table VII.

TABLE VIII. Total pairing energy P_n of the last pair of neutrons in the listed nuclei.

Isotope	N	P_n (Mev)	Isotope	N	P_n (Mev)
P^{31}	16	0.997±17	Ca^{42}	22	3.103±14
P^{33}	18	0.861± 7	Ca^{44}	24	3.211± 6
			Ca^{46}	26	2.985± 7
S^{34}	18	2.787± 4			
S^{36}	20	2.900± 7	Sc^{47}	26	1.871± 8
			Sc^{49}	28	1.8 ± 1
Cl^{35}	18	0.8 ± 3			
Cl^{37}	20	1.741± 6	Ti^{48}	26	2.737± 6
Cl^{39}	22	1.96 ± 2	Ti^{50}	28	2.794± 4
A^{38}	20	3.053± 4	V^{49}	26	1.03 ± 3
A^{40}	22	3.276± 8	V^{51}	28	1.704± 7
K^{41}	22	2.294± 4	Cr^{50}	26	2.3 ± 2
K^{43}	24	2.14 ± 4	Cr^{52}	28	2.805± 6
			Cr^{54}	30	1.783± 6
			Mn^{53}	28	1.46 ± 8
			Mn^{55}	30	1.264±13

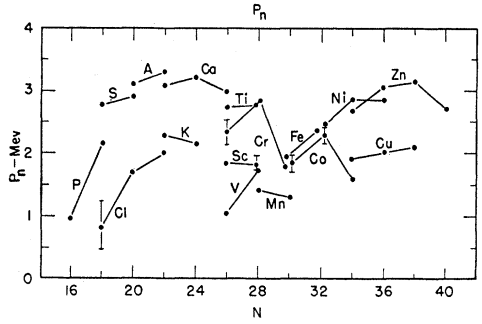

FIG. 5. Pairing energy P_n of the last neutron pair in the nucleus. Data taken from Table VIII.

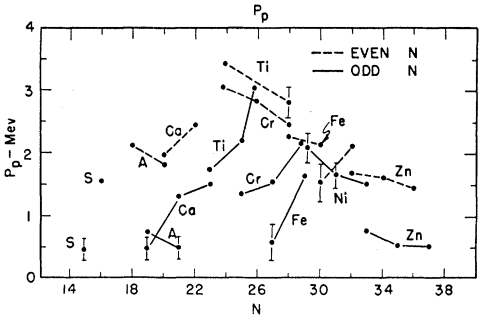

FIG. 6. Pairing energy P_p of the last proton pair in the nucleus. Data taken from Table IX.

even or odd Z, and one thus defines similarily a total proton pairing energy. The total neutron pairing energy has been calculated for all even-N nuclei in the present range of elements wherever sufficient mass data exists. The values are tabulated in Table VIII and are plotted in Fig. 5. Proton pairing energy has also been calculated wherever possible for even-Z nuclei in this region and the results are given in Table IX and plotted in Fig. 6. The neutron and proton pairing-energy values found in the iron-zinc region[3] are included in the figures to help give a clearer picture of the variations present.

It is interesting to note the sharp dip in neutron pairing energy following $N=28$, a magic number, which indicates a change in the strength of the neutron-neutron pair interaction following the filling of a shell. Otherwise pairing energies seem to exhibit no systematic pattern of behavior, as Fig. 6 indicates for the proton case.

TABLE IX. Total pairing energy P_p of the last pair protons in the listed nuclei.

Isotope	N	P_p (Mev)	Isotope	N	P_p (Mev)
S^{31}	15	0.58 ± 7	Ti^{45}	23	1.75 ±2
S^{32}	16	1.583± 7	Ti^{46}	24	3.454±4
			Ti^{47}	25	2.216±8
A^{36}	18	2.140± 4	Ti^{48}	26	3.055±7
A^{37}	19	0.760± 6	Ti^{50}	28	2.8 ±2
A^{38}	20	1.850± 5			
A^{39}	21	0.50 ±10	Cr^{48}	24	3.0 ±2
			Cr^{49}	25	1.38 ±3
Ca^{39}	19	0.50 ±10	Cr^{50}	26	2.839±8
Ca^{40}	20	1.960± 4	Cr^{51}	27	1.561±5
Ca^{41}	21	1.318±12	Cr^{52}	28	2.473±4
Ca^{42}	22	2.469± 4	Cr^{53}	29	2.18 ±3
Ca^{43}	23	1.47 ± 4			

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