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ISR PERFORMANCE REPORT

Run 508, 21st August 1974, Ring 2

Ionisation of sodium by protons of 26 GeV/c

The measurements of Run 492 using the clearing electrodes in I5 to determine the ionisation cross-section of sodium by fast protons, have been repeated and supplemented by measurements using the existing electrodes in the beam profile monitor (B.P.M.)

Determination of ionisation cross-section

The experimental arrangement as sketched in Figure 1 was the following. The electrodes in the B.P.M. were fixed at a potential of - 10 Volts and the potential of the clearing electrodes (C.E.) has been varied from - 50 to + 600 Volts. The measured currents are plotted in Figure 1. Index 0 refers to currents without sodium curtains whereas index Na refers to currents coming from the sodium only. The indices s and i refer to the upper and lower electrode in the B.P.M. respectively. We remark that the sum of the two ion currents equals the electron current measured by the clearing electrode when their potential becomes superior to 200 V. Furthermore, we notice that both currents increase with increasing neutralisation (decreasing clearing potential). We explain this effect by the fact that the primary electrons produce secondary ones and therefore the ion and electron current is bigger, when the electrons are not cleared from the beam. The neutralisation of the proton beam is characterized by the ratio of the electron density n_e to the proton density n_p. Then the ratio R of the production rate by the primary electrons to that by the protons is given by the following expression :

$$R = \frac{n_e \frac{1}{A} \int_{v_{min}}^{v_{max}} v \, \psi(v) \, \sigma_{e-Na}(v) \, dv}{n_p \, c \, \sigma_{p-Na}}$$

$$A = \int_0^\infty \psi(v) \, dv$$

$\psi(v)$ is the velocity distribution of the primary electrons, $\sigma_{e-Na}(v)$ is the cross-section for the ionisation of sodium by electrons, c is the speed of light and σ_{p-Na} is the cross-section for the ionisation of sodium by fast protons.

The latter value was chosen from our measurements (σ_{p-Na} = 0.86 ions/m torr). The functions $\psi(v)$ and $\sigma_{e-Na}(v)$ are given numerically in Solomon[1] and Landolt-Börnstein[2], respectively. Their product and integration were equally numerically calculated.

The final result is

$$R = 0.28 \frac{n_e}{n_p}$$

The values of R for a fully neutralized beam ($\frac{n_e}{n_p}$ = 1) can be compared satisfactorily with the one measured (R = 0.325).

At clearing voltages lower than 200 V the electron current is higher than the ion current. This effect is due to the increased number of electrons in the proton beam from the B.P.M. to the C.E. The production rate of secondary electrons in the residual gas is about 1.5 x 10^{-10} A. Since there are 1.5 times more electrons in the beam, when the sodium curtain is turned on, the production rate of secondary electrons is increased by this factor. Therefore there should be an addition of 2.25 x 10^{-10} A of secondary electrons (3 x 10^{-10} A measured).

Assuming that the interpretation of our results is correct, we take the assymptotic value of 2.08 x 10^{-9} A for the determination of the ionisation cross-section.

The density of the sodium curtain at the intersection with the protons was 7.45 x 10^9 atoms/cm^3 which is equivalent to a pressure of 4.7 x 10^{-7} torr. Knowing that the proton beam of 5.26 A traverses 1 mm of the sodium curtain, the primary ionization constant has been calculated to be 0.84 ($torr^{-1}$ m^{-1}).

The same measurements have been repeated with a proton current of 2.2 A. The results are plotted in Figure 5. The current I_i^{Na} is probably not correct and we suspect that an error in the polarisation of the electrode has occurred when measuring the current I_i^o produced by the residual gas. We obtained a negative value of 6.3 x 10^{-10} A. However, the electron current on the clearing electrode is also about 20% too low. The same effect has been observed at the last experiment and we conclude that the collection efficiency of the clearing electrodes decreases with a decreasing potential well depth.

Energy distribution of the primary electrons

The set-up for this experiment is drawn schematically in Figure 2. The proton beam was almost neutralized and therefore the effect of the slow secondary electrons is included in the measured distribution.

The electron current collected at the upper electrode was the same as the ion current of the preceding experiment, which indicates that all electrons were collected. The lower electrodes collected only half of the ions produced; the other half goes to the chamber wall. The electron current I_i^o produced by the residual gas and measured by the lower electrodes, is not correct, because the electrodes of the B.P.M. are mounted on insulators which were polarized by an electric field and yield a residual in time varying current of several 10^{-10} Ampères. Therefore our measurements of low currents are falsified. In Figure 3 the current measured at the upper electrode has been drawn as a function of the extractor voltage V^s. We notice that the number of ions and electrons is equal at a potential of 1 volt. This indicates that the proton beam was not fully neutralized and that the slow electrons having an energy of one electronvolt stayed locked in the potential well. If we assume that the potential distribution between higher and lower electrode looks like the one drawn on the schema in Figure 3, the current I_s^{Na} is an indirect measure of the energy distribution of the primary electrons. Further we must assume that the height of the proton beam is small compared to the distance of the electrodes. Then the electrons, which are ejected from the half plane toward the lower electrode are repelled by the electric field according to their initial vertical velocity. Hence the electron current I_s^{Na} beginning from half of its saturation value and normalized properly, represents the cumulative distribution function of the square of its initial vertical velocity. Since we assume that all electrons leave the proton beam uniformly distributed in a normal direction to it, the distribution of the horizontal initial velocity is identical to the vertical. Therefore the density distribution of the initial velocity is simply the auto-correlation function of the initial vertical square velocity distribution function. The cumulative distribution function of the square of the vertical initial velocity has been drawn in Figure 4. The values at low energies (several eV) are probably not very exact.

Conclusion

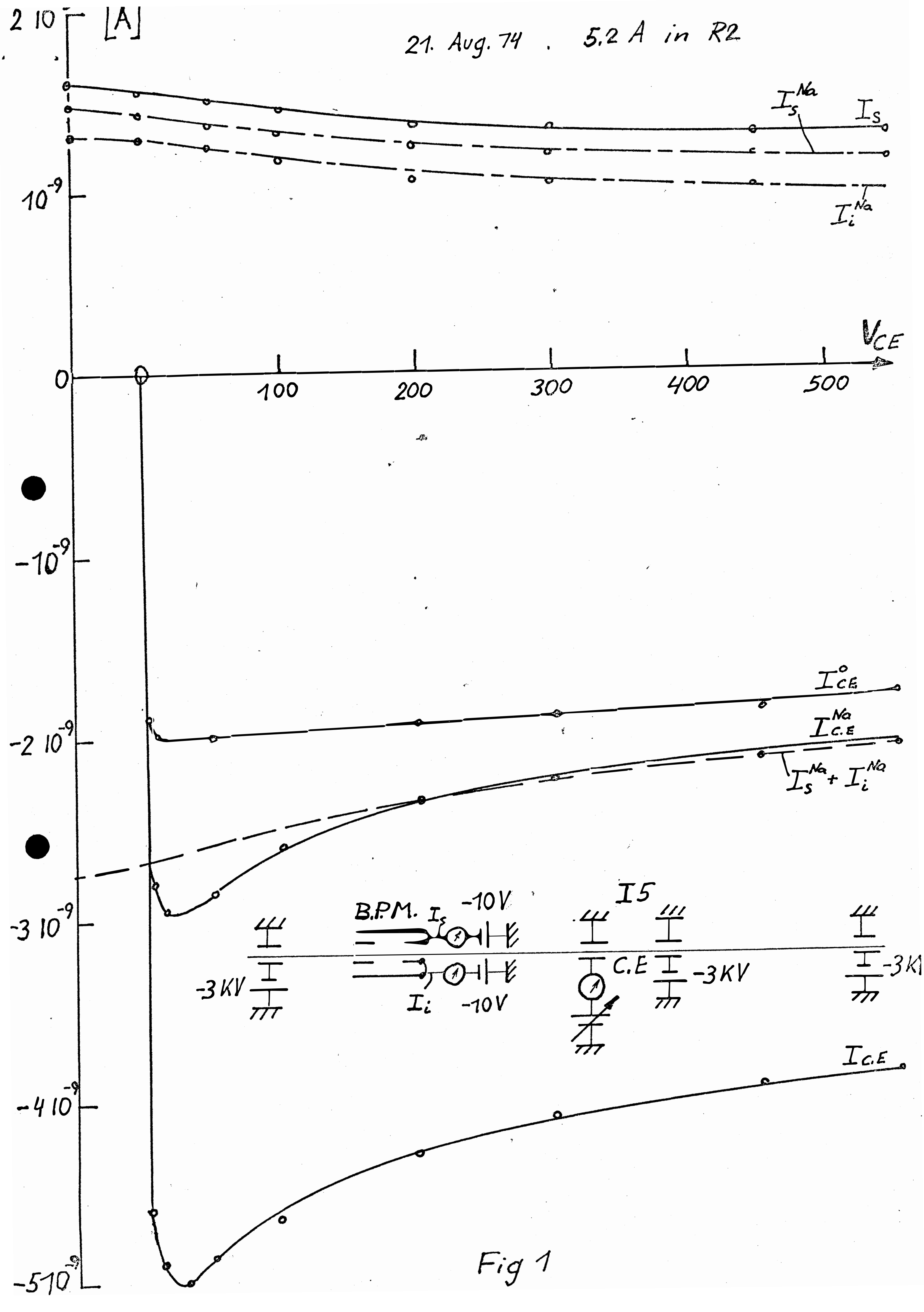
The specific primary ionization of sodium vapour by protons having a momentum of 26 GeV/c has been properly determined (0.84 $torr^{-1} m^{-1}$).

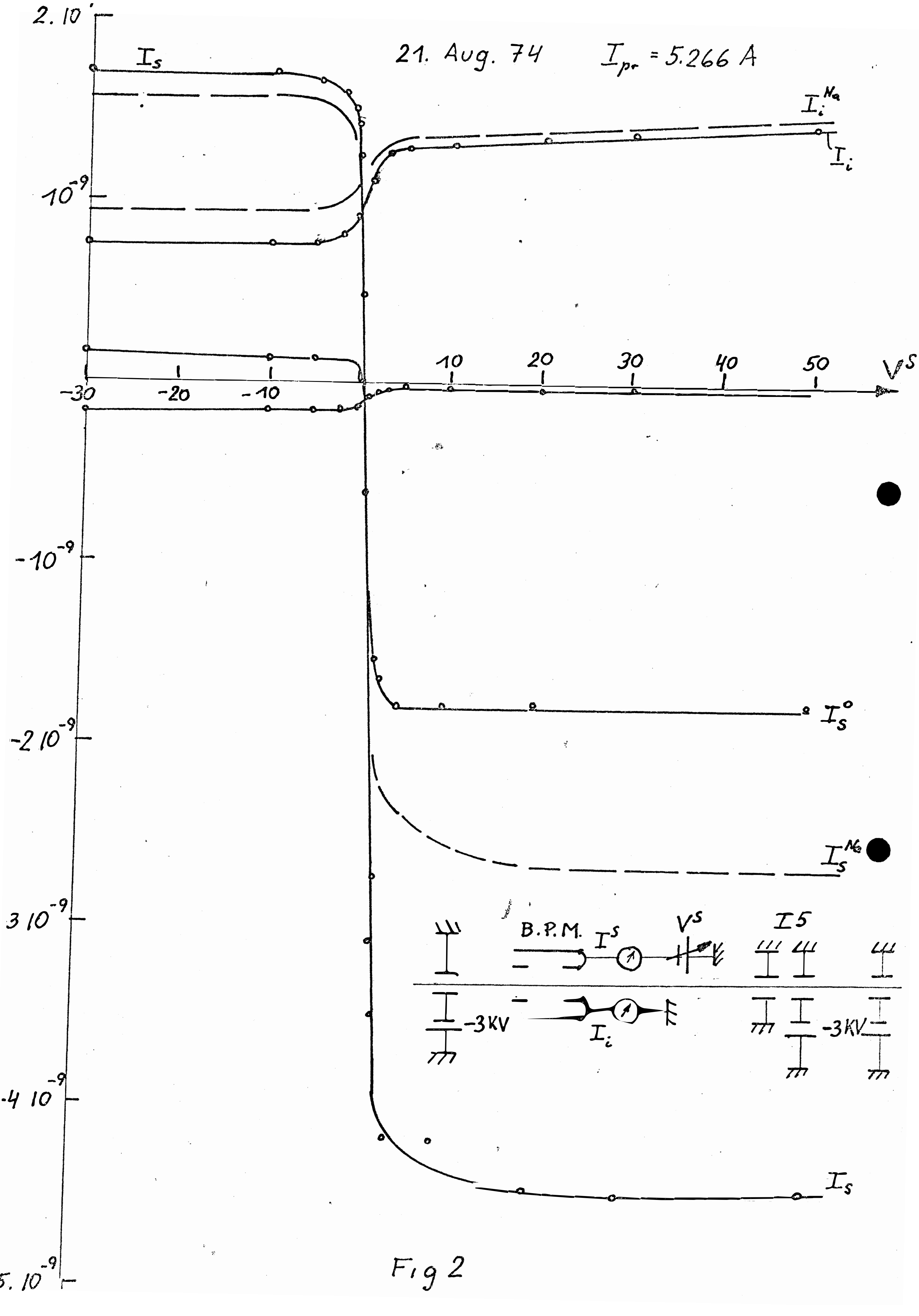
The energy distribution of the primary electrons could also be measured. However, there still remain some mysteries about the collection efficiency of Na electrons by the clearing electrodes at lower beam potential wells. In order to publish the results in a physical journal, some measurements at different proton energies would be welcome.

O. Gröbner B. Vosicki K. Zankel

1. J. Solomon, Théorie du passage des rayons cosmiques à travers la matière, Hermann, Paris (1936), p. 15

2. Landolt-Börnstein, Physikalisch-Chemische Tabellen, 2, 3, Erganzungsband, Springer, Berlin, 1301, (1935).


21. Aug. 74 . 5.2 A in R2
2 10 [A]
10^-9
0
-10^-9
-2 10^-9
-3 10^-9
-4 10^-9
-5 10^-9
V_CE
100
200
300
400
500
I_s^Na
I_s
I_i^Na
I°_C.E
I_C.E^Na
I_s^Na + I_i^Na
I_C.E
I5
B.P.M.
I_s
I_i
-10V
-10V
-3KV
-3KV
-3KV
C.E
Fig 1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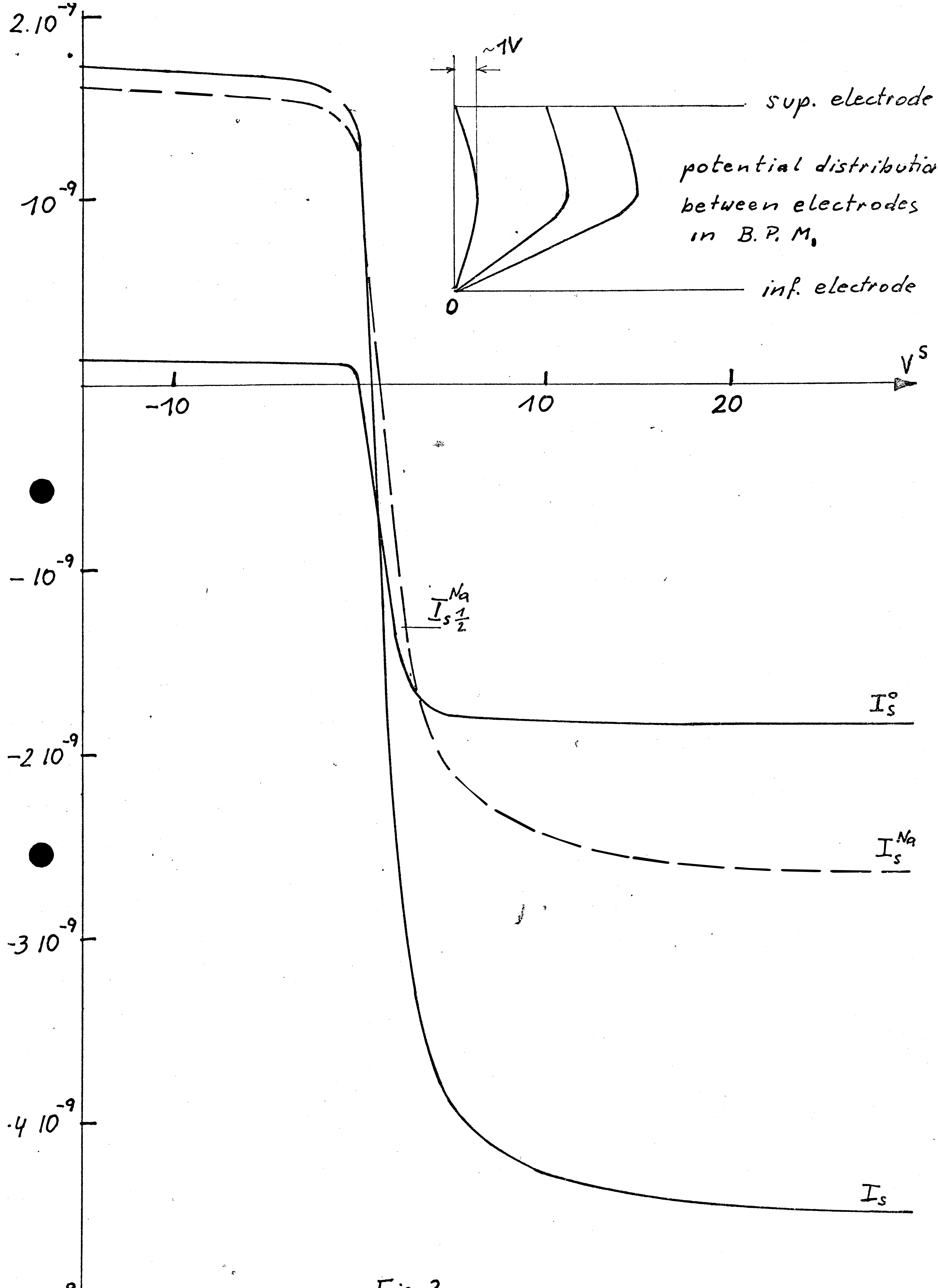
I_{pr} = 5.266 A
I_s
I_i^{Na}
I_i
2.10^{-9}
10^{-9}
-10^{-9}
$-2\,10^{-9}$
$-3\,10^{-9}$
$-4\,10^{-9}$
-5.10^{-9}
-30
-20
-10
10
20
30
40
50
V^S
I_s^0
I_s^{Na}
I_s
B.P.M.
I^S
V^S
$I5$
-3KV
I_i
-3KV

Fig 2



2.10^-9
10^-9
- 10^-9
-2 10^-9
-3 10^-9
-4 10^-9
5 10^-9
-10
10
20
V^S
~1V
sup. electrode
potential distributio
between electrodes
in B. P. M.
inf. electrode
0
I_s 1/2 ^Na
I_s^o
I_s^Na
I_s

Fig 3

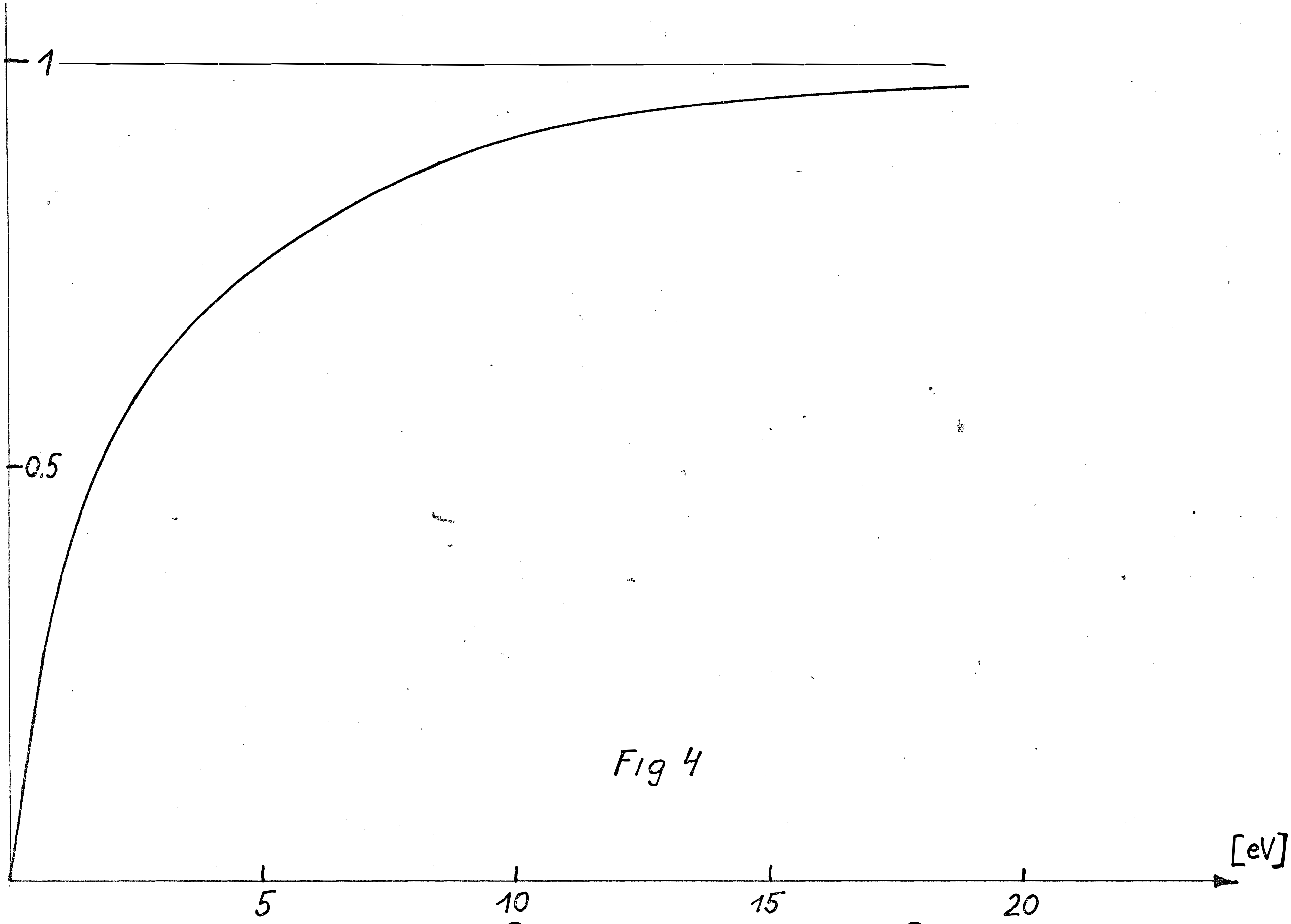
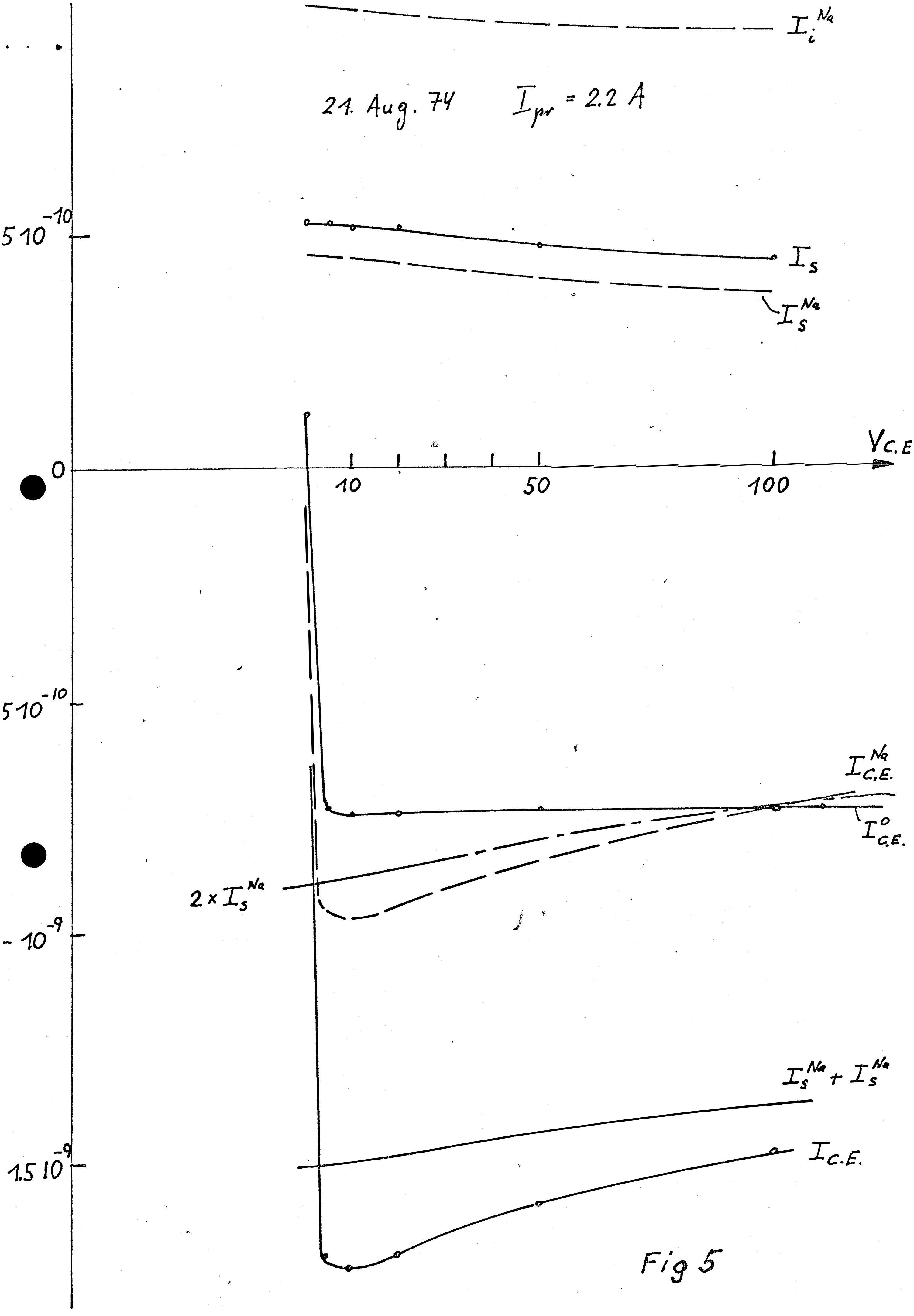


Fig 4



I_i^{Na}
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$I_{pr} = 2.2$ A
$5\,10^{-10}$
I_s
I_s^{Na}
$V_{C.E}$
0
10
50
100
$5\,10^{-10}$
$I_{C.E.}^{Na}$
$I_{C.E.}^{0}$
$2 \times I_s^{Na}$
-10^{-9}
$I_s^{Na} + I_s^{Na}$
$I_{C.E.}$
$1.5\,10^{-9}$

Fig 5