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A Vacuum Ultraviolet Source

by

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ABSTRACT

A low inductance three-electrode spark source for
the vacuum ultraviolet fed by a 20 kV, 13 μf capacitor
is described. Its main feature is its ability to generate
spectra of very high degrees of ionization. A 6 kV spark
produces spectra of C V and C VI as well as Fe XVI while
a 17-18 kV spark yields Fe XVIII, Al XII and Al XIII.

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I   INTRODUCTION

During the last decade advances in solar physics and in plasma physics have contributed to an increased interest in the spectroscopy of the far ultraviolet. In order to generate spectra of highly ionized atoms some powerful new sources have been developed: the NRL's Pharos[1], Los Alamo's Scylla I[2], Harwell's Zeta[3], etc., machines which were designed to produce hot plasmas. A useful source that has been developed from this work is the theta pinch[4]. A laser beam has also been used to generate highly ionized atoms[5]. Common to these new sources are complexity and high cost, precluding their use in an ordinary spectroscopy laboratory. In this article we describe a three electrode spark[6] version of the traditional high voltage spark source. It has the capability of producing spectra comparable to the sources mentioned above as well as spectra of low degrees of ionization. The main features of this arrangement are a comparatively low voltage with high capacitance and very low inductance.

II   THREE ELECTRODE SOURCE

For a pair of electrodes in vacuum the breakdown voltage for a separation of about 1 mm is 50 kV or more. It is possible to lower the breakdown voltage in a variety of ways. One such way is to provide an insulating surface between the

electrodes along which breakdown can occur - the so-called "sliding spark"[7]. Low voltage breakdown across gaps as large as a few centimeters are possible with this method. Another way is to inject charge carriers in the electrode gap to initiate a discharge. The three-electrode arrangement combines these two ideas. A third electrode is separated from the ground electrode of the spark gap by a ceramic insulator. At a predetermined time in the high voltage charging cycle a sliding spark is caused to occur along the ceramic, triggering the breakdown across the gap of the main electrodes. The nature of the sliding spark circuit is immaterial to the spectral characteristics of the main discharge. In our arrangement a Tesla coil is used, but a capacitor discharge circuit would work just as well.

We assume a series R-L-C circuit, (Fig. 1.) where C is the capacitance of the energy storage capacitor, R is the resistance, and L the inductance of the circuit including the spark gap. For the transient case of an R-L-C circuit excited by the discharge of the initial energy stored in element C, it can be shown[8] that

$$N = e^{-2\pi\alpha/\omega}$$

where N is the ratio of two consecutive maxima of the underdamped (oscillator) current $i(t)$, $\alpha = R/2L$, and $\omega = \left(\dfrac{1}{LC} - \dfrac{R^2}{4L^2} \right)^{\frac{1}{2}}$
The time separation of these maxima is $\Delta t = 2\pi/\omega$. From oscillograms made of the discharge (fig. 2) we have been able to

measure Δt and N. Since Δt and N are functions of R, L
and C, with C known, it is possible to solve for R and L.
Using our 13µf capacitor we found for our circuit R $= 13 \times 10^{-3} \Omega$
and L $= 160 \times 10^{-9}$ henry. A typical voltage of 18 kV would
produce, therefore an I_{max} of about 150,000 amperes.

III MECHANICAL DESCRIPTION

The chamber itself is constructed of stainless steel
(Fig. 2,3) and is roughly cube-shaped. The most important
characteristics however are its short path length to the
capacitor and the configuration of the electrode connections.
The energy storage capacitor is mounted a few inches below the
chamber and connects with the chamber via cylindrically sym-
metrical feedthroughs. The results is a circuit with neg-
ligible resistance and low inductance. The insulators have
been designed to withstand up to 50 kV although we have not
yet found it necessary to even approach this limit in order
to get the spectra we are interested in. The chamber connects
with the auxiliary pumping system via a port in its left side.
The top and right side of the chamber are fitted with ports
that are used for gauges, additional electrodes, test probes,
etc. The front plate which exposes the inside of the chamber
for changing electrodes, contains a cold trap and a window for
observation during operation. A thin gate valve separates the
chamber from the spectrometer, and another valve separates it
from the pumps. This enables us to isolate the chamber and

change electrodes or otherwise service the inside of the
chamber without breaking vacuum in the spectrometer.

IV   RESULTS

By operating the source at 12-18 kV we have recorded
spectra of the Na I, Ne I and F I isoelectronic sequences
for elements from scandium to zinc, in the wavelength range
of 8 Å to 60 Å.

Spectra of Al XII and XIII down to 6 Å were produced
with a 17 kV discharge. Voltages as low as 6 kV produce
spectra of C V and C VI between 26 Å - 40 Å. It is possible
to distinguish between the different degrees of ionization
by comparing spectrograms taken at different voltages. In-
creasing the voltage increases the intensities of the higher
degrees with respect to the lower degrees of ionization. For
instance, in iron the highest degree of ionization for a 6 kV
spark was found to be Fe XVI, for 12 KV Fe XVII was the
highest degree observed, and for 18 kV, Fe XVIII and probably
higher degrees of ionization were recorded. Increasing the
inductance by very small amounts would tend to emphasize
lower degrees of ionization.

All of the spectrograms were recorded on Kodak SWR plates
using a modified Jarrell-Ash, 3 meter, 88° angle of incidence
spectrometer, using a B&L 1200 ℓ/mm blazed gold replica
grating[9]. The number of sparks necessary to produce strong

spectrograms was from fifty to one hundred.

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Figure 1 - Schematic diagram of the discharge circuit,
where PS is the power supply, R_{ch} and L_{ch} are
the resistance and inductance of the charging
circuit, respectively, C is a $13\mu f$ - 20 kV
capacitor. L_1 is the inductance of the capac-
itor, and L_2 is the inductance of the transmis-
sion line and the chamber.

Figure 2 - Front view of the spark chamber with the cover
removed. Visible to the rear of the chamber are
the entrance slit housing, and the gate valve
that isolates the chamber from the spectrometer.
The arrow indicates the direction of the chamber
pumbing system. Ports in the top and side accomo-
date vacuum gauges and the electrical connection
to the Tesla coil circuit. The positive conductor
from the capacitor enters the chamber axially
through the Delrin insulator. The removable
electrode holder and the electrode are just visi-
ble in the window of the cap which is part of the
negative (ground) conductor. The negative conductor
is concentric with the positive conductor and also
enters the chamber through the Delrin insulator.

The cap is removable and contains the negative electrode, concentric ceramic insulator, and the trigger electrode that is energized by a Tesla coil. The chamber dimensions are approximately 7" x 8" x 7".

Figure 3 - Side view schematic diagram of the spark chamber and capacitor. Omitted from the diagram for the sake of clarity are ports in the top and side and the cold trap which is part of the removable cover. The cross-section of the chamber is approximately 7" x 7". The capacitor is not drawn to scale.
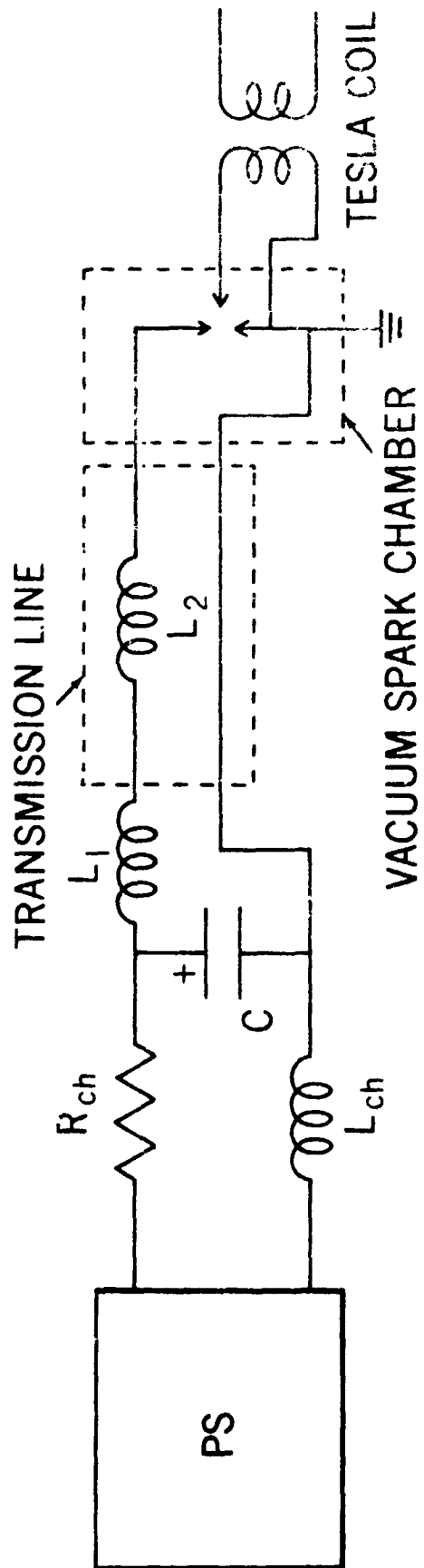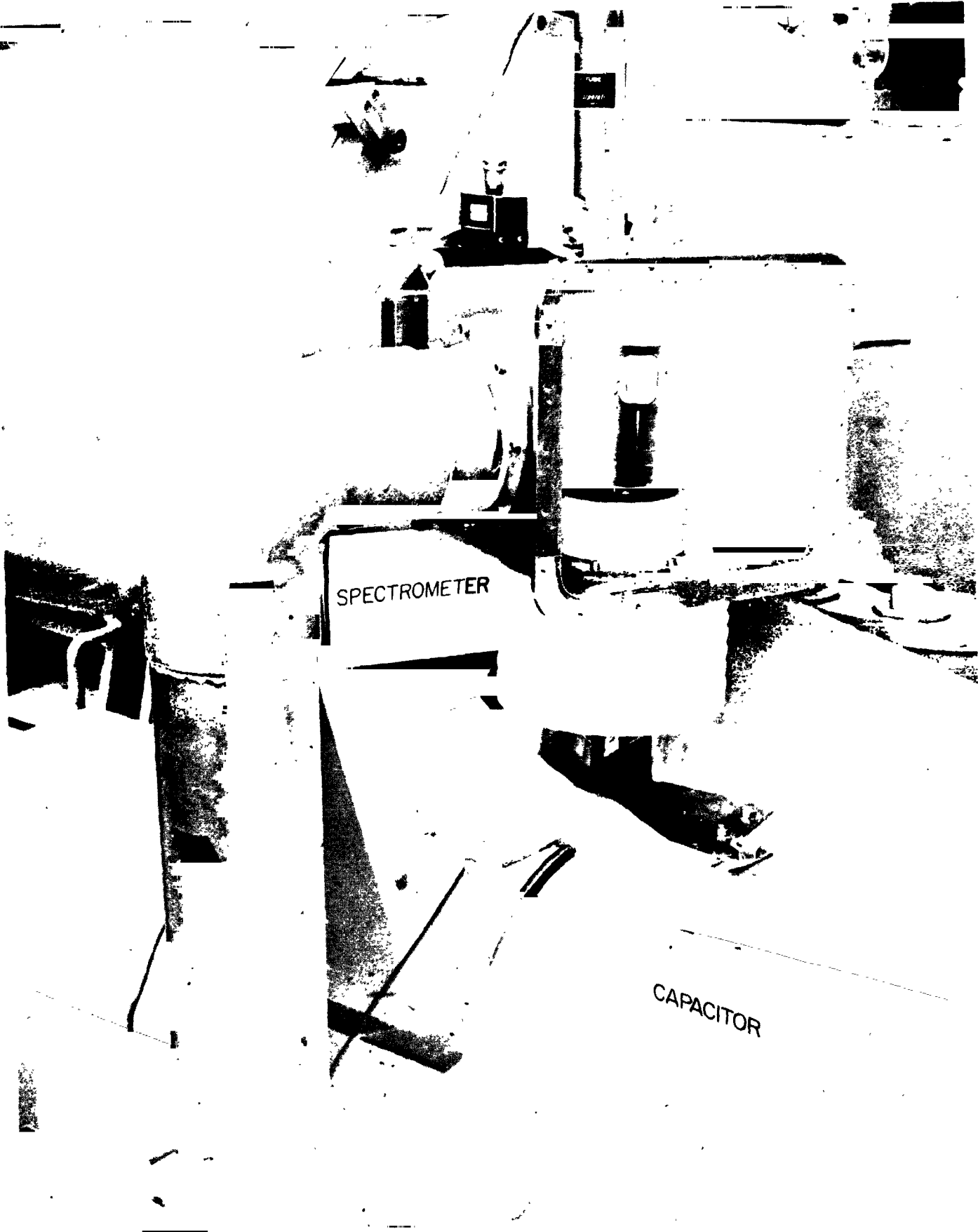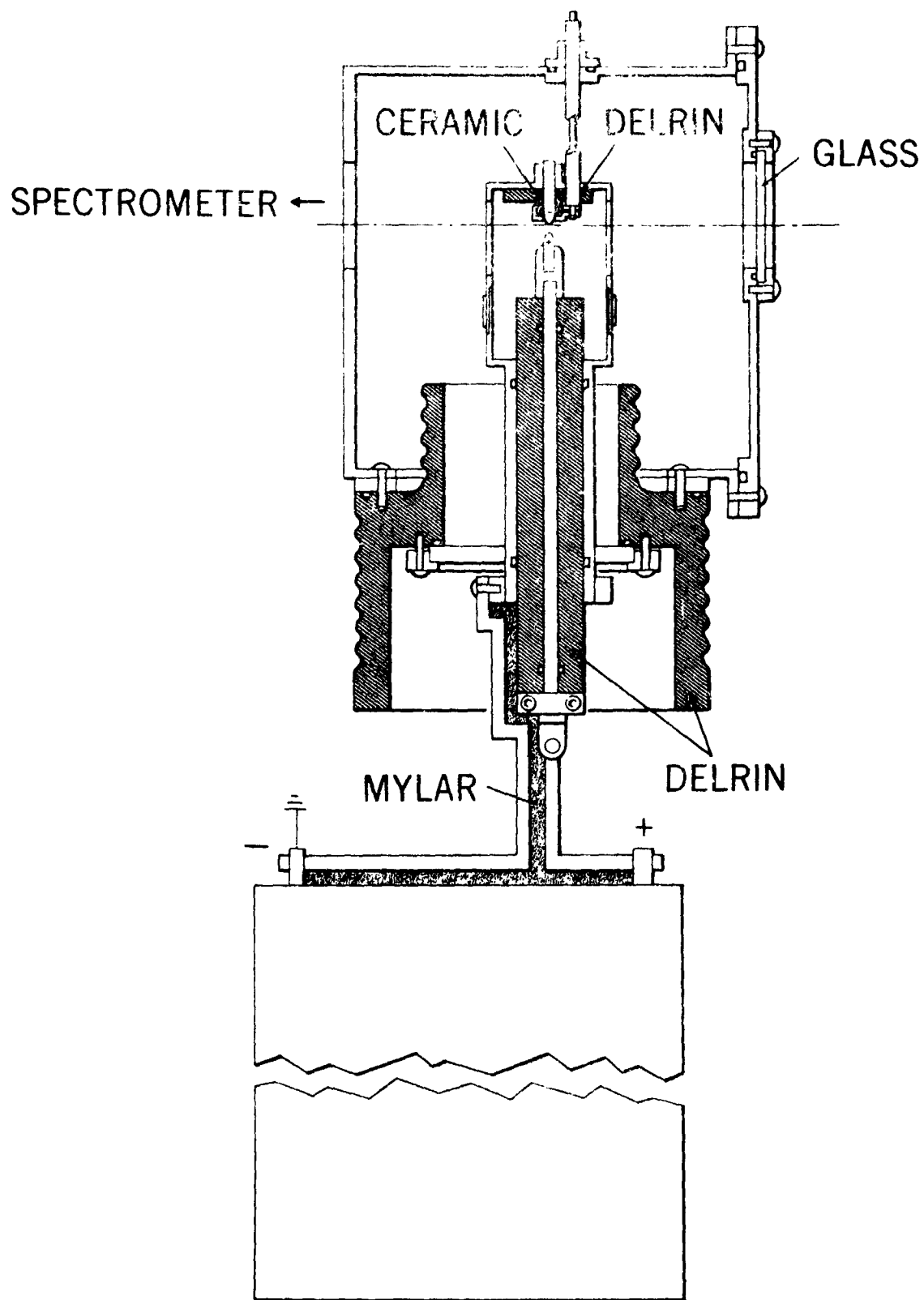
FIGURE 1

SPECTROMETER

CAPACITOR

FIGURE 2
- 11 -

FIGURE 3