

**The Design of a Heated Mass Spectrometer Ion Source
for Isotope Abundance Measurements.**

by

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ABSTRACT

A simple furnace type mass spectrometer positive ion source has been designed constructed and tested. This source operated satisfactorily under certain conditions and was used in the determination of the relative abundances of the copper isotopes.

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INTRODUCTION

Positive ion sources designed for mass spectrometer or mass spectrograph analyses of solids, non volatile at ordinary temperatures, have been reported in the scientific literatures, (1)....(37). Each of these is one of the three distinct types: (a) Furnace Source, (b) Heated Filament Source or (c) Spark Source.

Furnace Source.

The furnace source employs a small electrically heated vapourizing chamber or "furnace", containing the sample to be vapourized and mounted in such a manner that the emergent vapours pass into the ionizing chamber of the source. Ionization is brought about by bombardment with electrons of specific energy. The furnace, if constructed of metal, may carry the heating current, thus acting as both heating element and vapourizing chamber. Otherwise, the furnace is heated by an electrically insulated heating element, (1)...(16).

In order to produce positive ion currents of the order of 10^{-13} amperes the furnace must maintain a steady pressure of about 10^{-4} mm., due to the sample in the ionization chamber, (4),(14). This means it must operate satisfactorily at a temperature corresponding to a sample vapour pressure of approximately 10^{-3} mm. The substance from which the furnace is constructed places a maximum on its satisfactory operating temperature. Nier found this limit to be 1200°C . for Nichrome V, (4), while Bleakney and Sampson found it to be 2500°C . for tungsten, (5). However, samples have been analysed using this type of source at temperatures ranging from 38°C . to 2000°C . (Table 1).

Well resolved and steady ion currents are not readily obtained from samples which are hygroscopic. For best results such samples should be handled entirely in a desiccated atmosphere. A small furnace could be loaded under these conditions, but would necessarily be exposed to the atmosphere during the process of its being mounted in the mass spectrometer tube. White and Cameron state that if possible the sample in question should be studied in an element or compound form which is not hygroscopic, (1). Nier has obtained relative abundance measurements for normal uranium from samples of UCl_4 and UBr_4 , both of which are quite hygroscopic, (16). Random fluctuations in ion currents resulted in an isotope abundance ratio with 1.0% precision, although twenty-six separate measurements were made.

There is the possibility of preferential isotope evaporation when a furnace type source is used. Vapourization is a surface effect and when it takes place from the liquid state the lighter isotope (Mass M_1) is favoured in the vapour phase by a factor $(M_2/M_1)^{\frac{1}{2}}$. Until such time as a steady state is reached, vapourization takes place at a greater rate than mixing within the sample. There is, therefore, an isotope effect which gives rise to mass discrimination. If such an effect exists isotope abundance ratios are found to change with time of heating.

Nier investigated the abundance ratios for calcium in this respect, (4). He vapourized the calcium from the solid state and as would be expected, he found no change of the calcium isotope abundance ratios with time of heating. There is no appreciable mixing in the solid state and hence no change in the ratios with time.

For heavier ions this effect is less pronounced because with increase in atomic number there is a marked decrease in the factor $(M_2/M_1)^{\frac{1}{2}}$.

The furnace type source produces singly and multiply charged positive ions. This is an important factor in abundance ratio work. The presence of multiply charged ions permits the checking of relative abundances by the study of several different sets of ions for each sample analysed. With multiply charged ions, it is possible in general to make relative abundance measurements in a mass range free of residual ions.

Table 1 shows the solid samples which have been studied with mass spectrometers using furnace type positive ion sources. In all, thirty-three elements ranging in mass numbers from 7 to 238 have been vapourized from the liquid state or the solid state. Hygroscopic samples, samples which sublime and samples which decompose have been analysed successfully. The range of temperatures covered is from less than 200°C. to greater than 2000°C. Singly and multiply charged ions have been produced, although the latter have not been considered in every case. If obtainable in a suitable element or compound form having an appreciable vapour pressure at a temperature below 2000°C., any solid sample non volatile at ordinary temperatures may be analysed through the use of a furnace type positive ion source.

Filament Source.

The filament source employs a metal filament which may be a disc, tube, strip or helix, coated or impregnated with the sample. The passage of an electric current through this filament causes the

thermionic emission of positive ions, (17)...(27).

In order that the emission of positive thermions from a metal in vacuum be possible, the electron work function of the surface of the filament must exceed the ionization potential of the metallic sample with which the filament is coated or impregnated. The mechanism of thermionic emission is essentially the same as that of the formation of ions from vapour. In the case of thermionic emission the atoms to be ionized reach the surface by diffusion from within, a process which is enhanced by the heat of the filament. For positive ion emissions which are sufficiently steady to give reproducible values over a range of temperature the Richardson equation:

$$I = AT^2 e^{-b/T}$$

is found to hold. I is the saturation current per square centimeter of emitting surface. A is a universal constant, T is the absolute temperature and b depends upon the nature of the metal and the temperature. In general, positive thermions will be emitted from such samples if they are heated on suitable filaments to temperatures just less than their respective melting points, (38).

The lighter of two isotopes in a heated sample has the greater thermal velocity. Thermionic emission is a surface effect and if it proceeds from the liquid state, in which there is perfect mixing at the surface, the lighter isotope (mass M_1) is favoured in the vapour state by a factor $(M_2/M_1)^{1/2}$. If, however, the thermionic emission proceeds from the solid state, where there is no such mixing, this isotope effect is not detected, (21),(27). When a filament source

is used as a source of positive ions in mass spectrometer relative abundance studies, such an isotope effect would lead to mass discrimination.

Positive thermions are readily obtained from many salts. Most common salts emit positive ions when heated to about 700°C. The more electro-positive the metallic constituent of the salt the greater is the ion emission. The most mobile ion of the salt is found to be the one emitted, (38),(19). In the case of the lead halides only the negative halide ions are detected. Cd^{++} and Zn^{++} ions are emitted from CdI_2 and $ZnCl_2$. Investigations show that the positive ions emitted correspond in general to those formed during electrolysis of the salts. These are, in the case of CdI_2 and $ZnCl_2$, Cd^{++} and Zn . It is also known that, in thermionic emission from alkali metal salts, singly charged alkali ions attached to molecules of the salt are formed. That is to say, ionic and molecular evaporation proceed simultaneously, (38).

Ternary systems prove to be better thermionic emitters than do binary ones (17). This is because the ternary system is in all probability a three dimensional network of three different types of ions, - one of which floats in the "holes" characteristic of such networks. Therein, it is free to migrate to the surface and be emitted under the influence of a small potential. It has been established that such is the structure of the alkali aluminium silicates which have proven to be excellent emitters of alkali as well as aluminium positive thermions.

A good emitter should have an ionic lattice with the ions being held in the lattice by small forces only (17). Otherwise, the

compound should be thermally stable in order that available energy can be concentrated to break down the ionic lattice. If there is an absence of lattice structure of any kind, as is the case with metals, ideal vapourization may be realized.

Table (2) shows the samples which have been studied mass spectrometrically, using filament type sources. The elements investigated are mainly alkalis or alkaline earths. All of these elements with the exception of Al, Ce, Y, and V have been studied through the use of furnace type sources. A serious disadvantage of the thermionic emission or filament source is the absence of multiply charged ions in the majority of cases (17).

Spark Source.

The spark sources reported in the scientific literature are of two kinds. First, there is the Dempster Spark Source (29). In this positive ion source a high frequency oscillating spark is inductively coupled to two electrodes one or both of which may be the element or a compound of the element to be investigated. This nature of source is powerful. It will produce ions with platinum and gold, elements which are ionized with great difficulty by any means. Singly and multiply charged ions are produced. Secondly there is the discharge tube containing an inert gas. A high voltage discharge gives rise to positive ions of the cathode material or of the sample placed in the well of the cathode. The inert gas helps maintain the discharge across the tube. This source has been used effectively in spectroscopy for a number of years. It too is quite efficient (28)...(37).

Table (3) shows the elements which have been studied with mass spectrographs using one or other of these types of sources. This nature of source does not lend itself favourably to mass spectrometer work.

It produces multiply charged ions which, enroute to the focussing field, may change their charges, thus giving rise to spurious ion currents. Also there is the problem of shielding the ion current collector as well as the extremely sensitive D.C. ion current amplifier from the effects of the fluctuating fields set up by either of these ion sources. Finally a spark type source does not give rise to an ion current of constant magnitude. This is not serious in isotope detection work as done with mass spectrometers and spectrographs but it does make precision relative abundance measurements impossible.

EXPERIMENTAL

Apparatus

The mass spectrometer used is of a 90° sector type (39). Figure 2, (c) and (d) shows the small electrically heated furnace in detail. The 0.040" nickel sleeve, when loaded with a sample, is closed at each end with a nickel plug. A small hole is pricked at the centre of the loaded sleeve which is then spot welded to the lower terminals of the two small press seals held in place on the lid of the furnace with a spring clamp and screw (Fig. 2,d). Care is taken to have the hole in the sleeve opening downward. The lid is secured to the furnace by two small screws. With the pyrex cap of the source end of the mass spectrometer tube envelope removed, the loaded furnace may be lowered into place on the "A" plate of the source plate assembly (Fig. 1), (Fig. 2,d). Two studs on the "A" plate (Fig. 2,a) determine the position of the furnace.

Figure 1 shows the furnace mounted in such a manner that emergent vapours pass directly into the ionizing chamber of the source. The nickel sleeve acts as the heating element of the furnace. Power is brought to the loaded sleeve through 0.040" copper leads joining the upper terminals of the small press seals (Fig. 2,d) to a two wire press seal in the source end of the mass spectrometer tube envelope.

Power for the furnace is supplied by the output of a low voltage transformer (Hammond 1154), fed from a 25 cycle, 115 volt power line through two Variacs connected in series. The lower portion of the furnace projects through the two in order that there be no electrostatic disturbance of the ion accelerating potential or the ionizing electron beam by the A.C. supply of the furnace. One end

of the furnace heating element is connected electrically to the "A" plate. The furnace, therefore, floats at the accelerating potential level and as a result must be well insulated from ground. Variacs being autotransformers do not provide this insulation whereas the low voltage output, high voltage insulation transformer does. The series Variacs permit coarse and fine adjustment of the furnace temperature.

Residual gases in the mass spectrometer tube do not in general interfere unless they give rise to ions in the mass range to be studied. However, if the pressure due to residual gases is too great, serious scattering of the ion beam and hence poor resolution will result. Following an analysis the furnace box is thoroughly cleaned. Also the nickel sleeve and plugs are discarded and a new assembly employed for each consecutive sample. These precautions eliminate the possibility of contamination by previous samples. The mass spectrometer tube envelope is wound with a heating element for "baking" purposes. The tube may thus be kept at temperatures up to 400°C. for any desired "baking" period. There is a pyrex cap at the source end joined to the main envelope by a 50/50 ground glass joint using Apiezon black vacuum wax at the interface. A moistened towel keeps the temperature of the Apiezon wax below its melting point and so maintains a vacuum seal at the ground glass joint during "baking". If the pressure due to residual gases in the tube is low and the mass range in question is free of residual ions, the "baking" process may be omitted. It is necessarily omitted when the temperature involved is sufficient to cause the vapourization of the sample. In this case, it is necessary to evacuate the tube without "baking" to a pressure where scattering of the ion beam due to residual gases is negligible. Before each analysis the instrument is checked for residual ion currents due to tube contamination or residual gases.

Ions of different masses are brought to a focus on the collector by varying the current through the coils of the focussing electromagnet. The ratio of the potential between "A" and "J" to that between "A" and "C" is constant for all values of the accelerating potential "A" to "C" (Fig. 1). This arrangement reduces the analyzer mass discrimination to a minimum (46,47) for those cases where it is necessary to use different accelerating potentials in order to study the isotopes of a particular element in several mass range. e.g., U^+ , UCl^+ , UCl_2^+ , UCl_3^+ , and UCl_4^+ .

RESULTS

Uranium Tetrachloride.

A sample consisting of 15 milligrams of UCl_4 was placed in the furnace and the mass spectrometer tube was thoroughly "baked". Steady ion currents of the order of 10^{-13} amperes corresponding to U^+ were obtained continuously over a period of six hours. Poor resolution persisted for all settings of accelerating and focussing variables. This was attributed to the fact that considerable scattering was taking place. This scattering was probably due to the degassing of the UCl_4 . Good resolution was obtained with a similar sample which had been desiccated before being placed in the furnace. A value of $138 \pm 3\%$ for the ratio U^{238}/U^{235} was calculated from U^+ ion current measurements made on this sample. The results obtained with small samples (1 mg.) were unsatisfactory because of the difficulty in handling UCl_4 which is hygroscopic. However, UCl_4 and other hygroscopic materials can be used if kept at all times in a desiccated atmosphere. It has been suggested that these hygroscopic compounds be prepared in the furnace after the system has been dried and degassed.

Uranium Tetrafluoride.

With milligram samples of UF_4 no ion currents corresponding to U^+ , UF^+ , UF_2^+ , UF_3^+ , or UF_4^+ were detected until the furnace attained relatively high temperatures. At these temperatures there were detected UF_2^+ , UF_3^+ and UF_4^+ ion currents which increased in magnitude as the furnace temperature was raised but disappeared completely before becoming large enough to permit accurate measurements being made. After several such samples had been tested it became obvious that the accelerating potential was being shorted out. Either excessive heat from the furnace

or sample condensation caused the pyrex spacers of the source plate assembly to become conducting. This placed a high resistance short circuit from "A" to "C" (Fig. 1) thereby changing the accelerating potential value and causing the disappearance of the ion currents.

Cuprous Chloride.

Copper isotope abundance measurements were made on two samples of CuCl from the same source (Merck Reagent). Steady and well-resolved Cu^+ ion currents of 10^{-12} - 10^{-13} ampere magnitude were recorded graphically with a Leeds and Northrup Speedomax recorder. From this data $\text{Cu}^{63}/\text{Cu}^{65}$ isotope abundance ratios were measured. Table 4 gives the results of these measurements:

Table 4

Copper Isotope Abundances

<u>Sample</u>	<u>Ion Studied</u>	<u>$\text{Cu}^{63}/\text{Cu}^{65}$ Ratio</u>	<u>Precision</u>
Merck Reagent CuCl	Cu^+	2.293	± 0.002
" " "	"	2.294	± 0.001

Average 2.294 \pm 0.002

Each abundance ratio represents the average value calculated from eight pairs of Cu^{63} and Cu^{65} ion current peaks as recorded by the Leeds and Northrup Speedomax. (Table 5) shows the copper isotope abundance ratios as determined by other investigators.

Table 5

Copper Isotope Abundance Ratios

Investigator		$\text{Cu}^{63}/\text{Cu}^{65}$ Ratio
Inghrem	(48,49)	2.235 ± 0.010
Dempster	(50)	2.229 ± 0.033
Cameron and White	(1)	2.220 ± 0.020
Ewald	(51)	2.330 ± 0.030
Duckworth and Hogg	(52)	2.277 ± 0.017
This work		2.294 ± 0.002

Average 2.264

DISCUSSION

Other experimentors have reported similar difficulties in connection with small samples of hygroscopic substances such as UCl_4 . To obtain 10^{-13} ampere ion currents from UF_4 , a temperature above that at which the furnace can operate satisfactorily is necessary. Others have reported similar difficulties concerning the operation of ion sources at high temperatures (1)...(16). In each case the maximum temperature is different depending on the nature of the source. Samples, such as $CuCl$, which are not hygroscopic and have appreciable vapour pressures below $1000^{\circ}C$ are easily handled and investigated mass spectrometrically. Although the precision of the copper abundance measurements is better than ± 0.1 percent the absolute accuracy is probably no better than ± 1.0 percent.

The furnace used is capable of producing ion currents of sufficient magnitude for the mass spectrometric analyses of any sample which melts, decomposes or sublimes, provided the sample has a vapour pressure of 10^{-3} mm. in the liquid or solid state at a temperature in the range $50^{\circ} - 950^{\circ}C$. If arrangements are made to load and mount the furnace in a desiccated atmosphere, hygroscopic samples may also be studied.

TABLE (1)

<u>Sample</u>	<u>Ion Studied</u>	<u>Vapour Pressure (in mm)</u>	<u>Temperature at which vapour pressure determined (in C°)</u>	<u>Melting Point (in C°)</u>	<u>Boiling Point (in C°)</u>
AgCl (1)	Ag ⁺	3.7	882	455 ^X	1550 ^X
Ba (2)	Ba ⁺	10 ⁻³	701.1	850	1140
Be (3)	Be ⁺	7.6 x 10 ^{-4.5}	1077 (53)	1350	1500
Ca (4)	Ca ⁺	10 ⁻³	529	810	1170
Cb (5)	Cb ⁺			1950	2900
Ca (6)	Ca ⁺	10 ⁻³	219.1	312	767
CaI ₂ (7)	Ca ⁺ , CaI ⁺ , CaI ₂ ⁺			388	713
CaCl ₂ (1)	Ca ⁺	3.0	618	568	960
Co (5)	Co ⁺	10 ⁻³	1254	1480	3000
CoCl ₂ (8)	Co ⁺ , CoCl ⁺			subl.	1049
CrCl ₃ (1)	Cr ⁺				subl. 1300
Cu (3)	Cu ⁺	10 ⁻³	1320	1083	2300
Cu ₂ Cl ₂ (1)	Cu ⁺ , CuCl ⁺	1.0	500 (40)	422	1366
Fe (9,11)	Fe ⁺	1.0	1884	1535	3000
FeCl ₂ (1)	Fe ⁺			670	subl.
Ge (5)				1900	

TABLE (1), page 2.

Sample	Ion Studied	Vapour Pressure (in mm)	Temperature at which vapour pressure determined (in C°)	Melting Point (in C°)	Boiling Point (in C°)
In	In ⁺	7.7 x 10 ⁻⁴	815 (41)	150	1450
InCl ₃	In ⁺			subl. 586	volat. 600
Ir				2350	> 4800
K	K ⁺	10 ⁻³	162.3	62.3	760
Li	Li ⁺	5 x 10 ⁻²	630 (42)	186	> 1220
LiAlCl ₄	Li ⁺				
Mg	Mg ⁺	10 ⁻³	576	651	1100
Mn	Mn ⁺ , Mn ⁺⁺ , Mn ⁺⁺⁺	10 ⁻³	861	1260	1900
Mo	Mo ⁺	10 ⁻³	2293	2620	3700
Mo(CO) ₆	Mo ⁺			d. 150	
Ne	Ne ⁺	10 ⁻³	238	97.5	880
Ni	Ni ⁺	10 ⁻³	1250	1773.5	4300
NiCl ₂	Ni ⁺			subl.	973
PbCl ₂	Pb ⁺ , PbCl ⁺	1.7 x 10 ⁻³	400	501	950
PbI ₂ (14,15)	Pb ⁺ , PbI ⁺ , PbI ₂ ⁺	10 ⁻²	300 (43)	402	954
Pd				1553	2200

TABLE (1), Page 3

Sample	Ion Studied	Vapour Pressure (in mm)	Temperature at which vapour pressure determined (in C°)	Melting Point (in C°)	Boiling Point (in C°)
Pt	(5)	10 ⁻³	2080	1455	2900
Rb	(6)	0.75	306 (44)	38.5	700
Re ₂ O ₇	(1) Re ⁺			c.s. 220	subl. 450
Rh	(5)			1985	> 2500
Sb	(1) Sb ⁺	1.0	818	630	1380
SnCl ₂	(1)			246	623
Sr	(2,5) Sr ⁺	10 ⁻³	713.4	800	1150
TlF ₃	(4) TlF ₃ ⁺			d. 400	
Tl	(2) Tl ⁺	10 ⁻³	412.7	302	1457
UBr ₄	(16) U ⁺ , UBr ⁺				volat.
UCl ₄	(16) U ⁺ , UCl ⁺			subl.	618
W(CO) ₆	(12) W ⁺			d. 400	
Zn	(6)	10 ⁻³	296.3	419.4	907
ZnI ₂	(7)			446	624

All melting and boiling points and all vapour pressures with their temperatures, unless otherwise indicated, are taken from: Handbook of Chemistry and Physics, Chemical Rubber Pub. Co., 31st Ed., 1947.

TABLE (2)

<u>Sample</u>		<u>Ion Studied</u>	<u>Temp. in °C</u>	<u>Filament</u>	<u>Manner in Which Thermionic Source Prepared</u>
Al_2O_3	(17)	Al^+	1500	tungsten helix	coated with sample-water binder
BaO	(18)	Ba^+		tungsten	coated with sample
$(BaO)(Al_2O_3)(SiO_2)$	(17, 23)	Ba^+		tungsten helix	coated with sample-water binder
CaO	(30)	Ca^+		platinum	coated with sample
$(CaO)(Al_2O_3)(SiO_2)$	(17, 19)	Ca^+		tungsten helix	coated with sample-water binder
Ce_2O_3	(21)	CeO^+	1000	tungsten	coated with cerium in nitric acid solution converted to CeO_2 by application of heat prior to emission.
Ce_2O_3	(17)	CeO^+		tungsten helix	coated with sample-water binder
Cr	(9)	Cr^+	1200	tantalum	furnace containing small amount of Cr metal.
Fe	(22)	Fe^+		platinum	wire electroplated with sample
Ga_2O_3	(23)	Ga^+	1800	platinized tungsten	coated with sample
"	(17)	Ga^+	1800	tungsten helix	coated with sample-water binder
In_2O_3	(17, 18)	In^+	900	tungsten	coated with sample
"	(23)	In^+		platinum foil	" " "
K	(24, 28)	K^+		tungsten	nitrates of K and Fe fused, ignited and reduced in H_2 then pounded in grooves of a MgO tube surrounded by a helix.
$(K_2O)(Al_2O_3)(SiO_2)$	(26)	K^+		platinum	coated with sample
La_2O_3	(21)	LaO^+	1000	tungsten	coated with sample in nitric acid solution.

TABLE (2), cont'd.

<u>Sample</u>		<u>Ion Studied</u>	<u>Temp in °C</u>	<u>Filament</u>	<u>Manner in Which Thermionic Source Prepared</u>
Li	(27)	Li ⁺	760	platinum disc	impregnated with sample
(Li ₂ O)(Al ₂ O ₃)(SiO ₂)(19,26)		Li ⁺		platinum strip	printed with sample-water binder
" " "	(17)	Li ⁺		tungsten helix	coated with sample-water binder
(MgO)(Al ₂ O ₃)(SiO ₂)	(19)	Mg ⁺		platinum strip	printed with sample-water binder
" " "	(17)	Mg ⁺		tungsten helix	coated with sample-water binder
MnO	(17)	Mn ⁺		tungsten helix	coated with sample-water binder
Na ₄ P ₂ O ₄	(20)	Na ⁺		platinum	coated with sample
Rb	(27)	Rb ⁺	600	platinum disc	impregnated with sample
(Rb ₂ O)(Al ₂ O ₃)(SiO ₂)	(26)	Rb ⁺		"	" " "
SrO	(18)	Sr ⁺		tungsten	coated with sample
(SrO)(Al ₂ O ₃)(SiO ₂)(17,23)		Sr ⁺		tungsten	coated with sample-water binder
Ti ₂ O ₃	(17)	Ti ⁺		tungsten	coated with sample-water binder
V ₂ O ₃	(17)	V ⁺		tungsten	coated with sample-water binder
Y ₂ O ₃	(17)	Y ⁺		tungsten helix	coated with sample-water binder.

TABLE (3)Samples Studied with Mass Spectrograph using Spark Source

<u>Element</u>		<u>Nature of Spark Source Employed</u>
Al	(29)	Inductively coupled H.F. oscillating spark between 2 Al electrodes.
Al	(30)	Aluminum cathode in neon discharge tube.
Au	(29) (34)	Inductively coupled H.F. oscillating spark between gold electrodes - i.e. "Dempster Spark Source".
Be	(29)	Dempster Spark Source - Be electrodes.
Cd	(30) (31)	Cd cathode in neon discharge tube. Cd in well in cathode of discharge tube.
Ce	(32)	Dempster Spark Source - Nickel tubes with oxide of cerium and reducing agent as electrode.
Cu	(29)	Dempster Spark Source - Copper electrodes.
Dy	(32)	Dempster Spark Source - Nickel tubes with oxide and reducing agent as electrodes.
Er	(32)	Dempster Spark Source -- "
Gd	(32)	Dempster Spark Source -- "
Hf	(33)	Dempster Spark Source - Nickel tubes of the metal and its oxide as electrodes.
Li	(29)	Dempster Spark Source - Li electrodes.
Lu	(33)	Dempster Spark Source - Oxide plus tantalum in nickel tubes as electrodes.
Nd	(32)	Dempster Spark Source - Nd electrodes.
Ni	(29, 35)	" - Ni electrodes.
Pd	(34)	" - Pd electrodes.
Pt	(29)	" - Pt electrodes.
Sa	(32)	" - Oxide and reducing agent in nickel tubes as electrodes.
Se		Se in well of cathode in discharge tube.
Sn	(29)	Dempster Spark Source - Sn electrodes.
Ta	(33)	" - Ta electrodes.
Te	(36)	Te in well of cathode in neon discharge tube.

Table (3). cont'd.

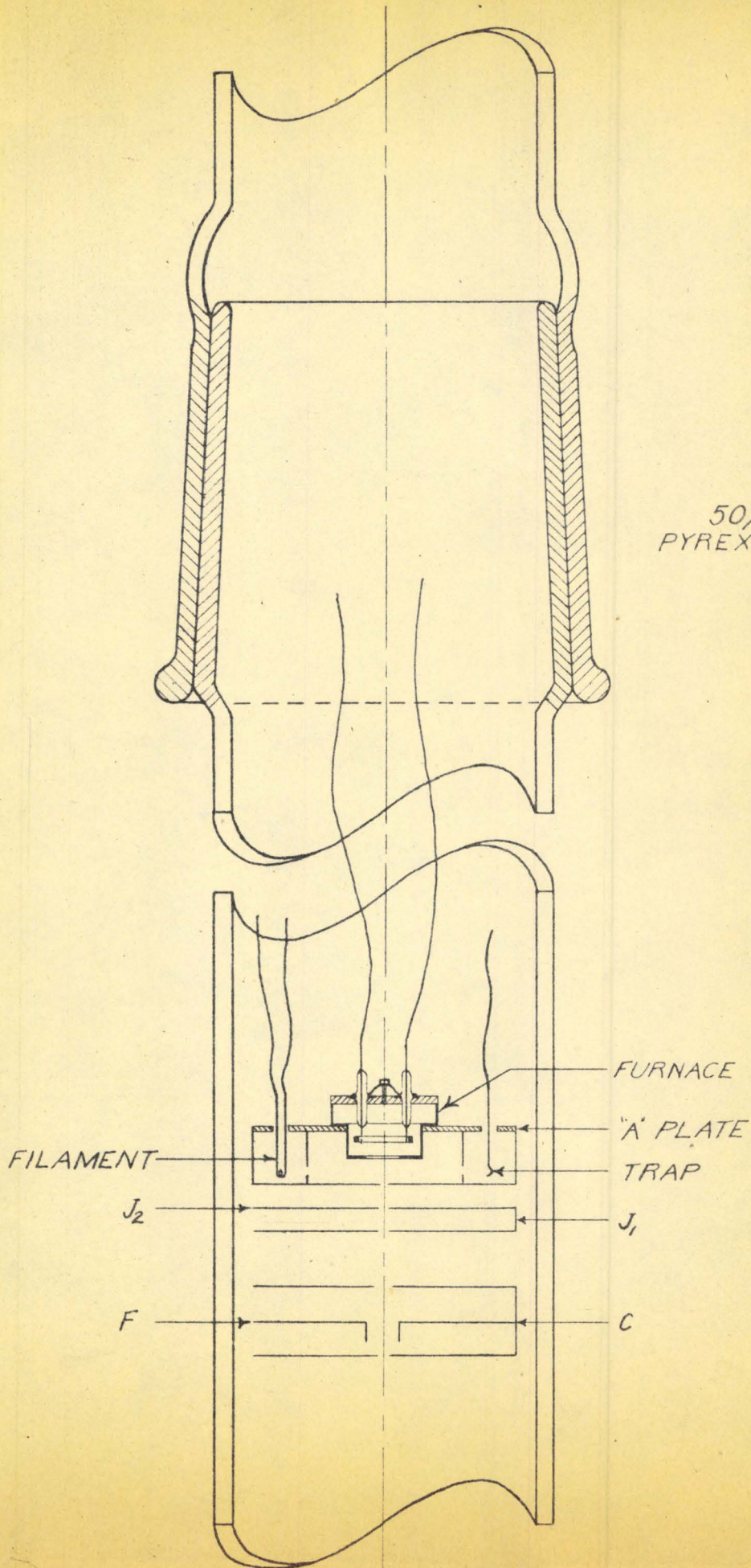
<u>Element</u>		<u>Nature of Spark Source Employed.</u>
Th	(37)	Dempsters Spark Source - Sn and Th electrodes.
U	(37)	" - Au and U electrodes.
W	(29)	" - W electrodes.
Y	(33)	" - Mixture of Yttrium oxide and lanthanum metal as electrodes.
Yb	(32)	Dempster Spark Source - Oxide plus reducing agent in nickel tubes as electrodes.
Zn	(30)	Zn cathode in neon discharge tube.

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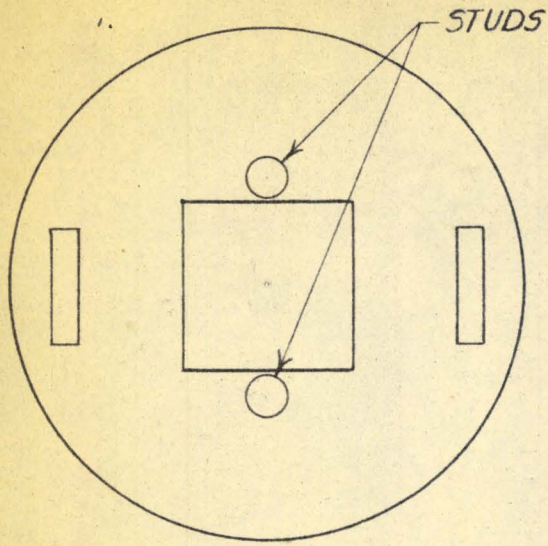
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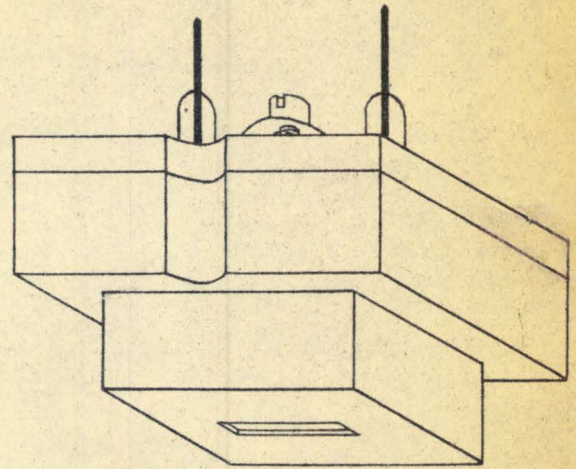
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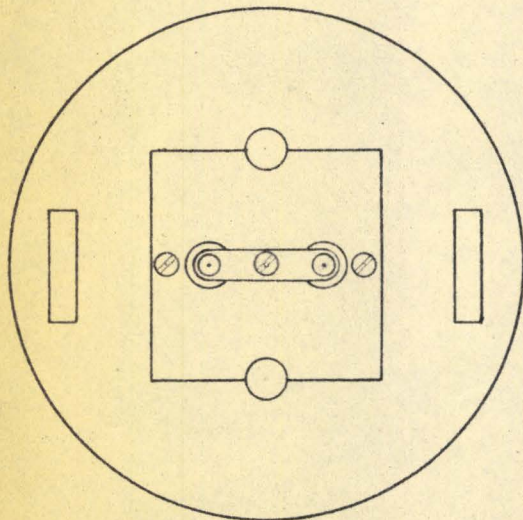
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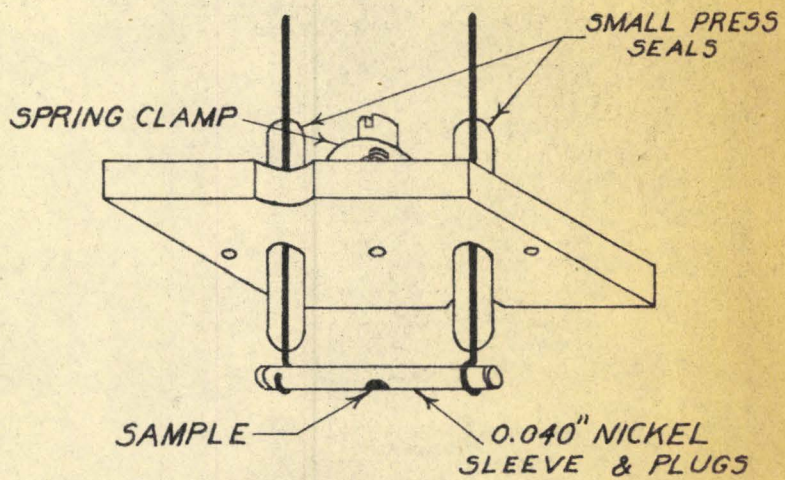
(a) TOP VIEW OF "A" PLATE



(c) ASSEMBLED FURNACE



(b) "A" PLATE WITH FURNACE MOUNTED



(d) INTERNAL VIEW OF FURNACE

FIG. 2