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EXPLORATORY
ENERGY CONVERSION STUDY
of
PHOTON THERMIONICS

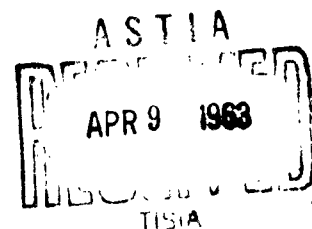
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Quarterly Technical Progress No. 2
Contract No. AF 33(657)-9202
Project No. 8173
Task No. 817305-18

February 1963

Aeronautical Systems Division
Air Force Systems Command
United States Air Force
Wright-Patterson Air Force Base, Ohio





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INTRODUCTION

Air Force Contract AF33(657)-9202 was initiated to conduct a research and development program to investigate the use of photon processes in thermionic converters. The objective is to determine the feasibility of enhancing the performance of the cesium vapor thermionic converter by photon processes, especially at low emitter temperatures (i.e., 1200°C). It is hoped that photon processes would generate sufficient excited and/or ionized cesium to cause breakdown at lower emitter temperatures and to maintain the arc discharge with a minimum plasma drop. Since the discharge mode of operation is not completely understood, it is difficult to predict converter performance when and if the number of densities and the spacial distribution of excited and/or ionized cesium could be altered by photon processes. Because of this, the main emphasis of this program is being placed on an experimental approach.

Two principal experimental approaches are being utilized. The first approach, preliminary in nature, is to study the effect of various radiation sources on existing tubes. The second is to test photon enhancement on a thermionic converter designed for this purpose. The preliminary experiments have provided an opportunity to test the experimental arrangements and to study the characteristics of the various light sources. Also, the results from these experiments should help in the design of the test converter.

EARLY EXPERIMENTAL TUBES

In the beginning of this report period, two experimental tubes, a tungsten-emitter tube and a molybdenum-emitter tube, were available for use on this program from previous work on an emission and discharge study program in cesium vapor. The general features of these tubes are shown in Figure 1. The tungsten-emitter tube contains an optical flat of glass and a guard ring around the collector. The molybdenum-emitter tube contained two sapphire windows spaced seven-centimeters from the emitter-collector gap and both an emitter and collector guard ring. The experiments using the tungsten-emitter tube were performed with the tube immersed in a silicone fluid bath, while those using the molybdenum-emitter tube were performed with the tube wrapped in heating tapes.

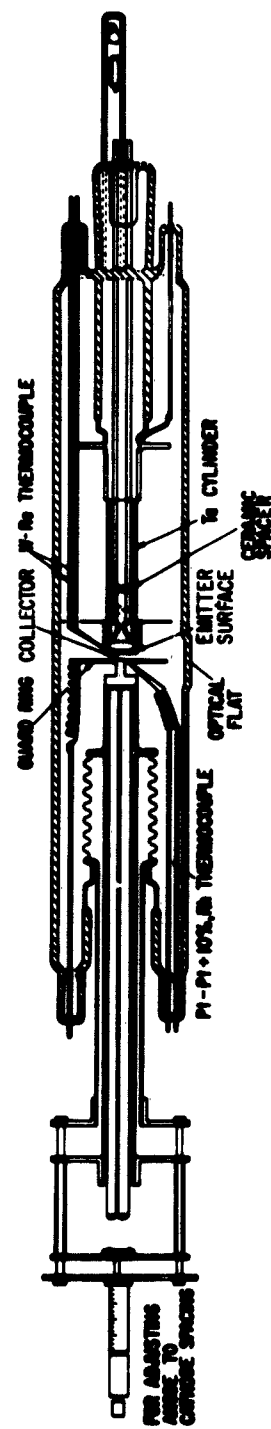


Figure 1 - General Features of the Tubes Used in the Preliminary Experiments

RADIATION SOURCES

The following radiation sources are available for this program; the CsI lamps, the tungsten strip lamp, the helium Osram lamp, and a cesium vapor lamp for use with radio-frequency excitation.

The most intense source of cesium radiation is the CsI-Hg lamp. This lamp is capable of delivering 48 lumens per arc watt and can be operated at a power level of 200 to 600 watts. When conditions are optimized, most of the radiation is that of the cesium line spectrum, with much of the radiation concentrated in the first resonance line of cesium. The principle of operation of this type of lamp is that once the lamp bulb temperature is sufficiently high, CsI atoms are added to the arc. At this point they dissociate, and the resulting cesium, because of the low lying energy levels, lowers the electron temperature of the arc. Even though the mercury pressure is of the order of several atmospheres and the cesium pressure is of the order of one millimeter, the cesium radiation predominates over that of the mercury. However, as the bulb temperature increases, lamp envelope deterioration also increases.

Several techniques are available to increase the lamp temperature other than by increasing the input power. Included are painting the bulb ends with a gold reflecting layer, and fabricating the lamp with a smaller diameter. Several of these compact lamps are being constructed and one is under test.

A spectrum of one of the compact CsI-Hg lamps operating at 250 watts is shown in Figure 2. This lamp has a volume of 40 percent of the standard 400-watt general purpose mercury lamp. The spectrum was taken with a S-1 surface photomultiplier and a Jarrell-Ash 500-mm Ebert scanning spectrometer.

Figure 3 shows the first cesium resonance lines taken with a standard size CsI-Hg lamp body and a power input of 400-watts. As can be seen in Figure 3, the first resonance lines show a sizable amount of reversal but are quite broad. The second resonance lines (4555 Å and 4593 Å) are much less intense, but do not show any self-absorption.

Another type of CsI lamp contains only CsI and argon. The mercury is omitted completely and the argon is increased. Although this lamp will

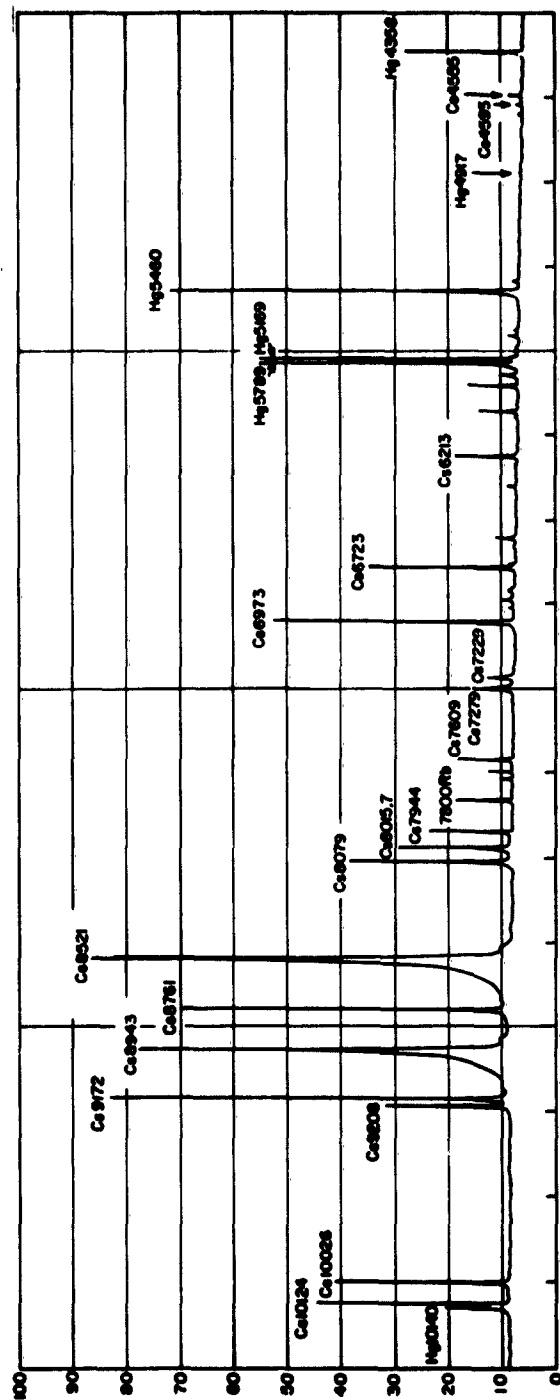


Figure 2 - Spectrum of the New CsI-Hg Lamp Running at 250 Watts

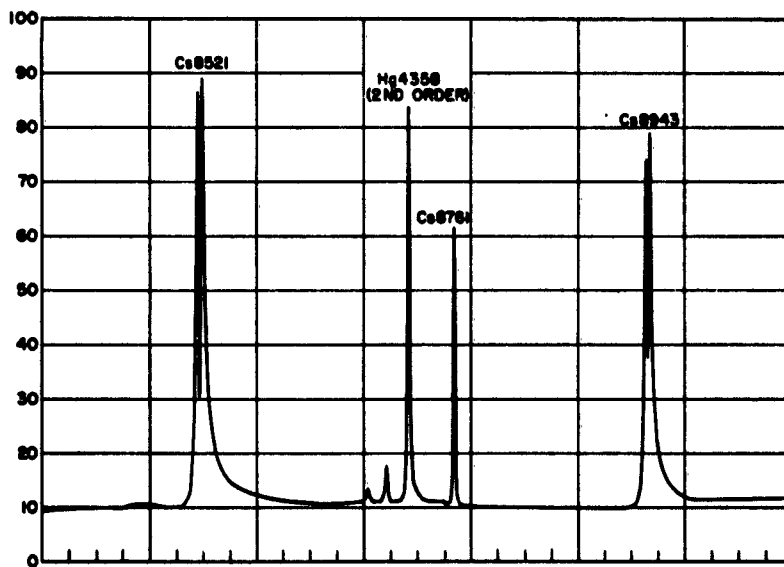


Figure 3 - First Cesium Resonance Lines Using the Standard CsI-Hg Lamp

probably be hard to start and will require more current, it is thought that the cesium resonance line will be less broadened and that most of the power will be emitted in the cesium radiation. This lamp is under construction.

Still another type of lamp consists of a cesium filled Pyrex tube with the center section constricted. This lamp, when excited by a radio-frequency oscillator, emits very sharp lines with little self-absorption. However, its intensity is considerably below that of the CsI-Hg lamp. The cesium vapor lamp will also be used on the final test converter.

PRELIMINARY EXPERIMENTS

The preliminary experiments to study the effect of various radiation sources on existing tubes were conducted using both the tungsten-emitter and the molybdenum-emitter tubes. In most of these experiments, the CsI-Hg lamp operating at 400 watts was used with a glass shield which cut off the ultra-violet mercury lines. The emission spectrum, the discharge current, and the breakdown voltage with and without the lamp radiation were observed when emitter temperatures were varied from below 1000°K to 1950°K , with the cesium reservoir temperature up to 310°C and the emitter-collector spacing from about 0.010 inch to 0.400 inch. The results are as follows:

- 1) When radiation from the lamps was focused on the emitter-collector region and the optical spectrum examined at right angles to the incident radiation, no effect on the emission spectrum was observed when the converter was running in the discharge mode. No change in the cesium spectrum was observed in either mode of converter operation.
- 2) No increase in current was observed in the discharge mode when the lamps were used.
- 3) No increase in space charge limited current was observed in the prebreakdown condition.
- 4) At low emitter temperatures, the order of 1000°K , the breakdown voltage for the discharge is lower slightly when the lamp is used. For example if six volts were required to cause breakdown, 5.9 volts would cause breakdown when the lamp was used. However, as the cathode temperature is increased, the breakdown voltages both with and without the lamp approach each other.

These experiments were also conducted using the helium Osram lamp and the tungsten strip lamp. Again, no significant effect was observed.

The inability of the tubes to interact with the cesium resonance radiation is due to the long absorption path between the window and the emitter-collector region (seven centimeters in the molybdenum-emitter tube and three centimeters in the tungsten-emitter tube). It was hoped that, as the cesium pressure was lowered, some effect would be observed; however, no change was observed. The short absorption path in the new experimental converter should solve this problem. The question of the proper cesium source still exists, and so the various types of lamps are being examined under different conditions in order to determine the source which will give the most intense radiation for any given wavelength.

Since the cesium resonance radiation is strongly self-absorbed at higher pressures, at first glance the radiation would not be expected to reach the converter gap. However, if a broadened line is sent into the converter gap, the center of the line would be expected to show sharp absorption due to the cooler cesium vapor, while the wings or outer edges of the line would only be absorbed by the hotter cesium atoms and ions on the converter gap in the vicinity of the hot emitter where the discharge is located and where a considerable amount of Stark broadening would occur. It was thought that photo-excitation would occur in the region of the emitter if broadened resonance lines were used.

Some absorption measurements of the first resonance line of cesium were attempted with the emitter both heated and not heated. Since these lines from the CsI-Hg lamp are partially absorbed, both the height of the center line and the line edge were monitored as a function of cesium pressure. These data are shown in Figure 4 where the relative intensity has been normalized to the second order of mercury line (4558). The data taken with increasing reservoir temperature for the cold emitter and with decreasing reservoir temperature for the hot (1750°C) emitter. The entire line, which is the order of ten angstroms, was absorbed at a cesium reservoir temperature of 285°C , when the emitter was cold; while, in the case of a hot emitter, the line was totally absorbed at a cesium reservoir temperature of 225°C . The fact that the whole line was absorbed at these pressures when the emitter was cold is surprising and is not fully understood. Whether this absorption is due to Holtsmark broadening (because of collisions with other

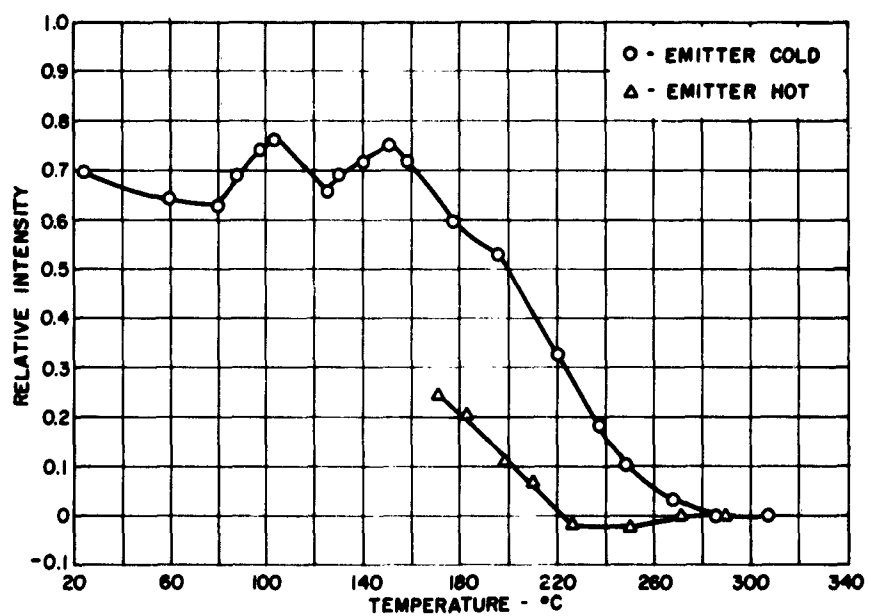


Figure 4 - Absorption of the Leading Edge of the 8521 Resonance Line versus the Cesium Reservoir Temperature

absorbing cesium atoms) or to an experimental problem with the windows is not known. Unfortunately, the molybdenum-emitter tube developed a crack in the glass envelope, and these measurements were not repeated. Also, as a result of the mishap with this tube, the experiments which were planned using ultra-violet radiation were not performed.

EXPERIMENTAL CONVERTER

The experimental converter designed to test the photon enhancement concept is shown in Figure 5. The distinctive feature of this tube is the integral sapphire window and collector which should permit the introduction of various cesium radiations with a minimum of absorption. The collector consists of 0.010 inch tungsten wires embedded in grooves in the inner sapphire window. These wires are spaced 0.030 inch from each other and protrude 0.002 inch beyond the surface of the window. Note that there are two sapphire windows; the outer one is the vacuum window, while the inner window has the tungsten grid embedded in its surface. Two pieces of sapphire were used because of possible fracture due to the thermal stress developing in the window close to the hot emitter.

The emitter electrode was to be a tungsten disc joined to the end of a tantalum cylinder. Tungsten was chosen since it is less likely to evaporate onto the window during processing. The original plan was to electron beam weld the tungsten disc into the tantalum cylinder. This has not been successful. The tungsten developed small cracks near the weld due to the expansion mismatch during the welding. To overcome this difficulty, a niobium braze was tried to join the tungsten disc to the cylinder. This braze has been successful and the emitter assembly thus formed will be used in the second converter. Another emitter was fabricated by electron beam welding a tantalum disc into the end of a tantalum cylinder. This also has been successful, and it will be used in the first experimental converter. Both discs have small black-body holes which will be used to measure the emitter temperature.

The tube will contain a molybdenum guard ring which, besides defining the emitting area of the disc, will also permit the side of the tantalum cylinder to serve as an emitter. Incident radiation can be made to pass between the cylinder and the guard ring, thus giving a larger interaction volume if necessary. This may be desirable when using ultra-violet radiation and also the higher resonance cesium lines. The spacing between the emitter disc and the collector grid will be adjustable by means of a stainless steel bellows and a micrometer assembly.

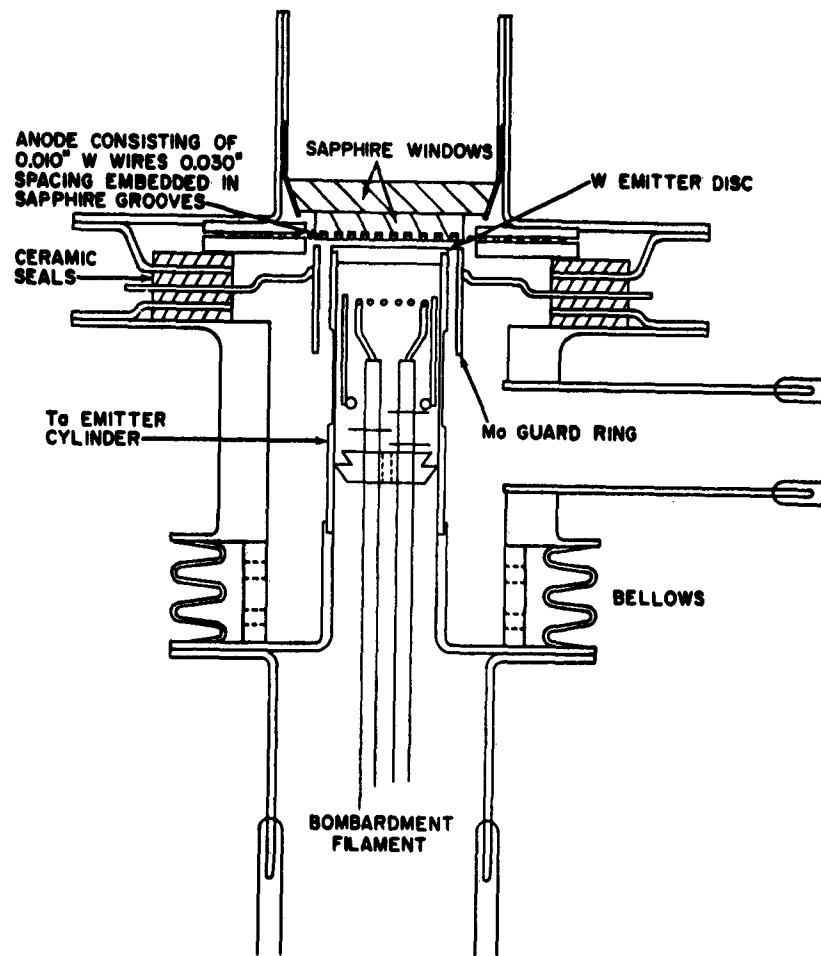


Figure 5 - Experimental Converter Designed to Test Photon Enhancement Concept

Components have been made for four converters, and subassemblies for one converter completed. One problem area is the nickel metal-to-ceramic seal. Although one tight seal is available, the processing of these seals has not been completely determined. It usually takes several experimental tries to obtain the proper processing for any particular type and configuration of a seal. However, it is believed that the processing has been controlled and the procedure determined. This fact will be demonstrated shortly when the next seal is attempted.

The final arc welds are being made on the tantalum-emitter converter, and this converter should be available for experiments shortly.

SUMMARY

Preliminary experiments using two experimental cesium tubes failed to show any effect when radiation from a CsI-Hg lamp, a tungsten strip lamp, and a helium Osram lamp was incident on the emitter-collector gap. The fabrication of one experimental converter designed to test photon enhancement is almost completed. Five different experimental lamps each with different radiation characteristics are available.

PROGRAM FOR NEXT PERIOD

Complete the construction of the experimental converters specifically designed to test the photon enhancement concept.

Perform the photon enhancement experiments with the new converter and with the various light sources.

M. D. Gibbons
March 21, 1963

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