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ADVISORY GROUP FOR AERONAUTICAL RESEARCH AND DEVELOPMENT

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THE PROPERTIES OF NITROGEN UP TO 15,000°K

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THE PROPERTIES OF NITROGEN UP TO 15,000°K

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H. Maecker

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SUMMARY

With a newly developed cylindrical cascade arc for high power input, and with the development of the theory of the arc, it has been possible to determine the electrical conductivity, the heat conductivity and the heat flux potential of nitrogen up to 15,000°K by means of electrical and spectroscopic measurements.

SOMMAIRE

La mise au point d'un nouveau arc cylindrique à grille pour obtenir une entrée élevée, ainsi que l'évolution de la théorie de l'arc ont permis la mesure, tant par des moyens électriques que spectrographiques, de la conductivité électrique, la conductibilité thermique et le potentiel du flux thermique de l'azote pour des températures allant jusqu'à 15.000°K.

'Above paper also presented by author at Fourth International Conference on Ionization Phenomena in Gases, Uppsala (Sweden) August 1959. Printed by North Holland Publishing Co. 1960'.

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NOTATION

r	radius of cylindrical arc
E	field strength
σ	electrical conductivity
d	diameter of cascade tube
κ	heat conductivity
T	temperature
S	heat flux potential
I	current

THE PROPERTIES OF NITROGEN UP TO 15,000°K

H. Maecker*

1. INTRODUCTION

For the determination of the properties of gases at elevated temperatures the electric arc is a suitable tool for steady state investigations. Before its application, however, two conditions must be fulfilled:

(a) a well defined arc design has to be established

(b) the theory of the entire arc phenomenon must be clarified.

2. EXPERIMENTAL DEVICE

For exact measurements the arc should be cylindrical because in that case the radius r is the only independent variable. Furthermore, with high power input, it should be capable of producing high temperatures and high degrees of ionization. For this purpose an arc design has proved successful which is composed of many insulated water-cooled copper plates with bores on their centre lines. All the bores together constitute the highly cooled arc tube. For a bore diameter of 5 mm a power input of almost 10 kW/cm arc length has been attained corresponding to a specific energy flow through the surface of 6 kW/cm^2. The field-strength E can be measured by the voltage difference between two separated plates divided by their distance with non-dependence on the voltage drop in the electrode regions. By this method the measured E-I-characteristic is very accurate and reproducible (see Fig. 1).

3. ARC THEORY

To evaluate the characteristic for obtaining properties of the arc gas, the theory of the cylindric arc must be mastered, beginning with the energy balance

$$\sigma E^2 + \frac{d}{r\,dr}\left(r\kappa\,\frac{dT}{dR}\right) = 0$$

according to which the Joule's heat supplied is to be transferred by heat conduction from the arc to the cooled tube walls. Since the heat conductivity κ depends on the temperature T only, one may replace $\kappa\,dT$ by

$$d\int_0^T \kappa\,dT = dS$$

calling $S = \int_0^T \kappa\,dT$ the heat flux potential.

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Introducing this new function in the energy balance equation, the only necessary material function is the relation between the electric conductivity σ and the S-function. By an approximate integration of the energy balance the E-I-characteristic of the arc can be derived from the $\sigma(S)$-function, wherefrom follows inversely that from the measured characteristic the function $\sigma(S)$ alone can be determined. The results of these calculations may be described roughly the the statement that both the characteristic and the $\sigma(S)$ curves have very similar shapes; they are only shifted and rotated with respect to each other in a certain manner (see Figs. 1 and 4). So the application of the theory to the measured characteristic results in the material function $\sigma(S)$. If the radiation is not negligible, it must be measured and taken into account in the calculations.

4. SPECTROSCOPIC TEMPERATURE MEASUREMENTS

More information may be obtained by means of spectroscopic temperature measurements. For this purpose the light of a nitrogen arc coming from a small slit of 0.5 mm width between two adjacent copper plates in the middle of the cascade was transmitted to a grating spectrograph of high resolution. The intensities of the N_2-bands and the N_2^+-bands, of an N-line and an N^+-line and of the continuous spectrum and the broadening of the H_β-line by Starck effect were employed to determine the radial temperature distribution (see Fig. 2), using arc currents from 10 to 250 amps. The results of the different measurements show good consistency and give axial temperatures from about 7000°K up to 16,000°K.

5. ELECTRICAL CONDUCTIVITY

Using the differential Ohm's law $j = \sigma E$ and Langmuir's formula for the electrical conductivity, the cross-section of the neutral particles and the ions for electron impact can be calculated from the measured temperature distributions. For the neutral N-particles a cross section of 6×10^{-16} cm^2 was found, while the cross-section of the ions appeared to be only 8% higher than that given by Spitzer.

6. HEAT CONDUCTIVITY

The determination of the heat conductivity κ is based on the once integrated energy equation, according to which the Joule's heat supplied to a certain cylinder with the variable radius r must flow through the surface of this cylinder at a rate proportional to the temperature gradient multiplied by the heat conductivity. The derivative of the temperature distribution with respect to the radius introduced in the equation described gives $\kappa(T)$. It shows (see Fig. 3) the expected maximum around 7000°K due to the diffusion of the dissociation energy of the N_2-molecules. After having passed a minimum the heat conductivity rises again to very high values caused by the corresponding ambipolar diffusion of ionization energy.

7. COMPARISON BETWEEN THE ELECTRICALLY AND SPECTROSCOPICALLY MEASURED $\sigma(S)$-Function

The integration of the heat conductivity over the temperature leads to the above mentioned heat flux potential S over which the measured electrical conductivity σ may be plotted and compared with the corresponding function evaluated from the characteristic measurements. The agreement between both is very satisfactory (see Fig. 4).

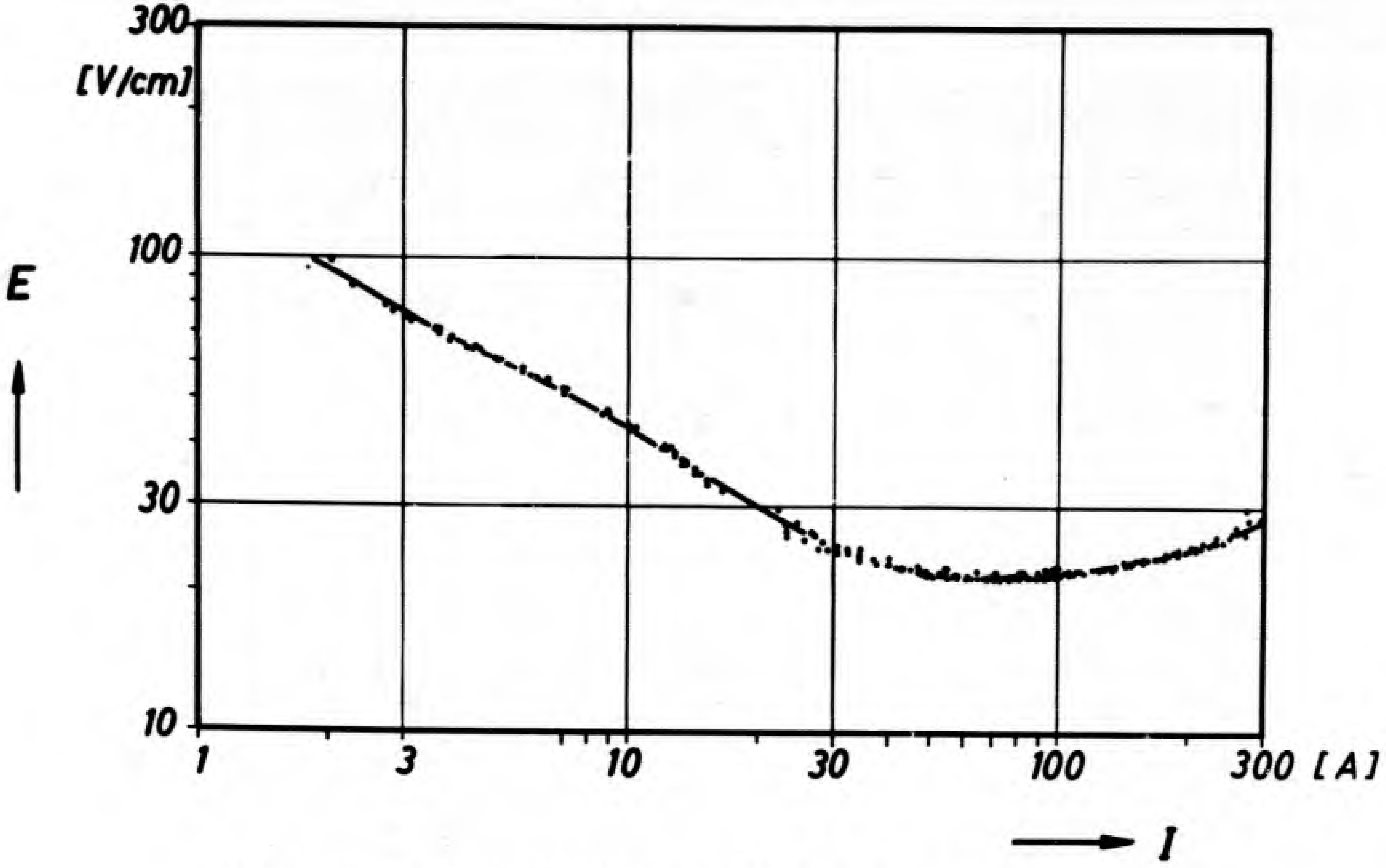

Fig. 1 Measured E-I-characteristic for the cylindric arc in N_2 with 5 mm cascade tube diameter

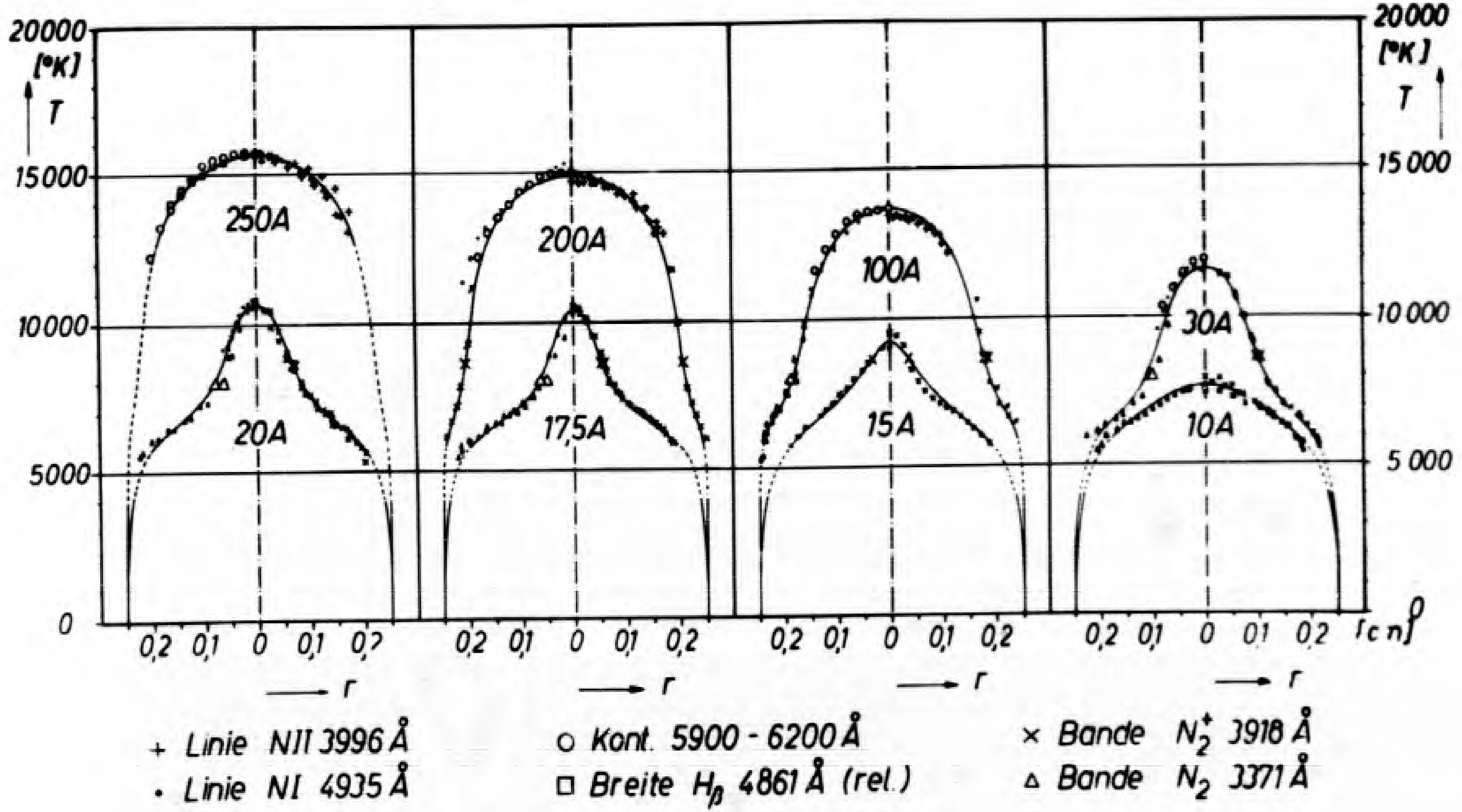

Fig.2 Spectroscopically measured temperature distribution TS in an N_2-arc with different currents

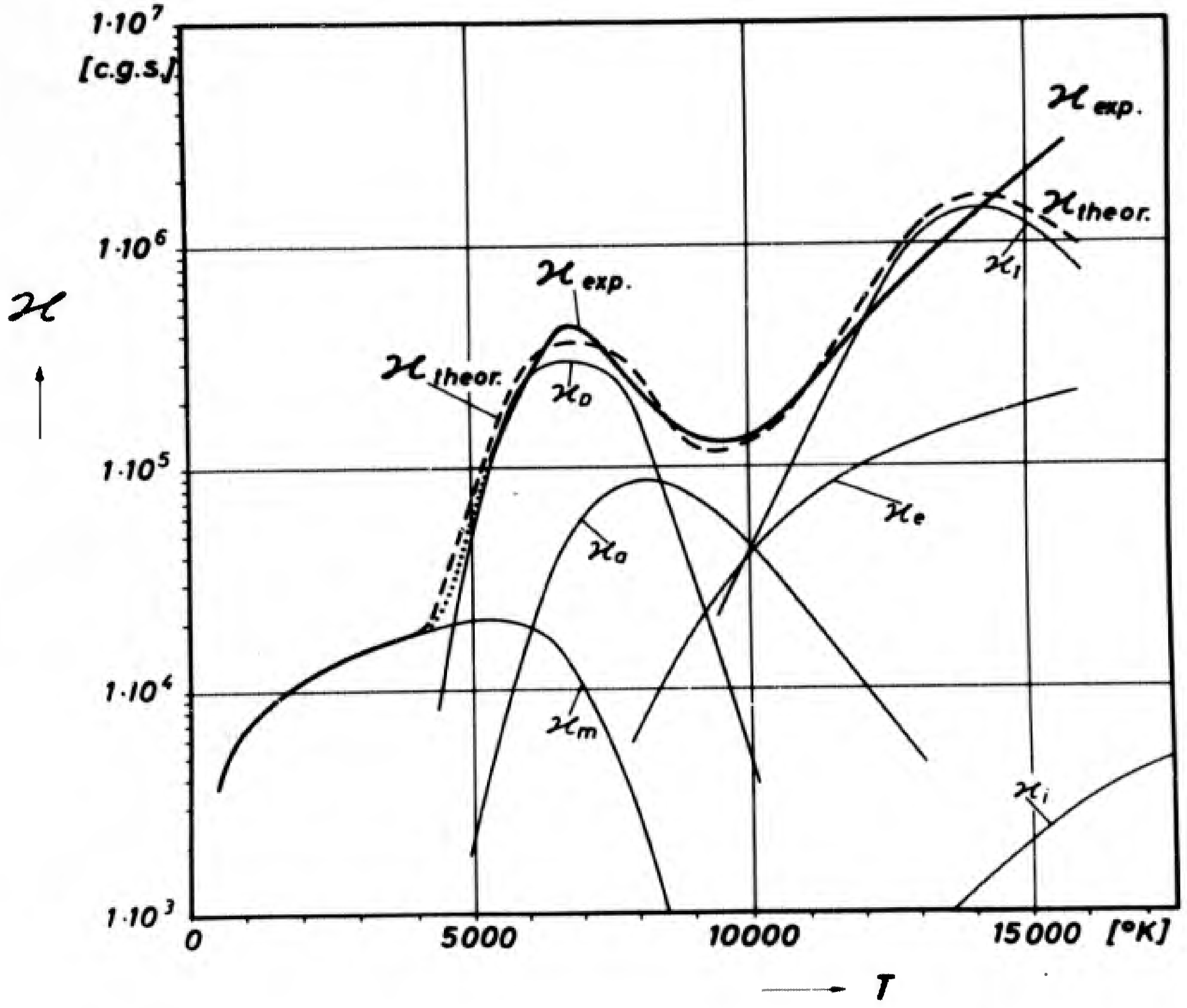

Fig.3 Heat conductivity κ of nitrogen vs temperature with the maxima due to diffusion of dissociation energy and ionization energy

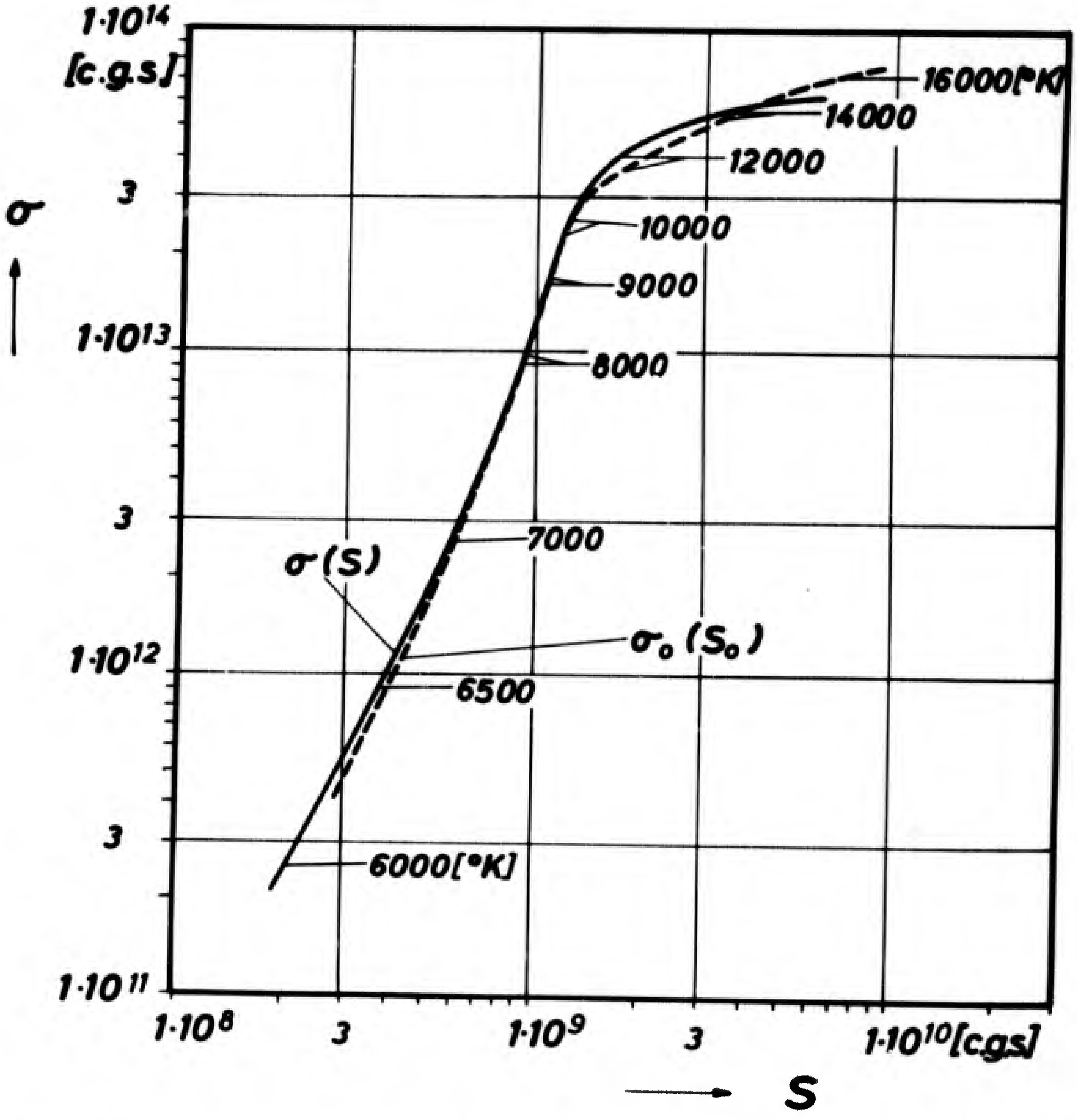

Fig.4 Electrical conductivity vs heat flux potential $S = \int_0^T \kappa \, dT$ resulting from the characteristic (dashed line) and from spectroscopic measurements (full line)