UCRL 8509

MASTER

UNIVERSITY OF
CALIFORNIA

Radiation Laboratory

HIGH - INTENSITY LIGHT SOURCES

BERKELEY, CALIFORNIA

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

UCRL-8509
Chemistry-General

UNIVERSITY OF CALIFORNIA

Radiation Laboratory
Berkeley, California

Contract No. W-7405-eng-48

HIGH INTENSITY LIGHT SOURCES

Earl Fremont Worden, Jr.

(Part II of Thesis)

October 9, 1958

Printed for the U. S. Atomic Energy Commission

Printed in USA. Price $2.50. Available from the
Office of Technical Services
U. S. Department of Commerce
Washington 25, D. C.

HIGH INTENSITY LIGHT SOURCES

Contents

Contents

(continued)

Contents

(Continued)

PART TWO

HIGH INTENSITY LIGHT SOURCES:*

A. A STABLE ARC SOURCE OF INTENSE CN λ3883 RADIATION

B. A METHOD FOR THE DETERMINATION OF BRIGHTNESS TEMPERATURES OF LIGHT SOURCES

Earl Fremont Worden, Jr.

Radiation Laboratory and Department of Chemistry
University of California, Berkeley, California

October 9, 1958

ABSTRACT

A. A stable carbon arc operated in controlled atmosphere is described. The arc was designed to serve as a light source during lifetime studies of the $B^2\Sigma$ state of the CN molecule. The CN radiation from the plasma of the arc was investigated and found to have a brightness temperature of 5500°K at λ3883 A. This is considerably higher than an estimate of the value required for lifetime measurements.

The stability of the carbon arc under various conditions is discussed.

B. For successful lifetime measurements, the light source employed must have a high brightness temperature (intensity). A method for the determination of the brightness temperature of a light source at a specific wave length is described. The method has been used for determining the brightness temperatures of some available light sources. Sodium, thallium, and mercury discharge lamps, a medium-pressure mercury arc lamp, and the carbon arc were studied.

*Part Two of thesis submitted for the degree of Doctor of Philosophy in Chemistry. Part One is "Spectra of Some Aliphatic Aldehydes and Their Monodeutero Derivatives," UCRL-8508, Oct., 1958.

A. A STABLE ARC SOURCE OF INTENSE CN λ3883 RADIATION

INTRODUCTION

A stable, high-intensity source of CN $B^2\Sigma - X^2\Sigma$ λ3883 emission is needed in order to determine the lifetime of the $B^2\Sigma$ upper state of the CN molecule. The intense source is to serve as a light source in the lifetime apparatus.* The light source for the lifetime apparatus must fulfill certain requirements. The source must have a minimum area, about 60 mm^2, and length, 10 mm. It should have a high brightness temperature (intensity) at, and, if possible, only at the wave length or wave-length range of interest. The light source must operate without rapid intensity fluctuations and be capable of uninterrupted operation for several hours.

A logical source for CN emission with high intensity is the carbon arc plasma or arc stream. The major part of the light emitted from the plasma of an arc between pure carbon electrodes results from the CN violet system, the emission desired here. For our purposes, the 0-0 band or the $\Delta v=0$ sequence starting at 3883 A is of primary concern, since it is the only emission from the light source that will be used for excitation of the CN molecules in the optical path of the lifetime apparatus. Light of other wave lengths must be filtered out, and, in order to minimize filtering problems, light emitted at wave lengths other than those of the $\Delta v=0$ sequence should be minimized. Thus, the carbon arc between pure carbon electrodes, with a stable plasma and burning in air or nitrogen, seemed ideal.

---

*The lifetime apparatus and reasons for determining the lifetime of the $B^2\Sigma$ state of CN are reported by Brewer.[1]

The carbon arc between solid carbon or graphite electrodes, however, is notoriously unstable, especially the arc stream or plasma. In a search of the literature (there is an excellent bibliography up to 1942),[2] it was found that most of the work on stabilization was directed toward stabilizing the anode hot spot[3,4] and increasing the emission of white light from the anode surface and from the vapor jet[5] issuing from the surface.[6] In general, the arc is stabilized by use of electrodes cored with oxides or halides of metals—usually the rare earth metals—which enhance the amount of white light emitted by the arc.[7] In a few attempts to stabilize the emission from the plasma of a pure carbon arc, the plasma was to serve for spectroscopic studies and a long-lived, very stable arc was not necessary.

Therefore the investigation of the carbon arc, first in air and later in controlled atmosphere, was initiated. The investigation was directed toward the production of a stable plasma between pure carbon electrodes, since cored carbons, although they yield a more stable arc, are known to lower the plasma temperature[8] and undoubtedly would lower the brightness temperature of the CN emission. Burning the arc in an atmosphere of nitrogen appeared promising because of the possibility of increasing the optical thickness of the CN in the excited state (CN^*) in the arc plasma.

If CN^* concentration is controlled by any or all of the reactions

$$C(gr) + 1/2N_2(g) = CN^*(g,B^2\Sigma) \quad , \quad \Delta H^\circ_{2750} = 160\pm6 \text{ kcal}^9$$

$$C(g) + 1/2N_2(g) = CN^* \quad " \quad , \quad \Delta H^\circ_{2750} = -10\pm6 \text{ kcal}$$

$$C_2(g) + 1/2N_2(g) = CN^* \quad " \quad , \quad \Delta H^\circ_{2750} = 63\pm6 \text{ kcal}$$

$$C_3(g) + 1/2N_2(g) = CN^* \quad " \quad , \quad \Delta H^\circ_{2750} = 92\pm6 \text{ kcal}$$

the concentration of CN^* will change with the square root of the

nitrogen pressure. Thus, increasing the nitrogen pressure at constant temperature increases the CN^* concentration. At constant nitrogen pressure the concentration of CN^* increases with temperature until the major gaseous carbon species becomes C(g) (~5500°K). The CN^* concentration is little affected by temperature until the concentration of molecular nitrogen is depleted by dissociation (~8000°K).[10] Above this temperature, the concentration of CN^* decreases with increasing temperature.

The arc was investigated first in air in order to determine whether or not such an arc was practical and, if not, to determine what factors contribute to the stability or instability of the arc.

EXPERIMENTAL PROCEDURE

The Carbon Arc in Air

Apparatus

The arc was operated in free air between vertical electrodes held by simple clamp electrode holders with provision for independent vertical adjustment. The electrical circuit and arrangement of the electrodes and the water-cooled copper constrictors (when they were employed) are represented in Fig. 1.

The electrodes are drawn as they appeared after the arc had been operated for a few minutes (all the electrodes employed assumed this general appearance). The cathode was symmetrical about its axis, while the anode was unsymmetrical, with a flat ellipsoidal face at an angle of about 60 degrees to its axis. The types of electrodes employed are listed in Table I.

The water-cooled copper constrictors, so called because they reduce the diameter of the arc plasma at their position, are sometimes referred to as diaphragms;[11,12] the name "constrictor" is preferred here. The use of constrictors was suggested by Maecker.[13] They were constructed by simply drilling a small hole in a piece of copper plate (about 35x35x1 mm) and soft-soldering a loop of 3/16-inch copper tubing (about 20 mm in diameter) to the plate together with a rod for clamping the constrictor in position. Water passing through the tubing provides sufficient cooling to prevent melting or gross deterioration of a 2 mm-diameter orifice even at arc currents up to 30 amperes. In most of the work with constrictors, two were placed between the arc electrodes as in Fig. 1. The diameter of the orifice in each of these constrictors was 2.1±0.1 mm. Several other constric-

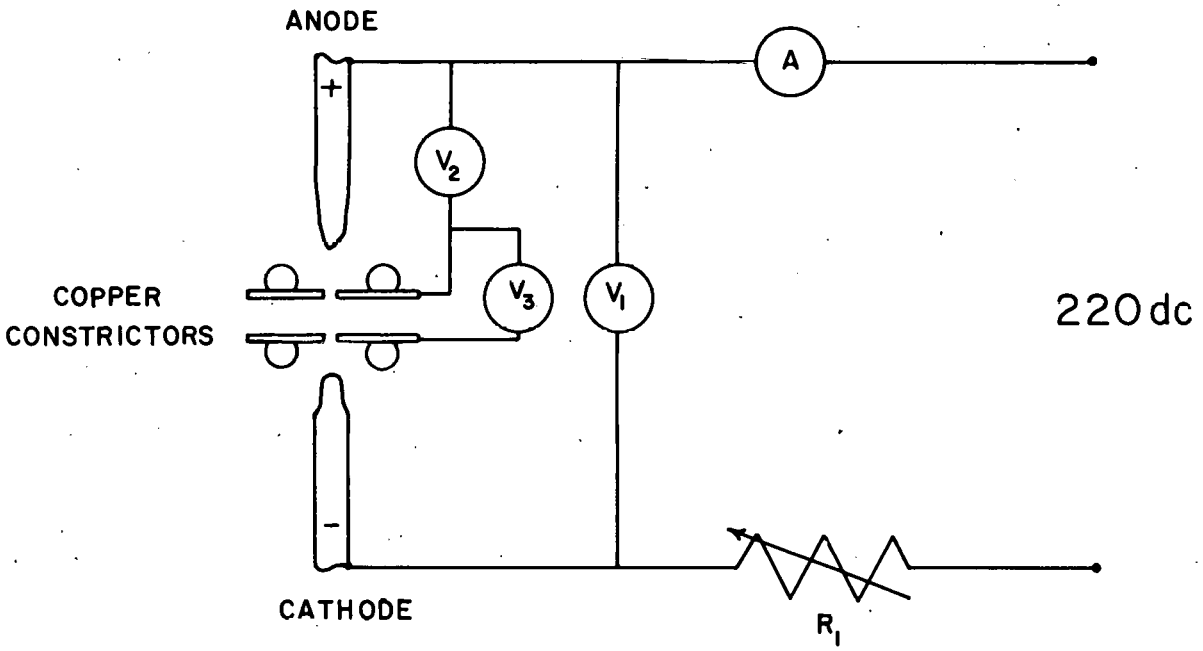


Fig. 1. Electrical circuit and arrangement of electrodes and water-cooled copper constrictors employed for the studies of the carbon arc in air.

V_1 and V_2. 0- to 300-v dc voltmeter.

V_3. 0- to 150-v dc voltmeter.

A. 0- to 30-amp dc ammeter.

Table I

Types of arc electrodes employed

Type of carbon	Diameter of carbon	Diameter of core[a]	Use
National Carbon Co.[b] Special Graphite Spectroscopic	(1/4 in) 6.3 mm	none	Anode and cathode
National Carbon Co. Microprojector Cored	5.8 mm	1.4 mm	Cathode
National Carbon Co. Microprojector Cored	8.0 mm	1.4 mm	Anode
National Carbon Co. H. I. White Light	11.0 mm	5. mm	Anode
Graphite (origin unknown)	9.3 mm	none	Anode
United Carbon Products Co.[c] Spectroscopic Graphite	(1/8 in) 3.2 mm	none	Cathode and anode

[a]The core materials are rare earth oxides, probably Ce.

[b]The National Carbon Co.
30 East 42nd St.
New York 17, N.Y.

[c]United Carbon Products Co., Inc.
1300 No. Madison Ave.
Bay City, Mich.

tors of varying orifice diameter, 1.5 to 4.4 mm, were constructed and used individually.

The ballast resistance, R_1, served to vary the power dissipated in the arc. With arcs operated without constrictors, a coiled iron wire resistor of 30-ampere capacity and 0-to-30-ohm resistance was employed as a ballast. Two of these resistors were used in parallel when the arc was operated with constrictors. This was necessary because of the higher intrinsic resistance of the arc when operated with constrictors.

The voltmeters V_1, V_2, and V_3 and ammeter A were Weston Electrical Instrument Corp. model 489 dc meters.

The power supply was the output of a 220-v dc generator.

The arc, when operated without constrictors, was struck by bringing the electrodes into contact (with the power already on) and drawing out the arc to the desired length. In operation with constrictors, the exploding-wire technique was employed: a length of 32-gauge copper wire was threaded through the constrictor or constrictors and aligned in contact with the electrodes, and then the power was turned on at fairly low ballast resistance to ensure striking. The wire must not be in contact with the constrictors if misfirings are to be avoided.

An image of the arc, magnified X3, was projected on a ruled screen and the arc length and electrode positions were controlled manually.

Measurements and Their Accuracy

The arc length was determined by measuring the distance between the cathode and anode hot spots on the screen and then dividing by the known magnification factor. The length was also measured with a vernier caliper rule after the arc was extinguished. The actual arc length was dependent on the nature of the electrodes, which determined the amount

of hot-spot wandering. The arc lengths determined in this manner are probably accurate to ±1 mm, the accuracy improving with improved hot-spot stability.

The distance between the facing surfaces of the constrictors was determined with a vernier caliper rule read to 0.1 mm. The constrictor orifice diameters were obtained by measuring the diameter of a drill just fitting the orifice.

The electrode dimensions were determined with the vernier caliper rule.

The current through the ammeter A could be read to 0.1 amp with a precision better than 0.1 amp, but because of the fluctuant nature of the carbon arc in air (except when operated under stringently controlled conditions[3,4]) the accuracy of the current readings was somewhat less. The uncertainty in the current readings is in general less than ±0.5 amp.

The voltmeters employed to measure the potential drop over various regions of the arc could be read to the nearest volt with a precision better than ±1 v. The accuracy of the actual readings, however, like the accuracy of the current readings, was dependent on the arc stability. The uncertainty in the voltage readings is about ±2 v.

PD_1, the potential drop across the arc, was read from voltmeter V_1; PD_2, the potential drop between the anode and the first constrictor was determined by voltmeter V_2; and PD_3, the potential drop in the region between the two constrictors, was given by voltmeter V_3.

Method

In order to determine what conditions produced the most stable arc in air at atmospheric pressure, measurements of the arc characteristics were made on arcs operating at different values of various parameters. The following parameters were varied:

a. The power input.

b. The arc length.

c. The electrodes, both their composition and their diameter.

d. The arc plasma dimensions, by use of constrictors.

The relative stability of the arc as the various parameters were changed was determined by visual observation as well as by the current-voltage readings. Attempts to use a recording spectrophotometer to determine changes in the intensity of the plasma radiation as the parameters were changed were unsuccessful in most cases because of the instability of the arc.

The Arc in Controlled Atmosphere

Apparatus

The arc chamber

The controlled atmosphere arc is shown schematically in Fig. 2. A partial view of a plane through the center is given in the figure.

The main body J of the chamber consists of a 7-in. length of 6-in. od brass pipe with four 2-1/4-in. od brass pipes 2 in. in length joined to the large pipe, each at right angles to its neighbor and the axis of the large pipe. The ends of the pipes have collars with provision for rubber O rings in order to permit vacuum seals to be made between the main body of the chamber and the accessories.

The arc chamber was cooled in order to remove the heat radiated by the arc. The cooling was effected by passing water through copper tubing soldered to the main body and the end plates of the chamber. The cooling was necessary to prevent overheating and deterioration of the O rings and the glands of the Wilson seals.[14]

The electrode-holding assembly is made up of a water-cooled electrode holder A, attached through an electrical insulator B, to a stainless steel tube F, which allows electrode position adjustment by sliding through the Wilson seal E. The Wilson seal is attached to the end plate of the arc chamber, with the O ring providing a vacuum seal. The electrode-position adjustment is effected by turning the ring C, which rotates the outer member of two threaded coaxial pipes (8 threads per inch). The inner member is held rigidly against the end plate of the arc chamber by a set of studs and wing nuts. The electrode holder and steel tube are held against the outer member by virtue of the reduced atmosphere in the arc chamber. In order to

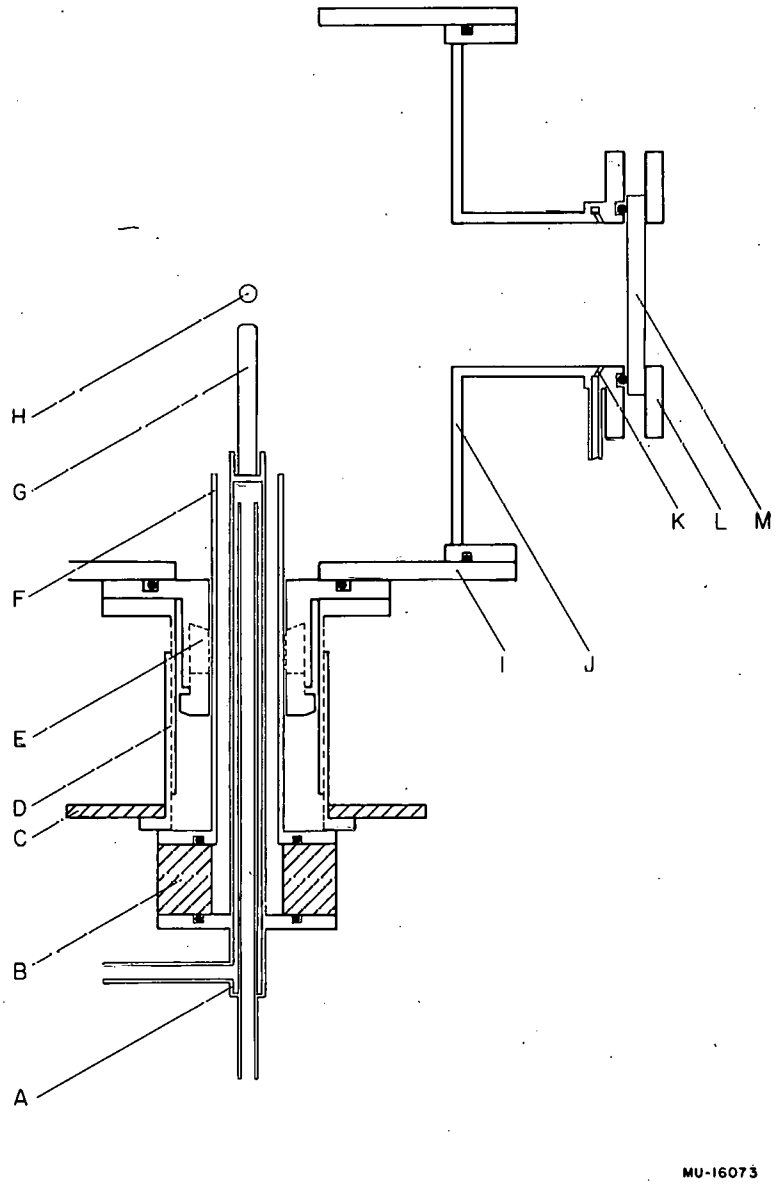


Figure 2

Fig. 2. The controlled-atmosphere arc chamber.

A. Water-cooled electrode holder.

B. Bakelite insulation for electrical shielding of the electrode holder from the body of the arc chamber.

C. Bakelite ring for rotating the outer member of the electrode-adjustment assembly.

D. Electrode position-adjustment assembly. Dashed line indicates threaded area.

E. Wilson seal. Gland (no details given) outlined by dashed lines.

F. Stainless steel cylinder which slides through the Wilson seal gland.

G. Cathode.

H. Anode.

I. End plate.

J. Main body of the arc chamber.

K. Gas vent.

L. Compression ring to hold window or adaptors.

M. Window.

operate at atmospheric pressure or above, the position-control mechanism and the Wilson seal would require modification.

The electrode-holder assemblies can be accommodated by the end plates, as shown in the diagram, or by any one of the four window ports. Thus it is possible to operate an arc between electrodes which are vertical and opposing, horizontal and opposing, or at right angles in any of three possible orientations. In any one of these possible orientations, the arc can be viewed through a window perpendicular to the plane containing the electrodes, or, when the electrodes are at right angles, parallel to the axis of either electrode.

In the view shown in Fig. 2, the orientation generally employed, the cathode and its holder assembly are in the plane of the paper, and the anode and its holder assembly are perpendicular to this plane.

Auxiliary equipment

The electrical circuit was as shown in Fig. 1, with R_1 a single 0-to 30-ohm resistor of coiled iron wire. The voltmeter V_1 and ammeter A served to determine the terminal characteristics of the arc. The power supply was the output from a 220-v dc generator, and the maximum line capacity, limited by circuit breakers, was about 30 amp.

In order to maintain a reduced atmosphere in the arc chamber under flow conditions, a 33 liters per minute (free air) vacuum pump was connected to the chamber through an adapter accommodated by one of the window ports. The pumping rate was controlled by a large glass stopcock. The exhaust gases from the pump were vented from the room.

Tank dry nitrogen was led through a reducing valve and rubber hose to the window vent where the anode electrode-holder assembly was housed. The flow of nitrogen was controlled by a small needle valve.

Air from the room, when used, was bled into the chamber through a window vent opposite the window used for spectral observation of the arc. The flow rate was controlled by a small needle valve.

The pressure in the arc chamber was measured with a conventional U-tube mercury manometer. The manometer was connected to the chamber through an adapter, usually housed at the top end plate of the chamber, and was protected from soot by a trap filled with glass wool.

Operation

The arc was started by bringing the electrodes into contact (with the power already on) and drawing out the arc until the electrodes were at predetermined positions. The electrode positions were controlled by maintaining the images of the electrode hot spots on a ruled screen at appropriate positions.

The pressure in the arc chamber and the flow rate of the ambient gas were adjusted before the arc was struck. Further adjustments were required after the arc was struck if a specific pressure was desired. For operation in pure nitrogen, the arc chamber was flushed with nitrogen before the arc was struck. The total flow rate of the gas through the chamber was usually around 1/2 liter per minute. With nitrogen-air mixtures, most of the ambient gas was nitrogen, since the air flow was about 10% of the total flow. The air flow was generally reduced to the lowest rate sufficient to remove the carbon vapor from the arc and prevent soot deposition.

The windows of the chamber had to be cleaned quite frequently when the arc was operated in pure nitrogen because of "fogging" (i.e. deposition of soot or dust), especially at high currents. With

nitrogen-and-air mixture, little or no fogging of the windows occurred. Fogging resulted if the flow rate was too rapid, especially when the gas flow was through the vent at the window in question, or through the vent on the opposite side of the chamber. (Although the window vents were intended to prevent fogging of the window, it was found in operation that the effect was just the opposite.) The soot or dust was blown or drawn by convection currents against the window, where it formed a film. For this reason, no gas was admitted through the vent of the window employed for spectral intensity investigations.

Slow flow rates were necessary for satisfactory operation of the arc. At high flow rates, the ambient gas became turbulent, which caused instabilities in the arc operation.

Measurements

The current through the arc was determined to the nearest 0.1 amp. The uncertainty in reading the ammeter was ±0.1 amp with stable arc operation and ±0.5 amp when the arc was unsteady.

The potential drop across the arc was read to the nearest volt. The uncertainty in the readings was less than ±1 v during stable operation and ±2 v during unstable operation of the arc.

The pressure in the arc chamber was determined while the arc was in operation. The pressure was read to the nearest 1 mm with an uncertainty less than ±1 mm under stationary flow conditions.

The intensity of the λ3883 CN emission from the arc plasma was measured with a spectrophotometer described in Part IIB of this thesis. The intensity determinations were made on a portion of the arc plasma viewed perpendicular to the plane containing the electrodes.

The arc stability was studied with different ambient gas compositions and pressures, different electrode types, and various power inputs. The intensity of the λ3883 CN emission was also studied as a function of the same variables.

The brightness temperature of the λ3883 CN emission was determined under various conditions of arc operation and at various positions in the arc stream (the method is described in Part IIB of this thesis).

RESULTS AND DISCUSSION

The Carbon Arc in Air

Stability

The stability of the carbon arc burning in air was found unsatisfactory for a light source with the requirements set forth in the Introduction. The results of the studies are reported here in full, however, since they describe the various phenomena characteristic of the carbon arc. Also, these studies played an important role in the determination of the conditions that would most likely produce the stable arc plasma desired. (The general stability of the carbon arc and details of the studies are more fully dealt with below.)

The carbon arc operated in air at atmospheric pressure between 6.3-mm diameter graphite electrodes and without constrictors was quite unstable. Arc stream or arc plasma oscillations, caused by the constant wandering of the cathode hot spot and occasional jumping about of the anode hot spot, coupled with intermittent eruptions of both electrodes (these eruptions changed the composition of the arc plasma and consequently its emission characteristics), rendered this type of arc useless for our purposes.

The stability of this arc was improved by using 5.8-mm cored carbons as cathodes. The oscillations produced by cathode spot wandering were removed, since the cathode spot was confined to the central, cored region of the cathode face. The arc plasma was still subject to intensity fluctuations from electrode eruptions and position instability caused by anode spot jumps. The use of 8-mm cored electrodes as anode material produced no marked improvement in the arc

stability. The use of larger-diameter electrodes gave less satisfactory operation.

The arc stability improved with decreasing arc length (from 20 mm down to a few mm), and as the power settings yielded conditions approaching those set forth by MacPherson.[3]

H. Maecker suggested the use of constrictors as a method of increasing the temperature of the plasma (if needed to enhance the intensity of "lines" requiring high excitation potentials).[13] More important, these constrictors serve to control the physical position of the arc plasma.

A single constrictor, placed a few mm from a graphite cathode, served to produce a fairly steady arc plasma between its orifice and a steady anode spot. The fixed constrictor orifice damped the oscillations produced by the wandering cathode spot. Two constrictors in series were, of course, more effective and the plasma between the constrictors was also quite stable. The intensity of the emission from these spatially stable regions of the arc stream was subject to fluctuations because of electrode eruptions as well as cathode spot wandering. The cathode spot wandering produces intensity fluctuations by changing the total arc length, and, consequently the energy dissipated per unit length of the arc stream; the cathode spot wandering was eliminated when cored carbons were used, but the intensity fluctuations from electrode eruptions remained.

The most stable arc obtained in open air was that between a 5.8-mm cored carbon cathode and an 8-mm cored anode, or between the same cathode and a 6.3-mm graphite anode with two constrictors in series—that is, an arc arranged as in Fig. 1, operating near MacPherson conditions.[3]

All the carbon arcs operated in air displayed some undesirable features. Because of the rapid consumption of electrode material, the electrodes required almost constant adjustment. In addition, the total continuous burning time of the arc was short, less than 1 hour. These failings could have been remedied by employing complicated electrode-feed mechanisms, such as designed by Finkelnberg and Latel.[6] Another undesirable characteristic, associated with the arc operated with constrictors, was the irksome job of aligning a copper wire between the electrodes in order to strike an arc through the constrictor orifice. The possibility of eliminating these undesirable features and the over-all appeal of working with a controlled atmosphere prompted the design and use of the controlled-atmosphere chamber.

Details of the Investigation of Arcs in Air

Characteristic curves

The characteristic curve for an arc is a plot of potential drop against the arc current. Figures 3 to 6 represent typical characteristic curves obtained for the carbon arc in air, operated as arranged in Fig. 3. Figure 7 is a characteristic curve for a pure graphite arc in air without constrictors. Curves a and c in Figs. 3 and 4 and the curve in Fig. 7 represent the terminal characteristics of carbon arcs operated under the conditions stated in the legend. The curves b and d in Figs. 3 and 7 represent the characteristic curve for the anode and the arc plasma between it and the first constrictor. The curves in Figs. 5 and 6 are the characteristic curves for the plasma between the two constrictors, and represent the general plasma characteristics.

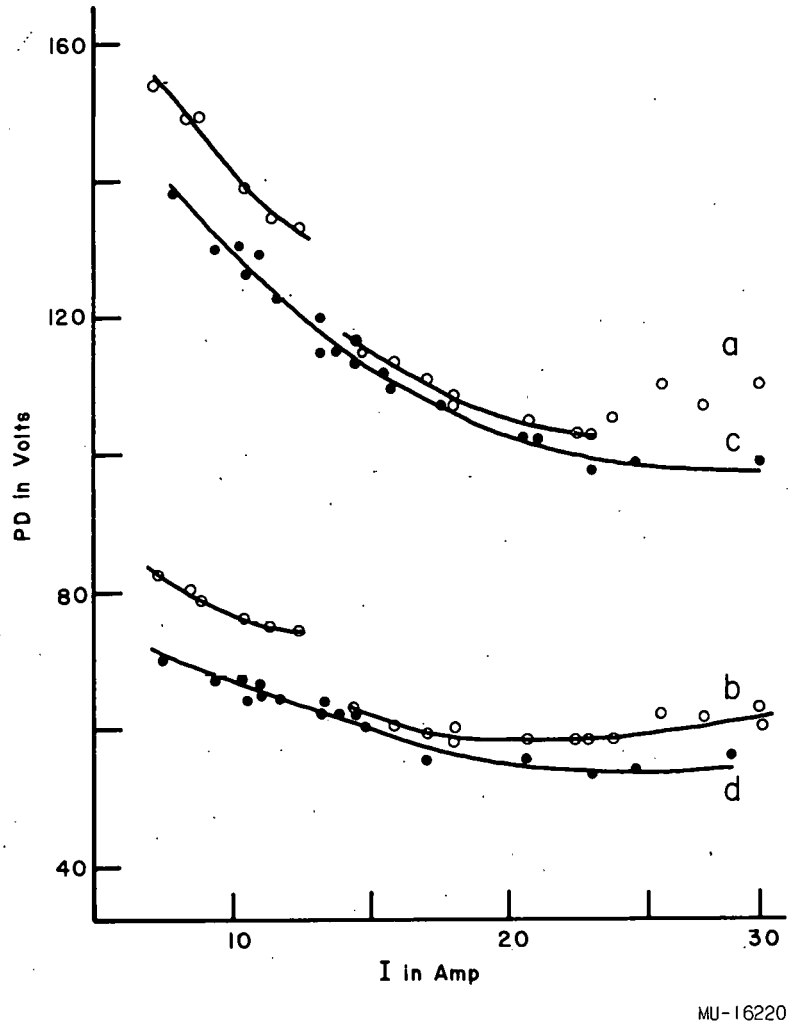


Fig. 3. Potential drop vs current for a carbon arc between graphite electrodes in air at atmospheric pressure (see Fig. 1 for arc arrangement). Electrode separation, 25 mm; constrictor separation, 7 mm.

a. PD_1 vs I
b. PD_2 vs I
} for an arc with 6.3-mm graphite anode and cathode.

c. PD_1 vs I
d. PD_2 vs I
} for an arc with 9.3-mm graphite anode and 6.3-mm graphite cathode.

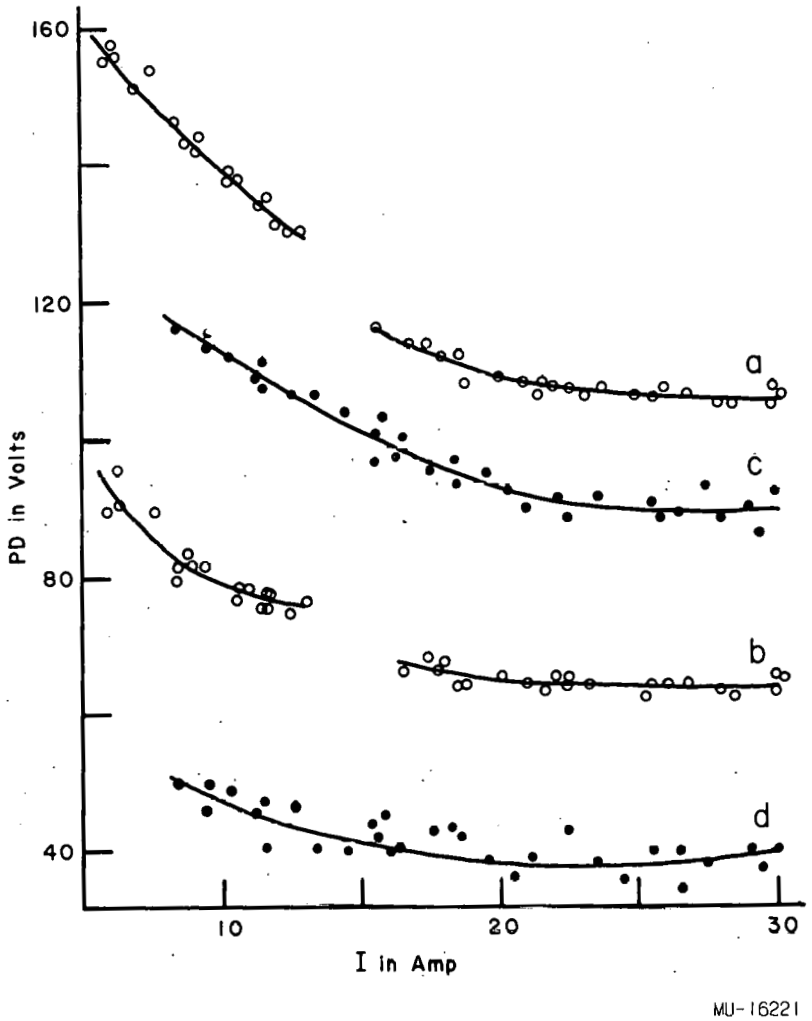


Fig. 4. Potential drop vs current for an arc in air at atmospheric pressure between cored carbon electrodes (see Fig. 1 for arc arrangement). Electrode separation, 25 mm; constrictor separation, 7 mm.

a. PD_1 vs I
b. PD_2 vs I
} for an arc with 5.8-mm cathode and 8-mm anode.

c. PD_1 vs I
d. PD_2 vs I
} for an arc with 5.8-mm cathode and 11-mm anode.

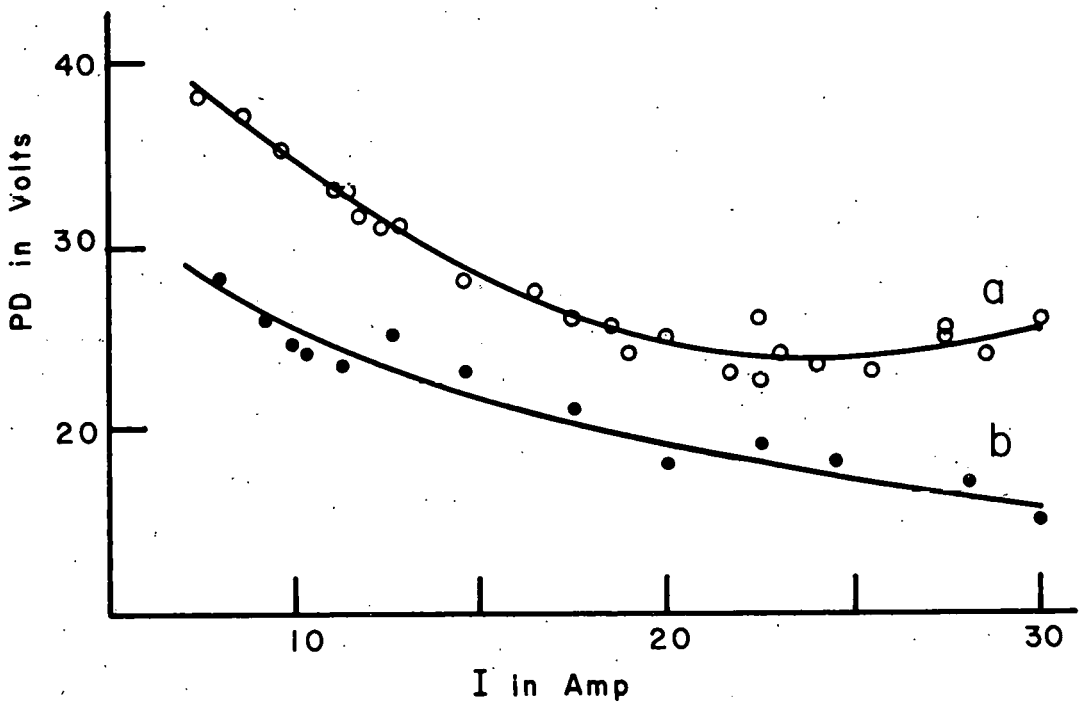


Fig. 5. Potential drop between the constrictors vs current for an arc between 6.3-mm graphite electrodes (see Fig. 1 for arc arrangement). Electrode separation, 25 mm; constrictor separation: curve a, 7 mm; curve b, 3 mm.

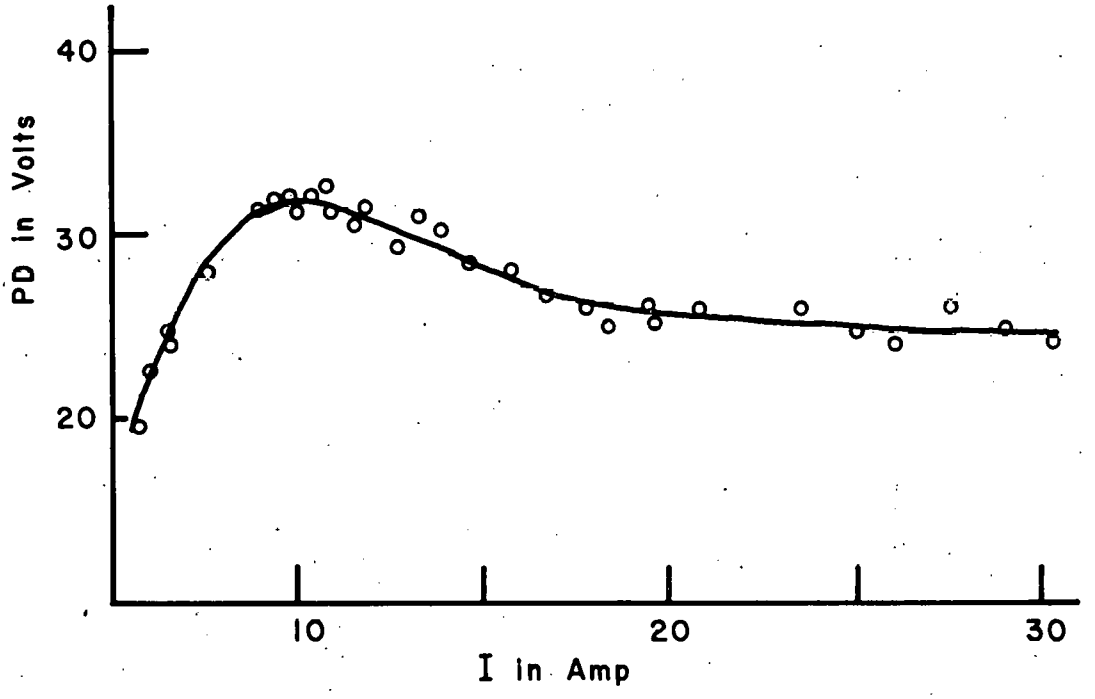


Fig. 6. Potential drop between the constrictors vs current for an arc between a 5.8-mm cored carbon cathode and an 8-mm cored carbon anode (see Fig. 1 for arc arrangement). Electrode separation, 25 mm; constrictor separation, 7 mm.

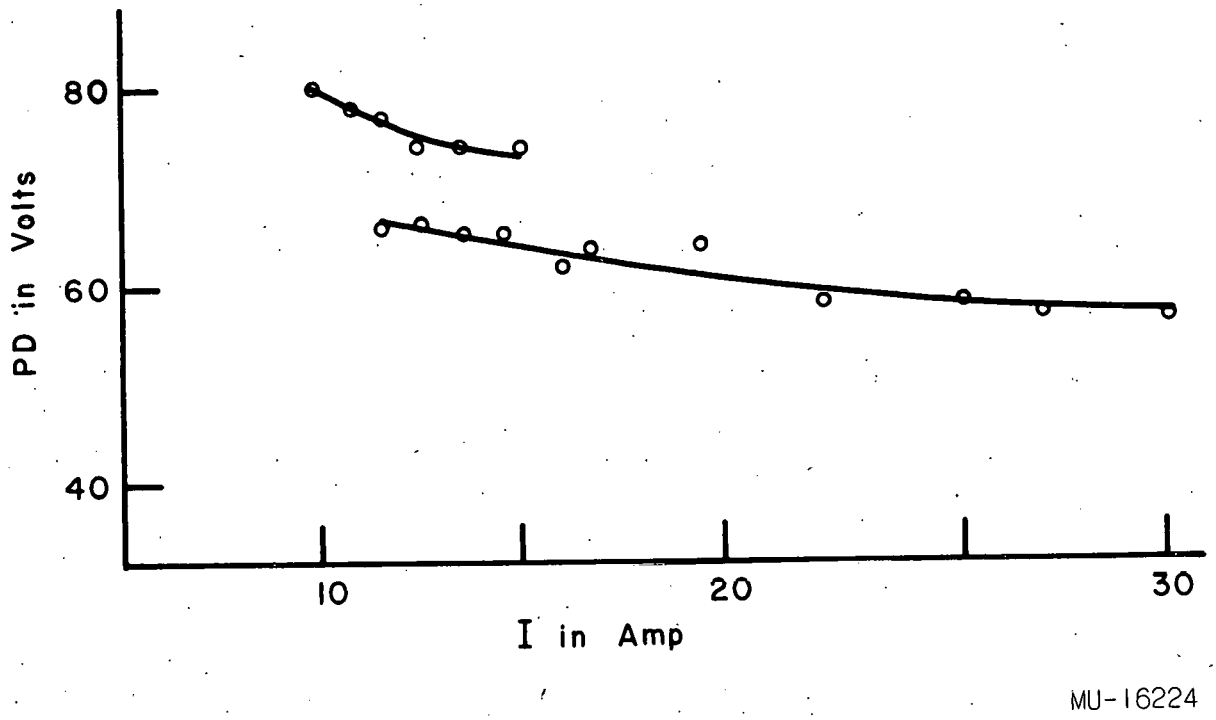


Fig. 7. Potential drop vs current for an arc burning free in air (no constrictors) between 6.3-mm graphite electrodes. Electrode separation, 13 mm.

The slopes of these characteristic curves are defined as the resistance characteristic of the arc.[15] For the low-current carbon arc, the slope is negative, and the arc is said to have a falling or declining characteristic, sometimes called a negative resistance. I prefer the term "negative-resistance characteristic" to describe this property.

All the curves have negative slopes in the low-current region except the curve in Fig. 6, which has a positive slope below 10 amp. Thus, the plasma between the constrictors of this arc has a positive-resistance characteristic. This behavior was observed only when cored carbons were employed as anode material. When the anode was still fresh and unshaped* the curve retained the negative slope below 10 amp characteristic of the pure carbon anode arc curve. With an anode that was shaped after some use, the positive slope always resulted. The core material must in some way affect the plasma between the constrictors or the potential of the constrictors. Although the resistance characteristic of this region of the arc was positive, the terminal resistance characteristic of the arc remained negative. Since the phenomenon seemed unimportant in the investigation for a method to produce a stable arc, no extensive studies were carried out and the phenomenon remains unexplained.

A well-known occurrence in carbon arcs in air is the discontinuity or "break" in the characteristic curve;[3,4,16,17] see Figs. 3, 4 and 7. Similar curves are reported by Schluge and Finkelnberg[18] and in Darrow.[17] The break in the characteristic curve is associated with

---

*The unshaped electrode would release a higher fraction of carbon into the arc stream than the shaped electrode.

a sharp change in the arc operation.

When an arc is being operated with proper electrode dimensions and at proper current the arc burns quietly with the anode face completely covered by a uniformly incandescent anode spot. On increase of the current, the anode suddenly starts hissing, and a sharp increase in current and decrease in potential drop occur with the outbreak of hissing. MacPherson has labeled the quiet-burning arc a normal arc and the hissing arc an overloaded arc.

From an examination of the characteristic curves in Figs. 3 and 4, it is readily seen that the transition is to be attributed to a change in the anode mechanism. Curves c and d show no break, because of the large anode diameters of these arcs, and represent the plasma characteristic over the break region of Curves a and b. By comparison of the curves, the anode potential drop (the anode drop) is estimated to be 9 to 10 v less in the overloaded arc than in the normal arc.*

The break in the characteristic curve, or the arc transition, occurs at a critical value of the current density at the anode surface. The value of the critical current density for the transition, and further details about the nature of the transition are included in the section entitled "The Anode."

The overloaded arc is also characterized by a rapid rate of electrode erosion at the anode surface, and, because of the nature of the anode mechanism, it is less stable at low power input than

---

*For a carbon arc with an anode which contains a large amount of core material, the opposite anode-drop change has been reported; see Refs. 15 and 18. The observation of about the same value for both the graphite and cored electrodes employed here indicates that the properties of the cored anode employed are determined by carbon. The 8-mm diameter cored electrodes employed here are largely carbon (see Table I).

the normal arc. The overloaded arc is therefore an undesirable form of the carbon arc as a source of steady plasma emission.

The contracted arc column

The contracted arc column in the carbon arc stream has been reported in the literature and discussed by several investigators.[5,11,13] The contracted arc column does not form in a free-burning arc in air until arc currents above 80 amp are reached. According to King,[11] the appearance of the contracted column is dependent on the ambient gas. Finkelnberg states that the contracted column conducts the major portion of the arc current at high current densities of 10 to 30 amp per mm^2.[5]

The contracted arc column can be formed at lower arc currents by employing constrictors.[11,13] The author, by employing constrictors of sufficiently small diameter, has produced contracted columns of appreciable length with a carbon arc in air at currents as low as 15 amp. To permit determination of the critical value of the current density for the formation of the contracted column, the arc was operated through constrictors with orifice diameters varying from 4.4 to 1.5 mm, and observations were made of the current when the contracted column first appeared in the center of the constrictor. From the known area of the orifice an average current density could be calculated in each case. A plot of log log current density versus area, when extrapolated to zero area—the area of the contracted column on formation—yielded a value of 12 ±2 amp per mm^2 as the current density required for formation of a contracted column in a carbon arc in air at atmospheric pressure.

The contracted column has a very high temperature, ~10,000°K, and emits largely atomic lines and continuum.[5,11] The contracted column with its high temperature is a poor source of CN emission because most of the CN in the arc stream would be decomposed at the temperature of the column. Indeed, when the plasma between two constrictors of a carbon arc was imaged on the slit of a recording spectrophotometer the intensity of the CN λ3883 emission was observed to decrease markedly when a contracted column was formed by suddenly increasing the arc current.

The Arc in Controlled Atmosphere

Stability

A pure graphite arc in nitrogen was found unsatisfactory as a stable source of CN emission. The cathode spot was unsteady, undergoing intermittent jumps from pit to pit. With a 5.8-mm cored carbon as cathode, the arc operated very steadily in nitrogen at reduced pressure (about 140 mm) for 15 to 30 min, but, after this time, sooting of both electrodes and deep pitting of the cathode caused migrations of both the anode and cathode spots, and the arc became unstable (further discussion of this instability is given in "The Anode" and "The Cathode"). The arc could be rejuvenated by burning it in air for some time, then returning to pure nitrogen, or by removing the pitted and sooted electrode ends. The tendency toward instability increased with increasing pressure of nitrogen. Somers and Smit, in their studies of the carbon arc in nitrogen, report that the arc between pure carbon electrodes at one atmosphere pressure of nitrogen becomes unstable after about 15 min of operation.[19] They also observed an increase in tendency toward instability with increase in pressure.

When the arc is being operated at increasing currents in nitrogen, and with a fresh 6.3-mm graphite anode, no sharp break or transition was observed. This is to be explained by the anode surface available in nitrogen, where little or no spindle of the electrode occurs.*

---

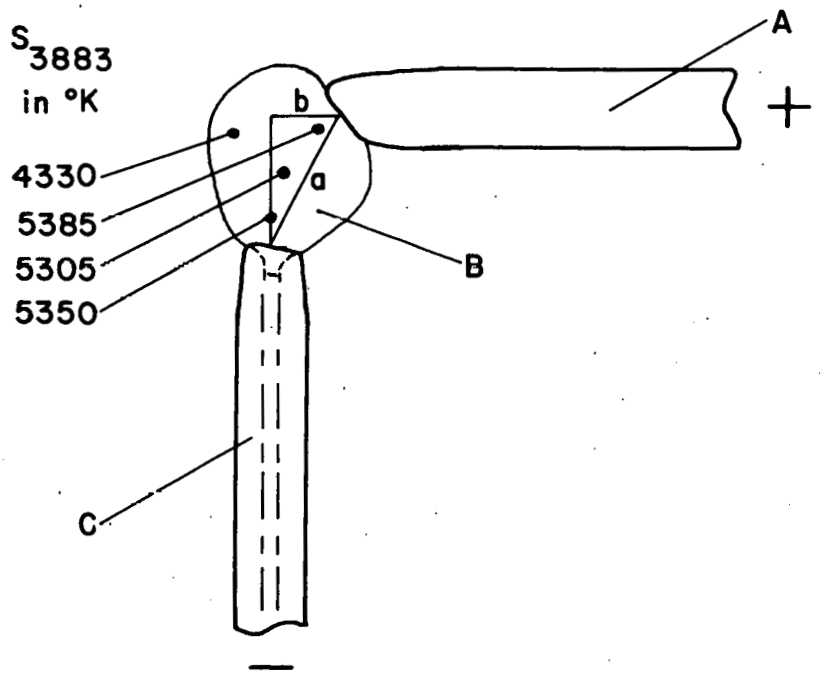
*The greater part of electrode spindle (tapering) is caused by oxidation rather than by evaporation.

From a measurement of the active anode crater area, the current necessary to produce a transition to the overloaded arc was estimated to be about 40 amp based on observations in air. (See section entitled "The Anode." The results of experiments to determine the current density at the anode when the transition occurs are contained in that section.)

In an atmosphere of nitrogen and a small amount of air at steady gas flow, the arc between 6.3-mm graphite electrodes was unstable because of the cathode wandering characteristic of the carbon arc in air. The average intensity of the plasma emission remained constant in time, but the wandering cathode spot—by causing plasma-position oscillations as well as arc-length changes—produced rapid intensity fluctuations, amounting to at least ±10% of the total intensity.

The arc with 5.8-mm cored carbon cathode and 6.3-mm graphite anode, burning in a nitrogen-air mixture, was the most stable arc produced. An arc of this type could be operated at least 4 hours, and up to 8 hours, without interruption, and with very little instability or change in the intensity of the plasma emission. Typical operating conditions for this stable arc are as follows: total gas flow, 0.5 liter per min; ratio of nitrogen to air flow, about 10 to 1; current, 9.5 amp; potential drop, 65 v; orientation of electrodes and plasma dimensions (see Fig. 8 and Table II).

The CN λ3883 emission from this arc was free from any rapid intensity fluctuations, but a slow drift in intensity, not entirely compensated for by electrode-position adjustment, was present. The drift toward lower intensity during a 1/2 hour period would amount to about 3 to 6% of the total intensity. Since only rapid fluctuations



MU-16225

Fig. 8. Electrode orientation for the carbon arc in controlled atmosphere. The distances a and b determine the arc trim. S_{3883} values are given at various positions in the plasma (see Row 2 in Table II for the arc operating conditions).

A. Anode, 6.3-mm graphite.

B. Violet core of the arc plasma.

C. Cathode, 5.8-mm cored carbon with the cored and pitted regions outlined by the dashed lines.

Table II

Values of S_{3883} obtained with conditions of arc operation

Electrodes		Potential drop (volts)	Current (amp)	Atmosphere	Pressure (mm Hg)	S_{3883} (°K)†	a* (mm)	b* (mm)
Cathode	Anode							
5.8-mm cored carbon	6.3-mm graphite	73	9.4	N_2	140	4780	12.6	5.2
5.8-mm cored carbon	6.3-mm graphite	70	9.4	N_2 + air	138	5350	12.6	5.2
3.2-mm graphite	6.3-mm graphite	63±2	12.7±0.3	N_2 + air	144	5450±90	14.3	7.4
3.2-mm graphite	6.3-mm graphite	70±2	10.5±0.3	air	136	5480±60	14.3	7.4

*Arc dimensions, Fig. 8.

†Brightness temperatures determined for a position in the plasma just above the cathode, see Fig. 8.

in the intensity have adverse effects on the measurements to be made with this light source, the slow intensity drift is tolerable.[1] The drift is usually coupled with a slight decrease in current and increase in potential drop. These changes result from an increase in the arc length caused by pitting of the core in the center of the cathode. The pitting produces an uncompensated change in the arc length, since the length is controlled by keeping the image of the cathode, viewed from the side, at a fixed position. This pitting can be eliminated at the expense of uninterrupted operation time by using a larger partial pressure of oxygen. Also, the use of cored electrodes with thinner carbon walls would prevent pitting.

The intensity drift can also be associated with slight fogging of the window with time. A carbon deposit on the window can be detected after a few hours of operation.

The spectral output of the plasma of this arc is confined largely to CN emission. No core-material lines were observed with intensities greater than that of a tungsten strip lamp at 2800°K in the spectral region 3800 to 6500 A. The absence of these lines results from the low concentration of core material in the arc plasma. The slow evaporation of cathode material and slow deterioration of the electrodes (limited oxidation by the small amount of oxygen) limit the concentration of core material entering the arc stream. This is in agreement with the findings of Somers and Smit[19] for electrodes cored with KCl burning in nitrogen.

Another condition favoring a low concentration of core-material atoms in the plasma is the direction of the potential field in the arc.

The rare earths (the materials usually present as oxide-carbon mixtures in the core) have low ionization potentials, and as ions in the plasma would tend to drift back to the cathode.

The Intensity of the CN λ3883 Emission

The intensity of the CN λ3883 emission from the arc plasma is discussed, in general, in terms of brightness temperature.* The brightness temperature of the CN λ3883 emission will henceforth be designated S_{3883}.

A plot of S_{3883} in °K versus power input in watts is given in Fig. 9. The brightness temperature was found to increase linearly in the region of power input investigated, with a two-fold increase in power input producing a 300°K rise in S_{3883}. The increase in S_{3883} results from an increase in the plasma temperature, which, in turn, depends on the increase in the current density. Since the plasma dimensions increase with increasing current, the increase in plasma temperature—and also the increase in S—is expected to be slight. Had the plasma dimensions been held constant, the increase in S_{3883} would have been more rapid.

The increase in S_{3883} with increase in plasma temperature does not continue indefinitely, as the increase in degree of dissociation soon outweighs the increase in degree of excitation, and the brightness temperature decreases.

Figure 10 is a plot of intensity vs pressure during a pumpdown of the chamber with the arc burning in pure nitrogen. As can be seen,

---

*See Part B for the definition of brightness temperature and the method of determination.

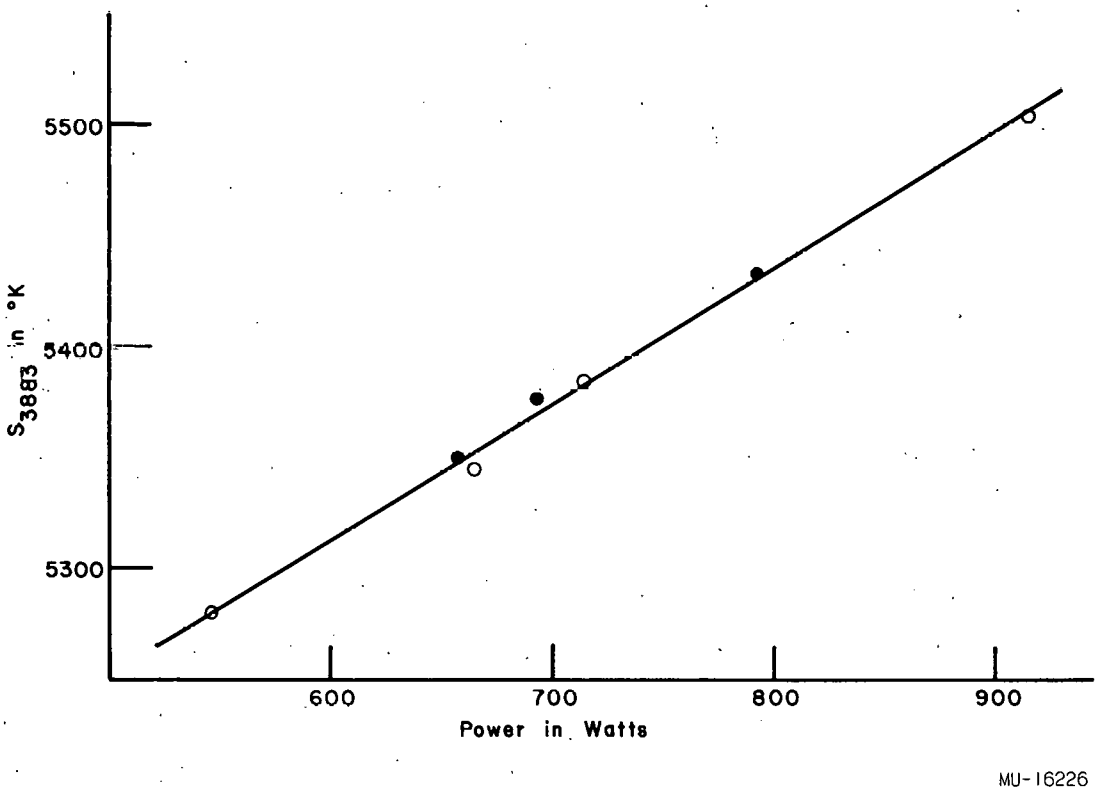


Fig. 9. S_{3883} vs power input for an arc in a nitrogen-air mixture at 140 mm Hg pressure. Arc dimensions: a, 12.6 mm; b, 5.2 mm. Aperture positioned near the cathode in the center of the plasma (see Fig. 8).

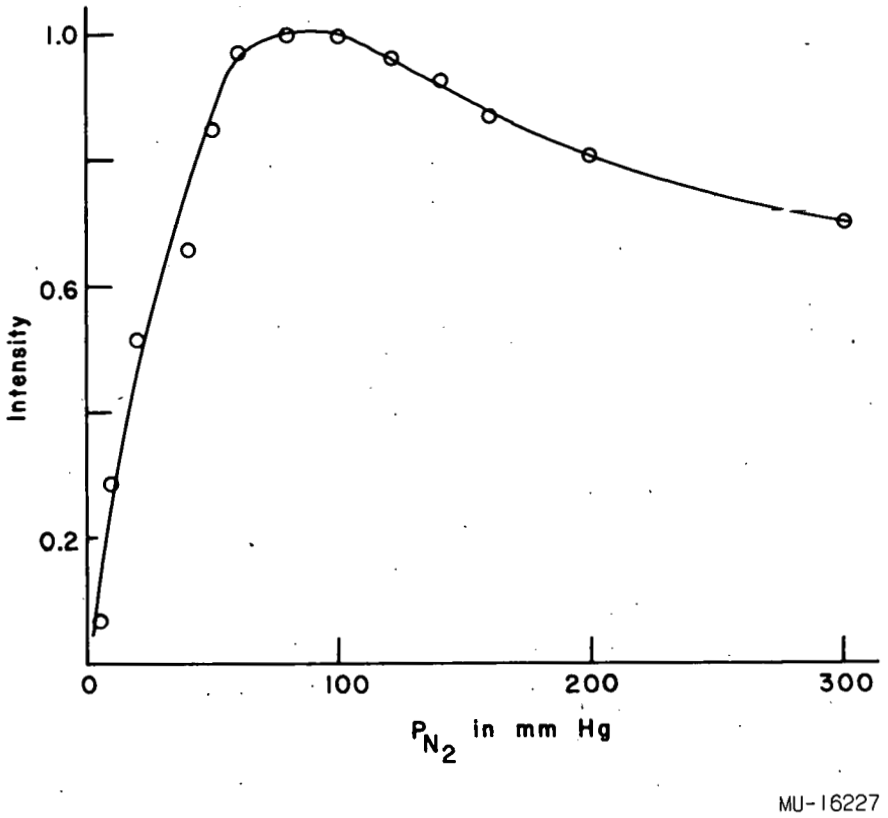


Fig. 10. Intensity of the CN 3883 radiation from the arc plasma vs nitrogen pressure during a pumpdown of the arc chamber. Total pumpdown time was 5 min.

the intensity first increases and then decreases as the pressure of nitrogen decreases. The pressure of nitrogen under static conditions giving the maximum intensity was found to be 140 mm Hg.

The decrease in intensity below 100 mm can be attributed to a decrease in the concentration of CN coupled with a decrease in the plasma temperature. (The plasma temperature of a carbon arc is known to decrease quite rapidly with decreasing pressure below 0.1 atmos. See refs. 20,21.) The decrease in intensity above 140 mm pressure can be attributed only to self-absorption. The effect of self-absorption is discussed in detail later, see p. 56. Briefly, at low concentrations of CN self-absorption by the cooler layers of CN surrounding the hot central plasma is unimportant, but at higher pressures of nitrogen, at which the concentration of CN has increased sufficiently, the cooler layers are very effective in absorbing the radiation from the hot central regions. As a result, the intensity of the CN emission is reduced.

A brightness temperature of 4780°K was observed for a carbon arc in pure nitrogen, and a value of 5350°K was observed for the same arc in a nitrogen-air mixture. The arc conditions are given in Table II rows 1 and 2. The increase in brightness temperature results from the presence of oxygen in the atmosphere around the arc stream.

In nitrogen, the arc burns surrounded by a mantle of carbon dust and cooling gases, among them some CN. The mantle acts to attenuate the intensity of the light emitted in the center of the arc stream. The introduction of a small amount of oxygen into the atmosphere immediately removes this mantle by burning the carbon evaporated from

the electrodes and, also, by oxidizing the carbonaceous gases in the cooling layers of the arc stream before they form carbon dust.

Thus a small amount of oxygen in the atmosphere around the arc is necessary for obtaining a higher brightness temperature of CN λ3883 emission.

Figure 11 gives the change in S_{3883} with pressure for an arc operating in a nitrogen-air mixture. The curve is very similar in shape to the curve obtained by Ornstein, Brinkman, and Beunes[20] for the plasma temperature of an arc at various pressures of air. As with nitrogen, it is concluded that at low pressures the intensity (brightness temperature) of the CN emission is decreased both by the lower plasma temperature and by the lower concentration of CN. Above 100 mm pressure, the increase in the brightness temperature is slow, and is probably due to the increase in plasma temperature rather than because of any increase in the concentration of CN.

The optimum pressure of nitrogen-air for operation of the arc is between 140 mm and 350 mm Hg. In this range of pressures, the change in brightness temperature with pressure is slow, and the arc assembly, especially the electrode-adjusting mechanism, is least troublesome.

The S_{3883} of an arc with pure graphite electrodes was determined (5450 ±90) (see Table II) and found to be higher than that of an arc with a cored carbon cathode (5350°K). The increased stability of the arc with cored carbon cathode is much more important than the slight increase in brightness temperature gained by the use of a graphite cathode.

S_{3883} was determined for an arc between graphite electrodes in a

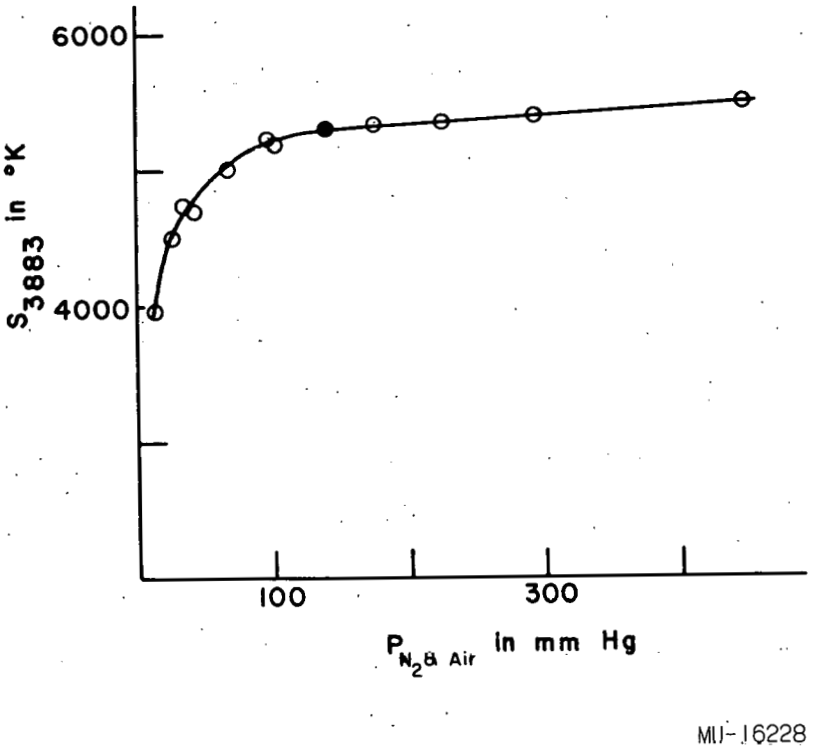


Fig. 11. S_{3883} vs pressure of the nitrogen-air mixture in the arc chamber for an arc burning between a 5.8-mm cored carbon cathode and 6.3-mm graphite anode.

nitrogen-air atmosphere and also in a pure air atmosphere (see Table II). The values were the same, within experimental uncertainty (5450±90 and 5480±60°K). This indicates that after the introduction of a small amount of oxygen into the arc chamber with the arc burning in nitrogen, further increase in the concentration of oxygen is ineffectual as far as increase in S_{3883} is concerned.

No determination of S_{3883} for an arc with a cored carbon cathode burning in air was made, but on the assumption that S_{3883} follows qualitatively the plasma temperature, a decrease in S_{3883} would be expected. (The plasma temperature of an arc between cored electrodes in air has been reported by a number of investigators to be lower than that of an arc between pure carbon electrodes.[8,12,21-24])

S_{3883} was determined at various positions, as shown in Fig. 8. The values vary with position in the expected manner and in qualitative agreement with the variation of plasma temperature in the low-current arc.[8,24,25] The arc-stream area between the electrode hot spots presents a source of CN λ3883 emission which is fairly uniform in brightness temperature.

Arc Stability and the Arc Mechanism

The arc stability is discussed in terms of the mechanisms occurring in the three regions of the arc; the cathode and its fall space, the anode and its fall space, and the arc stream or plasma. (The fall space is that space extending a few fractions of a mm in front of the electrode, which is characterized by a very steep potential gradient.)

The Cathode

In a carbon arc, the greater part of the arc current is carried by electrons, and the function of the cathode is to supply these electrons. The electrons are emitted thermally from the cathode surface, and the surface is maintained at the required temperature by the energy released from the impinging positive ions. The ions are accelerated by the sharp potential drop in the fall space; the drop in the carbon arc is about 10 v.[5,17] The temperature of the cathode spot depends on the composition of the electrode material, the work function, and conductivity, and the spot size depends on the conductivity and diameter of the electrode in addition to the current.

Let us first consider the carbon arc in air. The shape of the cathode (see Fig. 1) is determined by oxidation and not by evaporation.[26] In an arc with a 6.3-mm graphite cathode, which has a fairly high work function and heat conductivity in comparison with electrodes cored with rare earth oxides, the cathode spot is very small, less than 1 mm.[2] Aside from the cathode spot, the cathode surface is fairly cool because of the size and conductivity of the graphite electrode.

The heating at the spot is very shallow, permitting the hot spot to wander about the cooler cathode dome, which is fairly uniform in temperature. The constant wandering may result because the freshly oxidized surface at the edge of the hot spot offers a lower work function for the release of electrons. Migration up the side of the electrode is unfavorable because of the temperature gradient.

With cored carbon electrodes in air, the cathode spot is confined to the central cored region of the electrode by virtue of the low work function for electron emission at the surface of the rare earth oxide.

The energy dissipated per unit surface area of the cathode spot is given by the current density and the potential drop. The current density at the cathode spot on the 6.3-mm graphite cathode was estimated as 10 amp per mm^2, the spot area increasing with current. With the 5.8-mm-cored carbon cathode, however, the current density varied from 3 to 10 amp per mm^2 because the spot area remained essentially constant (the area of the core).

The high-current-density cathode spot in the graphite arc is the seat of the contracted column in the free-burning high-current arc,[5,11] since the plasma diameter is least at the cathode spot. In the investigations carried out with constrictors, I have observed that the formation of the contracted column in the constricted region was accompanied by the appearance of a similar contracted column at the cathode, independent of the constrictor diameter. As the current through the arc is increased, these columns increase in length and join in the diffuse plasma surrounding them. At the same currents in a free-burning arc no contracted column was observed. The prevention,

by the constrictor, of the expansion of the arc plasma along the length of the arc column as the current is increased (the usual occurrence in a free-burning arc) is offered as an explanation.

After operation of an arc between graphite electrodes in nitrogen, the cathode tip surface was found to be covered with lampblack and many pits or small craters, usually less than 1 mm in diameter. From this appearance it is possible to offer the following explanation for the instability of this arc in nitrogen. In air, the carbon evaporated from the hot spot is oxidized, and the electrode carbon itself is oxidized. Thus the cathode surface of an arc in air is a clean graphite surface. In nitrogen, the evaporated carbon is not consumed, no oxidation of the electrode occurs, and, furthermore, the carbon vapors diffusing from the cathode spot are condensed at the very edge of the spot by the cool electrode surface. This layer of lampblack or veil of amorphous carbon is a poor thermal or electrical conductor, and acts to prevent smooth migration of the hot spot. Since the cathode spot is trapped by the condensing vapors, it remains for some time fixed in position and forms a pit or crater in the electrode at this position. After an indefinite time interval, the hot spot migrates very rapidly, jumps from this crater, and forms another crater at a new site by the same process. Thus, the face of the cathode becomes covered with small craters, and jumping from crater to crater by the hot spot is quite common. The cathode spot sometimes wanders up the side of the electrode, especially after the face has become covered with a layer of lampblack.

This type of cathode mechanism renders the arc useless as a stable source of CN emission.

With the 5.8-mm cored carbon cathode, the cathode spot remained fixed and the arc operated very steadily. After some time, the arc became unsteady, with the cathode spot dancing about on the rim of the deeply cratered electrode. The deep crater results from the hot spot's being confined to the surface of the core and evaporating only core material. After the crater becomes about 5 mm deep the cathode spot migrates to the rim of the crater and produces an arc of the same type as formed with a graphite cathode. Migration back to the core is prevented by the depth of the crater. Removal of the crater walls in any manner, of course, restores the cathode spot to its position on the core.

The Anode

The anode of the carbon arc serves to receive the current-carrying electrons. The arc with a solid graphite or homogeneous carbon anode has two forms of anode spot, a low-current-density noiseless form, and a high-current-density hissing form. These two types of anode spots have been described in the literature many times.[3,4,5,17,27] Mechanisms have been presented for the low-current-density anode[28] and the high-current-density anode.[5,26,28] These mechanisms have been developed on the basis of observations made on arcs with large amounts of core material.

In the pure carbon arc, as in the cored carbon arc, the anode, in addition to receiving the electrons, provides by thermionic emission some of the positive ions necessary to neutralize the space charge in arc stream.[28] Thus, a certain potential drop, dependent on the work function for thermionic emission of positive ions at the electrode

surface, is required in the region just in front of the anode. In the pure carbon arc the anode drop may be 30 v,[5] while in arc with large central core, the anode drop may be 5 to 10 v.[15]

The temperature of the anode surface and the rate of evaporation of the anode material are dependent on the current density at the anode surface since the current density and the anode drop determine the energy dissipated at the surface.

The low-current-density noiseless anode spot is a uniformly incandescent surface which generally covers the entire face of the anode in a properly adjusted arc and represents the stable form of the low-current arc. If the current density at the anode is increased above a critical value (this value may be dependent on the electrode arrangement or trim), the high-current-density anode spot is formed. This form is characterized by a lower anode drop (about 10 v less), a marked increase in the rate of electrode evaporation, and a lower incandescent brightness,* in addition to the higher current density.

It was possible, with a properly adjusted arc arranged as shown in Fig. 1, to operate the arc fluctuating between the normal, low-current-density anode form and the overloaded, high-current-density anode form. Such an arc was interrupted and the effective area of the anode spot was measured (the area of the well-shaped crater).

---

*In determining the brightness temperature of the low-current-density anode spot, one found that the intensity of the radiation always decreased whenever the high-current-density anode spot was formed. At sufficiently high current densities, however, the intensity of the hot gases in front of the anode increases the intensity above that of the low-current-density anode. See Refs. 4 and 26.

From visual observation the area of the anode spot appeared to remain constant. If any change occurred, it was a decrease in the area of the spot on formation of the overloaded arc. From the currents observed for the arc in both forms, a current density of 1 amp per mm^2 as a maximum for the normal arc and a current density of 1.1 amp per mm^2 as the miniumum for the overloaded arc were obtained. The maximum current density for the normal arc operated as shown in Fig. 8 was found to be 1.2 amp per mm^2. The difference is in the expected direction, if the change in anode apot type is temperature-dependent, since in the vertical arc the hot column gases are passed over the anode by convection currents, but when the anode is horizontal, a large part of the column gases is carried away without passing over the surface of the anode.

The current densities given are for a graphite anode burning in an air atmosphere. The current densities at the transition points were determined for a graphite anode in nitrogen and found to be 1.4_2 and 1.5_4 amp per mm^2.

Since the transition region represents an unstable region of operation, current densities near these values are to be avoided if a stable arc of either form is desired.

With an improperly adjusted low-current arc, a high-current-density anode spot that is very unstable in position will be formed. This type of anode spot was observed when the power input was too low for the size of electrode employed. The anode spot of this type presumably arises by the following process. As the power dissipated at the anode surface decreases, the incandescent hot spot of the normal

arc is reduced in size because of the minimum temperature required to emit the positive ions necessary for the arc mechanism. If the electrode is of sufficient size (has sufficient heat capacity), the anode spot reduces in size until the current density and spot temperature reach the values needed for the transition to the high-current-density anode. Because of the small size of the anode spot, the energy dissipated per unit surface area is high, but, because of the rapid evaporation of anode material, the fraction conducted into the electrode is low. As a result, the heating at the anode surface is very shallow and the spot is capable of wandering about the surface of the anode and even up the side, sometimes to such distances that the arc is extinguished.

This type of arc is always formed when an arc is freshly struck between cold electrodes. The arc will persist in this form unless the total power input is sufficient for the small fraction conducted into the electrode to heat the electrode to a temperature high enough for the formation of the low-current-density anode.

Thus, the arc with a low-current-density anode has a minimum current (power input) requirement for stable operation as well as a maximum tolerable current, both dependent on the size of the electrodes.

With a carbon arc in nitrogen, the high-current-density anode arc (the migrating-spot type) arises in still another manner. Because of the absence of anode spindle in nitrogen atmosphere, the danger of reaching an overloaded arc is lessened. This advantage is removed by the effect of soot formed by this arc. The carbon vapors from the anode spot are condensed at the edge of the electrode and the carbon dust in the mantle around the arc stream forms a cone of soot around the end

of the electrode and restricts the plasma diameter at the anode. As a result, the current density is increased until a high-current-density anode spot is formed. This spot then wanders about on the anode by blowing off the soot in its path. The time required for this type of arc to form in 140-mm nitrogen was about 15 to 30 min.

The arc can be restored to the low-current-density anode type simply by introducing a small amount of oxygen into the atmosphere to remove the soot.

The Arc Stream or Plasma

The arc stream or plasma serves to conduct the current between the electrodes of the arc. The mode of conduction depends on the ambient gas and its conditions. In the carbon arc, most of the current is carried by electrons. The stability of the plasma when the arc is operated in a nonturbulent atmosphere is dependent only on the stability of the cathode and anode hot spots. Thus a stable set of electrodes guarantees a stable plasma.

The radiation emitted by the plasma is of importance here. The character of the light emitted by the plasma is dependent on a number of parameters. The molecules and atoms present in the plasma, the mode of excitation of the emitters, and the temperature and pressure of the emitting gas are amoung the more important parameters.[12,29]

In the low-pressure arc or discharge, the main mode of excitation of the emitters is electronic, that is, by collision with hot electrons. The temperature of the electron gas in the plasma is many times the gas temperature. As the pressure of the gas is increased, the frequency of collisions is increased and the two temperatures approach each other. Above 100 mm Hg the two temperatures are approximately equal, but the

electron-gas temperature must remain slightly higher, since the mode of heating is by energy transfer from the electrons accelerated by the potential gradient in the arc plasma.[8,12,21] At these pressures, the excitation is essentially thermal, and the gas emits as a gas at the temperature of the plasma. That the mode of excitation in the carbon arc in air at atmospheric is thermal, has been demonstrated by Kruithof[8] and Witte.[23]

In the pure carbon arc in air or nitrogen with a low-current-density plasma, the emission is from such species as N_2, CN, C, N, C_2 and smaller concentrations of other carbonaceous species. The oxygen is used up in the cooler layers of the arc and is unimportant as an emitter or an a constituent in emitting species. If the arc is operated between electrodes cored with metal oxides or other materials, lines from various species of the core material are also prevalent in the emission from the plasma. The intensity of a specific "line" depends on the concentration, optical density, or thickness[12] of the species, its transition probability, the excitation potential, and the effective excitation temperature of the plasma.

Before considering the intensity of the CN emission from the carbon arc plasma let us first discuss the effect of constrictors on the plasma.

The effect of constrictors on the plasma

When constrictors are present in the arc stream, the plasma within the orifice region is reduced in diameter, and its temperature is raised, producing a region of higher excitation temperature.[12] This may or may not be a favorable condition, as it may increase or decrease the concentration of the emitting species.

Spectra were taken of the emission from the plasma between the constrictor plates of an arc burning between cored electrodes. These spectra, in contrast to those taken of the plasma between the cored electrodes of an open arc, were devoid of core-material lines. The absence of these lines must be attributed to the action of the constrictor plates.

The atoms from the core materials, usually rare earth oxides, have low ionization potentials, and therefore exist in the plasma as ions and emit ion lines. The constrictors act to remove these ions at the orifices and prevent them from entering the plasma region between constrictors by the following mechanism. The electrically floating copper constrictors become negatively charged by the very mobile electrons colliding with the orifice walls. (See the discussion by Darrow[30] on the effect of probes in a discharge.) Thus a potential gradient is formed along the radius of the plasma in the orifice, and the ions in the plasma are accelerated to the walls of the orifice and collect there. The negative charge is maintained on the constrictors because of the higher mobility and velocity of the electrons as compared with that of the heavier ions.

Thus, the use of constrictors to enhance the intensity of an ion line through increase of the plasma temperature will result in a weakening of the line because of the reduction in the optical thickness of the ion in the plasma between the constrictors. For enhancing the intensity of atomic or arc lines, on the other hand, when the atom has a high ionization potential and the upper state of the line has a high excitation potential, the use of constrictors will prove profitable.

The intensity of the CN λ3883 emission

In an attempt to build up the intensity of the CN emission (increase S_{3883}), the logical mode of attack is to build up the optical density (concentration) of the CN in the plasma so that the intensity of the center of the λ3883 head will become equal to that of a black body at the temperature of the plasma, the maximum possible (S_{3883} equal to the plasma temperature). The optical density of CN should be highest in the plasma of a carbon arc burning in a nitrogen atmosphere, and indeed, it is. But, it is also very high throughout the entire region of the arc plasma, and, because of the temperature gradient along the radius of the arc column, S_{3883} is lowered by self-absorption effects.

At low pressures of nitrogen, S_{3883} increases with the pressure of nitrogen (from a few mm to 140 mm Hg) until the optical density of the CN becomes high enough so that the increase in self-absorption in the cooler layers of plasma cancels the increase in S_{3883} resulting from the increased plasma temperature at the center of the plasma. Further increase in the nitrogen pressure increases the optical density and self-absorption more rapidly than the plasma temperature, and, as a result, S_{3883} decreases with increasing pressure. Thus, even though S_{3883} may be very high at the center of the arc stream (possibly equal to the plasma temperature, 5800 to 6600°K), the measured S_{3883} of the plasma emission is below 4800°K.

S_{3883} has been found to be much higher when a small amount of oxygen is present in the ambient atmosphere. The increase results not only from removal of the mantle of carbon dust around the arc stream, but also, and more important, from reduction of the CN optical

density in the coller layers of plasma. The oxygen diffuses into the plasma and oxidizes the CN in the cooling self-absorbing layers, but, at proper concentration, does not reduce the concentration of CN in the central part of the plasma. Thus by reducing the amount of self-absorption without reducing the intensity of the emission from the central hot plasma, the oxygen serves to increase S_{3883} from ~4800 to 5300°K.

Comparison of S_{3883} and the plasma temperature

No measurements were made to determine the plasma temperature of the arc developed in this research, but, from the values reported for arcs operated under very similar conditions,[8,19] the plasma temperature is estimated to lie between 5800 and 6600°K. Because of the higher currents employed here (9.5 amp vs 5 amp or less) and because the anode employed here was uncored (solid graphite), the higher temperature is favored. The value of S_{3883}, around 5300°K, is in the expected range since high optical densities are generally not attained at high plasma temperatures,[12] and self-absorption by the cooler layers can hardly be expected to be completely removed. In addition, the value of 5300 represents a minimum value for S_{3883} for the arc at optimum conditions.*

The estimated value of S_λ of 5500°K (see p. 97) is about 1100°K below the estimated plasma temperature, 6600°K, the maximum S_λ possible. This means that the intensity radiated by the arc stream at 3883 A is about one-third the maximum possible intensity.

---

*Because of instrument limitations in the measurement of S_{3883}, the values reported here are suspected of being too low. See part IIB.

CONCLUSIONS

Studies have been carried out on various carbon arcs in air which have resulted in an understanding of the requirements necessary for the production of an arc with the desired stability. The features that rendered the carbon arc undesirable were studied and the critical conditions for their formation were determined in order that they might be avoided.

From these studies, it was established that for the stable arc required:

1. The size of the electrodes to be employed is determined by the power available. A certain power dissipation, dependent on electrode size, is required to establish stable electrode behavior.
2. The high-current-density anode spot is undesirable and can be avoided by adjusting the power input to yield the proper current density at the anode spot. For a 6.3-mm graphite anode, the arc current should be between 8 and 10 amp if the arc is operated in air, but the upper limit can be extended in controlled atmosphere.
3. The high-current-density contracted column is to be avoided when the amount of the emitting species can be depleted because of the high temperatures in the column plasma.
4. The use of a cored carbon cathode with a small core diameter is necessary to establish a stable cathode spot and prevent plasma motion.
5. Constrictors are useful for establishing a plasma that is

fixed in position and quite stable in emission characteristics.

6. The carbon arc in air, because of rapid electrode consumption, requires constant electrode adjustment in order to maintain constant intensity of emission from the plasma.

For the study of the carbon arc in controlled atmosphere, an arc chamber was designed which would allow considerable variation of the arc operation conditions.

As a result of the studies of the carbon arc in controlled atmosphere, a stable, intense source of CN emission has been produced. The following requirements have been found the most critical in establishing a stable carbon arc that will produce constant and intense CN emission:

1. A cored carbon cathode is necessary to establish a stable cathode hot spot. The core diameter should not be too large. The reduction in S_{3883} as a result of employing a cored cathode in place of a solid graphite column is negligible in comparison with the gain in stability.
2. A solid graphite anode is preferred over a cored anode because the arc with a graphite anode has a higher plasma temperature without loss in stability. The cored anode would add metal ions to the plasma and reduce the plasma temperature and S_{3883}.
3. The electrode orientation or trim should be that shown in Fig. 8, since the anode stability is enhanced if the anode is held horizontal and the cathode is held vertical and slightly below the end of the anode.
4. A reduced pressure is important, not only because it is

convenient for operation of the arc chamber, but also because the anode spot exhibits an enhanced stability below 400-mm Hg pressure with the atmosphere and currents employed here.

5. The atmosphere should be largely nitrogen in order to obtain a high CN concentration in the plasma and lengthen the life of the electrodes.

6. A small concentration of oxygen is required in the arc-chamber atmosphere for a number of reasons. It removes the mantle of carbon dust that surrounds the arc stream of a carbon arc in nitrogen and increases the intensity of emission from the plasma. It serves to reduce the adverse effects of self-absorption by oxidizing a large portion of the CN as it diffuses into the cooler layers of the plasma. The oxygen is also necessary to keep the electrodes clear of soot and, thereby, prevent electrode-spot instabilities. Slight oxidation of the cathode casing to prevent deep pitting at the core and the resultant instability is another function of the small oxygen content. High concentration of oxygen is to be avoided because of the rapid rate of electrode consumption resulting. In an arc with cored electrodes, the increased rate of consumption lowers the plasma temperature by introducing a large concentration of core material, metal ions, and atoms.

The most satisfactory conditions for the operation of the arc in the controlled atmosphere were determined by studying the arc stability

as a function of various parameters.

The brightness temperature, S_{3883}, of the CN emission from the plasma of the stable carbon arc developed was determined. The value obtained, ~5500°K, probably represents the highest attainable with the carbon arc because of the dissociation and self-absorption processes associated with the carbon-arc plasma.

B. A METHOD FOR THE DETERMINATION OF BRIGHTNESS TEMPERATURES

INTRODUCTION

A program directed toward the determination of radiative lifetimes of high-temperature molecules has been initiated in these laboratories. The apparatus employed for the determination of such lifetimes requires light sources with high radiant flux (intensity) at specific wave lengths[1] (see Introduction, Part A).

For our purposes, the most convenient method for expressing the intensity of a light source at a given wave length is through the brightness temperature. The brightness temperature* of a light source at a specific wave length is equal to the temperature of a black-body source which, at the same wave length, gives the same intensity per unit wave-length interval as the light source.

A knowledge of the brightness temperature of a light source at a specific wave length allows one to calculate the number of quanta emitted by the lamp at that wave length over a wave-length interval commensurate with the brightness temperature. Equation (B-1) gives the intensity in quanta per second per cm^2 source area per steradian per unit wave-length interval for a source with brightness temperature S_λ at λ.

$$R_\lambda = (2c_2/\lambda^4)\frac{1}{\exp(c_2/\lambda S_\lambda) - 1} \qquad \text{(B-1)}$$

From the known area of the source and the efficiency of the optical system, the effective number of quanta can be calculated for a given

---

*The brightness temperature at the wave length λ will be expressed in this thesis as S_λ.

system.

Richard Brewer, in his thesis, has outlined the method for calculating the minimum value of S_λ required for a light source to be useful for determining the lifetime of a specific species with the lifetime apparatus available.[1] It is important, for the success of a lifetime measurement, to know that the lamp has a sufficiently high brightness temperature at the required wave length.

In general, intensities of light sources are given in terms which do not allow us to determine the usefulness of a lamp for our purposes. Expression of the intensity in candles per mm^2, although useful for determining the lighting effectiveness of a lamp (admittedly, the purpose of most commercial lamps), is useless for the determination of the number of quanta emitted by the lamp at a specific wave length. The spectral energy distribution of a lamp expressed in watts per 100 A or other large wave-length interval, while more helpful than candles per mm^2 for determining the usefulness of a light source, does not yield the quanta per unit wave-length interval at a specific wave length unless the exact profile of the lamp radiation is known. This is especially true for sources that emit atomic lines or other sharp features, the kind of source of interest for our purposes.

Because of the lack of data of the type necessary to determine the brightness temperatures of available sources, the development of a method for determining S_λ values of light sources and application of the method to available light sources was initiated.

As stated earlier, light sources of high intensity at specific wave lengths are of interest for lifetime studies. Such sources as

commercially available vapor discharge and arc lamps prove useful if the lamp emits radiation at the wave length at which the species of interest absorbs. In some cases, especially in study of atomic species, sharp line sources are desirable, whereas for studies of molecular species in which a number of rotational lines are capable of absorbing radiation, a broadened line source such as a medium- or high-pressure arc lamp may be more desirable. Also, with broadened sources, the possibility of overlap of emitting and absorbing wave length is greater.

Perhaps the best sources of very intense sharp lines may prove to be microwave-powered sources similar to those described by Ham and Walsh[31] and by Branner, Ferguson, and Wehlen.[32] Ham and Walsh describe lamps for use in Raman studies containing mercury vapor, sodium vapor, or helium gas which emit very intense, sharp lines characteristic of the vapor or gas, and suggest that other vapors or gases could be employed. The mercury lamp described by Branner, Furguson, and Wehlen emits 0.01 watt per cm^2 per steradian at 5461 A from a line of 0.03 A-half width.[32] The brightness temperature of this line is calculated as ~7300°K. Thus it appears that microwave-powered sources may prove very useful as light sources for lifetime studies.

METHOD

The brightness temperatures of the light sources were determined by comparison of the intensity of the radiation from each source with that from a tungsten strip lamp of known brightness temperature at the same wave length and wave-length interval.

According to Wien's Law (which holds for the temperatures and wave lengths of concern here), the intensity of a source at the wave length λ is given by

$$I(\lambda)\, d\lambda = A(2hc/\lambda^5)\, e^{-(c_2/\lambda S_\lambda)}\, d\lambda, \qquad \text{(B-2)}$$

where S_λ is the brightness temperature and A is the area of the source.

If the intensities I_W and I for the tungsten strip lamp and the light source, respectively, are determined with equal source area, the brightness temperature of the light source, S_λ, can be calculated from

$$1/S_\lambda = 1/S_{W\lambda} - (2.303/c_2)\,\lambda\, \log(I/I_W), \qquad \text{(B-3)}$$

where c_2 is the second radiation constant (c_2 = 1.4380 cm deg, ITS 1948), λ is the wave length in cm, and $S_{W\lambda}$ is the brightness temperature of the tungsten strip lamp at the wave length λ.

$S_{W\lambda}$ can be calculated from S_{W6550} (as measured with an optical pyrometer) and the following equation:

$$1/S_{W\lambda} = 1/S_{W6550} - (2.303/c_2)(6.55\times10^{-5}\log(1/\tau\epsilon)_{6550} - \lambda\log(1/\tau\epsilon)_\lambda). \qquad \text{(B-4)}$$

In this equation, τ is the transmission of the lamp envelope at λ, and ϵ is the emissivity of cold-rolled tungsten at the wave length λ and the true temperature T of the tungsten strip filament. The wave

length 6550 is the effective wave length of the optical pyrometer used to determine S_{W6550} of the tungsten strip lamp. (The value λ_e = 6550 A is the value given by William T. Hicks for the pyrometer employed.[33])

Thus, in order to determine the brightness temperature of a light source by this method, one must determine the following quantities:

1. The ratio of intensities (I/I_W) at the wave length λ and wave-length interval $d\lambda$. (The importance of $d\lambda$ will be considered shortly.)
2. S_{W6550}, the brightness temperature of the tungsten strip lamp at the effective wave length of the optical pyrometer.

The methods employed in determining these quantities are related in the following sections.

The light sources of concern here are generally line sources, and, since the strip lamp emits a continuum, we are comparing the intensity of a continuum with the intensity of a line of finite width. In order to determine accurately the intensity of the peak of the spectral line from the light source, the wave-length interval $d\lambda$ should be small compared with the width of the line. The spectrometer must have sufficient resolving power to give the true shape of the spectral line, that is, the instrument must not broaden the line. Any broadening of the line by the instrument reduces the value of the intensity per unit wave-length interval at the peak of the line. This yields a low value of S_λ since a slight instrument broadening has no effect on the intensity per $d\lambda$ of the continuous emission from the tungsten strip lamp.

Unfortunately, in the measurements carried out here (with the exception of the work with medium-pressure mercury lamps), instrument broadening limited the usefulness of the method for determining the true value of S_λ for the narrow line sources investigated. The values

of S_λ obtained represent minimum values for determining the usefulness of a light source.

The problem of instrument broadening is given further consideration in the next section.

EXPERIMENTAL PROCEDURE

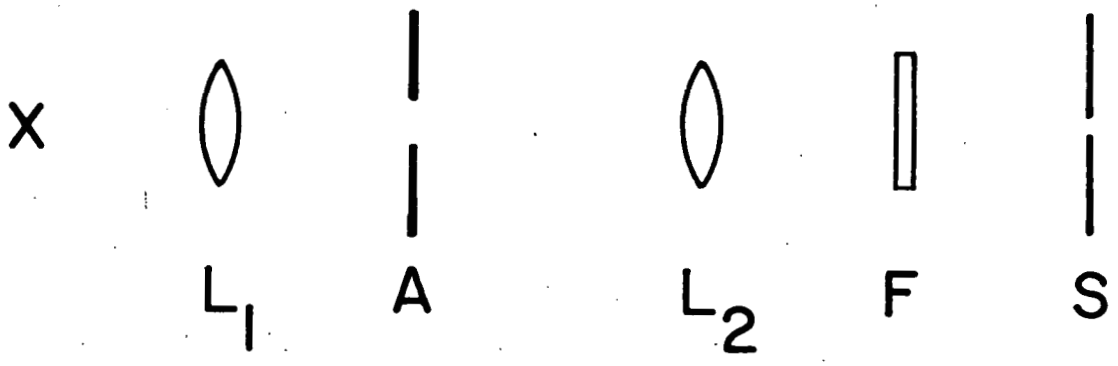
Determination of I/I_W

In determining the ratio of intensities, I/I_W, there are three conditions to be satisfied. First, the effective area of the light source and the strip lamp must be equal. Second, the intensities must be measured at the same wave length and, third, from the same wave-length interval. In carrying out the measurements, the intensity of the light source was determined first, then that of the strip lamp, with identical optics.

The optical arrangement employed in order to fulfill the requirement of equal effective source area is represented schematically in Fig. 12. An image of the light source or strip lamp filament X is formed on an aperture A by the lens L_1. It is important that this aperture be filled by the region of the light source which is of interest and, in turn, by the tungsten strip filament when each is in sharp focus with the same optics. With this accomplished, the requirement for equal source area is fulfilled.

The remainder of the optical train contains provisions for filters, which may be needed to weaken the intensity of the radiation (by neutral filters) or prevent light of certain wave lengths from entering the spectrograph slit (band-pass filters), and the lens L_2, which serves to form an image of the aperture on the slit of the spectrograph.

In order to fulfill the second and third conditions (at least in part) and, also, to measure the intensity, a 3-meter concave-grating spectrograph equipped with a scanning photomultiplier was employed. The output from the 1P21 photomultiplier is fed into an amplifier and



MU-16229

Fig. 12. Schematic of the optics employed for brightness-temperature determinations.

X. Light source or tungsten strip lamp.

L_1. Double convex quartz lens, 10- or 23-mm focal length.

A. Defining aperture, opening about 2mm in diameter.

L_2. Double convex lens, 23-cm focal length.

S. Entrance slit of the 3-meter grating spectrograph.

the amplifier output into a Brown "Electronik" strip-chart recorder. (The scanner and amplifier were constructed by Dr. John Phillips and have been described by him.[34])

The apparatus is so arranged that the image of the entrance slit of the spectrograph is focused on a slit placed in front of the photomultiplier. The slit is moved along the Rowland circle of the spectrograph by a synchronous motor and an appropriate gear train. Thus, the wave length λ is determined by the position of the slit on the Rowland circle, and the wave-length interval $d\lambda$ is determined by the width of the slit and the linear reciprocal dispersion of the spectrograph. The intensity of the light of wave length λ and wave-length interval $d\lambda$ is measured by the response of the amplifier and Brown recorder.

Procedure for Measurement of the Intensity

With the light source operating as desired, the spectral feature of interest from the lamp was scanned at the slowest scan speed (0.67 or 0.33 A per min, 1st or 2nd order, respectively) in both directions. An indication of the shape of the feature was gained in this manner. (The resolution of the 3-meter spectrograph is not sufficient to give the true profile of a sharp spectral feature.) After the shape of the feature (as given by the instrument) was revealed, the slit of the scanning photomultiplier was moved to the position of interest and a scan of intensity with time was taken. This was necessary in order to obtain a better measure of the true intensity (especially of sharp spectral features), since the response time of the amplifier-recorder circuit was too slow to give full response even at the slowest

scan speed.

The positioning of the photomultiplier slit was accomplished by slowly changing the position of the slit through hand rotation of the synchronous motor armature. When the feature had a single peak, the slit was moved until the position giving maximum recorder response was reached, and this intensity was recorded as the peak intensity of the feature. When the feature exhibited reversal, the same procedure was followed in order to obtain the maximum intensity of the wings and the minimum intensity of the central, reversed portion of the line.

After completion of the intensity measurements on the light-source feature, the light source was replaced by the tungsten strip lamp and the intensity of the strip lamp was measured with the photomultiplier slit at the peak intensity or center of the spectral feature.

When the light source contained several spectral features of interest, a separate experiment of this type was carried out for each feature.

Uncertainties in the intensity ratio

Because $S_{W\lambda}$ was, in general, much lower than S_{λ} for the spectral feature from the light source (~2700°K as compared with ~5000°K), a wide variation in gain factor was required (~600) in order to determine the intensity of both sources with any accuracy. The amplifier as designed was very well suited for this, as it is possible to change the amplification over a factor of 1000. The amplification factors were known with an uncertainty of about ±2%.*

---

*The author is indebted to Mr. John Engelke for the determination of many of the amplification factors.

The response of the amplifier-recorder circuit was linear to within ±1% and the intensities read from the recorder chart were within this range of uncertainty.

The above uncertainties are believed to be below the uncertainty in the intensity ratio which may arise from improper focus of the light source or the strip lamp on the aperture. Improper focusing at the aperture results in change in the effective area of the source of light, and this produces a change in the recorded intensity. In order to realize the uncertainty involved, the tungsten strip lamp was deliberately moved in and out of focus. When the lamp was obviously in bad focus, the intensity deviated from the value when the lamp was in focus by 10%. When the lamp was refocused, intensities were reproducible within ±2%.

About ±5% represents a good estimate of the uncertainty in the intensity ratio resulting from the uncertainties discussed. An uncertainty of ±5% in the intensity ratio produces an uncertainty of only ±1% in the value of S_λ when the value of S_λ lies between 3500 and 6000°K, the range for S_λ values determined in this research.

This uncertainty is representative of the uncertainty in the values of S_λ determined for features that are broad, such as lines from a high-pressure lamp or for the continuum from some high-intensity source such as the anode of a pyrometric arc. With the spectrometer employed in these studies, the values of S_λ for light sources emitting lines or sharp features with a width at half intensity less than about 0.1 A are subject to much larger uncertainty because of the effect of instrument broadening.

Instrument broadening

As stated earlier, it is important when this method is employed to determine S_λ that the spectrograph employed yield the true shape of the line in order that the intensity measured over the wave-length interval $d\lambda$ at λ be representative of the true intensity. Because of the narrow half width of the spectral features emitted by most of the light sources investigated here, the spectrograph employed was not capable of resolving the true line shape of the features.

The dispersion and resolving power of the 3-meter grating spectrograph are given in Table III. Since the width of the image of a monchromatic line formed at the Rowland circle of the spectrograph is given approximately by the sum of the theoretical resolving power and the entrance slit width (the width in A of the image of the entrance slit at the Rowland circle), it is possible to estimate the minimum line width of a spectral feature at the photomultiplier slit. The instrument broadening (width added to the inherent width of the spectral feature) estimated for the 3-meter spectrograph is given in Table IV for various slit widths employed. The estimated minimum instrument broadening with this spectrograph as employed is 0.07 A in the first order and 0.04 A in the second order. Thus, any spectral feature with a half-intensity width less than 0.1 A will be considerably broadened by the instrument.

The photomultiplier slit, which determined $d\lambda$, could be set at such a width that $d\lambda$ was much smaller than the instrument broadening. The intensities recorded are therefore representative of the feature as given by the instrument.

Table III

The resolving power and dispersion of the spectrographs employed

Spectrograph	Grating ruling	Order	Dispersion (A per mm)	Resolution (A at 4000A)
3-meter	~5 in at 15,000 lines per inch	1st	5.3	0.053
		2nd	2.7	0.027
21-ft	~5 in at 30,000 lines per inch	1st	1.32	0.027
		2nd	0.66	0.014

Table IV

Instrument broadening (an estimate of the width added to the natural width of a spectral feature)

Spectrograph	Entrance slit		Broadening in A at 4000A	
	Scale reading	Width (in mm)	1st order	2nd order
3-meter	20.0	0.004(minimum)	0.074	0.038
	21.2	0.0045	0.077	0.039
	21.6	0.0065	0.088	0.045
21-ft	29.6	0.004	0.03	0.016
	30.0	0.008	0.038	0.018

If the true profile of the spectral feature is known, an estimate of the true intensity can be gained. The peak height or intensity of a spectral feature is directly proportional to the half-intensity width if the feature is triangular in shape. Knowing the true half width of the spectral feature and the half width of the instrumentally broadened line one can obtain the true intensity by multiplying the observed intensity by the ratio of the half widths.

In order to gain a better estimate of the shape of the spectral features from the light sources investigated here, a 21-ft concave-grating spectrograph was employed. The dispersion and resolution of this spectrograph are given in Table III and the estimated instrument broadening in Table IV.

The spectra of the light sources were recorded photographically, and the plates were analyzed with a recording microphotometer. Hyperfine splitting and reversal of "sharp" lines which remained unresolved by the 3-meter spectrograph and scanner were resolved in this manner.

Estimates of the true widths of the spectral features were made from the spectra recorded with the 21-ft spectrograph. These estimated widths were used with the instrument broadening of the 3-meter spectrograph to estimate the true intensity of the spectral feature. The estimated width was added to the instrument broadening and taken as the width of the line at the photomultiplier slit. This width was divided by the estimated width and the observed intensity was multiplied by this quotient to give the estimated true intensity of the spectral feature.

Determination of S_{W6550} and $S_{W\lambda}$

The Tungsten Strip Lamp

The tungsten strip lamp employed as a source of radiation of known brightness temperature was a General Electric 18A/T10/2P-6V lamp with an SR6A filament. The lamp was operated at approximately 10 v dc and 18 amp. The power supply for the lamp consisted of a full-wave 30-amp selenium rectifier with a bank of storage batteries acting as a buffer to remove ripple from the rectifier output. The power supply for the rectifier was Sola stabilized 110v ac regulated by a powerstat.

The current through the lamp filament was determined by measuring the potential drop across a precision 0.01-ohm resistance with a precision potentiometer. The current was regulated by adjustment of the powerstat. After the lamp was sufficiently warmed, the current remained essentially constant.

In a few cases, the lamp temperature was determined from a previously determined curve of lamp temperature versus lamp current, but, generally, the temperature of the lamp was determined in position after the intensity determination (with the carbon arc) or during the intensity determination (with commercial lamps). The lamp current served as a check on the stability of the lamp during the intensity determination.

Measurement of S_{W6550}

The brightness temperature, S_{W6550}, of the tungsten strip lamp was measured with a disappearing-filament optical pyrometer. The number of temperature readings made during each intensity determination

but at least three and up to eight readings were taken each time. The mean deviation of the scale readings for any one intensity determination was less than ±2°K.

All the temperature measurements were made by using optical pyrometer No. 2,* Leeds and Northrup SN 749235. This pyrometer was compared with No. 3, Leeds and Northrup SN 709371, a pyrometer used only for comparison purposes and recently calibrated at the National Bureau of Standards in Washington, D. C. (Jan. 1958). The pyrometer scale readings were found to differ by a nearly constant amount (10.5±2°C) in the range of scale readings 2000 to 2600°C. This difference was subtracted from the scale reading of pyrometer No. 2 to give a value corresponding to a scale reading for pyrometer No. 3. The correction supplied by the National Bureau of Standards was then applied to this value and 273°C added in order to obtain S_{W6550}.

Thus, the temperature scale employed here is that of the National Bureau of Standards (1958) within the uncertainties involved in optical pyrometry. (The temperature scale is based on the Planck radiation law, with $c_2 = 1.4380$ and the gold point as 1336°K.) The lamp brightness temperatures are probably within ±5°K of this scale. At 2650°K, the usual value of S_{W6550}, an uncertainty of ±5°K in S_{W6550} will produce an uncertainty of less than ±1% in S_λ in the temperature range 3500 to 6000°K.

Determination of $S_{W\lambda}$

For the calculation of S_λ, the brightness temperature of the tungsten

*The optical pyrometers in the possession of this laboratory have laboratory identification numbers on their faces.

strip lamp at λ must be calculated by using (B-4). The emissivity or the tungsten strip and τ, the transmission of the lamp envelope, must be known at 6550 A and at λ.

For the emissivity of the tungsten strip at the true temperature of the strip and wave length λ, the values given by De Vos[35] were employed.*

The value of τ at various wave lengths was determined with the aid of a Cary model 14M Recording Spectrometer. The optical path of the instrument was masked, and the absorption of an area of the envelope equal to that in the optical train (Fig. 12) was determined for the lamp employed (intact). An envelope from a lamp of the same type was cut in half along the axis of the envelope and the absorption was determined for the whole envelope and for one-half of the envelope as it appears to the tungsten strip in the optical train. By multiplying the absorption of the intact lamp by the appropriate ratio of these absorptions, one could obtain an estimate of the absorption and, thus, the transmission of the lamp envelope in the optical path.

Values of $\tau\epsilon$ at the wave lengths where S_λ was measured are given in Table V, together with the calculated values of B, where

$$B = \frac{2.303}{c_2} (\lambda \log(\tau\epsilon)_\lambda - 6.55 \times 10^{-5} \log (\tau\epsilon)_{6550}). \qquad (B\text{-}5)$$

As seen in the table, the value of $\tau\epsilon$ is nearly constant; the change in τ nearly cancels the change in ϵ over the wave-length region of interest.

---

*De Vos states that the emissivities given in his paper may be applied to a well-annealed tungsten strip lamp with differences less than ±0.3% Operation of the lamp at about 3000°K serves to form a well-annealed tungsten strip. The lamp employed here had been treated in this manner.

Table V

Values of $\tau\epsilon$ and B at wave lengths at which S_λ values were determined (B as defined by Eq. (B-5))

λ (in A)	$\tau\epsilon$	B x 10^4
6550	0.380	0.000
5893	0.381	0.046
5780	0.383	0.055
5461	0.388	0.082
5350	0.385	0.085
4358	0.382	0.150
4047	0.381	0.169
3883	0.382	0.181
3775	0.378	0.185
3650	0.375	0.192

The uncertainties in S_λ resulting from uncertainties in the values of $\tau\epsilon$ employed are probably less than ±2%. This is well below the uncertainties produced in S_λ values because of instrument broadening.

Light Sources Investigated; Operating Conditions

The Thallium Lamp

The thallium lamp investigated was an Osram Spectral Lamp.* The lamp is a discharge lamp fitted with glow electrodes, and the emission from the lamp is radiated in the form of line spectra from the vapors in the lamp. Operating pressures are not available, but presumably they are low.†

The lamp was operated near the specified conditions of 14 v potential drop across the lamp and 1 amp current. The power supply was a 220-v dc source with ~200 ohms series resistance as a ballast. The lamp was allowed to warm for about 20 min before observations were made. The potential drop across the lamp and the current were recorded during the intensity measurements. The values are reported with the brightness-temperature values in Table VI in Results and Discussion, p. 84.

The Sodium Lamp

The Pirani-type sodium lamp investigated was a General Electric Na-I sodium lamp, operated under various conditions. The recommended voltage and current are 8 v and 3 amp. These operation characteristics are for operation with an ac voltage supply.

Here, a 110-v dc source with a series ballast resistance served

---

*These lamps are manufactured by Osram GMBH, Berlin, Germany and are available through George W. Gates and Co., Inc., Franklin Square, N. Y.

†The company estimates the thallium pressure as approximately 0.01 mm. The lamps are argon-filled to 20 mm Hg and operate at about 30-mm Hg pressure, according to the company. (Private communication from Osram GMBH, 1956.)

as a power supply for the lamp. The lamp contains coiled filaments which were heated by a 2-v storage battery. The heat from these filaments evaporates some of the sodium in the lamp and a discharge results, the whole lamp envelope becoming filled with sodium vapor radiation. The lamp also contains some rare gas filling. The vapor pressure of the sodium vapor in the lamp envelope depends on the temperature of the walls of the lamp. The discharge envelope is surrounded by an insulating evacuated jacket in order to reduce temperature gradients in the discharge tube.

The intensities of the sodium D lines were measured under various operating conditions. The conditions finally used during brightness-temperature measurements were potential, 3.5 v; current, 2.3 amp; and both filaments heated. The lamp operates satisfactorily if only the cathode is heated, but the intensity is increased slightly if both filaments are heated.

The intensity of radiation is not constant over the area of the source, but varies by a factor of about two from the most intense region (near the cathode) to the edges of the lamp. The brightness-temperature measurements were made at the most intense region of the lamp.

The Mercury Germicidal Lamp

A General Electric GL8T6 germicidal lamp was operated with a 4-watt fluorescent lamp power supply and 60-cycle 110-v ac. The lamp current is about 0.1 amp.

The pressure of mercury vapor in the discharge tube is controlled by the coolest part of the tube. The pressure probably reaches a few hundredths of a mm of Hg.

The Mercury H100A4 Lamps

Three General Electric H100A4 mercury lamps were investigated. The same power supply (200-v dc through 200 ohms series resistance) was employed for all three lamps. The lamp potential drop and current varied from lamp to lamp and also with the polarity employed. These quantities were determined during each brightness-temperature measurement

The lamps were allowed to warm for 15 to 20 min to give measurements which were constant in time. Intensity measurements were made during warm-up periods, also.

The H100A4 lamp is an arc lamp and operates at a pressure of about 10 atmospheres. The intense arc column of the lamp is about 3-mm in diameter and about 20-mm in length.

The Carbon Arcs

The brightness temperature of the emission from the plasma of the controlled-atmosphere arc described in Part A was investigated at 3883 A. The operating conditions such as ambient gas pressure, current, potential drop, and arc length are given in Table XI in Results and Discussion, p. 98. The ambient gas composition, electrode orientation, and composition of the electrodes have been discussed in Part A.

A pyrometric arc,[2,4] was approximated as closely as possible by using an available arc assembly. The emission from the anode was investigated in order to determine S_λ values at various wave lengths.

The arc was operated in air at atmospheric pressure with a 6.3-mm spectroscopic graphite anode and a 5.8-mm cored carbon cathode, held at right angles with the anode horizontal and the cathode vertical and

below the anode. (These electrodes are described in Table I, p. 12) The electrodes were held in position with a Bausch and Lomb micro-projector arc assembly, but with this arc projector independent adjustment of the electrodes was not possible, as the electrode holders were coupled to one adjustment control. Therefore, it was difficult to maintain the arc operating near the conditions specified for a pyrometric arc.[4]

Cored carbon electrodes were employed as cathode material in order to maintain an arc that was reasonably stable. The recommended graphite 3.2-mm electrodes gave unsatisfactory operation with this arc assembly.

Intensity measurements were made when the arc operated steadily. The optics were such that the anode was viewed normal to its surface. The arc current and potential drop were measured during intensity determinations, but the relative position of the electrodes, which is undoubtedly of importance in determining the anode temperature, was not measured because of the nature of the arc assembly.

RESULTS AND DISCUSSION

Each light source is here considered in turn, and the values of S_λ (the directly observed value and the estimated value) are discussed and evaluated. It becomes evident that the directly observed value of S_λ represents, in general, a minimum value of S_λ for sharp spectral features, and that the estimated value of S_λ, although more uncertain, is more representative of the true value of S_λ.

The Thallium Lamp

The values of S_λ were determined at λ3775.5 A ($7^2S_{1/2} - 6^2P_{1/2}$) and at λ5350.2 A ($7^2S_{1/2} - 6^2P_{1/2}$), and are given in Table VI. For

Table VI

S_λ values for an Osram thallium lamp

Current (amp)	PD (v)	Wave length (A)	"Component"	Intensity ratio	S_λ(obs) (°K)	S_λ(est) (°K)
1.16	16	5350.2	0	0.2	3860	3860
			+0.118 A	1.0		4620
1.02	14	3775.5	0	0.8	4060	4720
			+0.102	1.0	4480	4880
			+0.159	0.55	3810	4570

determination of S_λ at 5350 A, a Wratten No. 3 filter, which cuts off light below 4500 A, was placed in the optical train. For measurements at 3775.5 A, a Wratten No. 18a filter, which passes light in the wavelength range 3000 to 4000 A with peak transmission at 3600 A, was employed.

The intensity measurements at 5350 A were carried out by using the

3-meter grating spectrograph in the first order. The "line," as scanned, appeared asymmetric, with the most intense portion toward the red. The first-order spectra taken with the 21-ft grating spectrograph revealed that the "line" at 5350 A consists of at least two components (see Table VI). These components are the result of the hyperfine splitting in thallium. The details of the hyperfine structure of the thallium spectrum are given by Jackson[36] and Schuler and Keystone.[37]

Since naturally occurring thallium consists of two isotopes, each with a nuclear spin of 1/2, the thallium lines 5350 and 3775.5 A are expected to exhibit six components each.[37] The splitting of the 5350 A line is such that, even with high resolution, only four lines are observed[36] as two pairs of lines. The pairs are separated by 0.118 A, while the separation between the two " lines" in each pair is about 0.016 A.

The emission from the thallium lamp at 5350 A is expected to consist of two lines separated by 0.118 A, since the width of each component is expected to be large enough to cause overlap of the closely spaced lines. The width of each of the two lines was estimated as 0.025 A,* and the width of the line from the 3-meter spectrograph was estimated as 0.1 A. The width of the line recorded by the 3-meter spectrograph scanner (which included all components in one unresolved line) was 0.20 A.

The relative intensities of the "components" given in Table VI for the 5350-A emission were estimated from the photographic plates

---

*A component width of 0.008 A (Doppler width at 1000°K) was assumed and added to the separation of the closely spaced lines.

taken with the 21-ft spectrograph. The S_λ(est) values were obtained by multiplying the peak intensity from the recorder chart by the ratio of the estimated half widths and the relative intensities.

At 3775.5 A, one well-resolved line and a pair of partially resolved lines were observed by using the 3-meter spectrograph and scanner in the second order. The spectra taken with the 21-ft spectrograph exhibited three well-resolved lines. According to Jackson,[36] the six components appear as three pairs of lines and the separation of the lines in each pair is about 0.007 A. Again, the width of each component as emitted by the lamp is expected to cause overlap of the closely spaced lines in each pair. The width of each line was estimated as 0.013 A (0.007 A plus 0.006 A, the Doppler width of a line at 1000°K). The width of the 3-meter spectrograph line was estimated as 0.054 A; the width observed with the scanner was ~0.054 A.

The relative intensities of the lines at 3775.5 A were obtained from the scanner recorder chart and the photographic plates taken with the 21-ft spectrograph.

The S_λ(est) values given in Table VI are believed to be low estimates, but the true value is probably within 500°K of these estimates.

The lines emitted by the thallium lamp show no signs of reversal (the lines appear sharp, no flattened tops) within the limits of the 21-ft spectrograph. Examination of the lamp radiation with a Fabre-Perot interferometer would be required to determine the exact profile of the lines.

The Sodium Lamp

S_λ values at λ5890 ($3^2P_{3/2} - 3^2S_{1/2}$) and λ5896 ($3^2P_{1/2} - 3^2S_{1/2}$)

were determined for a General Electric Na-I lamp and the results are given in Table VII. The measurements were made with a Wratten No. 4 filter in the optical train. The filter removes all radiation below 4600 A, thus any light from higher orders was eliminated.

With the 3-meter spectrograph and scanner in the first order, the sodium D lines appeared as single triangle-shaped lines, and the intensity of each line was measured at the peak of the triangle. The spectra taken with the 21-ft spectrograph in the first order revealed that the lines were reversed (see Table VII). The relative intensities of the wing peaks and the reversed center of each line were estimated from the photographic plates, and values of S_λ(est) are given at these positions on the line profile, Table VII.

The widths of the D lines were estimated from the 21-ft spectrograph spectra and are given in Table VII, Column 4. The widths of the lines from the 3-meter spectrograph were estimated as 0.15 A at 5896 and 0.16 A at 5890. The corresponding values observed with the scanner were ~0.17 and ~0.20 A.

The S_λ(est) values were calculated by multiplying the peak intensity of the line read from the recorder chart by the ratio of the estimated half widths and by the relative intensities at the various positions on the line. The S_λ(est) values for the peaks of the wings may be slightly low, while the value for the reversed center may be too high. The true S_λ values at the wing peaks are probably within 200°K of the estimated values.

Because of the limited resolution of the 21-ft spectrograph, the extent of line reversal for the sodium D lines is not exactly known, but it is expected to be greater than the amount estimated.

Table VII

S_λ values for the Na D-lines emitted by a General Electric Na-I lamp

Current (amp)	Potential drop (volts)	Wave length (A)	Half width (A)	Position on line: λ (A)	Relative intensity	S_λ(obs)	S_λ(est)
2.2±0.1	3.55±0.05	5896	0.07	Peak of red wing: 0.03	1		4970
				Reversed center: 0	0.63	4330	4540
				Peak of violet wing: 0.02	0.82		4790
2.2±0.1	3.55±0.05	5890	0.08	Peak of red wing: 0.04	1		4840
				Reversed Center: 0	0.49	4290	4240
				Peak of violet wing: 0.03	0.87		4710

If the Na-I lamp were to be employed as a light source for the study of sodium-atom radiative lifetimes, the D lines emitted by the lamp should be investigated at higher resolution to determine the extent of the reversal.

It has been extimated that the minimum value of S_λ that a light source must have at the centers of the D lines in order to obtain meaningful lifetime measurements with the lifetime apparatus available is 1850°K.[1] Unless there is an extreme amount of reversal at the centers of the D lines emitted by the Na-I lamp employed here, the lamp appears to be an excellent light source for lifetime measurements on sodium. The lamp may also be useful for studies of molecules with lines which overlap the D lines.

The Mercury Germicidal Lamp

The General Electric G18T6 lamps are characterized by the narrow lines which they emit (this is not true for all these lamps, however). The lamp investigated did have very narrow lines and for this reason this lamp was used for focusing the spectrographs.

The values of S_λ for the 4358 and 4047 A lines emitted by the lamp are given in Table VIII.

Table VIII

S_λ values for a General Electric germicidal lamp

Wave length (A)	Transition	S_λ(obs) (°K)	S_λ(est) (°K)
4358	$7^3S_1 - 6^3P_1$	3450	4250
4047	$7^3S_1 - 6^3P_0$	3350	4200

The measurements for the determination of S_λ were carried out by using the second order of the 3-meter spectrograph. No band-pass filters were employed during the intensity measurements, but, in this wave length region, filters have no observable effect on the value of S_λ obtained because the sensitivity of the photomultiplier at 8000 A is extremely low.[38]

The half width of the most intense hyperfine component of the mercury lines[34] was estimated as 0.007 A and the width of the 3-meter spectrograph lines 0.044 A in order to obtain the S_λ(est) values. The width of the 4358 A line as recorded by the scanner was ~0.045 A, and for the 4047 line a width of 0.063 A was found. The 4047 A line had a larger width because of the presence of a second fairly intense unresolved hyperfine component (splitting 0.05 A; relative intensity ~0.2 according to spectra taken with the 21-ft spectrograph). (The hyperfine structures of the mercury lines from an unreversed arc are given by Pool and Simmons.[38])

In obtaining S_λ(est) the effect of the unresolved components on the intensity of the lines was neglected.

The values of S_λ(est) reported in Table VIII may be as much as 500°K from the true value of S_λ, but the values are considered as better estimates of the true brightness temperature in the same temperature range.

The Mercury H100A4 Lamps

S_λ values for three General Electric H100A4 mercury lamps were determined at various values of λ. Although the lamp operating voltage and current varied from lamp to lamp, the lamps were found to be quite

uniform in S_λ values, as can be seen in Table IX, which gives values of S_{5461} obtained for each lamp. The differences in the S_λ values for the three lamps at each wave length were in the same direction and of the same order of magnitude (~100°K) as those found at 5461 A. The values of S_λ obtained at various wave lengths for the lamp H100A4-II* are given in Table X together with the operating conditions of the lamp and the characteristics of the emitted mercury lines. The values of S_λ are given at the peaks of the wings and at the center of the reversed portion of lines exhibiting reversal.

The values of S_λ have been given to the nearest 10°K for this lamp, but the corresponding values for some other H100A4 lamp may differ by 100°K or more from these values.

Since the shapes of the lines emitted by these lamps are not uniform, reproductions of the lines as recorded by the 3-meter spectrograph scanner are given in Fig. 13. The wave length of the transition(s) responsible for the line are given below each profile. The ordinate in each case is relative intensity with the peak intensity normalized to unity. The abscissa is $\Delta\lambda$ in A, the distance from the center of the line. The center of the line was taken as the peak of the profile when the line was unreversed and as the center of the reversed portion when the line was reversed.

The lines are quite broad, as expected, since the pressure in the arc envelope during operation is about 10 atms.† Reversal is also

---

*The lamp has been identified by inscribing the numeral II on the base.

†Value given by the General Electric Company in a private communication (Aug. 1958).

Table IX

S_λ values at λ5460.7 for three General Electric H100A4 lamps

Lamp No.	Lamp voltage (v)	Lamp current (amp)	Polarity	Half width (A)	$\Delta\lambda(RW)^a$	λ	$\Delta\lambda(VW)^a$	S_λ (°K)
B	127	0.59	+	1.25	+0.25	5460.7	-0.25	5240 4800 5220
I	139	0.53	-	1.30	+0.29	5460.7	-0.25	5110 4750 5180
II	118	0.69	+	1.37	-0.31	5460.7	-0.27	5200 4820 5180

[a] $\Delta\lambda(RW)$ amd $\Delta\lambda(VW)$ are the distances from the center of the line to the peak of the red wing and violet wing of the reversed line. The wave lengths given for the centers of the lines are literature values; see Ref. 39, p. 202.

Table X

S_λ values for a General Electric H100A4 lamp

Lamp voltage	Lamp current	Wratten filter	Half width (A)	$\Delta\lambda$(RW)[a]	λ (A)	$\Delta\lambda$(VW)[a]	S_λ (°K)
121	0.66	18a	0.26		3341.5		4440
				+0.23			5300
122	0.68	18a	1.16		3650.2		4750
						-0.22	5350
122	0.68	18a	0.45		3654.8		5350
				+0.26			5180
122	0.68	18a	0.58		3662.9		4650
						-0.10	4790
				+0.19			5070
117	0.68	18a	0.79		4046.6		4790
						-0.15	5040
				+0.23			5100
117	0.68	47	1.00		4358.3		4400
						-0.21	5070
				+0.31			5200
118	0.69	-	1.37		5460.7		4820
						-0.25	5180
124	0.61	-	3.10		5769.6		3740
124	0.61	-	3.40		5790.7+ 5789.7		3680

[a] $\Delta\lambda$(RW) and $\Delta\lambda$(VW) are the distances from the center of the line to the peak of the red wing and violet wing of the reversed line. The wave lengths given for the centers of the lines are literature values; see Ref. 39, p. 202.

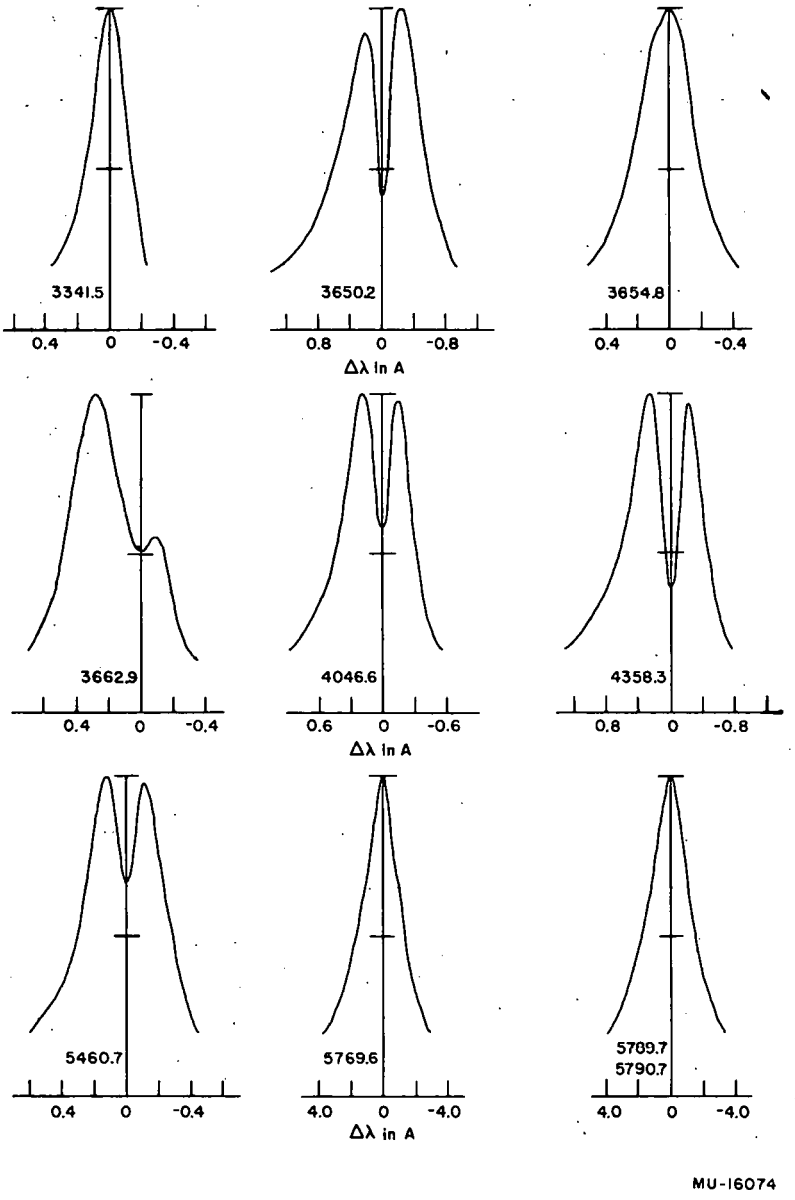


Fig. 13. Profiles of various mercury lines emitted by a General Electric H100A4 mercury lamp. Profiles taken directly from chart recordings of the 3-meter-grating spectrograph scanner.

expected when the line is very intense because of the large temperature gradient across the radius of the arc column and the high optical density (pressure) of the mercury vapor. The gas temperature at the center of the arc column is undoubtedly above 6000°K (see Ref. 26, p. 10), but the walls of the envelope surrounding the arc column a few mm away are probably below 1000°K.

The intensity of the emission from the H100A4 lamp when operated with a dc power supply was found to very slightly (not more than about 30%) along the length of the arc column. The brightness temperatures reported in Table IX are for the center of the arc column, which was not the most intense region of the column. The intensity, in general, decreased along the length of the column from one electrode to the other.

The intensity of the emission is increased slightly by air-cooling the lamp. The arc column was observed to decrease slightly in radius when the lamp was air-cooled; the resulting increase in power dissipated per unit volume of arc column produced the increase in the intensity.

Experiments were carried out in which the scanner slit was left at the center of the reversed portion of a line and the intensity was observed from the time the lamp was turned on until it was completely warmed. The intensity increased as the lamp warmed, reached a maximum, and then decreased. The maximum intensity was always greater than the intensity at the peaks of the wings when the lamp was fully warmed.

No experiments were made to determine the change in the intensity of lamp emission with change in power input, but it is possible, in view of the above, that the intensity at the centers of the reversed lines might be increased by operating the lamp at lower power input

(if more intensity at that wave length were desired).

The H100A4 mercury lamp offers a nymber of lines with peak S_λ values in the 5000°K range (see Table IX). From the profile and S_λ of the lines and a knowledge of the absorption profile of species of interest, one can calculate whether or not the lamp will be of use for the determination of the lifetime of that species with the lifetime apparatus available.[1]

The Carbon Arc Plasma

Values for S_λ were determined for the peak of the 0-0 head of the $\lambda 3883$ ($B^2\Sigma - X^2\Sigma$) CN system emitted from the plasma of the carbon arc described in Table XI contains S_λ values for the emission from the center of the arc plasma. Values of $S_{3883}(obs)$ from other parts of the plasma are given in Fig. 8.

The values of S_λ were determined by using the first and the second order of the 3-meter spectrograph. The emission from the plasma was photographed in the second order of the 21-ft spectrograph and the profile of the CN 0-0 head at 3883 A is given in Fig. 14. The width at half intensity of the triangle-shaped portion of the head was estimated to be 0.108 A, and the intensity corrections for instrument broadening by the 3-meter spectrograph were made from this width. The agreement between the $S_\lambda(est)$ values obtained in the two orders is close and serves as some justification of the method used (see Experimental Procedure, Instrument Broadening, p. 73).

The average of the $S_\lambda(est)$ values is 5490°K, thus the brightness temperature of the peak of the 0-0 head of the CN violet system emission from the center of the plasma of an arc run in controlled atmosphere as specified in the table and Part IIA is believed to be near 5500°K. This value is for an arc in a nitrogen-air mixture, the corresponding value for an arc in pure nitrogen is believed to be near 5000°K (see Table XI).

The CN emission from the arc appears (within the limits of the 21-ft spectrograph) to be unreversed (see Fig. 14). The absence of reversal can probably be attributed to the short life of the CN radical

Table XI

S_λ values for the λ3883 emission from the carbon arc plasma[a]

Arc		Pressure of N_2-(Air) (mm^2Hg)	Arc length (mm)	3-meter spectrograph order	S_λ(obs) (°K)	S_λ(est) (°K)
Potential drop (v)	Current (amp)					
71	9.3	167	11.8	1st	5050	5490
68	9.4	140	12.3	2nd	5270	5520[b]
65	9.6	142	11.4	2nd	5420	5670[b]
70	9.4	138	12.6	2nd	5320	5570
71	9.3	146	12.6	2nd	5000	5250
72	9.2	142	12.6	2nd	5200	5450
						av 5492
71	9.3	167	11.8	1st	4480	4820[c]
74	9.3	140	12.6	2nd	4750	4950[c]

[a]The arc plasma investigated was the plasma of the stable arc in controlled atmosphere described in Part A. A cored carbon cathode and graphite anode were employed during all the measurements reported in this table.

[b]A Wratten 18a filter was employed in the optics during these measurements.

[c]These values were obtained with the arc burning in a pure nitrogen atmosphere.

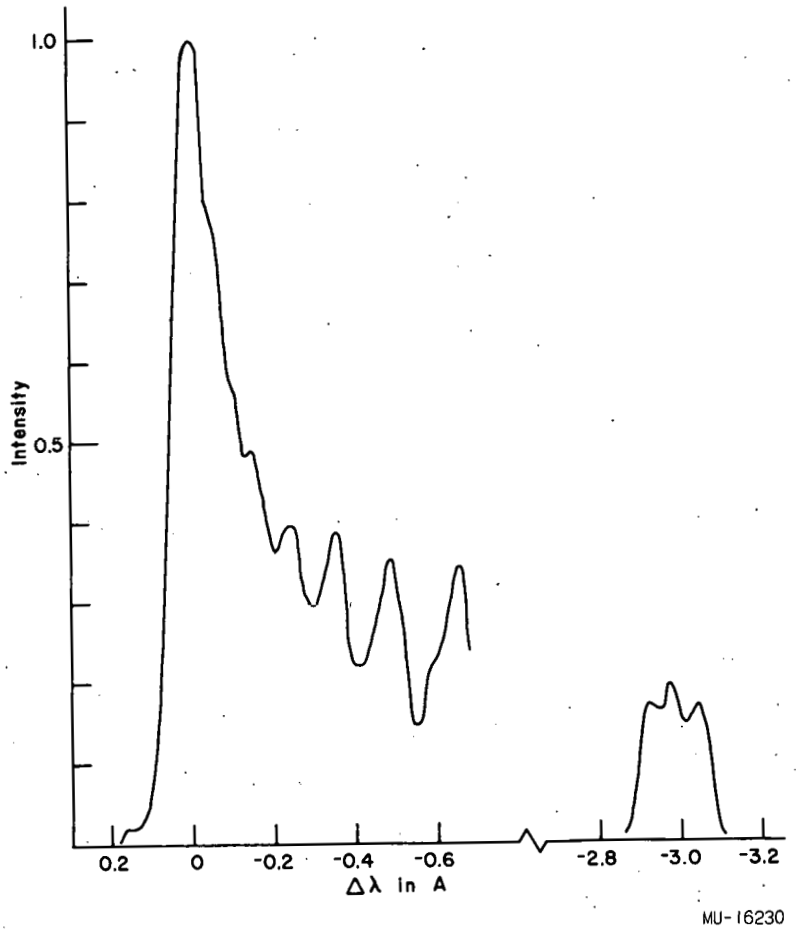


Fig. 14. The profile of the CN λ3883 band head emitted from the plasma of an arc burning in nitrogen-air mixture. The arc conditions were essentially those given in Table II, Row 2.

in the cooling gas layers surrounding the arc plasma. At sufficiently high pressures of nitrogen and in the absence of oxygen, self-absorption is known to be large (see Part IIA and Ref. 13) and it is possible that some reversal may occur.

From the profile in Fig. 14 it is readily seen that the intensity of the emission falls off quite sharply, since the rotational lines begin to open at a short distance from the head and the amount of overlap is reduced. At rotation line -37, +20 (two overlapping lines) the intensity has fallen to 1/3 the value at the peak. From this point to shorter wave lengths the decrease is slow. At rotation line -62, the intensity is about 1/10 that at the head and the corresponding S_λ value is about 4000°K.

Brewer has estimated the value of S_{3883} required for a light source in order to obtain a reliable measurement of the lifetime of the $B^2\Sigma$ state of the CN molecule with the available lifetime apparatus.[14] The value, 3150°K, is considerably below the value of 5500°K observed for the emission from the plasma of the carbon arc. Thus it appears that the arc source described in Part IIA yields about 100 times the minimum required radiation.

The Carbon Arc Anode

The brightness temperature of the anode surface of a carbon arc has been measured at various wave lengths and the values found are reported in Table XII. These measurements were carried out because the brightness temperature of the anode of a pyrometric arc at 6550 A appears to be the only directly measured brightness temperature in the literature.

Table XII

S_λ values for the anode of a carbon arc

Wave length (A)	Wratten filter	No. of determinations	S_λ ($^\circ$K)	Literature values of the brightness temperature	
6550	4	2	3820±40	3822±15[a]	3790[b]
				3805[c]	
5890	4	2	3800		
5780	4	2	3760		
5350	4	1	3770		
4358	–	9	3775	3855[c]	
4047	–	5	3805		

[a] Value reported by Euler[40] with $c_2 = 1.4380$.

[b] Value reported by Chaney, Hamister, and Glass, corrected for c_2 changes.

[c] Values calculated by using emissivities of the anode and the true anode temperature as reported by Euler.[40]

Because of the nature of the arc assembly employed (see Experimental Procedure, Light Sources Investigated, p. 82), the conditions specified by MacPherson for a pyrometric arc were undoubtedly not maintained constantly. Thus the values of S_λ reported here are not very reliable as values of the maximum brightness temperature of the pyrometric arc anode.

Euler has determined the emissivity of the pyrometric arc anode at arc temperature over a wide wave length region.[40] From the emissivity and true temperature of the anode, 3995±22°K,[40] the brightness temperature at wave length λ can be calculated. The values of

S_λ reported in Table XII for wave lengths below 6550 A are lower than these calculated values. A possible explanation may be absorption of the emission from the anode by the cool gas layers which it passes through. Most of the materials in the arc gases have transitions in the wave-length region below 6000 A. Irregularities in the emission at some of these wave lengths were observed when scans in wave length were taken.

At 6550, the value of 3820°K obtained in this investigation is in good agreement with the value reported by Euler[40] and in fair agreement with the value reported by Chany, Hamister, and Glass[3] (corrected for the change in the accepted value of c_2, 1.433 to 1.4380).

With a better arc assembly and carefully determined intensities, more reliable values of S_λ for the pyrometric arc could be obtained by using the method employed here.

The value of 3820°K is in agreement with literature values within the limits of uncertainty, ±1%, claimed for the method.

CONCLUSIONS

A method for determining directly the brightness temperature of a light source at a specific wave length λ has been developed and applied to several available light sources.

A measurement of the carbon-arc anode brightness temperature at 6550 A has been made and found in agreement with values reported in the literature.

Because of instrument limitations, the brightness-temperature values reported here for spectral features that have narrow half-intensity widths have considerable uncertainty associated with them. They do, however, represent minimum values of the brightness temperature for that spectral feature.

The brightness temperatures determined by this method may be used to establish the usefulness of a light source for the measurement of lifetimes with the available lifetime apparatus.[1]

The Pirani sodium lamp and the carbon-arc plasma have been found to have brightness temperatures (at the desired wave lengths) considerably higher than the minimum values estimated[1] as necessary for lifetime measurements on the sodium atom and CN radical, respectively.

ACKNOWLEDGMENTS

I wish to express my gratitude to Professor Leo Brewer, who suggested the problems and provided excellent guidance throughout the course of these investigations.

I am thankful for the use of spectroscopic equipment provided by Professors Francis A. Jenkins and John G. Phillips. I am indebted to Edward Pauletich for the construction of the arc chamber and to Mrs. Jane Waite for her secretarial assistance.

This work was done under the auspices of the U. S. Atomic Energy Commission.

REFERENCES (PART II A, B)

1. Richard G. Brewer, A Method for Determining Radiative Lifetimes of High-Temperature Molecules (Thesis), UCRL-8387, July 1958.

2. Mattie L. Houghten, The Electric Arc and Its Application to the Carbon Arc Lamp, Navships 250-337-1 (Bureau of Ships, Washington, 1946).

3. H. G. MacPherson, J. Opt. Soc. Am. 30, 189 (1940).

4. Chaney, Hamister, and Glass, Trans. Electrochem. Soc. 67, 107 (1935).

5. W. Finkelnberg, Phys. Rev. 74, 1475 (1948).

6. W. Finkelnberg and J. P. Latel, J. Opt. Soc. Am. 44, 1 (1954).

7. H. G. MacPherson, J. Appl. Phys. 13, 97 (1942).

8. A. M. Kruithof, Physica 10, 493 (1943).

9. Brewer, Templeton, and Jenkins, J. Am. Chem. Soc. 73, 1462 (1951).

10. W. Finkelnberg, The Behavior of Matter at High Temperatures, in High Temperature—A Tool for the Future, Symposium Proceedings (Stanford Research Institute, Menlo Park, Calif., 1956) p. 39.

11. L. A. King, Spectochemica Acta, 1957 Supplement, p. 154; Appl. Sci. Research 5B, 189 (1955).

12. W. Lochte-Holtgreven, Production and Measurement of High Temperatures, Reports Progr. in Phys. 21, 312 (1958).

13. H. Maecker, (private communication, 1956); Z. Naturforsch. 11a, 457 (1956).

14. Andrew Guthrie and Raymond K. Wakerling, Vacuum Equipment and Techniques. (McGraw-Hill, New York, 1949), p. 166.

15. Charles Sheer and Samuel Korman, "The High Intensity Arc in Process Chemistry" in Arcs in Inert Atmospheres and Vacuum (Wiley and Sons, New York, 1956).

16. Wolfgang Finkelnberg, Hochstromkohlebogen (Springer-Verlag, Berlin, 1948).

17. Karl K. Darrow, Electrical Phenomena in Gases (Williams and Wilkins, Baltimore, 1932).

18. H. Schluge and W. Finkelnberg, Z. Physik 122, 714 (1944).

19. P. J. Somers and J. A. Smit, Appl. Sci. Research 6B, 75 (1957).

20. Ornstein, Brinkman, and Beunes, Z. Physik 77, 72 (1932).

21. R. C. Mason, Physica 5, 777 (1938).

22. R. Mannkopff, Z. Physik 76, 396 (1932).

23. Helmut Witte, Z. Physik 88, 415 (1932).

24. G. Righini, Physica 2, 585 (1935).

25. H. Maecker and J. Sperling, Naturwissenschaften 35, 253 (1948).

26. H. G. MacPherson, J. Soc. Motion Picture Engrs. 38, 235 (1942).

27. W. Weizel and J. Fassbender, Z. Physik 120, 252 (1943).

28. W. Finkelnberg, J. Appl. Phys. 20, 468 (1949).

29. W. Elenbaas, The High Pressure Mercury Discharge (Interscience, New York, 1951).

30. Karl K. Darrow, Trans. Electrochem. Soc. 69, 67 (1936).

31. N. S. Ham and A. Walsh, Spectrochemica Acta 12, 88 (1958).

32. Branner, Ferguson, and Wehlen, Can. J. Phys. 36, 871 (1958).

33. William T. Hicks, Spectroscopy of High-Temperature Systems (Thesis) UCRL-3696, February 1957, p. 71.

34. John G. Phillips, Astrophys. J. 119, 274 (1954).

35. J. C. de Vos, Physica 20, 690 (1954).

36. D. A. Jackson Z. Physik 75, 223 (1932).

37. H. Schuler and J. E. Keystone, Z. Physik 71, 413 (1931).

38. Marion L. Pool and S. J. Simmons, Phys. Rev. 44, 744 (1933).

39. Gerhard Herzberg, Atomic Spectra and Atomic Structure (Prentice-Hall, New York, 1944) p. 202.

40. J. Euler, Ann. Physik 11, 203 (1953).

This report was prepared as an account of Government sponsored work. Neither the United States, nor the Commission, nor any person acting on behalf of the Commission:

A. Makes any warranty or representation, express or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately owned rights; or

B. Assumes any liabilities with respect to the use of, or for damages resulting from the use of any information, apparatus, method, or process disclosed in this report.

As used in the above, "person acting on behalf of the Commission" includes any employee or contractor of the Commission to the extent that such employee or contractor prepares, handles or distributes, or provides access to, any information pursuant to his employment or contract with the Commission.