Their values disagree with the values of Benson et al. It may be noted that Kerr and Duckworth employed only a part of a large mass spectrometer under construction. The employed part has only single-focusing properties. Also, their quoted errors are much larger than those of Benson et al.

In view of these considerations, the masses for mercury and lead isotopes of Benson et al. have been adopted with a few minor changes. These changes were made to obtain atomic masses consistent with the nuclear values for isotopic mass differences, and also consistent with the adopted values of Table II of the present work. The experimental masses of Benson et al. were in no case changed by more than 30 μmu.

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Gamma Rays from the Proton Bombardment of Natural Silicon*

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The gamma-ray yield curve was observed when thin targets of natural silicon were bombarded with monoergic protons in the energy range of 300 to 1840 kev. In order to take small steps in proton energy, a target potential modulation technique was used. Fifty-five resonances were observed, all but fifteen of which have been observed elsewhere using targets enriched in Si^{29} or Si^{30}. The fifteen resonances at 369, 1096, 1134, 1204, 1290, 1382, 1472, 1484, 1507, 1570, 1598, 1617, 1625, 1630, and 1653 kev are presumed due to the $Si^{28}+p$ reaction.

In an earlier attempt at this laboratory to measure the gamma-ray yield versus proton energy[1] resulting from proton bombardment of natural silicon, it was found that the resonances in the thin-target yield curve were very sharp and extremely small. The agreement of these earlier data with other comparable data[2,3] was generally good but certain discrepancies did exist.

Possible sources of discrepancies seemed to be (1) impurities in targets, (2) the size of steps taken in proton energy, and (3) the statistical accuracy of individual yield points. Detailed checks showed our targets free of contaminants in amounts sufficient to give detectable resonances. Great improvements were desired, however, in counting rates and in the method of taking steps in proton energy. A larger gamma-detector and the energy modulation system developed by Cranberg *et al.*[4] offered attractive improvements.

In the energy modulation system, the potential of the target is swept from 20 kv to −20 kv by a 10-cps "saw-tooth" high-voltage source. A single energy setting of the Van de Graaff is all that is necessary, in principle, to cover a 40 kev range of the yield curve. Correlation of a particular gamma ray with the energy of the proton which caused its emission is done by amplitude modulation of the pulses put out by the single-level, pulse-height discriminator in the gamma detection system. The modulated pulses are then analyzed in a multichannel pulse-height analyzer.

In the present work, protons were accelerated in the University of Kansas Van de Graaff generator, separated from the heavier hydrogen ions, passed through an electrostatic analyzer, and allowed to bombard thin targets. The electrostatic analyzer was a 1-meter radius, 127-degree deflection unit used as a relative instrument. It was calibrated by observation of the gamma resonance at 992-kev proton energy[5] in the aluminum yield curve. Linearity between the voltage across the analyzer gap and the generator voltage was verified by observation of many of the resonances in this same yield curve.

The thin targets were prepared by evaporation onto outgassed tungsten disks in a radio-frequency induction vacuum furnace.[6] Ultra-high purity silicon[7] was used to form targets of several-kev thickness. Several silicon targets, calibration targets, and a viewing disk of quartz were simultaneously mounted in a multiple-target chamber which was so designed that a 3 in.×3 in. NaI(Tl) gamma detector could be placed within $\frac{1}{2}$ inch of the disk being bombarded. A corona-reduction shield surrounded the target chamber.

The method of varying the potential of the target was identical to that developed by Cranberg *et al.* but a somewhat different system of pulse amplitude modu-

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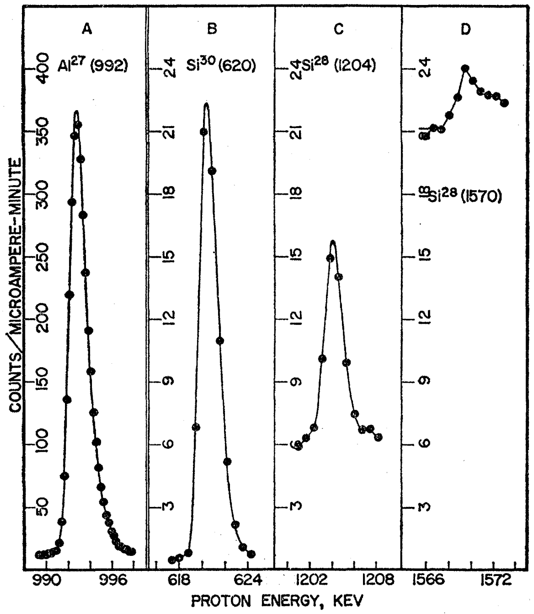

FIG. 1. Part A shows the 992-kev resonance in the aluminum yield curve. It was measured using a 10-kv peak-to-peak target potential modulation. Part B shows the 620-kev resonance due to Si^{30}. Parts C and D show the resonances believed due to Si^{28} at 1204 and 1570 kev. The silicon data were taken using approximately 40-kv peak-to-peak target potential modulation. All the points plotted are the sums of five adjacent channels.

lation was used.[8] The amplitude-modulated pulses were analyzed by a 256-channel analyzer. At least 20 channels (and often more) on each end of the pulse-height distribution were ignored on each run. In the target potential modulation system, it was impossible to avoid some curvature of the sides of the "saw-tooth" potential form and this curvature was most pronounced at the extreme points of the form. Since care was taken that the amplitude-modulation form was almost identical in shape and in phase with the target potential form, such curvature did not introduce error in the correlation of a given gamma ray to a specific proton energy, but it did cause some deviation from linearity in the amount of time spent in each proton energy interval. The amount of deviation was checked by a random count run made with the target potential modulation and pulse amplitude modulation systems functioning but with no protons bombarding the target. The gamma rays in such a run were furnished by a Cs^{137} source and thus were non-time-synchronous with the modulating systems. Random count runs taken many times during the course of the experiment showed that fictitious resonances would not be introduced if data near the ends of the distributions were ignored. During the random-count runs, gamma rays with energy of 600 kev or greater were counted. To avoid 1.43-Mev gamma rays present as background in the laboratory, only gamma rays of greater energy were counted in the silicon runs.

The target potential modulation technique appears to be an excellent one for careful search for sharp resonances of almost any size over a wide range of bombarding energies. Figure 1 shows that details of resonance shape and size are easily obtained by this technique where the resonances are large compared to background, but when the resonance size is not large with respect to the counts per channel between resonances, observation of such details is poor.

To determine the point in the pulse-height distribution corresponding to zero volts on the target, a "marker" was placed upon each distribution as follows. After a run had been made and the data printed, the input to the pulse amplitude modulation system was grounded and more data taken. All these marker pulses were recorded in a narrow band of channels and thus caused a superposed peak in the distribution. In order to evaluate the displacement in proton energy of a given resonance from the marker, sweep calibration runs were made. The calibration was made by observing how much a given resonance was displaced when the Van de Graaff generator voltage was changed a small known amount.

The resonances observed are listed in Table I. The proton energies are believed to be accurate within ±2 kev. Most of the resonances are believed to correspond to resonances seen in work done at other laboratories on enriched Si^{29} and Si^{30} targets.[9–15] The peaks at 369, 1096, 1134, 1204, 1290, 1382, 1472, 1484, 1507, 1570, 1598, 1617, 1625, 1630, and 1653 kev were not seen in the work on the heavier silicon isotopes and thus are presumed due to Si^{28}. As shown in Fig. 1 and in Table I, all the natural silicon resonances were small. The heights and widths of all peaks near the centers of data runs were measured. To minimize nonlinearity corrections, peaks near the ends of runs were not measured for other than proton energy. Peaks were considered superimposed on a base line background and this background was subtracted visually. Target thicknesses were not the same for all runs. Height measurements were arbitrarily normalized to a certain

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TABLE I. Resonances in the gamma yield from natural silicon + p.

E_p (lab) in kev	No. obs.	Mean value of peak counts per μa-min	% dev. from mean	E_p (lab) in kev	No. obs.	Mean value of peak counts per μa-min	% dev. from mean
325^{a-d}	2	0.6	1	1333^{a}	5	1.7	13
369^{e}	2	0.3	34	$1374^{a,i}$	2	1.6	11
$414^{a-c,f,g,d}$	2	3.5	7	1382^{e}	4	3.4	19
$496^{h,g,d}$	2	2.0	12	$1394^{h,i}$	4	7.9	14
$620^{h,g,d}$	2	22.0	3	$1402^{h,i}$	3	13.3	14
$669^{h,g,d}$	2	1.4	12	$1426^{h,i}$	2	4.1	38
$696^{a,f,g}$	3	3.1	20				
$729^{a,c,f,g}$	3	1.1	28	1472^{e}	4	2.0	9
$759^{h,g,d}$	2	2.7	6	$1479^{a,i}$	2	6.2	49
$775^{h,g,d}$	2	7.2	16	1484^{e}	4	7.8	17
$835^{h,g}$	3	2.3	26	$1491^{h,i}$	2	7.0	2
$917^{a,c,g,i}$	2	0.9	27	1507^{e}	5	6.5	28
$942^{h,i}$	2	4.7	28	$1512^{a,i}$	4	8.5	18
$956^{h,g}$	1	0.4	...	$1519^{h,i}$	3	3.0	35
$958^{a,c,g,i}$	1	0.8	...	$1530^{h,i}$	1	3.6	...
$980^{h,g}$	3	4.0	37	1570^{e}	3	1.9	31
$983^{h,g,i}$	4	7.9	39	1598^{e}	3	2.2	11
1096^{e}	3	1.2	54	$1606^{h,i}$	3	1.8	17
$1111^{h,i}$	2	0.9	25	1617^{e}	3	2.2	24
1134^{e}	2	1.0	26	1625^{e}	2	1.9	14
$1176^{h,i}$	3	2.2	7	1630^{e}	1	0.9	...
1204^{e}	4	10.2	5	$1643^{a,i}$	3	1.5	27
$1213^{h,i}$	1	0.6	...	$1653^{e,j}$	2	3.4	42
1290^{e}	2	1.0	2	$1693^{a,i}$	4	2.5	26
$1303^{h,i}$	4	3.0	11	$1700^{h,i}$	2	3.7	3
$1305^{h,i}$	4	5.5	14	$1752^{a,i}$	1	9.8	...
$1307^{a,i}$	3	1.0	32	$1775^{a,i}$	1	9.9	...
$1325^{h,i}$	6	8.4	21	$1833^{h,i}$	1	9.5	...

[a] Resonances also seen in Si^{29} work at other laboratories.
[b] See reference 9.
[c] See reference 10.
[d] See reference 13.
[e] Resonances seen in natural silicon work but not seen in Si^{29} or Si^{30} work and thus presumed due to Si^{28}.
[f] See reference 11.
[g] See reference 12.
[h] Resonances also seen in Si^{30} work at other laboratories.
[i] See reference 14.
[j] See reference 15.

target thickness by comparison of a single peak on different targets. The targets were run quite hot, sometimes a dull red heat. It was found that the yield of a given target decreased with bombarding time. Height measurements were also corrected for this effect. The observed normalized heights are given in Table I along with a percent deviation from the mean value of each height. With the exception of one peak, all widths at half maximum (above the visually subtracted base line) fell within 1.7 to 3.3 kev. Since these data came from unnormalized runs on various thickness targets, it is felt the widths are instrumental rather than fundamental. The mean value of the width of the peak at 1374 kev was 5.1 kev with an average deviation from the mean of 30%.

Note added in proof.—Difficulty with the power supply of the electrostatic analyzer prevented the obtaining of more than one good run of data above 1700 kev. The peaks listed in Table I above 1700 kev were unmistakeable. Indications of resonances also occurred at 1717, 1729, 1763, 1817, and 1825 kev. Further work must be done to verify their existence.