THE ATOMIC MASS OF Ni^{60}

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By

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SCOPE AND CONTENTS:

A new technique for measuring doublet separation is described, and some recent mass spectroscopic measurements of the Ni^{60} mass are reported. The new value is compared with some previously reported values, and its effect on some existing discrepancies between mass spectroscopic and transmutation data is discussed.

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Introduction

By studying the deflection of positive rays under the influence of electric and magnetic fields, J. J. Thomson laid (1) the foundation for mass spectroscopic determination of atomic masses in 1912. His apparatus was simple: crossed electric and magnetic fields acting upon a well collimated beam separated the ions of different mass to charge ratio, each species tracing out a parabolic pattern on a photographic plate normal to the incident beam. After the First World War, his student, Aston, greatly improved (2) the instrumentation by using a circular magnetic field section separate from and subsequent to the electric field region. This arrangement spread the beam components into a true mass spectrum and had the further advantage that it was velocity-focusing; that is, it would accept and focus ions of a given type which left the source with a small spread in velocity. However, this instrument was not direction-focusing, but relied on a finely collimated incident beam.

In the following decade, physicists such as Dempster, Bainbridge and Mattauch developed and constructed a variety of velocity or direction-focusing instruments for mass study, but the greatest advances in precision mass spectroscopy came (3) only after Herzog's comprehensive study of electro-magnetic ion optics in 1934. This analysis culminated earlier studies which had been confined to particular cases of double-focusing, and pointed the way to the practical design of instruments capable of focusing the mass components of a beam which was neither monoergic nor perfectly collimated. Since that time, several such double-focusing mass spectrometers have been put into operation by various groups and have produced a wealth of precision mass data.

While the science of mass spectroscopy was striding through adolescence towards its prime, a younger member of the physics family began to take its first unsteady steps. This was the science of transmutation studies. By measuring the Q-value of a nuclear reaction, that is, the net energy release between the initial components and the final products of the reaction, the mass difference between the parent and daughter nuclide may be deduced. Although the early results were approximate only and did not compare in precision with the contemporary mass spectroscopic data, many groups became active in the field and better methods of measurement were soon developed. Since the Second World War, and particularly during the past five years, the instrumentation and techniques employed by workers in the field of transmutation studies have enabled them rapidly to narrow this gap, and perhaps even overtake the mass spectroscopist.

Although the results from both fields have been generally quite compatible, it has recently been pointed out (4,5) that in the Fe-Ni-Zn section of the atomic mass table there exist discrepancies between mass spectroscopic and transmutation data. Further, these differences suggested that the masses of the nickel isotopes, as determined by mass spectroscopic methods, might be too low by about

0.6 mm. If such an error were indeed present in these mass values, its correction would cause the disappearance of most of the discrepancies in this region. It was decided to check this possibility by some new studies of the nickel isotopes, using only hydrocarbons as comparison and dispersion lines wherever possible.

The Instrument

The instrument used was constructed at Wesleyan University in 1949 under the direction of Dr. H. E. Duckworth and moved to McMaster University with him in 1951. It is a Dempster-type double-focusing mass spectroscope, having a radius of curvature in the magnetic field of 9.1 inches and a resolution of about 1 part in 7000. The basic instrument is well described (6) elsewhere and, apart from the source and some minor current stabilizer circuitry, no changes have been made. Figure 1 shows the arrangement of the slit system and the two analyser sections. (The notation used is that introduced (3) by Herzog.) The detector is a photographic plate located, as shown. The source employed for the study of mixed doublets, that is, closely spaced lines produced from solid and gaseous samples in the source, is a modified Shaw-type source, also described (7) in detail elsewhere. The source has an oven heated by an enclosed filament. The oven contains a crucible to hold the solid sample and a means is provided to introduce the gaseous sample into the oven as well. The filament emits electrons which bombard the crucible due to a potential difference of about 600 volts. This bombardment current serves to heat the solid sample, ionize some of the resulting vapour, and ionize some of the gas sample. An ion

Dempster Double-focusing Arrangement

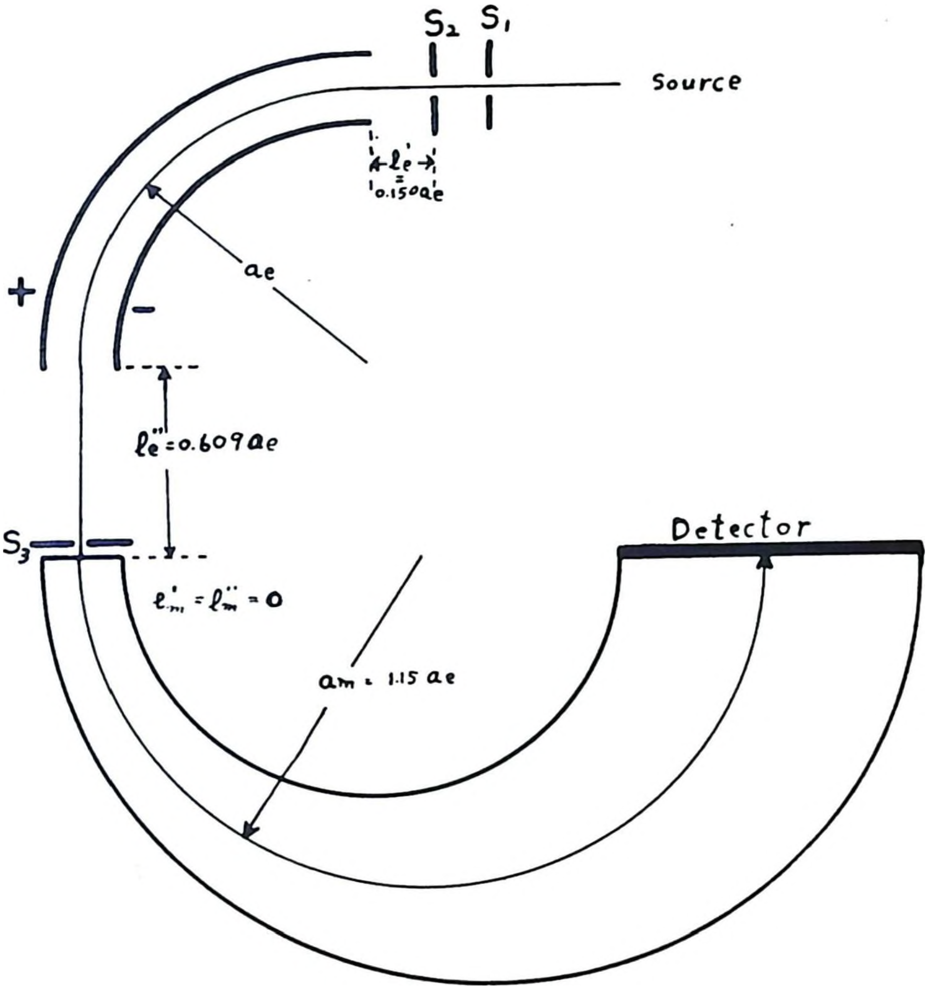

FIGURE 1

beam is drawn out through a hole in the oven and accelerated to the slit system by a potential of about 17,000 volts. In this type of source, the relative intensity of the doublet lines can be varied over a considerable range by means of the filament current value which controls the bombardment current. This is possible because the intensities of the ion beam components from the solid and from the gas will not have the same functional dependence on the bombardment current. The need for this relative intensity adjustment will be outlined in the next section.

The Doublet Method

A doublet is a pair of mass spectral lines produced by two species of ion whose mass to charge ratio is almost, but not quite, equal. From the doublet separation and a knowledge of the dispersion of the instrument, the mass difference between the two doublet members may be calculated. Hence, if one be accurately known, the other is readily calculable. In the instrument used for the work in this paper the dispersion is obtained by measurement to a second line of known mass in the immediate region of the doublet. The spectral lines are recorded on a photographic plate and their separations are measured, using a travelling microscope. The analytical treatment necessary to derive the unknown mass is developed in Appendix I.

In order to be acceptable for measurement, the doublet lines must satisfy several conditions. They must be sharply focused to enable precise location. They must be sufficiently exposed to give a reasonable intensity without excessive line-broadening or background scatter. Finally, they must be very closely matched in intensity. This last condition is essential primarily because of the assymetrical distribution of ions across the image width. This would cause the apparent centre of a lightly exposed line to shift if the exposure were increased to blacken a portion of the emulsion to saturation. This effect could produce an error if the doublet lines were not equally matched in intensity but, if both lines activated the emulsion to the same degree, any shifting would, presumably, be equal and the line separation would remain unchanged. A second factor is the difficulty, be it psychological or physiological, experienced in accurately setting the microscope cross-hair on closely spaced lines which differ greatly in intensity. This possible source of error is minimized by using only well matched doublets.

Once a series of well matched doublets has been obtained, the necessary doublet and dispersion measurements are taken from the plates, using a travelling microscope with an accurately calibrated screw thread. In the measurement of closely spaced doublets, it has been the practice previously in this group for an observor to measure a given doublet separation several times and average the values obtained. This served to reduce the random error associated with the setting of the cross-hair on the line centre. In order to eliminate much of the drudgery associated with these many readings and recordings, a travelling microscope table has been conceived and constructed. This consists of a screw-driven device which replaces the fixed stage of the microscope with a table which is movable in a direction parallel to the motion of the travelling microscope head. Since the table is always stationary when the head is in motion, and since no measurement is taken of the table travel, no precision machining was necessary and the design could be kept quite simple. The method employed to take a series of measurements on a doublet and to calculate the average separation is best illustrated by reference to Fig. 2.

The photographic plate is first carefully positioned on the travelling stage. The head screw H is then set at zero to eliminate a subtraction step to find the total head travel. Then the cross-hair and one line are brought into superposition by use of the stage screw S. This is the initial condition as shown in Fig. 2, Section a. The head screw is then used to move the cross-hair to the other line, as shown in b. The head screw calibration now reads one doublet spacing. In c, the stage is again moved to bring the first line back under the cross-hair, and in d the head is moved again so that the cross-hair comes to rest over the second line. The calibration now reads two doublet spacings and, since the process is additive, the two steps may be repeated several times, after which the total head travel is read off and the average is computed. If ten such sequences are used, the averaging becomes trivial and the final result can be written down at once.

The main advantage of this method is the elimination of over 90% of the mechanical reading, recording and computation involved in doublet measuring, but there are other points in its favour. The danger of subconscious memory associated with taking several position measurements near the same scale reading is eliminated. The effect of an observer's "favourite digit" is

DOUBLET MEASURING

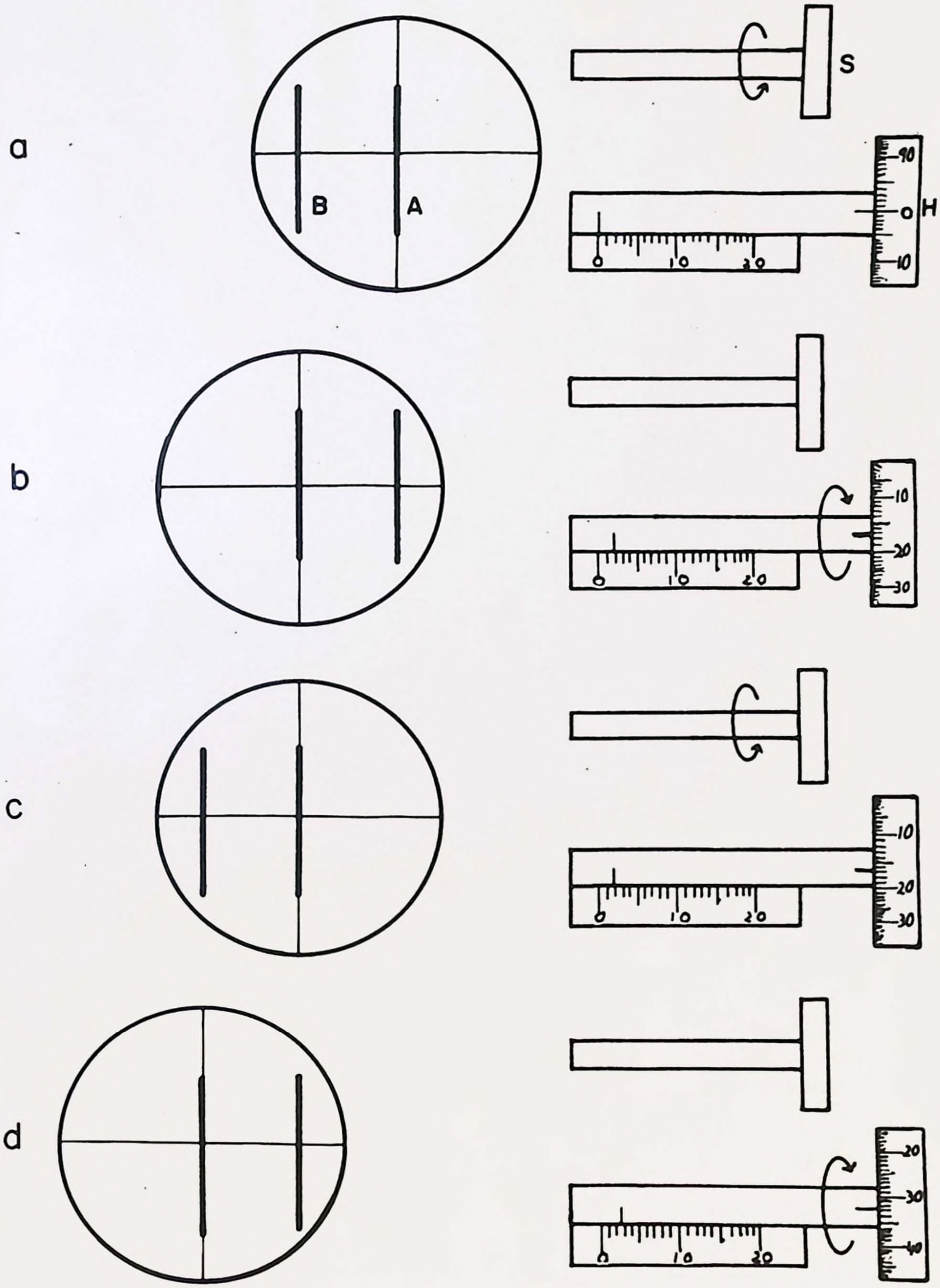

FIGURE 2

greatly reduced. Screw back lash need be considered only in the initial and final settings of the head screw. This removes the necessity of approaching a line always from the same side, which speeds the settings and reduces another potential source of error. Finally, the ease of the method leads one to make several measurements and hence arrive at better statistical values for the doublet and dispersion spacings. Since its construction, the travelling stage has been used for measuring several sets of plates by various members of the group, and it is generally agreed that what was once a tedious chore has become an almost pleasant interlude.

The Experiment

Since Ni^{58} had been studied (7) by a previous student, the author chose Ni^{60} as his subject. A survey of the Catalogue of Mass Spectral Data (8) was made and several sources of hydrocarbon fragments at mass number 60 were considered. Acetic acid was finally chosen since the complete molecule $C_2H_4O_2$ gave a good yield at mass 60. Its liquid state and reasonable vapour pressure at room temperature indicated that it should be an easy substance to handle and introduce into the source. In addition, it was readily available. For the dispersion line it was decided to use the hydrocarbon fragment C_3H_6O which was usually present as a background line, or could easily be introduced by leaving a little pump oil in the source region.

A crucible consisting of a 0.020 inch thin walled nickel tube, supported by a copper wire, was constructed. Later the copper was replaced by tungsten in an effort to maintain the crucible at a higher operating temperature for a given bombardment current value. The tube was tightly packed with anhydrous nickel chloride to act as a source of nickel ions. A small reservoir of glacial acetic acid was connected through a capillary leak and valve to the gas inlet part of the source. The source was then carefully aligned with the analyser slit system and a series of exposures was made.

It was found that the acetic acid had such a high vapour pressure at room temperature that the $C_2H_4O_2$ completely dominated the Ni^{60} in the ion beam, even with the finest capillary leak which could easily be employed. Some small success in matching the doublet was obtained by lowering the reservoir to dry ice or liquid air temperatures, but the majority of the satisfactory doublets were matched by the following technique. The valve between the reservoir leak and the source was opened momentarily and then closed off. After an interval of 15 or 20 minutes, a series of exposures was taken. The process was repeated for each new plate. The period of time between the closing of the gas line and the exposure of the doublets allowed the excess vapour to be pumped away from the source region, leaving a $C_2H_4O_2$ background just sufficient to give a few well matched doublets. The bombardment current had to be decreased and the exposure time increased for successive exposures across the photographic plate to maintain the match in intensity as the background vapour was used up. This made the procedure rather unreliable, but sufficient well matched doublets were obtained to make it satisfactory. Figure 3 shows some of the photographs magnified about four times. Although the lines suffer somewhat in the reproduction, their relative intensities are affected only slightly. Of these doublets, c and e were rejected as not well enough matched.

From the fifty or sixty well focused doublets which were obtained, twelve very well matched sets were selected. These were carefully measured by three independent observers, using the method outlined in the previous section. The value R, defined in Appendix I as the ratio of doublet spacing to dispersion spacing, was calculated by each observer for each of the twelve cases and the results were treated statistically to arrive at the best value. This value was then used, together with Nier's most recent value (9) for carbon and hydrogen, i.e. $C^{12} = 12.0038167 \pm 8$, $H^1 = 1.0081442 \pm 2$ amu, to calculate the mass difference between the doublet lines. This difference was found to be 90.84 ± 15 mmu. The value for the nickel mass in question was then calculated to be $Ni^{60} = 59.94937 \pm 15$ amu. The statistics and calculations are found in Appendix II. Pressure in the instrument when these doublets were exposed varied over the range of $2 - 4 \times 10^{-6}$ mm Hg, as measured by an ionisation guage calibrated for air.

Table 1 lists some previously obtained values for the mass of Ni^{60}. These have been corrected using the C^{12} and H^1 values given above wherever possible. The value obtained in this experiment agrees within the stated errors with the value derived from the $Si^{30} - 1/2\ Ni^{60}$ doublet in 1950, using the same instrument. Nier's 1956 value is higher, while his 1952 value is lower than that given in this thesis. The two earlier values are less reliable, but there is good agreement

Some Typical Doublet and Dispersion Lines

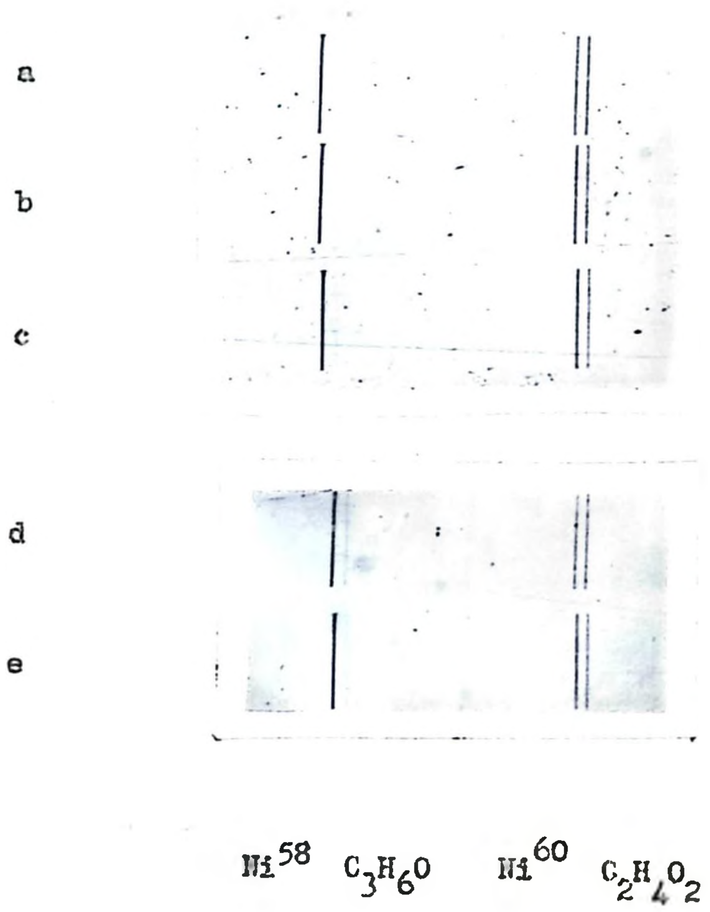

Figure 3

TABLE 1

Mass amu	Doublet	Source	Date
59.94949 ± 31	$C_5 - Ni^{60}$	Okuda (10)	1941
59.9477 ± 5	$C_5 - Ni^{60}$	Shaw (11)	1949
49.94926 ± 14	$Si^{30} - 1/2\ Ni^{60}$	Duckworth (12)	1950
59.94883 ± 29	$C_5 - Ni^{60}$	Nier (13)	1952
59.94984 ± 25		Wapstra (5)	1955
59.949823 ± 6	$C_2H_4O_2 \pm Ni^{60}$	Nier (14)	1956
59.94937 ± 15	$C_2H_4O_2 \pm Ni^{60}$	This thesis	1956

with one of them. Wapstra's value is higher, but note that his masses are arrived at by a synthesis of mass spectroscopic and transmutation data, with the emphasis on the transmutation data in this case.

Conclusion

Although it is true that the new mass value appearing in this thesis is slightly higher than the previous value reported by this group, the increase is much less than the postulated 0.6 mmu error. A recent publication, included as Appendix III, has discussed (15) the new nickel mass data and considered it in conjunction with some transmutation results. It concludes that the previously suggested (4,5) changes in the nickel masses may not be the answer to the discrepancies which exist. The work of this thesis has shown that any error in the

McMaster mass value for Ni^{60} must arise from some systematic effect. One such effect, which has been previously reported (16) as possible, is the dependence of the doublet spacing on the residual gas pressure within the instrument. Some studies of this effect have recently been made (17), and the results pertinent to nickel are included in Appendix IV. Although these deal with the Ni^{58} doublet, it is reasonable to suppose that the Ni^{60} would not be too far different. The magnitude and direction of the pressure dependence coefficient obtained could not account for an error as large as 0.6 mmu.

In any event, it is certain that, with the ever improving techniques at their disposal, the mass spectroscopist and the transmutationist will soon arrive at a solution to their differences which will be satisfactory to all.

APPENDIX I

An Analytical Mass Calculation

Let m_1, m_2, m_3 be the images of three different species of ion focused from a monoergic beam (energy E) by a 180° magnetic analyser. Let their mass to charge ratios be m_1, m_2, m_3, respectively, with m_2 and m_3 forming a doublet. Finally, let r_1, r_2, r_3 be their respective radii of curvature in the magnet field (strength B). From the equations of mechanical and electromagnetic force acting upon the charged particles travelling in the magnetic

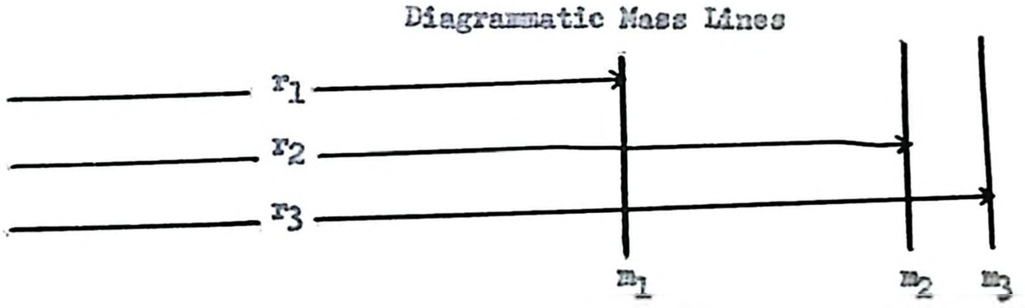

Figure 4

field one obtains the result

$$B\ e\ v = \frac{mv^2}{r} \qquad (1)$$

which simplifies to

$$m\ v\ a\ r \qquad (2)$$

Since the beam is monoergic, one has

$$mv^2 = 2\ E \qquad (3)$$

From (2) and (3) one derives

$$r^2 = 2 E m \qquad (4)$$

which leads to $$m \propto r^2 \qquad (5)$$

This fact is not directly useful since the radius cannot be measured with precision, but if two of the masses are known, the third can be calculated as follows:

Let m_2 be the unknown mass. Measure the $m_3 - m_2$ and $m_3 - m_1$ separations and calculate the ratio $R = \frac{r_3 - r_2}{r_3 - r_1}$

Using (5) note that $R = \frac{\sqrt{m_3} - \sqrt{m_2}}{\sqrt{m_3} - \sqrt{m_1}}$

Define $a = R(\sqrt{m_3} - \sqrt{m_1})$ and note that $a = \sqrt{m_3} - \sqrt{m_2}$.

Rearranging this expression gives $\sqrt{m_2} = \sqrt{m_3} - a$

whence $$m_2 = m_3 - 2\,a\sqrt{m_3} + a^2 \qquad (6)$$

Since the doublet mass difference is what is actually measured, (6) may be rewritten as

$$\Delta m = m_3 - m_2 = 2a\sqrt{m_3} - a^2 \qquad (7)$$

In the instrument used for these experiments, the magnetic field falls off slightly for larger radius ion paths. This causes a change in dispersion along the photographic plate which necessitates a small mass correction. The correction is obtained from an empirically derived formula best written as follows:

$$\delta(\Delta m) = 0.205\,\frac{I_1 - I_3}{m_1 + m_3}\,\Delta m \qquad (8)$$

$\delta(\Delta m)$ is the correction to the Δm of Equation (7) and I is the mass number. If (8) is introduced into (7) the final result may be written

$$\Delta m_c = \left(1 + 0.205\,\frac{I_1 - I_3}{m_1 + m_3}\right)(2a\sqrt{m_3} - a^2) \qquad (9)$$

where the subscript c denotes the corrected mass difference.

APPENDIX II

The Calculation of the Mass of Ni^{60}

Table 2 lists the values of R obtained by the three observors. By assigning a weight factor inverseley proportional to Σd^2, a weighted average R is obtained and a probable error is assigned to it. This value is $R = 0.04568 \pm 3.4$. Using the values of C^{12} and H^1 given in the body of the thesis, the following masses are calculated:

$$C_3H_6O = 58.06032 = m_1$$

$$C_2H_4O_2 = 60.04021 = m_3$$

Then $\alpha = R(\sqrt{m_3} - \sqrt{m_1}) = 0.0058843$ and formula 9 from Appendix I gives

$$\begin{aligned} \Delta m_c &= \left(1 + 0.205 \frac{I_1 - I_3}{m_1 + m_3}\right)(2\alpha\sqrt{m_3} - \alpha^2) \\ &= (1 - 0.00347)(0.091190 - 0.000035) \\ &= 0.99653 \times 0.091155 \\ &= 0.090839 \text{ amu} \end{aligned}$$

By noting that the probable error in R is less than 0.08% and that this error carries on through the α to give the main error in Δm_c, a probable error of the same percentage may be assigned to Δm_c. Thus the result is seen to be

$$\Delta m_c = 0.09084 \pm 7 \text{ amu}$$

and hence $$Ni^{60} = 59.94937 \pm 7 \text{ amu}$$

It is felt that the empirical correction may not be accurate to this degree, so the probable error has been raised considerably for publication.

TABLE 2

Determination of R for Ni^{60} Using 12 Doublet Sets

Observer	Bainbridge		Duckworth		Eastman	
R and d	0.04563	62	0.04551	7	0.04537	31
	0.04567	58	0.04569	11	0.04571	3
	0.04675	50	0.04594	36	0.04599	31
	0.04598	27	0.04543	15	0.04575	7
	0.04647	22	0.04564	6	0.04563	5
	0.04623	2	0.04561	3	0.04572	4
	0.04630	5	0.04536	22	0.04543	25
	0.04708	83	0.04554	4	0.04533	35
	0.04563	62	0.04549	9	0.04543	25
	0.04559	66	0.04515	43	0.04535	33
	0.04691	66	0.04568	10	0.04624	56
	0.04677	52	0.04593	35	0.04624	56
$\bar{R}$	0.04625		0.04558		0.04568	
Σd^2	33099		5491		11857	
$\frac{10^5}{\Sigma d^2}$	3.02		18.2		8.41	
W	0.10		0.61		0.29	
P	10.6		4.3		6.4	

Weighted Result $R_w = 0.04568 \pm 3.4$

Definitions and Formulae $d = |\bar{R} - R|$, $W \alpha \frac{1}{\Sigma d^2}$,

$$P = 0.67 \left(\frac{\Sigma d^2}{n(n-1)}\right)^{\frac{1}{2}}$$

$$P_w^2 = \frac{1}{\Sigma \frac{1}{p^2}}$$

~~P.C. Eastman, Ne. R. Isenor G. R. Bainbridge~~
~~and H. E. Duckworth, The Physical Review **103**(1),~~
~~145 (1956).~~

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H.E. Duckman, The Physical Review **103**(1), 145 (1956)

APPENDIX III

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Atomic Masses of Ni^{58} and Ni^{60}†

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(Received March 20, 1956)

Mass spectrographic measurements are reported of the mass differences $C_2H_4O_2-Ni^{60}$ and $C_3H_6O-Ni^{58}$. These results are used, together with existing data, to discuss certain discrepancies between transmutation and mass spectroscopically determined masses in the Fe-Ni-Zn section of the atomic mass table.

I. INTRODUCTION

It has been pointed out[1,2] that in the Fe-Ni-Zn section of the atomic mass table there exist discrepancies between mass spectroscopic and transmutation data. Further, these differences suggest that the masses of the nickel isotopes, as determined by mass spectroscopic methods, may be too low by ~0.6 mmu. If such an error indeed be present in these mass values, its correction would cause the disappearance of most of the discrepancies in this region. With this in mind, some new mass studies of nickel isotopes were undertaken in this laboratory, and are reported herein.

II. EXPERIMENTAL

The masses of Ni^{58} and Ni^{60} have been redetermined using only hydrocarbons as comparison and dispersion lines. The hydrocarbons C_4H_9 and C_3H_6O, came from pump oil vapor, while $C_2H_4O_2$ was obtained from glacial acetic acid, introduced into the source region through a slow leak from a variable temperature reservoir. Nickel ions were obtained from $NiCl_2$ in the crucible of a modified Shaw source.[3] The mass spectrograph was a Dempster double-focusing instrument[4] possessing a resolution of about 1 part in 7000.

The effect on the doublet spacing of pressure changes in the analyzer section of the mass spectrograph has also been investigated, and will be reported in the *Canadian Journal of Physics*.

III. MASS OF Ni^{58}

Several photographs of the $Ni^{58}-C_3H_6O$ doublet were obtained in March, 1955 and May, 1955. From these were chosen the eight best-matched, low-pressure doublets, which were then measured by four individual observers. After routine statistical analysis, the following mass difference was obtained: $C_3H_6O-Ni^{58}=106.52\pm15$ mmu. From this, the Ni^{58} mass is calculated to be 57.95380 ± 15 amu. C^{12} and H^1 were taken to be

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* Holder of a National Research Council of Canada Bursary.

‡ Holder of a Shell Oil Company of Canada Scholarship, 1954–1955. Now in the Department of Physics, University of New Brunswick, Fredericton, Canada.

[1] Kerr, Taylor, and Duckworth, Nature 176, 458 (1955).

[2] A. M. Wapstra, Physica 21, 385 (1955).

[3] A. E. Shaw, Phys. Rev. 75, 1011 (1949).

[4] H. E. Duckworth, Rev. Sci. Instr. 21, 54 (1950).

TABLE I. Comparison of the new Ni^{60} and Ni^{58} atomic mass values with some others previously reported.

	Nier[a]		Duckworth[b]		New values		
Nuclide	Mass (amu)	Comparison mass	Mass (amu)	Comparison mass	Mass (amu)	Comparison mass	Mass difference (mmu)
Ni^{60}	59.94887±29	C_5	59.94926±14	Si^{30}	59.94939±15	$C_2H_4O_2$	90.82±15
Ni^{58}	57.95333±10	C_4H_{10}	57.95375±15	Si^{29}, COH, C_2H_5	57.95380±15	C_3H_6O	106.52±15

[a] See reference 6.
[b] For doublets including Si^{29} and Si^{30}, see reference 8. For doublets including COH and C_2H_5, see reference 7.

12.0038174±18* and 1.0081439±5* amu, respectively, as recently determined[5] by Scolman, Quisenberry, and Nier. The dispersion line was C_4H_9.

IV. MASS OF Ni^{60}

Twelve well-matched $Ni^{60}-C_2H_4O_2$ doublets were selected from plates taken in September, 1955, and January, 1956. These were measured by three observers whose weighted result was $C_2H_4O_2-Ni^{60}=90.82\pm15$ mmu, which leads to the mass value $Ni^{60}=59.94939\pm15$ amu. In this case, the dispersion line was C_3H_6O.

V. DISCUSSION OF RESULTS

Table I gives a comparison of our new mass values with those of Nier[6] and Duckworth[7,8] which have been corrected using the carbon and hydrogen values mentioned above. These new masses agree well with the previous values from this laboratory, which were obtained from different doublets. Our considered mass values for these two nuclides are now $Ni^{58}=57.95378\pm12$ amu and $Ni^{60}=59.94932\pm11$ amu. These, as before, are higher than those obtained by Nier and his colleagues.

We had hoped that this work would remove the discrepancy between the mass spectroscopic and transmutation values for the $Ni^{60}-Ni^{58}$ mass difference. However, as can be seen from Table II, this is not the case. Instead, we have obtained identically the same answer as Nier and his colleagues, which differs from the transmutation value by ~0.45 Mev. This discrepancy is particularly disturbing when one reflects that these two nuclides are connected, transmutation-wise, by a series of four reactions, for each of which the Q value has been determined[9,10] with high precision.

TABLE II. The $Ni^{60}-Ni^{58}$ mass differences, as derived from transmutation and mass spectrographic data.

Source of data	$Ni^{60}-Ni^{58}$ (amu)
Transmutation[a]	1.99606±1
Nier (Minnesota)[b]	1.99554±14
Duckworth (McMaster)[c]	1.99554±16

[a] See reference 11.
[b] See reference 6.
[c] Considered values, this paper.

Some months ago we reported[11] the new mass value $Zn^{64}=63.94909\pm15$ amu, from which, using accurate transmutation data, one may compute $Cu^{63}=62.94923\pm15$ amu. This may be combined with the new Ni^{60} value to compute the energy difference

$$(Cu^{63}+H^1)-(Ni^{60}+He^4)=3.9\pm0.2 \text{ Mev.}$$

This figure is of interest in connection with the Ghoshal experiment[12] for testing the compound-nucleus theory. In this experiment, the compound nucleus, Zn^{64}, was formed by both proton bombardment of Cu^{63} and by alpha-particle bombardment of Ni^{60}. To produce the same degree of excitation of the compound nucleus as that produced by protons, the alpha particles should require additional energy of this amount, that is, 3.9±0.2 Mev. This energy shift has been found experimentally to be 7±1 Mev (Ghoshal) or 6.4±1.0 Mev (John[13]), seriously disagreeing with the value derived from mass data, and, possibly, representing a black mark against the compound-nucleus concept. An increase in the values of the nickel masses by 0.6 mmu. would make this disagreement greater. Moreover, it would not improve the $Ni^{60}-Ni^{58}$ mass spectrographic mass difference relative to that derived from transmutation data. This makes the previously suggested[1,2] changes in the nickel masses somewhat less attractive.

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*More recent C^{12} and H^1 mass values used in this thesis have caused only slight modifications of the computed masses.

APPENDIX IV

The Effect of Residual Gas Pressure on the Spacing of the C_3H_6O - Ni^{58} Doublet

It has been demonstrated (16) that a positive ion, in its passage through a mass spectrometer, may suffer significant energy loss without appreciable change in direction. Furthermore, the extent of the energy loss was found to depend upon the nature of the ion and the pressure in the analyser sections of the instrument. This could lead to a change in doublet spacing with pressure if one member was affected to a different degree than the other. In order to assess the effect of this on the C_3H_6O - Ni^{58} doublet, the ratio R has been determined from doublet exposures taken at different pressures by three observors. The results have been analysed in search of some significant correlation.

Thirteen well matched doublets were employed, two at 5.5×10^{-6}, six at 14×10^{-6} and five at 59×10^{-6} mm Hg. The pressure was determined by an ionisation guage calibrated for air. The doublet mass differences calculated from these are shown in Figure 5, in which the several values at each pressure have been averaged.

Although the evidence is not too conclusive, it does suggest that the doublet spacing decreases with increasing residual gas pressure, the rate of change being approximately - 0.035 mmu per 10^{-6} mm Hg pressure increase. This latter was obtained by a least squares treatment of all the data summarized in Figure 5, that is, the thirteen measurements of each of the three observors.

The Dependence of the $C_3H_6O - Ni^{58}$ Doublet Spacing on Pressure

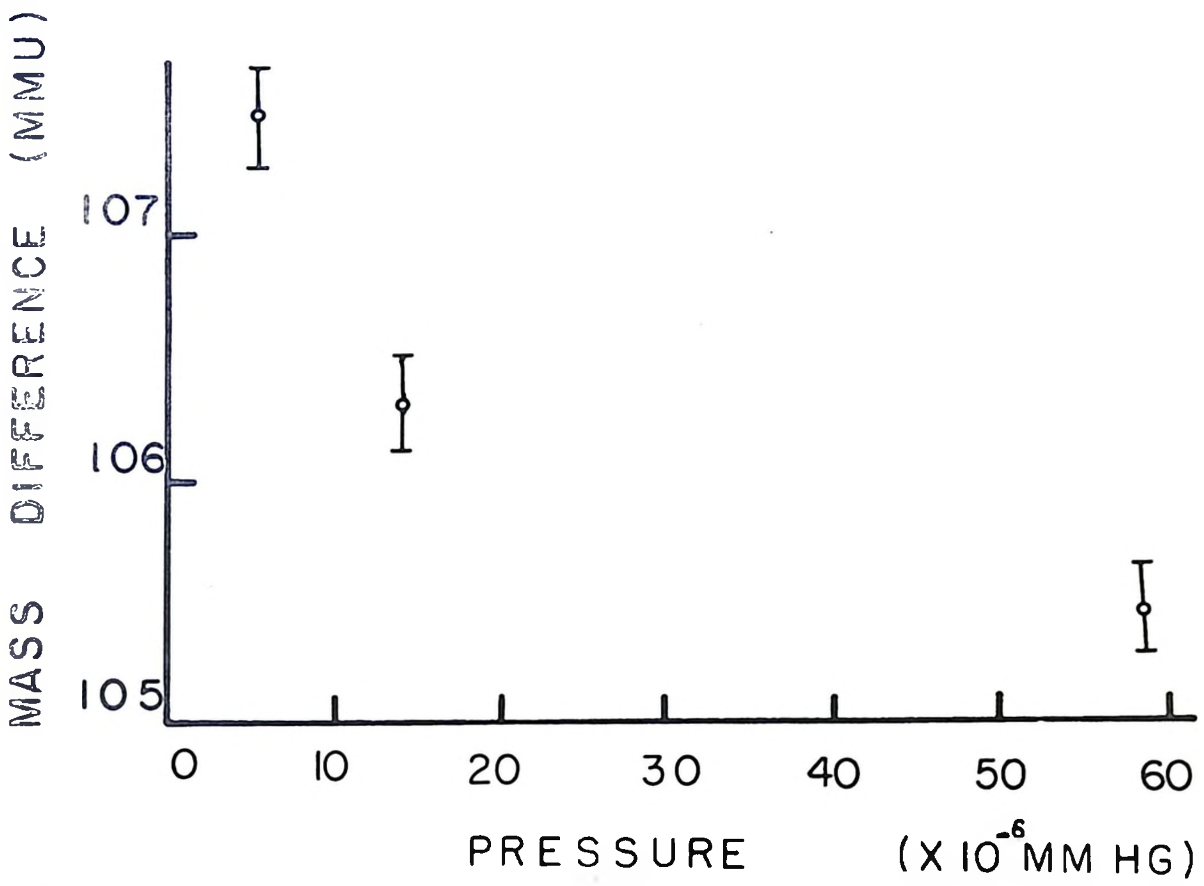

FIGURE 5

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