

A GLASS-COVERED PLATINUM MICROELECTRODE*†

CHRISTIAN GULD

The Institute of Neurophysiology, University of Copenhagen, Denmark

Abstract—The preparation of glass insulated platinum electrodes, described by WOHLBARSHT *et al.* (1960), has been improved by following the different steps of the procedure quantitatively: electrolytic sharpening, coating with molten glass and exposing and platinizing the tip. Etching at 12 V r.m.s. in a slightly undersaturated sodium cyanide solution down to 30 per cent of the initial etching current gave the best electrode shape and surface properties. To coat the tip of the electrode with glass required a narrow temperature range. The temperature of the molten glass was gauged from the resistance of the platinum heating loop measured in a Wheatstone bridge. The insulation of the electrode was tested by measuring the capacitance between the platinum core and an outer fluid. To remove the glass from the tip of the microelectrode and to platinize the tip a negative rectangular pulse of 0.1 sec duration was applied to the electrode placed in 0.1 per cent chloroplatinic acid. 8–15 V pulses resulted in electrode impedances of about 20–1 M Ω as measured by means of a ramp pulse applied to the electrode via a small condenser. In cerebral cortex the platinum electrodes found more units which had amplitudes larger than 1 mV than the glass pipette electrodes. Metal electrodes with high impedance could hold more units for longer than five minutes than could glass pipette electrodes with high impedance.

1. INTRODUCTION

POTASSIUM- and sodium-filled glass pipette electrodes and metal microelectrodes are used to record extracellular potentials from single cells and fibers in the central nervous system (FRANK, 1959). Glass insulated platinum-iridium microelectrodes, said to be preferable because of their mechanical stability and chemical inertness, have recently been developed by WOHLBARSHT *et al.* (1960).

It has been our experience that the glass insulated platinum microelectrodes differed from each other in physical characteristics and in the success of recording with them. In an attempt to obtain reproducible results the preparation of electrodes was systematized, each step in the procedure was analyzed, and the physical features of the microelectrodes were correlated with the parameters of the potentials recorded.

I have followed the procedure described by WOHLBARSHT *et al.* (1960) in general. The wire used was an alloy of 70 per cent platinum and 30 per cent iridium with a diameter of 0.25 mm; it was straightened by stretching it and passing it through a small flame. To etch the tip, the wire was immersed in a NaCN solution and an electrolyzing alternating current was passed through it; NaOH was added to the solution to prevent the formation of HCN. The tip and shaft of the electrode were coated by passing the wire through a drop of molten glass contained in a heating wire of Ω shape (Corning 7570 solder glass). Finally the glass was removed from the tip of the electrode and platinum black deposited on it by dipping the electrode in a solution of platinum chloride (PtCl₄) and applying a negative voltage to it. The procedure described below differs in a number of details from the original description of the method.

* Based on a paper presented at the 5th International Conference on Medical Electronics, Liège, July 1963.

† This investigation was supported in part by Public Health Service Grant NB-3943-01 from the Division of Research Grants.

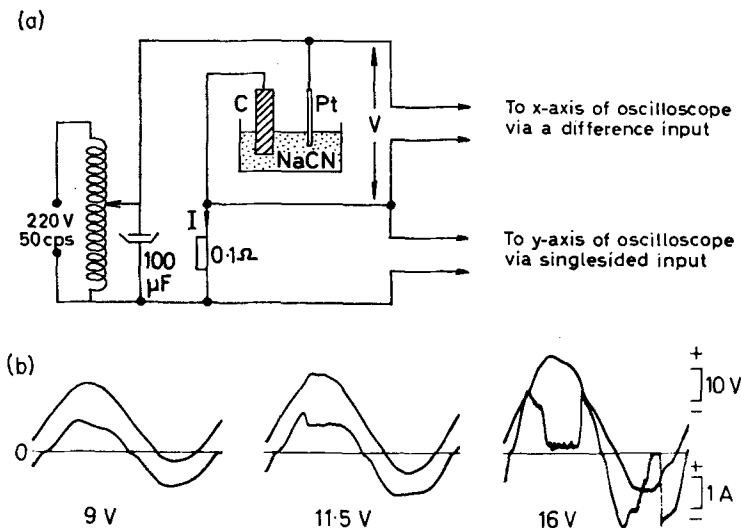


FIG. 1(a). Setup to measure waveform of the current (I) and voltage (V) during the etching of the platinum electrode (Pt) in sodium cyanide ($NaCN$). C : Carbon electrode area $> 10 \text{ cm}^2$. The $100 \mu\text{F}$ condenser prevents oscillations arising from the capacitance of the etched surface and the transformer inductance.

(b). Shape of electrode voltage (upper trace) and current (lower trace) at etching voltages of 9, 11.5 and 16 V r.m.s.

2. ETCHING OF THE ELECTRODE TIP

The variables in the electrolyzing process were studied: the flow of current as a function of the applied alternating voltage, the temperature and concentration of the $NaCN$ solution, and the depth to which the wire was immersed. The platinum-iridium wire was placed in a micromanipulator for precise adjustment of the depth of immersion. The current was passed through the microelectrode and a carbon electrode with an area of more than 10 cm^2 to ensure an insignificant voltage drop so the full electrolyzing voltage was applied over the platinum electrode (Fig. 1a).

The waveform of the alternating current is far from sinusoidal (Fig. 1b). In the experiment shown in Fig. 2 the current is given in units as measured by an instrument which gives r.m.s. values independent of the waveform. This "true" r.m.s. value of the current is at most 10 per cent less than that determined with a peak measuring instrument calibrated in r.m.s. Except for Fig. 2 in the following all values of

current and voltage are given in "r.m.s." as determined with a peak measuring instrument.

To determine the current-voltage relationships at different temperatures the surface of the electrode must not be reduced markedly by etching during the measurement. Therefore for rapid measurement the alternating current and voltage were rectified and applied to the x and y axis of an oscilloscope (Fig. 2a). The temperature was measured with a thermistor. The current-voltage relationships of an electrode in $10M NaCN$ at 24°C and at 46°C are shown in Fig. 2(b). The current density increased proportional to the voltage applied until a saturation level was reached at about $0.25 \text{ A r.m.s./mm}^2$. Thus the saturation level is a gauge of the area of the electrode exposed to etching. The voltage at which this saturation occurred diminished from 10 to 7 V r.m.s. when the temperature of the bath was increased from 24°C to 46°C . This temperature dependence is of practical importance since about 400 cal are deposited in the $NaCN$ bath during the etching

of one electrode (about 3 min). A bath of 100 to 500 ml was therefore used to restrict the increase in temperature. The originally recommended 6–10 V r.m.s. for etching are on the steep slope of the voltage–current characteristic (Fig. 2b). When etching was performed at a voltage (12 V r.m.s.) at which the etching current was

independent of the voltage over the electrode and of the temperature of the bath, more reproducible results could be expected.

The shape of the electrode is determined by the depth of immersion and the etching time. The shape was characterized by measuring the diameter at 10 μ , 150 μ and 1 mm from the tip

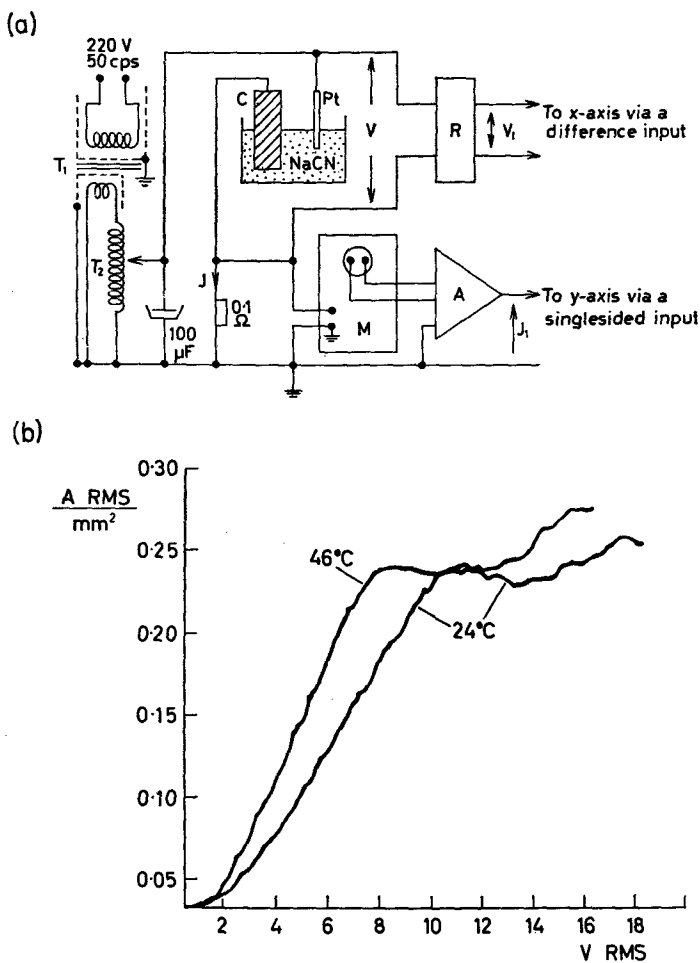


FIG. 2 (a). Measurement of voltage (V)–current (I) characteristics of platinum electrode (Pt) during etching in sodium cyanide (NaCN). C: carbon electrode, area $> 10 \text{ cm}^2$. R: diode rectifier and RC filter. V_1 measures V in r.m.s. M: a.c.-voltmeter measuring “true” r.m.s. A: d.c.-difference amplifier measuring the voltage over the instrument in M. J_1 measures the current I in “true” r.m.s. T_1 : double screened step-down transformer. T_2 : adjustable autotransformer. 100 μ F: see text Fig. 1.

(b) Voltage–current characteristics of the etching of platinum in sodium cyanide (NaCN) at 24 and 46°C, as measured with the circuit in (a). Ordinate: etching current/ mm^2 measured in units of true r.m.s. Abscissa: etching voltage in r.m.s.

and by the length L measured from the tip to the point on the electrode where etching stopped (Fig. 3f & g). The depth of immersion was measured by the initial etching current (0.55, 0.85 and 1.5 A r.m.s. in Fig. 3a-e). The current dropped with time as the electrode was etched away (Fig. 3a). Figure 3 (b-e) give for different electrodes the characteristics of shape at different final etching currents. The length L (Fig. 3b) fell gradually with final currents. The diameters at 10 μ , 150 μ and 1 mm (Fig. 3c, d & e) fell with the final current to a minimum and increased again with further decrease of the final current. The minimal diameters were smallest with the deepest immersion where $d_{10\mu}$ was about 1 μ and $d_{1\text{mm}}$ was 15 μ . The tips were too small to be measured accurately by light microscopy; they were about one third of $d_{10\mu}$. At a given immersion (or initial current)

the minima of the three diameters occurred at about the same final current. Stopping the etching at this current thus gave the electrode with the most gradual taper, the shape usually aimed at. The final current which gave the slenderest electrode was nearly 30 per cent of the initial current for all three depths of immersion.

A smooth surface on the electrode and a regular contour were aimed at since they give an electrode which is strong, is suitable for coating with glass, and platinizing can be confined to the tip. The electrodes etched at 12 V r.m.s., i.e. on the plateau of the current-voltage curve (Fig. 2b), had this feature (Fig. 3f, g & h), their surface being characterized by longitudinal stripes (Fig. 3h). The uneven surface (Fig. 3j) was found on electrodes etched at a voltage above 12 V r.m.s. whereas the

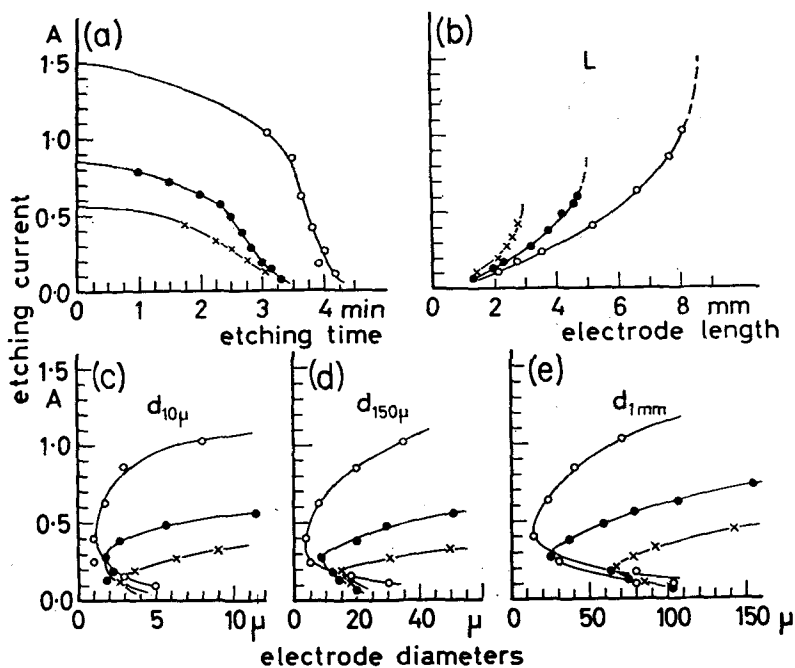


FIG. 3. Electrode shape as a function of the depth of immersion and of the final current (A "r.m.s."). The initial current (a, at 0 min) was the gauge of the depth of immersion. Etching was stopped at the various points of (a), which represent the final current. The electrode shape is given by (b-e) characterized by the length L and the electrode diameters (f & g). The extrapolations (stippled line) in (b) indicate the initial depth of immersion. (h, j & k) electrode surfaces and contours in 10 M sodium cyanide. (h) with an etching voltage (r.m.s.) of 12 V, (j) of 16 V and (k) of 6 V.

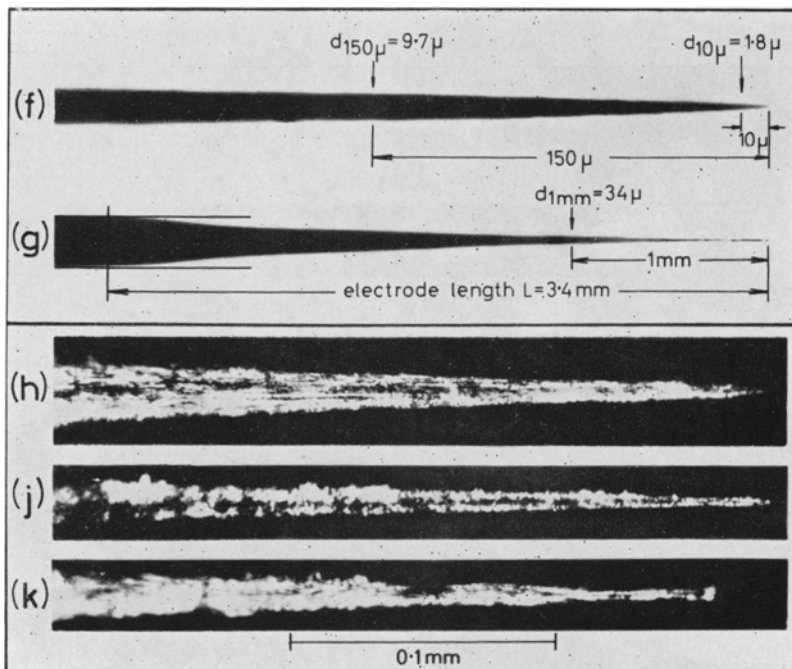


FIG. 3. (f-k). For caption see p. 320.

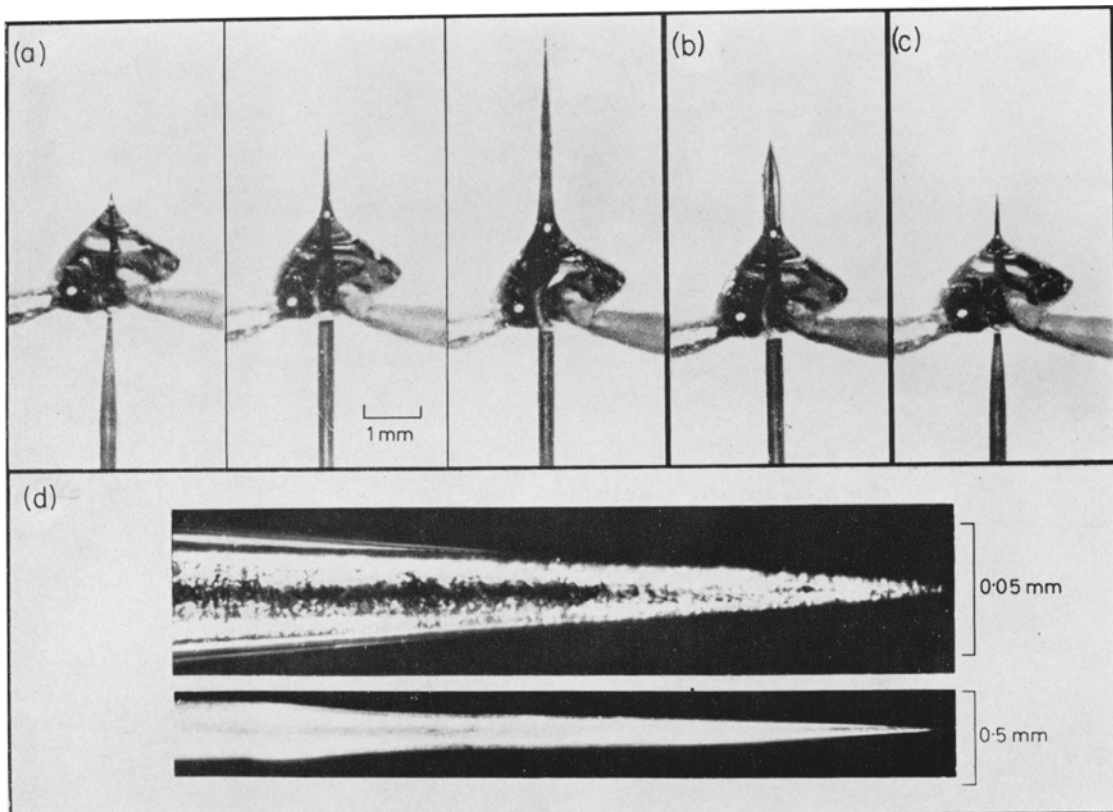


FIG. 6. Coating of electrodes with glass. (a) three steps of coating; the temperature was adjusted such that a smooth coating was obtained as shown in (d) at higher magnification. (b) the temperature was increased too slowly. (c) the temperature was increased too fast.

irregular contour (Fig. 3k) occurred on electrodes etched at voltages below 12 V r.m.s. This may have to do with the variation of the shape of the alternating current at different voltages (Fig. 1b).

An uneven surface and contour (Fig. 3j & k) might even happen at 12 V when a saturated NaCN solution (10M) was used. With an 8M NaCN solution the etching voltage could be varied over a wider range. Etching in still lower concentrations gave an irregular contour similar to that shown in Fig. 3(k) and prolonged the etching time about inversely proportional to the concentration.

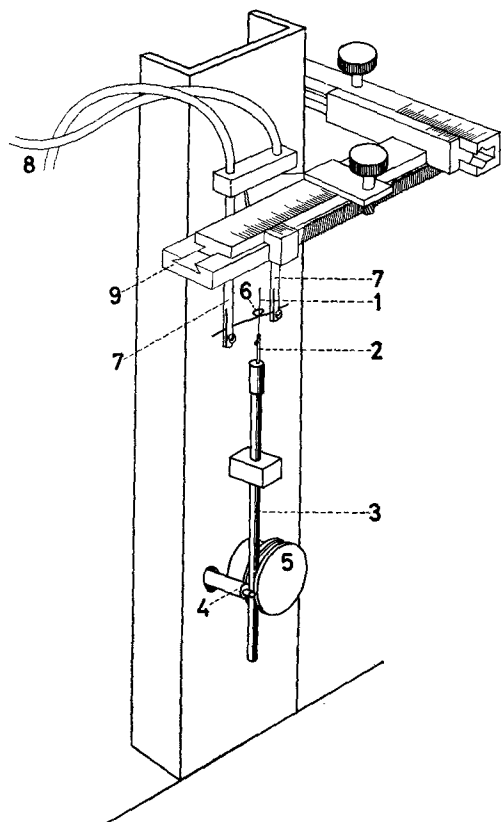


FIG. 4. Glass coating of metal electrodes. The electrode (1) is placed in the holder (2) and is transported by the bar (3) driven by a motor via the shaft (4) which presses (3) against the wheel (5). The electrode is placed in the centre of the platinum heating loop by adjusting the microscope stage manipulator (9). The heating loop (6) is supplied with current via the rods (7) and the wires (8).

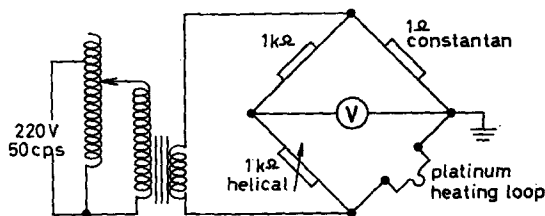


FIG. 5. Measurement of the temperature of the molten glass by determining the resistance of the platinum heating loop. V: a.c. voltmeter with maximal sensitivity of 10 mV, full deflection.

Thus etching at 12 V r.m.s. in a slightly undersaturated NaCN solution and stopping the etching at 30 per cent of the initial current gave the best electrode shape and surface properties.

WOHLBARSH *et al.* (1960) recommend that the NaCN solution be stirred by a magnetic stirrer during the etching process. This was no advantage in our experience, since it resulted in electrodes with oblique tips.

3. GLASS COATING OF THE PLATINUM ELECTRODE

The electrode tip and shaft were coated with Corning No. 7570 solder glass with a thermal expansion coefficient of about 8.5×10^{-6} , the same as that of the platinum iridium alloy. The tip and the shaft of the electrode were coated by passing the electrode (1, Fig. 4) through a drop of molten glass contained in a heating loop (6, Fig. 4).

To coat the tip the temperature of the glass must be maintained within a narrow range. The temperature was measured by the resistance of the Ω shaped heating wire, as one branch of a Wheatstone bridge (Fig. 5). To coat the thicker part of the electrode, which has a larger heat capacity than the thin tip, the temperature of the glass drop was increased, as quickly measured by the unbalance of the bridge. The proper temperature could best be maintained when the tip was pushed up through the glass drop, resulting in a smooth and complete coating; if one attempted to coat the electrode by pulling it out of the drop, it was either covered with a large glass globule or it was not

coated at all. The tip was placed in the molten glass drop and the temperature adjusted to that value found by experience to give the best coating of the tip. The electrode was transported at a speed of 1 cm/min by means of a small motor drive (4, Fig. 4). When the tip had passed through the surface of the glass drop, the temperature was raised gradually to coat the tapered part of the electrode. This procedure was watched through a microscope. The shaft was coated at a still higher temperature. In properly coated electrodes, the thickness of the glass layer was nearly proportional to the thickness of the electrode (Fig. 6a, d). When the temperature was increased too fast, the glass layer on the tapered part of the electrode was too thin (Fig. 6c); when it was increased too slowly, the coating was too thick (Fig. 6b). Impurities on the electrode surface could cause air bubbles and prevent proper coating. This could be avoided by storing the electrode in

distilled water overnight or by passing the electrode through a very hot drop of glass before coating it.

4. TESTING THE INTACTNESS OF THE GLASS COATING

To ensure that platinization is confined to the tip, it, the tapered part and the shaft of the electrode were first completely covered with glass. Whether coating was complete was ascertained by measuring the impedance of the insulation. The completely insulated electrode behaves in a conducting solution (0.9% NaCl) as a pure capacitance when the impedance is measured between the platinum core and the solution. A surface of exposed platinum core has an impedance corresponding to a capacitance of about $100 \mu\text{F}/\text{cm}^2$ ($1 \mu\text{F}/\mu^2$). Thus a hole in the insulation of $1 \mu^2$ adds $1 \mu\text{F}$ to the capacitance of about $2 \mu\text{F}$ of the completely insulated tip. Since the capacitance of bare

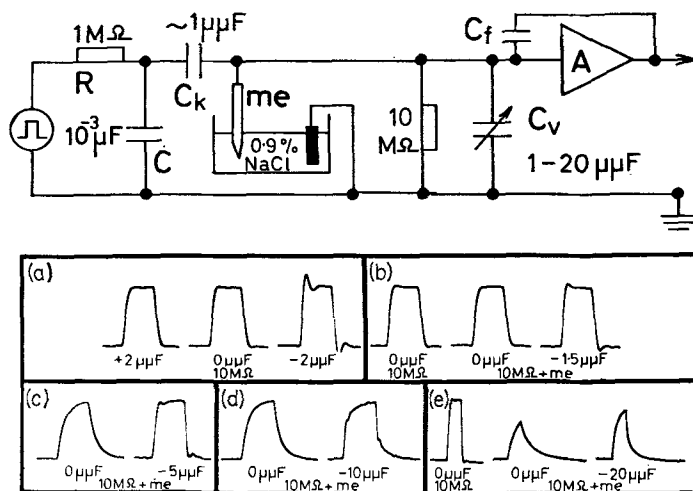


FIG. 7. Measurement of the insulation of the glass coating of the microelectrode (me) by measuring the electrode capacitance with a negative input capacitance, $(A-1) C_f$; C_v : calibrated air condenser; a 10 mV pulse of 1 m sec duration was applied to the electrode via the circuit R, C, C_k . (a) output pulses with $10 \text{ M}\Omega$ between input and ground (me not immersed) showing the effect of an increased or decreased C_v (ΔC_v) on the critically damped response ($0 \mu\text{F}$). (b-e) output pulses with $10 \text{ M}\Omega$ between input and ground and with the microelectrode in parallel with $10 \text{ M}\Omega$. (b) responses from a properly insulated electrode: a ΔC_v of $-1.5 \mu\text{F}$ adjusts to the same response as obtained with $10 \text{ M}\Omega$ alone. (c, d & e) responses from electrodes with incomplete insulation.

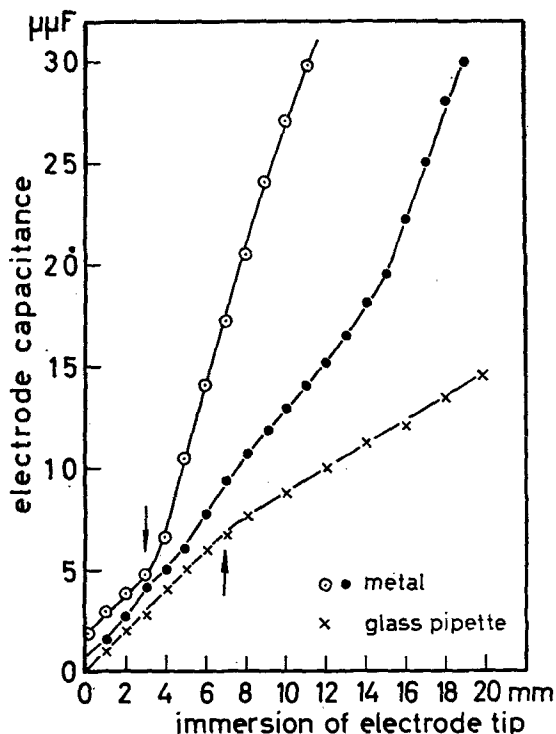


FIG. 8. Capacitance as a function of depth of immersion of metal and glass pipette electrodes. The arrows indicate the transition from the tapered part of the electrode to the shaft.

platinum is complex and frequency dependent, holes of about $1 \mu^2$ could be detected with a sensitive capacitance measuring device (e.g. a negative input capacitance Fig. 7). To measure the capacitance of the insulation the electrode impedance was placed between input and ground, parallel to a $10 \text{ M}\Omega$ resistor and a calibrated variable capacitance C_v . A triangular monitoring impulse was applied to the input via a condenser of about $1 \mu\text{F}$ (GULD, 1962). With the electrode in air, neutralization was adjusted to critical damping of the rectangular output pulse. The tip was then just immersed and C_v was readjusted to critical damping, the variation in C_v being a measure of the tip capacitance. A tip capacitance of less than $2 \mu\text{F}$ was aimed at, since this indicates a glass layer on the tip similar to that of glass pipette microelectrodes (Fig. 8). If insulation was incomplete

it was not possible to readjust to a critically damped response, and the output pulse had a slow rise after an initial fast rising phase (Fig. 7c, d & e). The slow phase is due to the frequency dependent impedance of platinum. Thus, if the response with the electrode tip immersed indicated a capacitance larger than $2 \mu\text{F}$, or deviated from a critically damped output response coating was incomplete and the electrode was rejected. The coating of the tapered part of the electrode and of the shaft was controlled in the same way. A proper coating had a capacitance of about $2 \mu\text{F}/\text{mm}$ (Fig. 8), i.e. double that of the tapered part of a glass pipette microelectrode. The electrode was stored in air until platinization, which was performed immediately before recording.

5. PLATINIZING OF THE ELECTRODE

To remove the glass from the tip of the electrode and to deposit a layer of low impedance platinum black on the platinum tip WOHLBARSHIT *et al.* (1960) applied -15 V d.c. for 15 to 30 sec to the electrode in a solution of 1% PtCl_4 . To avoid the etching effect on the glass of a 1% solution we have used a 0.1% solution. With the electrode negative, 8–15 V were applied for 10 msec. The electrode impedance was measured immediately after platinization (Fig. 9). A rectangular pulse could either be applied directly to the electrode placed in 0.1% PtCl_4 solution or to the input of a negative input capacitance via the network RCC_k (GULD, 1962) and with the electrode placed in 0.9% NaCl solution. To measure the impedance, the pulse duration was 1 msec and the amplitude adjusted to give a suitable output when the electrode was substituted by the $10 \text{ M}\Omega$ resistor used for calibration of electrode impedance, the amplitude of the output being proportional to the electrode impedance (GULD, 1962). When calibrating with the $10 \text{ M}\Omega$ resistor the output response was rectangular, whereas the platinum electrode gave a response which rose exponentially for 1 msec and then decayed to zero with a long time constant (Fig. 9a, b & c). The amplitude reached after 1 msec was used as a

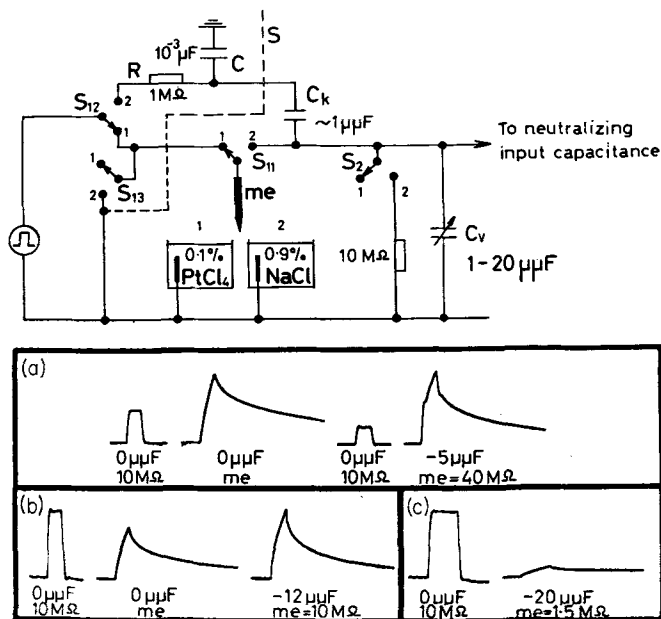


FIG. 9. Circuit for successively platinizing and measuring the impedance of metal microelectrode (me). Platinizing with negative 100 msec pulses of 8–15 V, (S_1 and S_2 in position 1 and me in 1). Impedance measurement with 1 msec, 2 mV pulses (S_1 in position 2). Impedance calibration with 10 MΩ: S_2 in position 2 and me in air. For the measurement of impedance of me: S_2 in position 1 and me in 2. Switch S_{13} and the screen S prevent coupling by stray capacitance. (a–c) impedance measurements; 10 MΩ, 0 μμF: the calibration pulse was critically damped; me, 0 μμF: 10 MΩ was replaced by the electrode, and the impedance measured after compensation of the capacitance of the electrode (–5 μμF, –12 μμF and –20 μμF).

measure of the impedance of the platinum electrodes. With platinizing voltages of 8–15 V the impedance could vary between 20 and 1 MΩ, the lower voltages giving the higher impedances. The desired impedance was obtained by repeated platinization.

6. CORRELATION OF THE PHYSICAL FEATURES OF MICROELECTRODES WITH THE PARAMETERS OF THE POTENTIALS RECORDED

Glass pipette microelectrodes filled with 5M NaCl solution have been widely used to record extracellularly in the brain. The electrodes have the disadvantage that it is difficult to hold units for hours with them, though the head is immobilized and the brain stabilized with a

fluid-filled chamber. The possibility exists that the units recorded from suffer damage because the concentrated salt solution leaks out of the electrode tip. Metal microelectrodes as described by ROSE and MOUNTCASTLE (1954), HUBEL (1957), GESTELAND *et al.* (1959) and WOHLBARSH *et al.* (1960) do not have this disadvantage.

In this laboratory Dr. Lennox and I have used both glass pipette and metal microelectrodes (glass insulated, platinized platinum iridium) to record from single cortical units in the visual cortex of cats and monkeys; we have correlated the amplitude and shape of the potentials recorded with the impedance and tip size of the electrodes used in an attempt to ascertain the desirable features of each type of

electrode and the differences between glass and metal microelectrodes.

When using both types of microelectrode the animals were anesthetized with chloralose-urethane and the brain was stabilized with a fluid-filled chamber, the fluid being mineral oil. In the case of recording with glass microelectrodes the signal was led off via a cathode follower (GULD, 1962), the final input capacitance with electrode being about $5 \mu\text{F}$. Recording with metal electrodes the signal was led off via a negative input capacitance adjusted to maximal compensation of the electrode impedance (Fig. 9 a-c). The metal microelectrodes were etched with an initial current of 0.85 A "r.m.s." down to about 0.3 A "r.m.s." (Fig. 3).

Both metal and glass pipette electrodes found positive and diphasic potentials of significantly larger amplitude than the negative potentials (Figure 10; Table 1). The positive and diphasic potentials recorded with metal electrodes were significantly larger than those recorded with pipette electrodes, whereas the reverse was the case for negative potentials. These differences

suggest that a different population of cells or fibres is recorded from the two types of electrodes. The sweep speed used in most of our recordings did not permit a judgement as to which potentials originated from fibres and which from cells.

Comparing the number of units recorded with electrodes of low and high impedance (Table 2), metal electrodes of high impedance found significantly more positive potentials than those with low impedance. The glass pipette electrodes showed only a slight correlation in the same direction. Thus, assuming that positive potentials are recorded close to cells or fibres, metal electrodes must be able to record without causing damage when placed nearer to the cell or fibre than glass pipette electrodes, supporting the suggestion that glass pipette electrodes may fail to record due to leakage of the 5M NaCl.

The glass pipette electrodes of high impedance recorded significantly higher amplitudes than those with low impedance, but held fewer of the units for more than 5 min. The metal electrodes

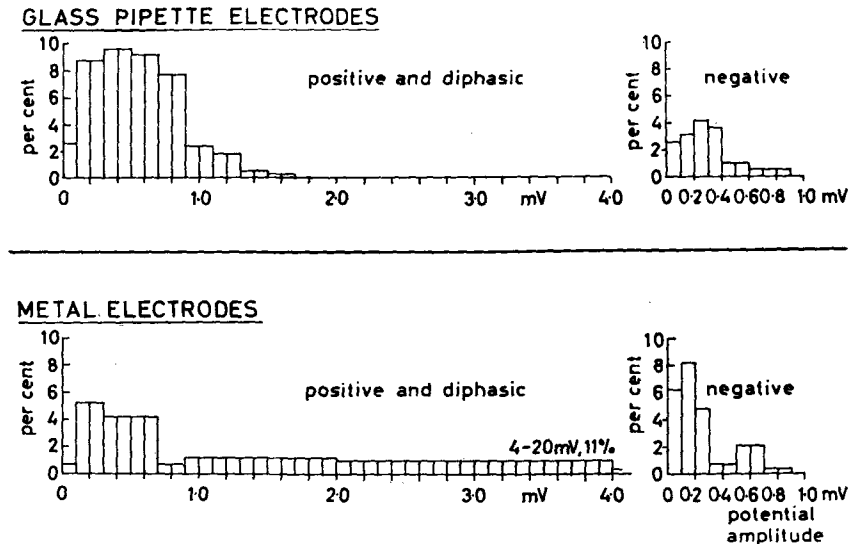


FIG. 10. Amplitudes of positive and diphasic or negative unit potentials recorded from visual cortex with glass pipette and metal microelectrodes. Ordinate: incidence of units in per cent of total number of potentials. Abscissa: amplitude in mV in classes of 0.1 mV (cf. Table 1).

Table 1. Amplitude of positive or diaphasic and of negative potentials recorded from the cerebral cortex with glass pipette electrodes and metal electrodes

Electrode type	metal		glass pipette		metal
No. of electrodes	16		27		16
Sign of potentials	positive	+	diphasic		negative
No. of potentials	84 + 22		125 + 37	33	39
Median amplitude	(mV)		(mV)	(mV)	(mV)
s.d.	1.3		0.53	0.27	0.17
P*	-1.0, +2.7		±0.30	±0.16	-0.09, +0.36
		<0.001		<0.001	<0.01

* Calculated from the amplitude distribution by means of the χ^2 test.

of high impedance showed no more than a tendency to record higher amplitudes, but held more units for a longer time than did electrodes with low impedance.

In the case of NaCl-filled glass pipette electrodes, the impedance depends on the size of the tip; using metal microelectrodes it was possible to vary the impedance independently of tip diameter. Therefore, with metal electrodes the correlation of potential parameters with the impedance and the size of the tip of the

electrode could be analyzed separately. There was no correlation between the diameter of the tip (0.5–3 μ) of the metal electrodes and the number of units found per electrode, the sign and amplitude of the potentials, nor with the time the potentials could be held.

Comparing glass and metal microelectrodes, the metal electrodes have the chief advantage that 45 per cent of the potentials recorded had an amplitude of more than 1 mV (maximum 21 mV) whereas only 5 per cent of potentials

Table 2. Sign, amplitude and time held of single unit potentials recorded with glass pipette and metal electrodes of low and high impedance

Electrode type	Impedance range (M Ω)	Glass pipette		Metal	
		2-7	10-40	1-4*	6-25*
No. of electrodes		9	18	7	9
No. of units					
Sign of potentials	Mainly positive	42	83	26	58
	diphasic	15	22	11	11
	Mainly negative	17	16	22	17
	P†		<0.2		<0.02
Amplitude of potentials	< a (mV)‡	36	22	37	42
	> a (mV)	38	99	22	44
	P		<0.001		<0.1
Time held	< 5 min	54	104	52	59
	> 5 min	21	16	7	27
	P		<0.02		<0.01

* measured in 0.9% NaCl solution above the cerebral cortex.

† calculated by the χ^2 test.

‡ for glass pipette, $a = 0.3$ mV; for platinum-metal, $a = 0.8$ mV.

recorded with glass pipette electrodes were more than 1 mV (maximum 1.7 mV). Comparing only electrodes with high impedance (Table 2), the second advantage of the metal electrodes was that it was more often possible to hold units for more than five minutes than with glass pipette electrodes ($P < 0.02$). Finally, metal electrodes have greater mechanical strength and can be used to record from units after piercing the intact dura. We have used them in this way successfully but could not do so for the purposes of the present study since their impedance rose after they pierced the dura, and the correlation of physical characteristics with potential parameters would then have been impossible.

REFERENCES

- FRANK, K. (1959) *Identification and analysis of single unit activity in the central nervous system*. Chapter X in Handbook of Physiology, Section 1: Neurophysiology, Vol. 1, pp. 261-277. American Physiological Society, Washington, D.C.
- GESTELAND, R. C., HOWLAND, B., LETTVIN, J. Y. and PITTS, W. H. (1959) Comments on microelectrodes. *Proc. Inst. Radio Engngs.*, **47**, 1856-1862.
- GULD, C. (1962) Cathode follower and negative capacitance as high input impedance circuits. *Proc. Inst. Radio Engngs.*, **50**, 1912-1927.
- HUBEL, D. H. (1957) Tungsten microelectrode for recording from single units. *Science*, **125**, 549-550.
- ROSE, J. E. and MOUNTCASTLE, V. B. (1954) Activity of single neurons in the tactile thalamic region of the cat in response to a transient peripheral stimulus. *Johns Hopk. Hosp. Bull.*, **94**, 238-282.
- WOHLBARSH, M. L., MACNICHOL, E. F., JR. and WAGNER, H. G. (1960) Glass insulated platinum microelectrode. *Science*, **132**, 1309-1310.

UNE MICRO-ELECTRODE EN PLATINE RECOUVERTE DE VERRE

Sommaire—La méthode de préparation d'électrodes en platine avec isolant en verre, décrite par WOHLBRASHT *et al.* (1960), a été améliorée en employant un dosage judicieux à chaque échelon de la procédure: affilage électrolytique, recouvrement par verre coulé, exposition et platinage de la pointe. L'attaque à 12 V RMC dans une solution de Cyanure de Sodium, légèrement sous-saturée, ramenée à 30% du courant attaquant initial, a donné les meilleurs résultats quant à la forme et la surface de l'électrode. Le recouvrement par verre de la pointe de l'électrode a nécessité une détermination précise de la température. La température du verre coulé a été définie d'après la résistance de la boucle chauffante de platine, mesurée dans un pont de Wheatstone. L'isolation de l'électrode a été éprouvée en mesurant la capacitance entre le noyau de platine et un corps fluide extérieur. Afin d'enlever le verre de la pointe et la platiner, la micro-électrode a été placée dans une solution à 1% d'acide chloreplatine et soumise à une impulsion négative rectangulaire d'une durée de 0,1 sec. Des impulsions de 8-15 V ont provoqué des impédances de l'électrode d'environ 20 M Ω , selon les mesures prises. Il a été constaté que les électrodes de platine détectent, dans le cortex cérébral, des ondes d'amplitude supérieure à 1 mV en plus grand nombre que les électrodes en verre. Des électrodes en métal à haute impédance peuvent retenir les valeurs pendant 5 min de plus que les électrodes en verre à haute impédance.

EINE GLASÜBERZOGENE PLATIN-MIKROELEKTRODE

Zusammenfassung—Die von WOHLBARSH *et al.* (1960) beschriebene Herstellung glasisolierter Platin-Elektroden wurde durch folgendes Verfahren quantitativ verbessert: elektrolytisches Schärfen, Überziehen mit geschmolzenem Glas, Freilegen der Spitze und Überziehen mit Platin. Ätzung bei 12 Veff in einer leicht ungesättigten Natriumcyanidlösung durch einen bis auf 30% des ursprünglichen Wertes abnehmenden Atzstrom ergab die beste Elektrodenform und die besten Oberflächeneigenschaften. Das Überziehen der Elektroden spitze mit Glas erforderte einen definierten Temperaturbereich. Die Temperatur des geschmolzenen Glases wurde über den mit einer Wheatstoneschen Brücke gemessenen Widerstand der Platinheischleife bestimmt. Die Isolierung der Elektrode wurde durch Messung der Kapazität zwischen Platinkern und Flüssigkeit nachgeprüft. Um das Glas von der Spitze zu entfernen und um diese mit Platin zu überziehen, wurde die sich in einer 0,1 prozentigen Chloroplatinsäure befindliche Elektrode einem negativen Rechteckimpuls von 0,1 sec Dauer ausgesetzt. 8-15 V Impulse ergaben Elektrodenimpedanzen von ungefähr 20 m Ω , die mittels eines durch einen kleinen Kondensator an die Elektrode gelegten Stufenimpulses gemessen wurden. In der Hirnrinde erhielt man bei Platin-Elektroden mehr Werte mit Amplituden über 1 mV als bei Glas-Pipettenelektroden. Metallelektroden hoher Impedanz konnten mehr Werte über fünf Minuten speichern als Glas-Pipettenelektroden hoher Impedanz.

The Russian translation of the abstract to this paper will be printed in a loose-leaf insert to be distributed with the next issue of the Journal.