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A STUDY OF A HIGH-PRESSURE THERMAL ARGON PLASMA AS A HIGH-RADIANCE STANDARD*

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Abstract—This work represents a first step in the realization of a plasma source emitting blackbody radiation. A theoretical evaluation of the conditions to be fulfilled in order to obtain strictly planckian radiation from a pure argon plasma has been made. The plasma generator is a wall-stabilized arc 49 mm in length, burning stably under pressure as high as 50 atm. Spectroscopic diagnostics of the plasma have been performed by using various methods and using the hypothesis that L.T.E. obtains. For a constant value of the electrical intensity (150 A), the electronic temperature decreases from about 14,000 °K at atmospheric pressure to about 11,500 °K at 50 atm. The continuous radiation has been measured between 1 and 50 atm.; the values of the monochromatic brightness temperature were deduced from it and compared with the value of the electronic temperature. For the maximum values of pressure, length, and temperature, the emitted radiation is not Planckian but the brightness temperature T_L of the continuum remains constant in a wide spectral range ($3500 \leq \lambda[A] \leq 6500$). In addition, discrepancies also appear between the theoretical forecasts and the experimental values. However, the arc which has been realized can constitute a useful reference source of high radiance in the visible and near u.v. range, because of its time stability and of the reproducibility of the emitted light intensities.

1. INTRODUCTION

THE INTERNATIONAL scale of temperature is defined on the basis of fixed points, the highest of which is the melting point of gold ($T = 1337.58$°K). From this point, the calibration of high-temperature measurement apparatus is made through extrapolation methods and by application of Planck's Law. This method leads to an accumulation of uncertainties which become more and more difficult to evaluate the further the data are removed from the reference point. On the other hand, the solid sources which can be used as standards have temperatures lower than 4000°K.

The purpose of the work presented here is essentially the realization of a high-temperature source, fulfilling the blackbody conditions, the temperature of which can be determined by a direct method. A plasma sufficiently long, and under sufficient pressure, can fulfill these conditions. For this purpose, we have developed a wall-stabilized arc, 5 cm long and burning under high-pressure ($p \leq 50$ atm). In Section 1 of this paper, using the continuum radiation theories of a plasma, we evaluate the ranges of plasma pressure, temperature and length in which Planck radiation can be expected. The extent of this range determined the choice of the plasma generator used, which is described in Section 2,

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as well as the measuring device. In Section 3, we discuss the methods of spectroscopic diagnostics used, in particular precautions to be taken to allow for self-absorption of radiation. Finally, measurements of continuum intensity, in terms of pressure and temperature, and comparison of experimental results with theory are presented in Section 4.

2. EVALUATION OF THE BLACKBODY CONDITIONS FOR AN ARGON PLASMA

To determine the range of plasma temperature, pressure, and length, in which planckian radiation can be expected from an argon plasma, we have calculated the intensity emitted from a homogeneous plasma column in local thermodynamic equilibrium (L.T.E.) for various continuum wavelengths, in the spectral range 0.2 μ–1 μ.

The solution of the transfer equation for a homogeneous plasma column in L.T.E., of length l, temperature T, and pressure p, gives the intensity $I_\lambda(T, p, l)$ emitted as

$$I_\lambda(T, p, l) = B_\lambda(T)[1 - \exp(-k_\lambda(T, p)l)], \tag{1}$$

where $B_\lambda(T)$ is the Planck function for the plasma temperature T and $k_\lambda(T, p)$ the total coefficient of continuous absorption corrected for stimulated emission.

Several processes contribute to continuous absorption, namely, recombination of electrons and ions (free–bound radiation), bremsstrahlung of the electrons in the field of ions (free–free radiation), bremsstrahlung of electrons by neutral atoms when the ionization degree is low. The last process has been neglected. For the absorption coefficient, $k_\lambda(T, p)$, we use the expression calculated by BIBERMAN *et al.*[1] and, in a more precise manner, by SCHLÜTER[2] on the basis of the BURGESS–SEATON[3] quantum defects method:

$$k_\lambda(T, p) = \frac{4\sqrt{(2\pi)}e^6}{3\sqrt{(3km^3)}hc^4} N_e(T, p)N_i(T, p)\frac{\lambda^3}{\sqrt{T}}\left\{\xi(\lambda, T)\left[\exp\left(\frac{hc}{\lambda kT}\right) - 1\right] + 1\right\}, \tag{2}$$

where N_e and N_i are the electronic and ionic densities and the values of the coefficient $\xi(\lambda, T)$ are those calculated by SCHLÜTER.[2] Assuming the plasma is in L.T.E., N_e and N_i have been calculated by using Saha equation, Dalton's law and assumption of quasi-neutrality.

Figures 1a and 1b show the values of the temperature, pressure and length of the argon plasma which must exist simultaneously in order to obtain blackbody radiation. It can be seen from Fig. 1a that the shorter the wavelengths, the more demanding are the conditions to be fulfilled. Figure 1b shows the intensity emitted at $\lambda = 3000$ Å, with the product pl[atm cm] used in first approximation as the characteristic parameter. As long as $N_e \ll N_0$, for a constant temperature, the intensity depends only on pl; this result may be compared with the one obtained by YACOBI *et al.*[4] for hydrogen, which is contrary to the result of PETERS.[5] However, for higher temperatures and, consequently, a higher degree of ionization, this first approximation cannot be justified, as can be seen on the curve corresponding to $pl = 100$, as long as the pl value is lower than the one determining the blackbody radiation for this temperature. The blackbody conditions obtained in this way are more severe than those calculated for an argon plasma by MOSKVIN[6] taking into account the contribution of the line spectrum.

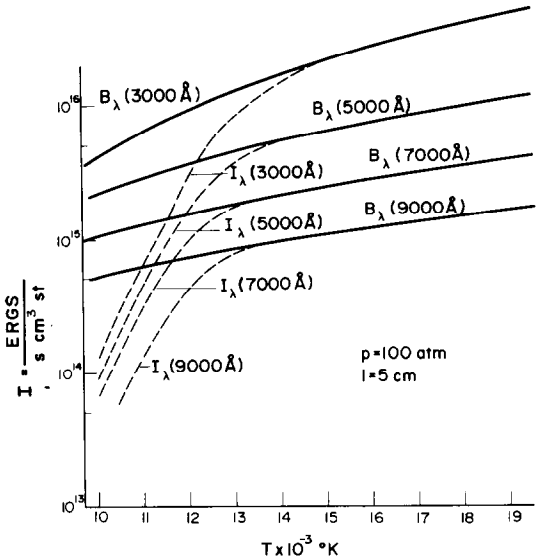


FIG. 1a. *Dashed lines*: theoretical intensities of the continuum emitted at various wavelengths by a pure homogeneous argon plasma of 5 cm length at a pressure of 100 atm, as a function of the electronic temperature. *Solid lines*: blackbody radiation intensities at the same wavelengths.

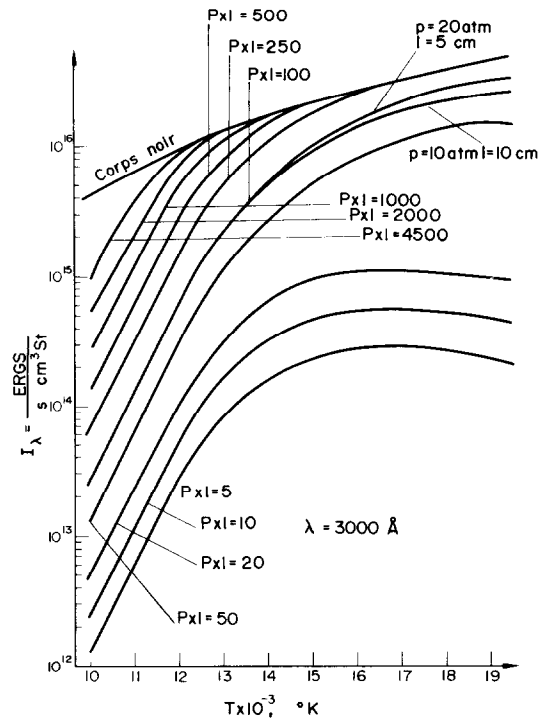


FIG. 1b. Theoretical intensity emitted at $\lambda = 3000$ Å by a pure argon plasma, as a function of the temperature, the characteristic parameter being pl[atm × cm]. The blackbody radiation at the same wavelength is also shown.

3. DESCRIPTION OF THE EXPERIMENTAL APPARATUS

3.1. *The wall-stabilized arc*

The design of the wall-stabilized arc is well-known (MAECKER[7]). However, the copper-plates have been specially designed to withstand high pressure (100 atm). The arc bursts in an argon atmosphere between thoriated tungsten electrodes, which are perforated so that end-on observations can be made. The restriction channel is of 5 mm dia. and 49 mm length (Fig. 2). The plasma is confined between the electrodes by four copper-plates, electrically insulated and water-cooled (the water is at 2 atm pressure). As shown in Fig. 3, each plate is composed of an external ring (A) forming the body of the plate, with four holes to allow the positioning of the plate and its concentric water supply (two entrances and two exits); the central "diabolo" (B) which forms the heat exchange chamber; the crossbar (C) which increases the resistance to crushing of part (B) and makes utilization of pressurized cooling-water unnecessary for pressures as high as 100 atm.

Each plate is insulated by four ceramic rings, using water-tight rubber O-rings. The arc is detonated in argon at atmospheric pressure by a tungsten-rod guided along the electrode axis. The arc burns stably for currents between 50 and 200 A under atmospheric pressure and between 50 and 150 A under 50 atm. The arc is enclosed in a cylindrical steel container 16 mm thick which will support 300 atm. There are 4 quartz portholes (thickness 20 mm) allowing side-on and end-on observations. The container is mounted on rails and its displacement, perpendicular to the plasma axis, can be measured to an accuracy of 0.01 mm. To obtain data for the Abel inversion of the side-on intensities, the plasma image is scanned across an auxiliary slit by moving the arc.

3.2. *Optical and recording devices*

In end-on observation, the light intensity must be measured so that only the light coming from the plasma axis enters the monochromator, requiring that the aperture of the light beam be very small (about 10^{-4} steradian). For side-on observations, the optical device contains an auxiliary slit (Fig. 4). The plasma image is first formed in magnification 1:1 with a small aperture (about $f/50$) on the auxiliary slit which thus determines the plasma layer observed. Its image is then formed on the entrance slit of the monochromator with an opening of about $f/5$, permitting use of the whole grating surface (7×7 cm^2). We use a Perkin–Elmer grating monochromator with a 0.3 m focal length, the dispersion of which, in first order, is 55 Å/mm. With a 20 μ slit, it is possible to separate two wavelengths at a 1 Å distance, which is sufficient for continuum measurements. Frequency range filters allow for the elimination of the higher diffraction orders of the grating. The absolute calibration of the light intensities is performed with a tungsten ribbon lamp (T_{true} = 2800°K), the image of which can be substituted for the plasma image on the auxiliary slit by using the revolving mirror M_1. The radiation emitted from the plasma can be optically reduced by the factor 10^{-3}, which brings it to a value not greater than 100 times the radiation emitted by the lamp at the same wavelengths. The output of the photomultiplier (EMI 9558 QB, photocathode S 20) is electrically integrated to reduce fluctuations and is also traced using a pen-recorder.

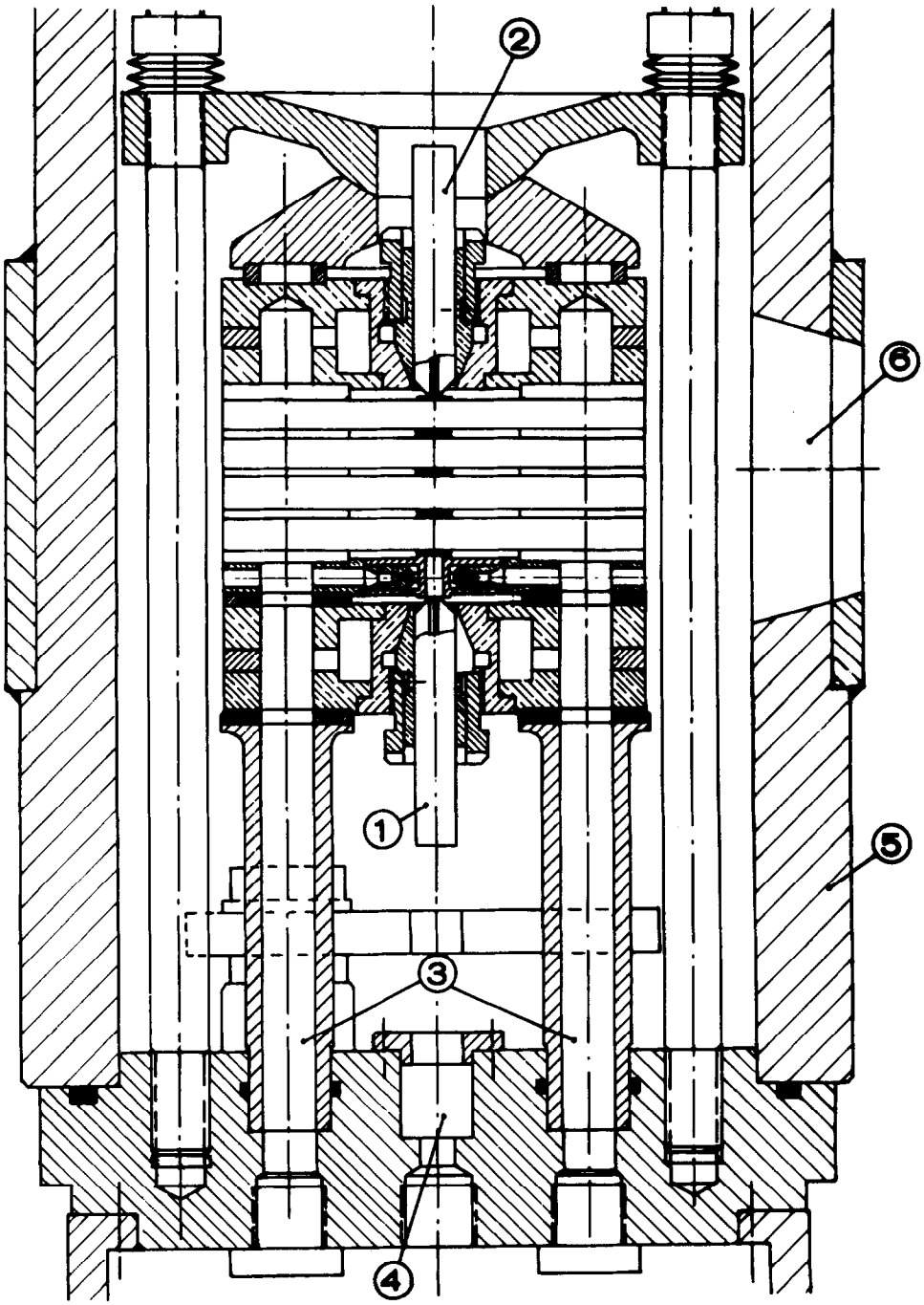


FIG. 2. Schematic diagram of the wall-stabilized arc: (1) cathode, (2) anode, (3) water circuit, (4) gas inlet, (5) casing, (6) quartz-window (side-on observations).

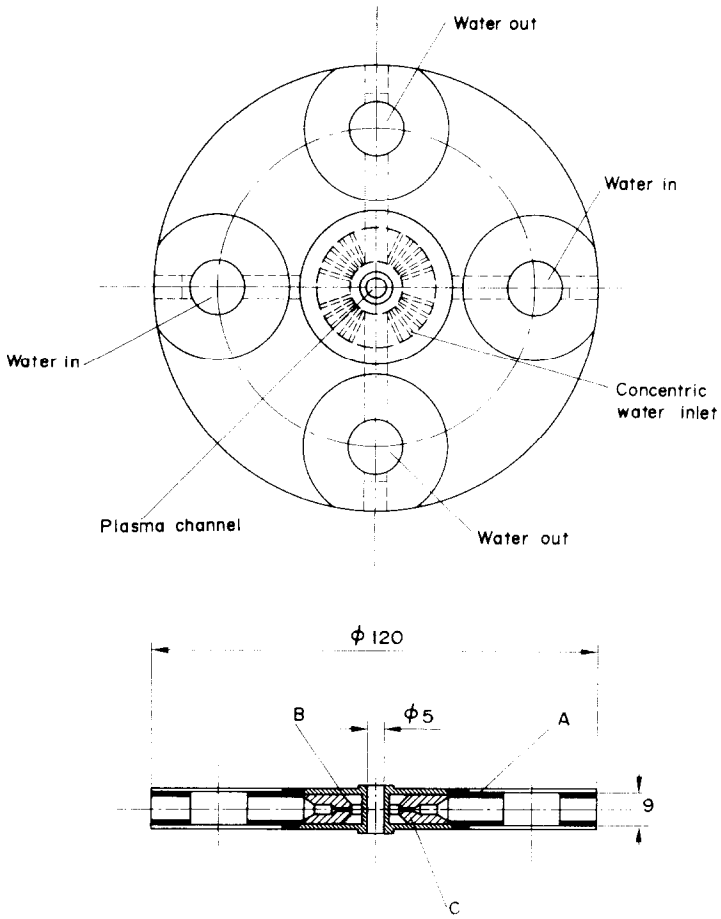


FIG. 3. Diagram of a copper plate (please see signification in text of (A), (B), (C)).

4. DETERMINATION OF PLASMA TEMPERATURE

4.1. *Introduction*

For the spectroscopic diagnostics we ensured, by measuring the electronic density, that the electronic collisions created L.T.E. in the plasma at atmospheric pressure,[8] on the basis of the GRIEM[9] and DRAWIN[10] criteria. The various methods used allow us to check the validity of this assumption a posteriori.

Side-on diagnostics were used only at atmospheric pressure. The measurement of the optical depth realized by a two-path method[11] seems to indicate under high pressure, the presence of strong gradients of the refractive index which are connected with the density gradients in the plasma–gas transition layer, a phenomenon which certainly affects the measurements. We used the numerical coefficients given by BOCKASTEN[12] to perform the Abel inversion, through which it is possible to deduce the local values of the emission

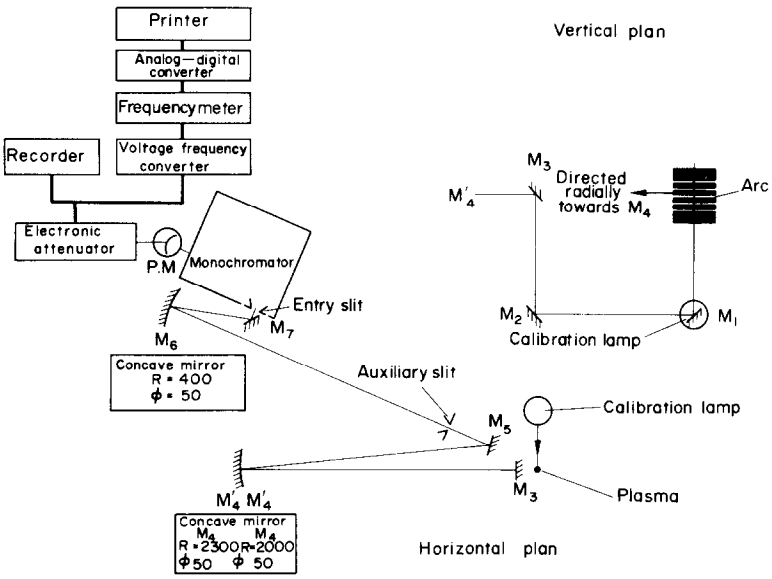


FIG. 4. Schematic diagram of the optical device.

coefficient from the measured intensities. Some of the argon lines used for diagnostics are no longer optically thin under pressure and for end-on observations. Consequently, we have determined the temperature from the absolute intensity of the continuum, taking self-absorption into account for end-on observations.

4.2. *Measurement of the absolute intensity of an argon II line*

The plasma being in L.T.E., the populations of the various levels are given by Boltzmann's law and excitation temperature can be deduced from the absolute emission coefficient, ε, of the Ar II line $\lambda = 4806.02$ Å (see Table 1). At atmospheric pressure, this line is optically thin and ε is given by

$$\varepsilon = \frac{1}{4\pi}\frac{g}{U(T)}Ah\nu\, N(T)\exp\left(\frac{-E}{kT}\right),$$

TABLE 1. CHARACTERISTICS OF THE SPECTRAL LINES USED FOR DIAGNOSTICS

	4300.10 Å Argon I	4158.59 Å Argon I	4806.02 Å Argon II
Transition	$5p[5/2] \rightarrow 4s[3/2]^\circ$	$5p[3/2] \rightarrow 4s[3/2]^\circ$	$3p^4(^3P)4p \rightarrow 3p^4 4s$
Excitation energy of the upper level E	116,999 cm^{-1} $\simeq$ 14.50 eV	117,184 cm^{-1} $\simeq$ 14.52 eV	155,043 cm^{-1} $\simeq$ 19.20 eV
Statistical weight of the upper level g	5	5	6
Transition Probability A	3.94×10^5 S^{-1}*	1.45×10^6 S^{-1}*	7.9×10^7 S^{-1}*

* According to WIESE *et al.*[13]

where $U(T)$ is the partition function of the ion and $N(T)$ its density. The relative error in the temperature is then

$$\frac{\Delta T}{T} \leq \frac{kT}{E}\left(\frac{\Delta\varepsilon}{\varepsilon}+\frac{\Delta A}{A}\right) \simeq \frac{1}{20}\left(\frac{\Delta\varepsilon}{\varepsilon}+\frac{\Delta A}{A}\right) \text{ for } T = 11{,}500°\text{K}.$$

In this calculation, the uncertainty introduced by $N(T)$, which is equivalent to $(1/kT)(\Delta\chi/\chi)$ has also been neglected. Taking into account the errors introduced by the Abel inversion, we find that $(\Delta\varepsilon/\varepsilon) \leq 30$ per cent, $(\Delta A/A) = 10$ per cent and $(\Delta T/T) \leq 2$ per cent.

Since the accuracy is higher for small kT/E, we chose an Ar II line rather than an Ar I line for measurement.

4.3. *Measurement of the ratio of intensities of two lines*

The accuracy of this method is only satisfactory if the difference between the excitation energies of the two lines is much greater than $kT = 1$ eV. Thus, we measured the ratio R of the emission coefficient of an Ar I line ($\lambda = 4300.10$ Å, $\lambda = 4158.59$ Å) to that of an Ar II line ($\lambda = 4806.02$ Å).

At atmospheric pressure, these lines are optically thin and R is given by

$$R = \frac{\varepsilon_1}{\varepsilon_2} = \frac{h^3}{2(2\pi mk)^{3/2}}\frac{A_1 g_1 \lambda_2}{A_2 g_2 \lambda_1} N_e(T) T^{-3/2} \exp\left(-\frac{E_1 - E_2 - \chi}{kT}\right).$$

The indices 1 and 2 refer to the atomic and ionic lines respectively, and χ is the ionization energy of the neutral atom (15.75 eV); $N_e(T)$ is the electronic density.

The relative error in the temperature can be written as

$$\frac{\Delta T}{T} \lesssim \frac{kT}{|E_1 - E_2 - \chi|}\left(\frac{\Delta\varepsilon_1}{\varepsilon_1}+\frac{\Delta\varepsilon_2}{\varepsilon_2}+\frac{\Delta A_1}{A_1}+\frac{\Delta A_2}{A_2}\right) \simeq \frac{1}{20}\left(\frac{\Delta\varepsilon_1}{\varepsilon_1}+\frac{\Delta\varepsilon_2}{\varepsilon_2}+\frac{\Delta A_1}{A_1}+\frac{\Delta A_2}{A_2}\right).$$

Here we have again neglected the uncertainty introduced in the calculation of $N_e(T)$. Taking for $\Delta A/A$ and $\Delta\varepsilon/\varepsilon$ the preceding values, we obtain $(\Delta T/T) \lesssim 4$ per cent.

4.4. *Determination of the electronic density: half-width of the hydrogen H_β line measurement*

We used a gas mixture of 98 per cent argon and 2 per cent hydrogen. The ionization potential of hydrogen being close to that of argon, we assume, in first approximation, that the electronic density measured with this mixture is the same as that of a pure argon plasma. The number density N_e is $N_e = C(N_e, T)\Delta\lambda_S^{3/2}$, where $\Delta\lambda_S$ is the half-width of the H_β line, broadened by the Stark effect, and $C(N_e, T)$ is a coefficient calculated by GRIEM[9] the value of which remains almost independent of temperature in the range $8000 \leq T[°\text{K}] \leq 40{,}000$. By introducing the value of N_e thus obtained into the expression of Saha's law the ionization temperature can be calculated, the plasma being in L.T.E., and self-absorption being neglected.

4.5. *Measurement of the absolute intensity of the continuum*

In the spectral region studied, $\lambda \leq 7000$ Å, bremsstrahlung radiation can be neglected when considering recombination radiation. The emission coefficient of the continuum

can, therefore, be expressed for a plasma in L.T.E. as

$$\varepsilon_\lambda = 1.62\,10^{-28}\frac{N_e^2(T)}{\sqrt{T}}\xi(\lambda, T)\,\text{ergs. S}^{-1}.\,\text{cm}^{-4}.\,\text{ster}^{-1},$$

where $\xi(\lambda, T)$ is a coefficient tabulated by SCHLÜTER[2] which varies slightly with temperature; $N_e(T)$ is the electronic density in cm^{-3}; λ is the wavelength in cm; T equals the temperature in °K.

When the plasma is optically thin, the intensity I_λ emitted end-on from a homogeneous plasma column in L.T.E. of length l is given by $I_\lambda = \varepsilon_\lambda l$. The electronic temperature can be deduced from the measured intensity of the continuum at a given wavelength (our measurements were made at $\lambda = 5080$ Å, in a spectral region where the detector sensitivity is good and where there is no contribution from the wings of broadened lines). As the pressure is increased, the absorption coefficient k_λ of the continuum increases. For example, for $\lambda = 5080$ Å and $T = 12{,}000$°K, the value of k_λ calculated by using equation (2) goes from about $3.10^{-4}\,\text{cm}^{-1}$ for $p = 1$ atm to $2.10^{-2}\,\text{cm}^{-1}$ for $p = 50$ atm. In end-on observations, the plasma for $p = 50$ atm has an optical depth equal to 0.1 for $\lambda = 5080$ Å. The monochromatic intensity, emitted by this homogeneous plasma column in L.T.E., of temperature T and length l, is then given by the expression (1), which can be written as

$$k_\lambda = f_\lambda(T, I_\lambda), \tag{3}$$

where $I_\lambda(T, p, l)$ is considered to be an experimental parameter. Equation (2) may then be expressed as

$$T = g_\lambda(k_\lambda). \tag{4}$$

The value of the temperature T being arbitrarily fixed, it is possible to deduce the value of k_λ from equation (3) if $I_\lambda(T, p, l)$ has been measured. From equation (4), we extract a value of T that we then introduce in equation (3) and so on. This iterative process, which allows determination of the temperature, has been produced graphically for every value of the pressure in a (k_λ, T) plane; the process converges to the intersection of the curves $k_\lambda = f_\lambda(T, I_\lambda)$ and $T = g_\lambda(k_\lambda)$.

Reabsorption has only a slight influence on the temperature. Thus, when $p = 50$ atm, $T = 12{,}000$°K, $\lambda = 5080$ Å, this correction represents less than 5 per cent. Therefore, we used in the iterative process the theoretical values of k_λ, which have never been measured at high pressure.

4.6. *Experimental results*

The experimental results are given in Tables 2 and 3. Table 2 shows that the difference between the temperatures obtained by the various methods is never greater than 5 per cent, which remains within the range of measurement errors and seems to confirm, a posteriori, that L.T.E. occurs in the plasma. Furthermore, the temperature obtained on the discharge axis from side-on observations agrees with the value obtained from end-on observations: the plasma region observed end-on is quite homogeneous in temperature.

Table 3 shows that, when the current is constant, the temperature decreases with the pressure. The average value $\overline{T}$ of the temperature, obtained by using the various methods explained in Part 4, characterizes the physical properties of the plasma.

TABLE 2. DETERMINATION OF THE TEMPERATURES [°K] AND OF THE ELECTRONIC DENSITIES [cm^{-3}] AT ATMOSPHERIC PRESSURE

	Side-on observations				End-on observations			
I (A)	Absolute intensity (ArI 4806 Å)	Ratio $\left(\frac{\text{ArI 4300 Å}}{\text{ArII 4806 Å}}\right)$	Ratio $\left(\frac{\text{ArI 4158 Å}}{\text{ArII 4806 Å}}\right)$	Absolute intensity of the continuum at $\lambda = 5080$ Å	Half-width of Hβ and Saha law (for T) T	N_e	Absolute intensity of the continuum at $\lambda = 5080$ Å	$\bar{T}$
60				11,850	12,325	7.80×10^{16}	11,800	11,990
100	12,700	13,030	13,110	12,850	12,950	1.03×10^{17}	12,700	12,890
150	13,900	14,260	14,380	14,050	13,700	1.35×10^{17}	13,850	14,020
180	14,000	14,600	14,470	14,200	14,225	1.60×10^{17}	14,250	14,290

TABLE 3. DETERMINATION OF THE TEMPERATURE [°K] UNDER PRESSURE [atm] FROM THE ABSOLUTE INTENSITY OF THE CONTINUUM FOR λ = 5080 Å, CORRECTED FOR SELF-ABSORPTION (END-ON OBSERVATIONS)

I[A] \ P[atm]	1	10	30	50
60	11,800	11,300	11,000	10,850
100	12,700	11,800	11,250	11,000
150	13,850	12,150	11,680	11,500
180	14,250	12,530	11,980	

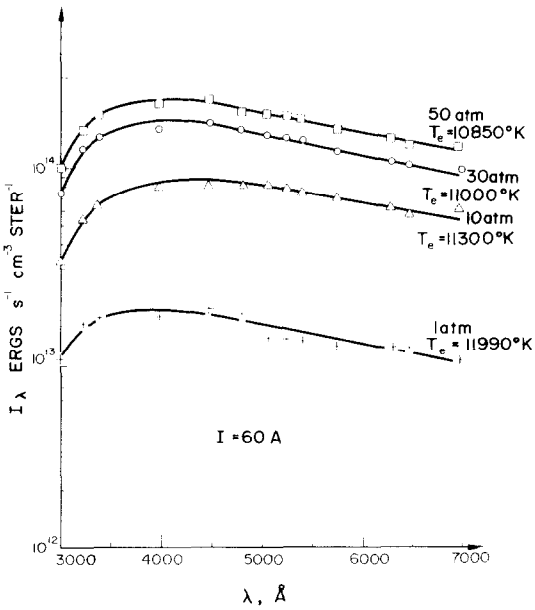
From the continuous intensity emitted end-on by the plasma, we will deduce (Part 5) a brightness temperature T_L which characterizes the radiation. The comparison of these two temperatures allows determination of the extent to which blackbody radiation is approximated (in this case, $\bar{T} = T_L$).

5. CONTINUUM INTENSITIES EMITTED AXIALLY (END-ON OBSERVATIONS) FOR $3000 \leq \lambda[A] \leq 7000$

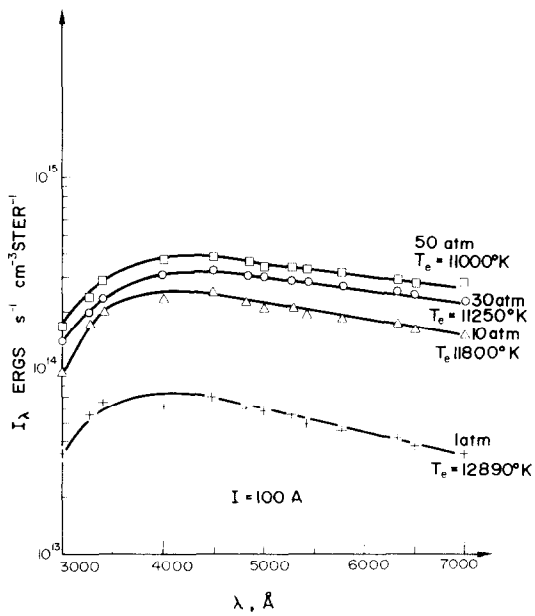
To determine the absolute intensities of the continuum, we choose wavelengths allowing only a weak contribution of the far wings of the Ar I lines, even though greatly broadened under pressure. In the near ultra-violet, the scattered light has been measured by using a frequency-range filter and deducing its value from the recorded intensity. The instantaneous fluctuations of the intensity do not exceed 4 per cent at 50 atm and the reproducibility of the measurements is better than 5 per cent. Figures 5a–d give the values of the continuum intensities emitted by a 4.9 cm long plasma column for electrical intensity between 60 and 180 A and pressure between 1 and 50 atm. Figure 6 shows the variation of the radiation intensity (λ = 5080 Å) as a function of temperature and pressure. The solid lines represent the theoretical variation of this intensity, deduced from equations (1) and (2). In Figure 7 are given the intensities emitted in the spectral range $3000 \leq \lambda[A] \leq 7000$, by the plasma column ($l$ = 4.9 cm, the electrical intensity being 150 A and the pressure 50 atm) and by the following two reference sources: a tungsten ribbon lamp (T = 2800°K, the values of the monochromatic emissivity being those given by DE VOS[14]) and the positive crater of a carbon arc (superficial temperature 3926°K, from MAGDEBURG and SCHLEY)[15] It will be noted that the radiation emitted by the arc in the near u.v. is of particular interest since only few sources of high radiance exist in this region.

On Fig. 7, we can also compare Wende's data[16] (for a wall-stabilized arc 14.2 cm in length, and 7 mm dia., burning at atmospheric pressure with a 110 A current) against our own results obtained with a 5 mm dia. arc at atmospheric pressure, 110 A current and 4.9 cm in length. The difference in these two series of results can be explained, in the visible range, by the different values of the temperature: about 12,300°K in Wende's experiment, nearly 13,000°K in ours.

Finally, on Fig. 7 it can be noted that the values of the continuum intensity, for a 150 A electrical intensity and a 50 atm pressure, lie, in the spectral range $3500 \leq \lambda[A] \leq 6500$, very close to the curve of the Planck function at T = 7500°K. In this spectral range, the brightness temperature has thus a constant value equal to 7500°K, while the "physical"


50 atm
T_e =10850°K
30atm
T_e =11000°K
10atm
T_e =11300°K
1atm
T_e = 11990°K
I = 60 A
I_λ ERGS s^{-1} cm^{-3} $STER^{-1}$
10^{14}
10^{13}
10^{12}
3000
4000
5000
6000
7000
λ, Å

(5a)


50 atm
T_e = 11000°K
30atm
T_e = 11250°K
10atm
T_e 11800° K
1atm
T_e = 12890°K
I = 100 A
I_λ ERGS s^{-1} $cm^{-3}STER^{-1}$
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3000
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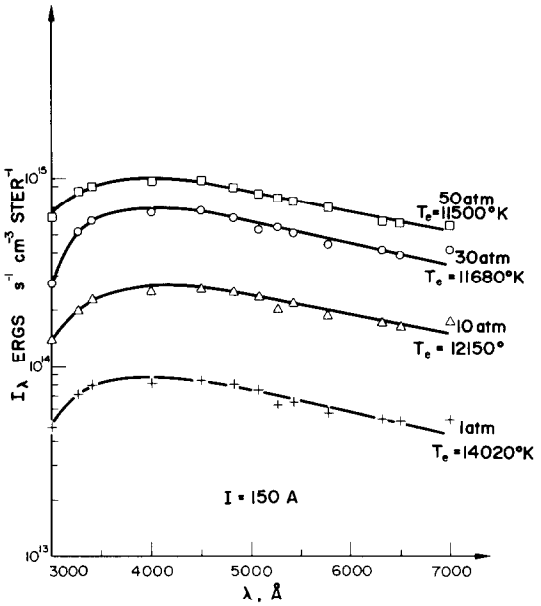
6000
7000
λ, Å

(5b)



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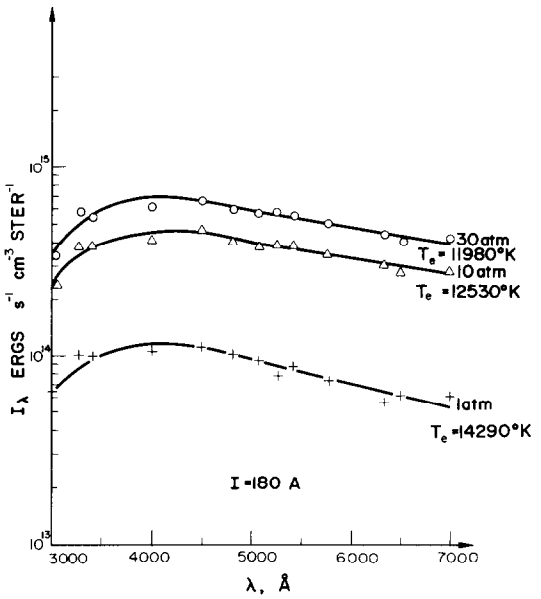

(5d)

FIG. 5. Experimental intensities of the continuum emitted by the plasma as a function of the wavelength for various pressures and various currents. For each pressure, the corresponding electronic temperature has been indicated; 5-a, I = 60 A; 5-b, I = 100 A; 5-c, I = 150 A; 5-d, I = 180 A.

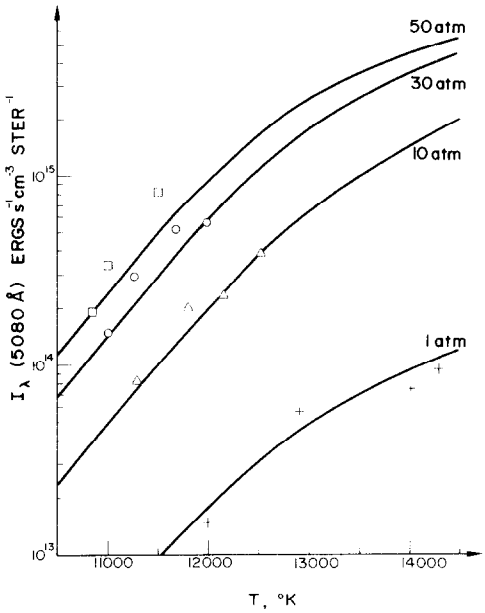

FIG. 6. Continuum intensity, at $\lambda = 5080$ Å, as a function of the electronic temperature; + experimental values, $p = 1$ atm; △ experimental values, $p = 10$ atm; ○ experimental values, $p = 30$ atm; □ experimental values, $p = 50$ atm. The solid lines represent the theoretical variation from Schlüter's theory for various pressures.

(electronic) plasma temperature reaches 11,600°K (cf. GOLDBACH *et al.*[17]). This result does not agree with the conclusions that can be drawn from equation (2) and which are represented by the solid lines on Fig. 8. Figure 8 also gives the experimental values of the absorption coefficient k_λ of the continuum, deduced from the measured intensity $I_\lambda(T, \mathrm{p}, l)$ through equation (1), viz.

$$k_\lambda = -\frac{1}{l}\log\left[1 - \frac{I_\lambda(T, p, l)}{B_\lambda(T)}\right],$$

where l is the length, T the electronic plasma temperature, and $B_\lambda(T)$ the Planck function. The precision of the k_λ values, obtained by this method, is no better than 25 per cent.

CONCLUSIONS

The very high values of the product pl and of the temperature which are theoretically necessary to obtain Planck radiation from an argon plasma are not yet experimentally accessible. For the highest value of pl ($pl = 250$ atm cm, $T_e = 11{,}500$°K) reached, disagreement between theory and experiment may be noted. To explain these discrepancies we advance two hypotheses: (a) the parasitic influence of the far wings at Ar I lines, strongly broadened under pressure. In fact, two groups of intense lines are located between $3800 \leq \lambda[A] \leq 4700$ and between $6670 \leq \lambda[A] \leq 9000$, which might cause a superposition of a weak pseudo-continuum on the recombination continuum at the points where the

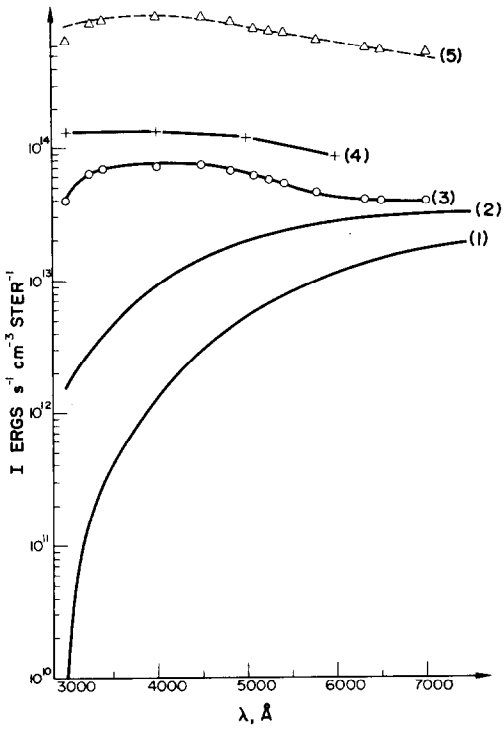

FIG. 7. Intensity emitted by various sources as a function of the wavelength. (1) Tungsten ribbon lamp [T = 2800°K][14]; (2) Positive crater of the carbon arc [T = 3926°K][15]; (3) Our experiments at p = 1 atm, l = 4.9 cm, T = 13.000°K, I = 110 A; (4) Wende's experiments at p = 1 atm, l = 14.2 cm, T = 12,300°K, I = 110 A[16]; △△△ our experiments at p = 50 atm, l = 4.9 cm, T = 11,500°K, I = 150 A; (5) blackbody radiation for T = 7500°K.

measurements were made; (b) the contribution of bremsstrahlung associated with collisions between electrons and neutral atoms. This bremsstrahlung has been neglected although the degree of ionization α decreases (at constant temperature) when the pressure increases; for example, T = 12,000°K, $\alpha = 1.2\ 10^{-1}$ for p = 1 atm and $\alpha = 1.7\ 10^{-2}$ for p = 50 atm. To clarify the observed discrepancies, a detailed experimental study of the plasma absorption coefficient will have to be carried out (for example, by varying the plasma length) while, simultaneously, extending the pressure and the temperature ranges experimentally attainable. Nevertheless, the arc which has been constructed could be a useful reference source of high radiance in the visible and near u.v. range because of its time stability and because of the reproducibility of the emitted light intensities.

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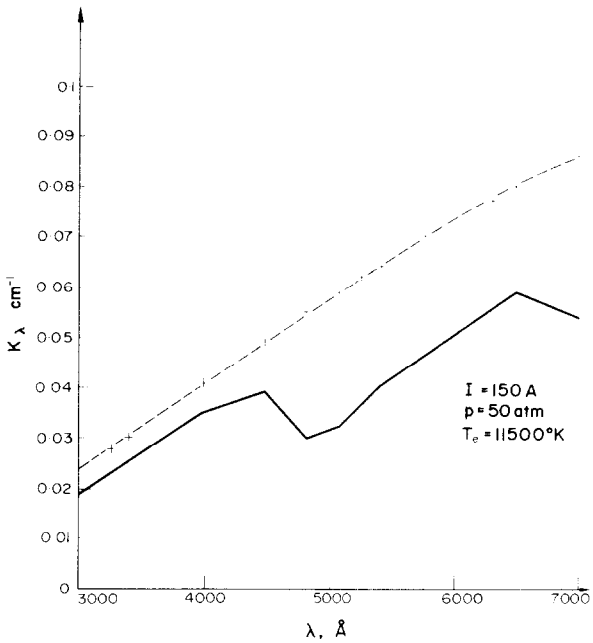

FIG. 8. *Dashed line*: Experimental values of the absorption coefficient of the continuum from the measured intensities, at $p = 50$ atm, as a function of the wavelength; *Solid line*: theoretical values derived from equation (2).

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