we may be said to attribute it to the interaction of neighboring electrons through the phonon field. This interaction is analogous to the (retarded) Möller interaction resulting from the virtual quanta of the electromagnetic field.

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Alpha-Alpha Scattering*

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THE differential scattering cross sections for 20.4±1.0-Mev alpha-particles by helium were determined at center-of-mass scattering angles of 60° and 90°. The experimental results are shown in Table I.

The scattered particles were detected by a proportional counter. The amplified pulses from the counter went to a pulse-height discriminator circuit which rejected pulses of amplitude appreciably smaller than those desired. The unscattered particles were collected in a faraday cage which was connected to a one-μf condenser. The voltage across the condenser was measured by a null method using a Compton electrometer as the null device.

There was an appreciable background counting rate resulting from the neutron flux accompanying the operation of the cyclotron. This background was reduced somewhat by shielding the counter with borax and paraffin. The background counting rate was determined before and after each set of scattering runs. Based on the internal consistency of the background data and the number of counts taken, a precision of ±10 percent was assigned to the background correction.

The scattering chamber was filled to a pressure of about 2.2 cm of Hg with helium of 99.5 percent purity furnished in standard cylinders by the Ohio Chemical Company. The pressure was determined by a U-tube manometer filled with Apiezon oil B. Impurity scattering is not believed to be important in this work because the alpha-alpha scattering cross section is at least as great as the alpha-air scattering cross section for the angles studied, hence the possible 0.5 percent impurity in the scattering gas could contribute a maximum error of 0.5 percent. Furthermore, the pulses produced by impurity-scattered particles were smaller than the genuine pulses, and experimental tests showed that impurity-caused pulses were counted with poor efficiency. Outgassing of the metal surfaces of the scattering chamber or leaks in the system would have caused the pressure of the scattering gas to increase during a period of data taking. No increases in pressure greater than one percent were noted.

No direct data on the cyclotron alpha-particle beam energy are available, so it has been estimated from measurements of the proton and deuteron beam energies. The probable errors quoted for the scattering cross section in Table I include the statistical probable error, the probable error in the background counts, and a collection of minor errors that are discussed in a paper on proton-alpha scattering[1] in which the same apparatus was used. A more detailed account of the apparatus and the procedure used in taking data are included there. The paper also describes the procedure by which proton-proton scattering was used to calibrate the apparatus, thus making a precise knowledge of certain geometrical factors and the capacitance of the condenser connected to the faraday cage unnecessary.

TABLE I. Results of the alpha-alpha scattering work for incident alpha-particles of 20.4±1.0 Mev. θ is the scattering angle in the center-of-mass system, n is the number of counts observed, R is the ratio of the number of genuine counts to the number of background counts, and σ is the differential scattering cross section in the center-of-mass system expressed in barns/sterad.

θ	n	R	σ
60°	900	19	0.086 (±5.5 percent)
90°	900	26	0.14 (±5.5 percent)

The results of the present work are directly comparable with those of Mather[2] who used the same cyclotron, but employed an entirely different apparatus which used photographic plates for the detection of the scattered particles. Mather gives the value 0.123±0.008 barn/sterad for the differential scattering cross section in the center-of-mass system at 60°. He gives no value for 90°, but his cross sections near 90° tend upward in qualitative agreement with the present work. The reasons for the large discrepancy between the present results and those obtained by Mather are not clear.[3] As explained in the account of proton-alpha work,[1] the present method yielded absolute proton-proton scattering cross sections within the estimated probable error, ±5 percent. The alpha-alpha work was made more difficult by the low alpha-particle beam current from the cyclotron (0.14×10^{-8} ampere into the scattering volume) which makes the procurement of data on alpha-alpha scattering require roughly 40 times as long as the procurement of an equivalent amount of data when accelerated protons are used. However, no reasons have been found for suspecting large errors resulting from this increased time required for obtaining the data.

* Assisted by the joint program of the ONR and AEC.
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[3] Our attention has been called to unpublished work on alpha-alpha scattering at 30 Mev by E. Graves at the Massachusetts Institute of Technology. Graves' work indicates that the scattering cross section is quite energy-dependent. A possible explanation of the discrepancy between Mather's results and the present results may be that, because of changes in the cyclotron operating conditions, the present work was performed at an energy slightly different from that used by Mather.

Nuclear Binding Energies for Isotopes with Masses between 50 and 60

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RECENTLY we computed a list of nuclear binding energies and masses[1] for mass numbers <43, using recent reaction energy data[2] and the new mass spectrographical results of Ewald.[3] We tried to extend this list up to about $A=65$. In this mass region several reaction energy data are known, which appear to be reasonably reliable since similar measurements for lower mass numbers, often by the same authors, are in good agreement with one another and with Ewald's results. In the same region several stable isotopes have been measured mass spectrographically.[4–6] Among these measurements, which are not mutually consistent, we consider first those of Duckworth *et al.*[6] Their measurements of the Si- and S-isotopes are in reasonable agreement with the values computed from our aforementioned list (Table I).

It is of great interest to compare the differences in binding energies computed from Duckworth's results for the isotopes with masses $50<A<60$ (collected in Table II, column 3) with the values derived from reaction energy data (Table III). Table II, column 4, shows the binding energies derived from Duckworth's

TABLE I. Packing fraction differences (10^{-4} MU).

Doublet	Duckworth	Computed
$C_2H_4-Si^{28}$	19.45±0.06	19.42 ±0.01
C_2O-Si^{28}	6.45±0.03	6.43 ±0.01
CH_2-Si^{30}	24.53±0.03	24.46 ±0.01
O_2-S^{32}	5.50±0.03	5.54_4±0.00$_3$

results making use of the binding energy values of the C-, O-, and Si-isotopes collected in our list and the conversion factor 1 MU =931.15 Mev.[7,8] For isotopes measured in more than one way a mean result is given. The differences in these binding energies are shown in Table IV, column 2. The corresponding differences derived from reaction energy data are given in column 3.

TABLE II. Binding energies computed from doublets.

Nuclide	Doublet	$f(10^{-4}$ MU)	Binding energy (Mev)	Assumed value (Mev)
Cr^{52}	$C_2H_3-Cr^{52}$	17.47±0.04	456.24±0.20	456.24
Fe^{54}	$C_2H_3-Fe^{54}$	19.91±0.04	471.77±0.20	
	$C_2H_3-Fe^{54}$ [a]	19.99±0.04	472.17±0.20	
		mean result:	471.97±0.16	471.96
Fe^{56}	$Si^{28}-Fe^{56}$	3.32±0.02	491.81±0.14	
	$CO-Fe^{56}$	9.80±0.02	492.05±0.14	
	$C_2H_4-Fe^{56}$	22.93±0.07	492.79±0.38	
		mean result:	491.97±0.12	492.43
Ni^{58}	$Si^{29}-Ni^{58}$	3.07±0.02	506.45±0.14	
	$COH-Ni^{58}$	12.09±0.04	506.25±0.22	
	$C_2H_6-Ni^{58}$	24.73±0.04	506.77±0.22	
		mean result:	506.48±0.12	506.23
Ni^{60}	$Si^{30}-Ni^{60}$	2.90±0.02	527.29±0.14	526.83

[a] The second $C_2H_3-Fe^{54}$ result is a combination of the doublets $C_2H_3-Pd^{108}$ and $Pd^{108}-Fe^{54}$.

Comparing these two columns it appears that for $Fe^{56}-Fe^{54}$ and $Ni^{58}-Fe^{56}$ the consistency is outside the errors indicated. Since the reaction data are reliable, as mentioned previously, we arrive at the conclusion that the errors in Duckworth's measurements must be a little underestimated.

We are now able to compute what we think at present are the most reliable values of the binding energies of the isotopes involved. For that purpose we assume rather arbitrarily that the differences in binding energies have the values of Table IV, column 4. Next we adjusted the binding energies to these differences with the least possible deviations from Duckworth's values; the results are shown in Table II, column 5. It is seen that almost

TABLE III. Reaction energies (Mev).

No.[a]	Reaction	Q[b]	No.	Reaction	Q
1	$Cr^{53}(\gamma, n)Cr^{52}$	−7.5 ±0.3	10	Co^{57} (K)Fe^{57}	>1.0
2	$Cr^{53}(p, n)Mn^{53}$	−1.37±0.05	11	$Ni^{57}(\beta^+)Co^{57}$	4.55±0.10
3	$Fe^{53}(\beta^+)Mn^{53}$	4.4 ±0.1	12	$Ni^{58}(\gamma, n)Ni^{57}$	11.7 ±0.2
4	$Fe^{54}(\gamma, n)Fe^{53}$	−13.8 ±0.2	13	$Co^{58}(\beta^-)Ni^{58}$	>−0.8
5	$Fe^{54}(n, \gamma)Fe^{55}$	9.30±0.03	14	$Co^{59}(\gamma, n)Co^{58}$	−10.0 ±0.3
6	$Mn^{55}(p, n)Fe^{55}$	−1.01±0.01	15	$Co^{59}(n, \gamma)Co^{60}$	7.73±0.04
7	$Mn^{55}(n, \gamma)Mn^{56}$	7.25±0.03	16	$Co^{60}(\beta^-)Ni^{60}$	2.04±0.01
8	$Mn^{56}(\beta^-)Fe^{56}$	2.91±0.05	17	$Ni^{58}(n, \gamma)Ni^{59}$	9.01±0.03
9	$Fe^{56}(n, \gamma)Fe^{57}$	7.63±0.01	18	Ni^{59}(K)Co^{59}	>0.8

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[b] For β-processes the table gives the resulting change in binding energy.

all deviations from Duckworth's results are less than 0.5 Mev. Therefore we think that the error in our values will not exceed 0.5 Mev.

The binding energies of the Ni-isotopes computed from the mass spectrographical results of Shaw[4] are about 2 Mev higher than the values computed above; the binding energies of the Cu- and Fe-isotopes computed from Ogata's results[5] scatter around our values by amounts up to 4 Mev, both in violent disagreement with nuclear reaction data.

TABLE IV. Differences in binding energies (Mev).

Difference	Duckworth	Q-values	Assumed
$Fe^{54}-Cr^{52}$	15.73±0.28	15.53±0.4	15.72
$Fe^{56}-Fe^{54}$	20.00±0.25	20.47±0.07	20.47
$Ni^{58}-Fe^{56}$	14.51±0.17	<13.78±0.23	13.80
$Ni^{60}-Ni^{58}$	20.81±0.19	>19.58±0.04 <20.57±0.3	20.60

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Note: After this paper had been submitted for publication a new paper (R. Canada and A. C. G. Mitchell, Phys. Rev. **83**, 955 (1951)) changed the β-decay energy of Ni^{57} to 4.01 Mev. This increased the Q-value (Table IV) for the difference $Ni^{58}-Fe^{56}$ to <14.32 Mev, greatly diminishing the largest deviations from Duckworth's results. We would now suggest the following binding energies: Cr^{52}—456.25, Fe^{54}—471.85, Fe^{56}—492.25, Ni^{58}—506.55, and Ni^{60}—527.15 Mev, with an estimated mean error of 0.3 Mev. These changes do not affect the general conclusions in the following paper.

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Nuclear Masses and Closed Shells in the Region $A<65$

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SOME time ago Low and Townes[1] computed a set of nuclear masses and showed that these masses do not indicate closed nuclear shells for neutron and proton number N or $Z=20$. Recently Duckworth and Preston[2] published a new packing fraction curve which indicates several magic numbers, not, however, including N or $Z=20$. We thought it worthwhile to repeat these investigations using our new list of nuclear masses.[3] For that purpose we made a diagram of the difference between our mass values and the masses computed by Metropolis and Reitwiesner[4] from the Weizsäcker-Bethe formula. We found that the part of this formula describing the even-odd staggering—namely $(0.036/A^{\frac{3}{4}})\lambda$, in which λ is $+1$ for $e-e$ nuclides and 0 and -1 for $e-o$ and $o-o$ isotopes, respectively—exaggerates the real effect. In fact, in the region $15<A<50$ the formula 0.0018λ proves to be a better approximation. Therefore we made this correction in Metropolis and Reitwiesner's values for all masses $A<50$, before subtracting them from the real mass values.

The result is shown in Fig. 1 (in 10^{-4} MU). The errors in the values for $A<43$ are about 1 unit (10^{-4} MU) or less with only a few exceptions. The region $50<A<61$ has been discussed in the preceding letter; the values for $43<A<50$ and $61<A<67$ are computed from Duckworth's[2,5] measurements of Ti^{48} and Cu^{65} in combination with various nuclear reaction data. The errors in these values are thought to be of the order of 5 units (5×10^{-4} MU). One notices at once that the minimum in the mass differences around the magic numbers is fairly wide. This implies that it is often difficult to choose between two possible values for a magic number. For instance the lower masses in the region around $A=14$ (to be seen most clearly from the values for even-odd isotopes) may be caused by N or $Z=8$, but also by N or $Z=6$. But even allowing for this fact, the magic character of Z or $N=20$ hardly