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Extent of the continuous spectrum emitted by exploding wires

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THE EXTENT OF THE CONTINUOUS SPECTRUM
EMITTED BY EXPLODING WIRES
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EMITTED BY EXPLODING WIRES

by

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There are certain branches of Physics in which a simple method of producing continuous spectra is of great importance. Continuous Spectra (with absorption lines and bands) exist in the star spectra and direct comparison with these is often desirable. However, the most valuable use for continuous spectra in the terrestrial laboratory is in the study of absorption spectra. An absorption spectrum is created by the absorption of energy used to excite atoms and/or molecules from the normal (i.e. lowest energy) state. This is, of course, under normal laboratory conditions. This gives a direct method of determining the lines whose final (in emission spectra) level is the normal level. Most of such lines for the elements and the more common compounds lie in the region of the spectrum below 2000 Å.

At present, there are two practical laboratory methods of producing continuous spectra in the region below 2000 Å. 1) A discharge tube containing Helium\(^1\) will emit such a spectrum if excited sufficiently by electrical means. This method is seriously limited in use since the limits of the continuous spectrum so emitted are about 600 Å to 1400 Å. 2) The passage of a very heavy current through a capillary tube will produce a much more extensive continuous spectrum.\(^2\) The drawback to this method is that the heavy current enlarges the inside of the
capillary so that after a few discharges it becomes too large and must be replaced. There is the additional danger of too high current density with an attendant shattering of the capillary and, occasionally, other parts of the equipment.

A third possible method for exciting continuous spectra in the extreme ultraviolet is the exploding of fine wires by the passage of a relatively large amount of electricity thru them in a short period of time. This procedure was investigated by Anderson and Vandervelde who studied the visible and near ultraviolet spectra emitted by these exploding wires. Using a capacitor of .4 mfd charged to a potential of 25,000 volts, Anderson found a continuous spectrum extending from 2250 A. to 5700 A. In this case approximately 50 calories of energy are dissipated in $10^{-5}$ seconds, in a wire weighing 2 mg. It is calculated that the brightness of this discharge is 100 times the brightness of the solar surface. It is in this that suggests that one explosion might give a satisfactory exposure on the photographic plate and make the new method practicable.

EXPERIMENTAL PROCEDURE

ELECTRICAL CIRCUIT: The electrical circuit used in this investigation is quite similar to that used by Anderson in his work. (See Plate I) The transformer, $T_1$, is a 25,000 volt Thordarson transformer. The resistance, $R_1$, was placed in the primary circuit in order to retard the charging rate of the
capacitor for better control. $R_2$, in the primary of the filament transformer is for the same purpose but may not be necessary in all instances. The capacitor, $C_2$, is actually 8 .125 mfd capacitors in parallel, totalling 1 mfd.

The spark-gap is enclosed in a box and is adjustable, one electrode being threaded and insulated from a handle for this purpose. There is a scale external to the box for ease in setting.

The entire electrical circuit, particularly the secondary, is closely spaced to reduce both resistance and inductance. For the same reasons, nearly all secondary conductors are aluminum or copper bands. (See Plate III) The inductance is of particular importance and must be kept to a minimum. The inductances shown (I) are placed in the circuit in series with the tube as a protection from the high charging current.

The principle of operation of the electrical system is as follows. The high voltage A.C. from the secondary of the transformer is rectified by the type 706A high voltage diode. This D.C. voltage is then applied across the capacitor, charging it. At a voltage determined by the length of the spark-gap the space between the electrodes breaks down electrically and the resistance becomes quite small due to the ionisation of the air. The current builds up rapidly to a high peak, probably to several thousands of amperes, instantaneous peak value. The small wire in the tube is heated to the vaporisation point and beyond so quickly that it is, in fact, an explosion. It is this heating
and consequent atomic excitation that is the source of the spectrum that is sought. Of course, there is an oscillatory current in the secondary circuit, its frequency being determined by the values of capacitance and inductance in the circuit. Probably most of the energy is expended in the first half cycle.

Assuming 20,000 volts as an average value of the voltage across the capacitor, it is calculated that there is a potential energy of about 90 calories stored in the capacitor at the moment of discharge.

THE DISCHARGE TUBE: There are several requirements that the tube must satisfy. It must have some facilities for fitting onto the Vacuum Spectrograph. It is advantageous to have a vacuum pump on the tube as well as on the spectrograph. The most important, and at the same time the requirement most difficult to satisfy, is that of simple access and ease of wire replacement.

Two general designs were tried. (Figs. 1 and 2) The first introduces the leads into the top of a vertical tube. The two electrodes, one straight and one "J" shaped are fastened on the leads so that a vertical gap is left for the small wire. The second design introduces the leads thru the sides of the tube, uses
straight vertical electrodes and a horizontal gap. The first
design is hard to lead and the second is structurally weak. The
final design incorporates the good features of both the previous
designs. (See Plates II and III) The leads are introduced through
the top of the tube, as in the first design, but the gap remains
horizontal. The most important feature of the tube is that it is
constructed from a large standard taper. This is the seal between
the top and the bottom of the tube, allowing simple disassembly
for replacement of the wire. There is also a small standard
taper on the vacuum line to facilitate complete removal of the
tube from the system for cleaning and repair. There is one
feature of the electrode construction that is not apparent from
the two Plates. The holes for the insertion of the leads are
drilled about 25 mm deep to allow for the adjustment of the
electrodes so that the wire may easily be centered on the slit
in the spectrograph. Both the electrodes and the wire are
held in place by set screws.

THE VACUUM SYSTEM: There are two complete evacuating systems,
one connected with the relatively large volume of the spectro-
graph, the other with the smaller volume of the tube. The former
is a two stage mercury diffusion pump backed up by a Cenco Hysac
mechanical pump. The evacuating system connected with the tube
is a single stage diffusion pump backed by another Cenco mecha-
nical pump. Two McLeod gauges, one for each system indicate the
degree of vacuum.

THE VACUUM SPECTROGRAPH: The Vacuum Spectrograph was de-
signed by C. B. Jepeson and was constructed by the instrument
shop at the University of California Physics Department. The concave grating was ruled at the Johns Hopkins University shop. It is of glass with 11,800 lines per centimeter. The focal length is 42 cm. Dispersion is about 10 A. per millimeter in the second order.

PROTECTION FOR GRATINGS: There is one more thing which should be mentioned. At the high vacuum that is required to prevent absorption of the wavelengths desired, the mean free path of the vaporized particles moving from the area of the explosion becomes long enough to endanger the grating unless precautions are taken. In order to keep from coating the grating with particles of the metal composing the wires being exploded the slit of the spectrograph is covered over with a piece of flourite whose limit of transmission is 1250 A. The rapid deposition on the flourite reveals need for this protection.

PHOTOGRAPHING THE SPECTRUM: It is first necessary to line up the wire to be exploded with the slit of the spectrograph. This may be accomplished by means of a small nichrome wire and a battery to make it glow. The glow may be seen easily through the window in the spectrograph and the proper adjustment made. The nichrome wire is then replaced with the wire of the proper material to be exploded and the photographic plate is placed in position. Several attempts with the use of iron and copper wires lead to no satisfactory results. The wire finally used is the grid wire (composition unknown) from a Type 6F 51 vacuum tube. This
wire is uniform, small enough to explode (0.120 mm) and easily available.

It is found necessary to prepare the system by pumping with the mechanical pumps for an hour or more in order to reach a high vacuum. This is probably due to air which has been absorbed by the various surfaces in the system. At the end of an hour the two diffusion pumps are turned on and a "sticking" vacuum is obtained before exploding the wire.

In order that the capacitor have the largest feasible charge before the wire is exploded it is a good procedure to separate the spark-gap electrodes more than the full voltage of the transformer will pass, in this case about one centimeter. After the passage of time, determined by experience, the adjustable electrode of the spark-gap is slowly adjusted to a smaller gap. At the critical gap length the capacitor discharges exploding the wire with a brilliant white light and considerable mechanical energy as evidenced by the vibration of the leads and electrodes within the tube.

RESULTS: It had been hoped that one explosion would furnish sufficient radiation to expose the plate to a practicable extent. It appears that, under the present situation, the radiation is not of sufficient intensity. It is found that from five to twenty explosions are necessary to get a printable plate.

It seems that Schumann film, prepared according to Hopfield and Appleyard, is not sensitive enough to give an exposure under these circumstances. As is well known, an ordinary film may be
sensitized to wavelengths below 2500 A, by coating the surface with a fluorescent material. Cenco Ryva Pump oil is highly fluorescent in the presence of ultraviolet radiation. It is diluted 20 parts of Benzol to one part of oil and the mixture is wiped onto the surface of the film with cotton. After exposure Benzol is used to remove the oil before development, which is done as usual for the type of film used.

A high speed panchromatic sheet film (Defender Arrow Pan) treated with an oil coating gives the spectrum shown in Fig. 3.

![Fig. 3](image)

It is noted that the spectrum seems to continue from the long wavelength region (2250 A) to the central image of the grating. This should not be, since the fluorite window used to protect the grating will not pass wavelengths shorter than 1250 A. It appears that there is some reflection from some portion of the interior of the spectrograph, the diffused light from which is sufficient to expose the panchromatic emulsion. It does appear, however, that the density of the deposit on the plate is heavier on the long wavelength end, suggesting that there may be a radiation in the extreme ultraviolet present.
Another exposure on a medium speed orthochromatic film (Eastman Verichrome) which has been oil treated gives the result shown in Fig. 4.

![Fig. 4](image1)

It appears then that this method of excitation of a fine wire does give a continuous spectrum extending at least to 1390 A. Further investigation might be undertaken to determine if it extends appreciably farther.

The exposure on the panchromatic film is 5 explosions and that on the orthochromatic film is 10 but the latter needs intensification of the plate to be printable.

![Fig. 5](image2)

Fig. 5 shows the visible spectrum of the explosion as taken with a prism spectrograph centered on the green line of Hg.

**SUGGESTIONS AND IMPROVEMENTS:** Although this method of excitation of a spectrum in the extreme ultraviolet does not at present appear of practical value because of the large number of explosions necessary to obtain a printable plate,
there are several things pertaining to the method that would bear
investigation. With regard to the electrical circuit, it is known
that there is considerable inductance still present in the second-
ary. The spark-gap could be redesigned and all leads kept
in a straight line and parallel. Higher potentials and capaci-
tance might be tried. The wire used here is chosen more or less
on the basis of availability. Other wires composed of materials
of higher melting points might be tried if they could be secured.
An appendix of possible materials is included. Smaller wires,
possibly of the order of .05 mm might be tried.

With regard to the film used, a more careful preparation
and aging of Schumann film might give sensitivity great enough
for its use, but the use of oil-coated film, particularly the
very high speed films now available, offers perhaps as great
sensitivity as any method. Along this line, the use of a Press
Ortho film (ASA 125 or more) with the minimum necessary exposure
(1 or 2 explosions) and a very careful treatment of all possible
reflecting surfaces inside the spectrograph might give results.
APPARATUS IN PLACE

CAPACITORS SHOWING INDUCTANCE REDUCING CONDUCTORS
<table>
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<th>Element</th>
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<td>Copper</td>
<td>1085</td>
<td>2310</td>
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<tr>
<td>Iron</td>
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<tr>
<td>Platinum</td>
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<td>4300</td>
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<td>Tungsten</td>
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<td>5900</td>
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<tr>
<td>Molybdenum</td>
<td>2620</td>
<td>3700</td>
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