

### 3.6 Measurements on a wall-stabilized cascade argon arc

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#### 1. Introduction

Wall stabilized arcs of the kind first developed by Maecker<sup>1)</sup> are stationary and extremely stable high current plasma sources. Improved versions of these arcs are suitable for high power input<sup>2,3)</sup> and high pressures<sup>4)</sup>. Our arc chamber for the ultraviolet and visible spectral region was designed basically as that in ref.<sup>3)</sup> and is shown in Fig. 1.

#### 2. Experimental

The arc chamber consisted of 12 water-cooled nickel-coated copper plates, 6 mm thick and with a 3 mm central bore for the arc channel. The plates were insulated by means of 0.25 mm thick PTFE rings. The cooling channel (4 mm in diameter) of each plate consisted of three straight segments surrounding the central bore. The outlets were connected with the water supply by means of flexible pipes. This system proved simple and efficient. The cathode consisted of a tungsten disc 4 mm in diameter, inserted in a cooled copper plate. The anode was the same as the cathode but with a central bore (1 mm in diameter) through which the plasma column near the arc axis was observed end on. The arc burned in argon which was continuously fed at  $G_1$  and  $G_{12}$  at a rate  $4 \text{ cm}^3/\text{s}$  and a pressure of 1 atm. The flow was directed from electrodes to the exit at  $G_6$ . A small amount of hydrogen with a flow rate of  $0.1 \text{ cm}^3/\text{s}$  was introduced at  $G_2$  for the measurement of  $H_\beta$  half-widths. The argon flow prevents the hydrogen to diffuse into the inhomogeneous electrode region. The homogeneous plasma column was 100 mm long. The arc was run with currents from 6 to 20 Amps supplied by a well filtered 400 V rectifier. The burning arc voltage was about 90 V.

The central part of the arc was collimated by means of two 0.5 mm diaphragms 10 cm apart and imaged with a lens on the slit of an SPM-2 Zeiss grating monochromator (inverse linear dispersion  $38 \text{ \AA}/\text{mm}$ ). A precise alignment of the optical system was achieved with a He-Ne laser. The experimental set up is shown in Fig. 2. The spectra were detected photoelectrically with a photomultiplier tube (RCA 1P28 for visible, and RCA 7102 for infrared) coupled to a recorder (Zeiss G1B1). The absolute calibration was made with a tungsten strip standard lamp (Osram Wi 17/G). For the absorption measurements a concave mirror was placed with the chopper behind the arc chamber in order to reflect light back through it.

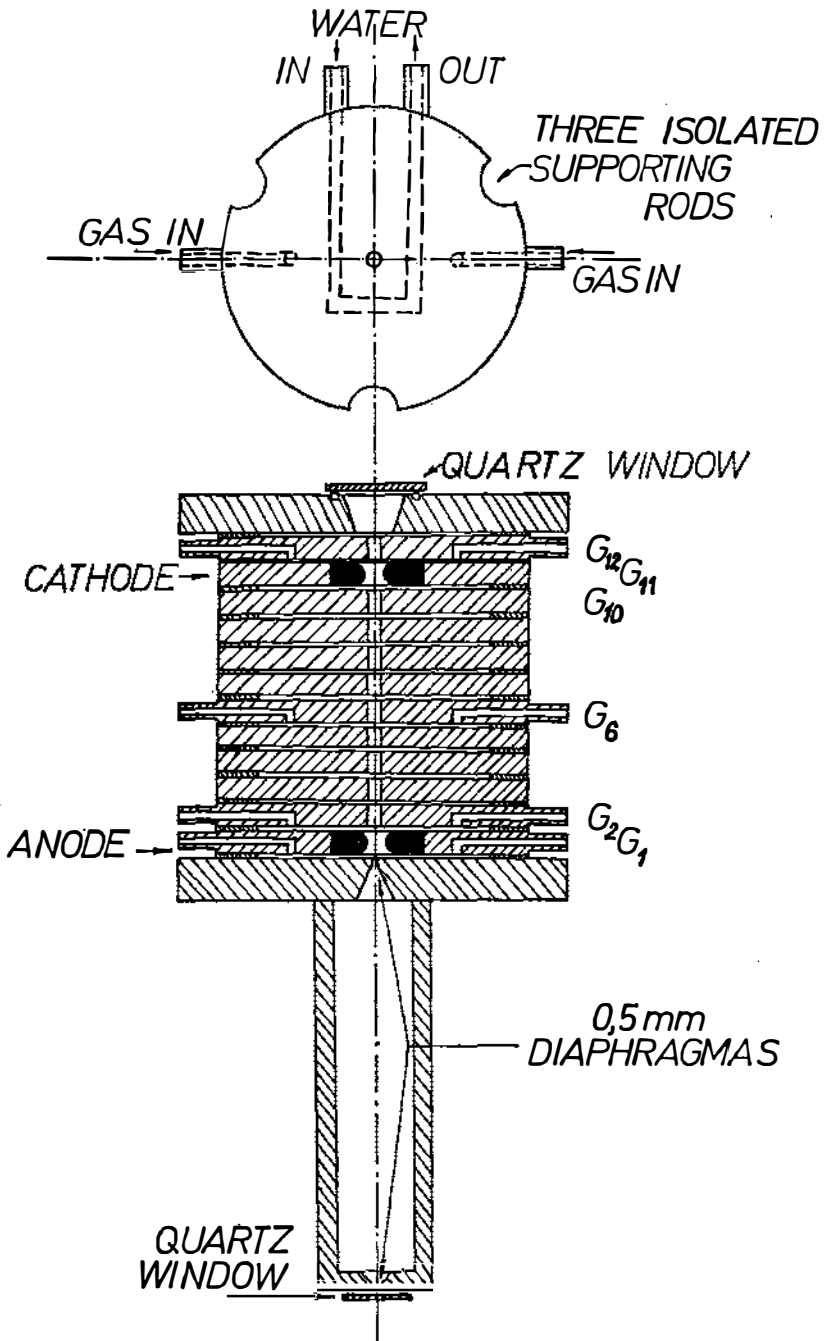


Fig. 1 Scheme of the cascade arc.

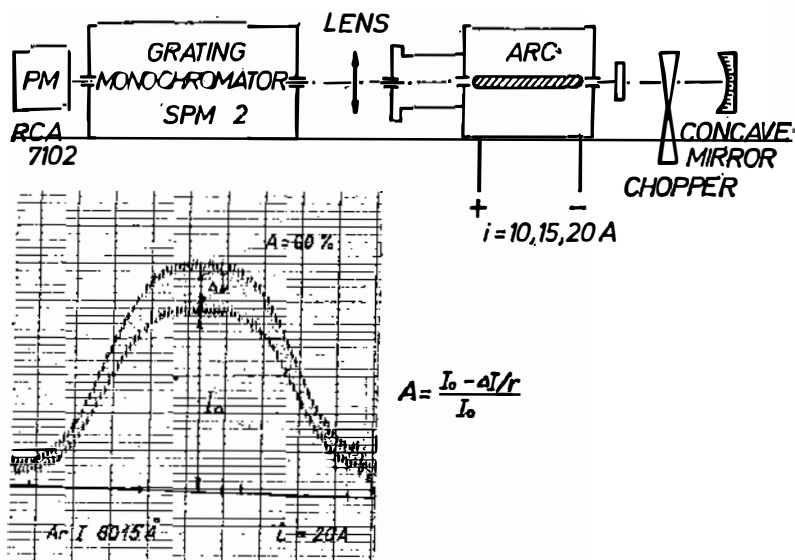


Fig. 2 Experimental arrangement for emission and absorption measurements. The absorption of lines was evaluated from the tracings in the insert.

### 3. Temperature measurement

The temperature was determined by three independent methods (Fig. 3):

- a) absolute intensity measurement of argon line 4300 Å and other blue lines;
- b) absolute intensity measurement of argon continuum near 4300 Å;
- c) half-width of the H<sub>β</sub>-line and plasma composition.

The most accurate method of measuring temperature is measurement of the absolute intensity of the 4300 Å line. Several authors<sup>5)</sup> give a consistent value for the transition probability of this, equal to  $3.1 \times 10^5 \text{ s}^{-1}$  with an error of 3%. The strong dependence of intensity on temperature gives rise to a small error of the measured temperature, according to the relation:

$$\frac{E_n}{kT} \left| \frac{\Delta T}{T} \right| = \left| \frac{\Delta A}{A} \right| + \left| \frac{\Delta I}{I} \right|.$$

The first term on the right hand side is equal to 3%. The second term is in the range of 10—15% for which one has to take into account uncertainty in the effective length of the arc<sup>4)</sup> (5—10%), the uncertainty in tabulated tungsten radiance<sup>6)</sup> (2%), and the uncertainty in setting the tungsten strip lamp current (less than 1% as follows from Fig. 5 in ref.<sup>6)</sup>). However, since  $E_n$  was about 15 eV and  $kT$  about 1 eV, the temperature error amounted to 1%.

In our measurements for currents from 6—20 Amps and using the transition probability from ref.<sup>5)</sup>, the obtained temperatures ranged from 9250

to 10950 K. In three trials we found a reproducibility of temperature of 2.5%. Using the transition probability for the 4300 Å line given by Wiese et al.<sup>7)</sup>, temperatures ranged from 9120 to 10 750 K, i. e. about 1.5% lower. The same temperature range was determined by the absolute intensity measurement of the lines 4044, 4158, 4259, 4272 and 4300 Å using data from ref.<sup>7)</sup> but the spread of results led to errors of up to 2.5%.

The absolute continuum intensity depends very little on temperature<sup>8)</sup> and the method gives the largest error, as can be seen from the following formula:

$$\left| \frac{\Delta T}{T} \right| = 4 \left| \frac{\Delta N_e}{N_e} \right| + 2 \left| \frac{\Delta I}{I} \right|.$$

If only the uncertainty in absolute intensity measurement were taken into account (10–15%), the error in temperature would be at least 20%. We obtained temperatures ranging from 9300 to 10 900 K with a fairly bad reproducibility.

The relation between the electron concentration and the  $H_\beta$  half-width is given by<sup>9,10)</sup>:

$$N_e = K (\Delta\lambda)^{3/2}, \quad K = 3.13 \times 10^{14} \text{ cm}^{-3} \text{ \AA}^{-3/2} \pm 5\%.$$

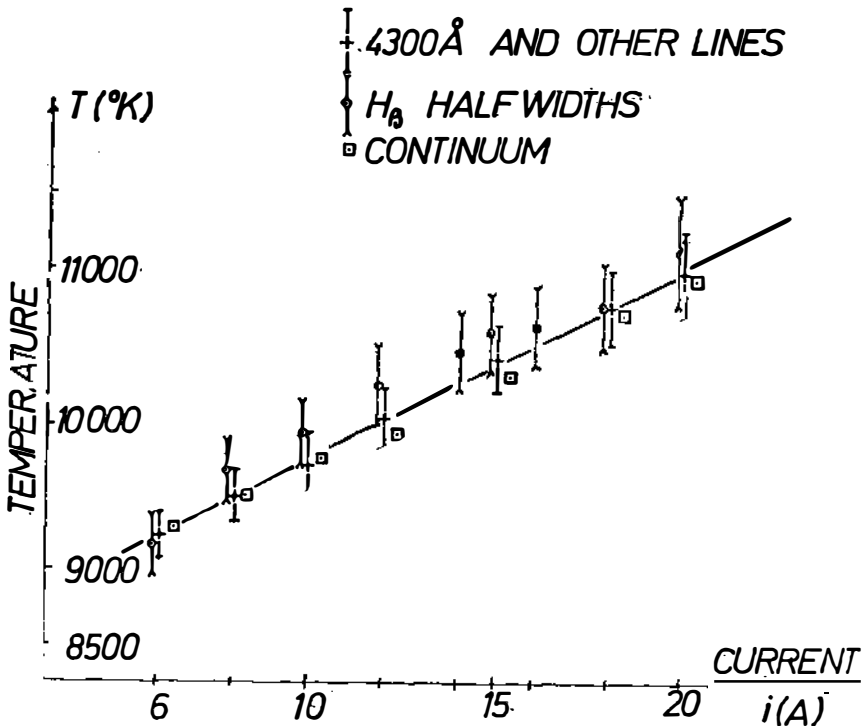


Fig. 3 Plot of the axial temperature versus current (3 mm channel).

The relative error of measured electron concentration is equal to:

$$\left| \frac{\Delta N_e}{N_e} \right| = \left| \frac{\Delta K}{K} \right| + \frac{3}{2} \cdot \frac{\Delta(\Delta\lambda)}{\Delta\lambda}.$$

If the  $H_\beta$  half-width is measured with an uncertainty of 10%, the electron concentration is uncertain within 20%. From the measured  $H_\beta$  half-widths the electron density was found in the range between  $7.9 \times 10^{15} \text{ cm}^{-3}$  and  $4.4 \times 10^{16} \text{ cm}^{-3}$  if the  $H_\beta$  half-widths were not corrected for hydrogen gas-flow. When the  $H_\beta$  half-widths were extrapolated to zero gas-flow (decrease in half-width amounted to 6.5%), the concentrations decreased by 15%, i. e. they ranged from  $6.8 \times 10^{15}$  to  $3.7 \times 10^{16} \text{ cm}^{-3}$ .

For conditions of local thermal equilibrium where the Saha-Eggert equation is valid, the temperature can be found from the measured electron density. For this we used a pure argon plasma composition as tabulated by Popenoe and Shumaker<sup>11)</sup> who took into account the first order Debye corrections. Griem's treatment<sup>12)</sup> of high density corrections to plasma composition calculations suggests that the table in ref.<sup>11)</sup> should be accurate to approximately 1%. The temperature determined in this way ranged from 9200 to 11 180 K with a maximum relative error of 2.5%. This is given by the following relation:

$$\left( \frac{3}{2} + \frac{\kappa - \Delta\kappa}{kT} \right) \left| \frac{\Delta T}{T} \right| = 2 \left| \frac{\Delta N_e}{N_e} \right| + \left| \frac{\Delta N_o}{N_o} \right| + \left| \frac{\Delta(\Delta\kappa)}{kT} \right|.$$

The measurement of the line absorption was undertaken in order to find whether the red argon lines are suitable for the determination of temperature. The upper levels of transitions which lead to the appearance of red argon lines are separated from the upper levels of transitions leading to blue for more than 1 eV and could be used for the method of relative line intensities. The total line absorption was measured by:

$$A = \frac{I_o - \frac{\Delta I}{r}}{I_o},$$

where  $I_o$  is the signal of the direct beam (Fig. 2),  $\Delta I$  is the difference in signals when chopper transmits the reflected beam, and  $r$  is the reflectivity of the mirror (0.5 in red, measured by the continuum which is optically thin). The absorption of the lines 6965, 7067, 7383, 7503, 7514, 7635, 7948, 8006, 8014, 8103 and 8115 Å was as high as 70%. Absorption was not found in blue lines.

#### A c k n o w l e d g m e n t

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### 3.7 Some characteristics of plasma in high pressure pulsed discharge

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High pressure pulsed discharges have been extensively investigated<sup>1)</sup> in order to get intense light sources, especially for laser pumping, and to produce dense plasma. However, little is known about the characteristics of plasma produced in such a type of discharge<sup>2)</sup>. The purpose of this work is to determine the electron concentration and the temperature from calculations according to Saha equation. The cylindrical tubes (ID 8 mm, inter-electrode distance 100 mm) filled with pure xenon (10, 50, 100, 200 and 500 mm Hg) were operated by nearly trapezoidal pulses (rise and fall time 15–20 μs, plateau length 100–120 μs). The initial voltages were 420–840 volts, current densities at plateau of the order of 450–1520 A/cm<sup>2</sup> and the energies of discharges 14–56 joules. In such conditions there is a rather large period of quasistationary state of discharge, which

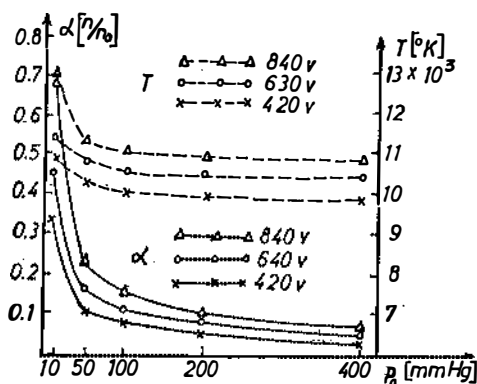


Fig 1

is characterized not only by constancy of current but also by constancy of voltage and of light output.

As it was shown earlier<sup>3)</sup>, the emission spectrum at plateau is mostly continuous, so that the plasma diagnostics methods based on spectral line intensities and broadening measurements are not convenient in this case. On account of that, electron concentration have been measured by laser interferometric method described in<sup>4)</sup>. A beam of He-Ne laser at 6328 Å wavelength, collimated with a system of two lenses placed in resonant cavity, traverses the discharge tube and is detected by a photomultiplier. The signal from PM and current pulse are recorded simultaneously by an oscilloscope. The maximal electron concentration was calculated from:  $n = f/2 L \lambda$   $4.48 \times 10^{-14}$ , where  $f$  is number of fringes (from the beginning of the pulse to the inflexion point),  $L$ (cm) — plasma length and  $\lambda$  (cm) — wavelength of interfering light.