ON THE SELECTION OF EFFECTIVE IMPULSE FREQUENCIES FOR SPECIFIC MOVEMENTS OF FISH IN AN ELECTRICAL FIELD*

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In order to determine effective pulse limits for *Salmo irideus, Cyprinus carpio, Gasterosteus aculeatus, Tinca tinca, Salmo fario* and *Idus melanotus* in impulse D. C. for galvanotaxis and galvanonarcosis, studies were carried out with rectangular and square impulses. The narcotizing pulse limits remained constant for each variety in an impulse D. C. of specific wave form. The anodic effect of fishes were better in square wave form and varied with the variation of temperature of surrounding medium. *S. fario* reacted better when placed parallel to the lines of electrical force. Transversal escape movement occurred when the axis of fish body was at right angles to the direction of current.

INTRODUCTION

The tendency of fish to exhibit directional swimming (galvanotaxis) in an electrical field has been utilised in capture fisheries by designing suitable electrical fishing gear. For effective catching, fishes must react anodically, which is one of the most important factors in designing electrofishing gear. The fish at times undergo narcosis, sink to the bottom and disappear. It was observed by Burnet (1952) that a frequency of 20/second with rectangular impulse form of 1 ms has got significant catching effect on fish. With higher frequency, the fish showed reduced anodic reaction. The scope of the present paper is to determine the limiting impulse frequencies with optimum impulse and pause duration for anodic galvanotaxis of fish in relation to variety of fishes, conductivity and temperature of water, impulse form and frequency of impulses. Since different species of fish react differently to the pulsation rhythm, a selectivity in anodic galvanotaxis was arrived at by setting the equipment at a pulsating rate adopted to one particular species. The studies were carried out in

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Materials and Methods

The experiments were conducted in a wooden trough of 200 cm x 54 cm x 25 cm size with zinc plates of 54 cm x 25 cm attached vertically to the breadthwise sides which served as electrodes. The tank was filled with water to a depth of 10 cm. The electrodes were connected to the output terminals of electronic impulse transmitter through a voltmeter and variable resistance, current being drawn from A.C. mains. Siemen's pantostat 523 and electronic impulse transmitter were used for producing impulse D. C. of rectangular and square wave forms. Both the impulse transmitters produced continuous D. C. and impulse D. C. of variable frequencies. The potential drops between the electrodes and the amount of current drained were recorded by voltmeter and milliampere meter respectively. The wave form of impulse D. C. along with duration of impulse and pause were checked through cathode ray oscilloscope. A thermometer, suspended from a clamp attached to the tank was used to record the water temperature during the experiments.

The test fish after being acclimatised for 24 hours in the laboratory and measured for total length was released in the experimental tank and allowed to settle. The conductivity of water was measured with Siemen's conductivity meter and was expressed as Siemen's conductivity per cc. The field intensity was then raised from zero till the fish exhibited forced directional movement (galvanotaxis). The initial and the final positions of fish during galvanotaxis were recorded. With further rise of current intensity, the fish ceased all voluntary movements and lay on its side, when the field intensity reached the threshold value for narcosis. The final position of fish during galvanonarcosis was also recorded. A fresh fish was used for each experiment. The conductivity of water was raised by dissolving sodium chloride. Direct current and impulse D.C. were used for different series of experiments. One series of experiments were conducted with beheaded fishes. The head of the fish was cut off behind the gill, both the head and trunk put in the field immediately and the movements during galvanotaxis recorded.

Results and discussion

S. irideus of 131 to 200 mm showed 100% anodic movement during galvanotaxis and galvanonarcosis in water temperature of 17°C in impulse frequency of 82/ second (table 1.) 100% of anodic galvanotaxis was observed at 11°C and 15°C. 50% of cathodic galvanotaxis occurred at 6°C. Oscillotactic and unspecific movements of *S. irideus* were found at a temperature of 3°C which did not exceed 14%.

Using impulse D. C. of square wave form *S. irideus* of 141–200 mm, exhibited 100% anodic galvanotaxis and galvanonarcosis in impulse frequency of 82/ second with impulse duration of 5 ms and pause duration of 7.2 ms in water conductivity of 2×10^{-4}/ cc (Table–2). Similar reactions of fish were observed in higher water conductivity (10×10^{-4}/cc) and impulse frequency of 82/ second when 100% anodic galvanotaxis and galvanonarcosis occurred.

The pulse threshold for *S. irideus* of 141–200mm in impulse D.C. of rectangular wave shape was 34/ second with impulse duration of 9 ms and pause duration of 20 ms irrespective of conductivity of water (table 3) while in continuous D. C. fishes exhibited 82% cathodic galvanotaxis and 100% anodic galvanonarcosis in waters having conductivity of 2×10^{-4}/cc.

Table I Specific movements of *S. irideus* during different reactions in relation to water temperature
Conductivity of water in Siemen's conductivity per c. c. 2x10-4

Nature of current: Impulse D. C. square wave form Impulse frequency: 82/sec.

Size group in mm	No. of fishes	Temp. of water °C	% of specific movements of fish during galvanotaxis				% of specific movements of fish during galvanonarcosis			
			Anodic	Cathodic	Oscillo-tactic	Unspecific	Anodic	Cathodic	Oscillo-tactic	Unspecific
161-200	84	3	86	—	—	14	50	40	10	—
161-200	65	6	50	50	—	—	55	45	—	—
151-200	102	11	100	—	—	—	45	55	—	—
141-200	78	12	89	11	—	—	87	13	—	—
131-180	62	15	100	—	—	—	62	38	—	—
131-180	72	16	90	10	—	—	76	24	—	—
151-190	74	17	100	—	—	—	100	—	—	—

Table 2 Specific movements of *S. irideus* during different reactions in relation to impulse frequencies

Water temperature: 15°C. Nature of current: D. C. and Impulse D. C. of square wave form.

Size group in mm	No. of fishes	Impulse frequency per sec.	Impulse duration ms	Pause duration ms.	Conductivity of water	% of specifie movement of fish during galvanotaxis				% of specific movement of fish during galvanonarcosis			
						Anodic	Cathodic	Oscillo-tactic	Unspe-cific	Anodic	Cathodic	Oscillo-tactic	Unspe-cific
131-180	94	88	5	6.4	2x10-4/cc	66	34	—	—	66	27	7	—
151-190	100	85	5	6.8	,,	40	60	—	—	86	14	—	—
141-200	110	82	5	7.2	,,	100	—	—	—	100	—	—	—
141-200	85	80	5.4	7.2	,,	72	28	—	—	73	20	7	—
151-190	88	79	5	7.7	,,	30	56	14	—	73	20	7	—
131-200	62	76	5	8.2	,,	44	56	—	—	72	28	—	—
151-200	85	89	5	6.2	10x10-4/cc	58	28	14	—	93	7	—	—
131-210	88	88	5	6.4	,,	73	20	7	—	93	7	—	—
141-200	105	82	5	7.2	,,	100	—	—	—	100	—	—	—
141-200	108	80	5.4	7.2	,,	72	14	14	—	65	28	7	—
131-210	102	76	5	8.2	,,	40	46	14	—	52	28	20	—
131-180	86	DC	—	—	,,	100	—	—	—	100	—	—	—

Table 3 Specific movements of *S. irideus* during different reactions in relation to different impulse frequencies

Water temperature: 16°C — Nature of current: D. C. & Rectangular impulse from pantostat

Size group in mm.	No. of fishes	Impulse frequency/sec	Impulse duration : ms	Pause duration ms	Conductivity of water :	% of specific movement of fish during galvanotaxis				% of specific movement of fish during galvanonarcosis			
						Anodic	Cathodic	Oscillo-tactic	Unspecific	Anodic	Cathodic	Oscillo-tactic	Unspecific
111–180	175	48	1	20	2x10-4/cc	4	8	—	88	32	32	36	—
111–170	75	48	20	1	,,	24	52	—	24	32	36	32	—
111–180	175	43	3	20	,,	8	32	—	60	20	32	45	—
121–160	75	38	6	,,	,,	48	48	—	4	44	32	24	—
141–170	75	34	9	,,	,,	72	20	—	8	68	20	12	—
121–190	125	31	12	,,	,,	40	52	—	8	48	28	24	—
121–170	125	26	18	,,	,,	39	—	—	61	47	35	15	—
111–190	175	2	225	500	,,	40	20	—	40	68	24	8	—
111–190	175	DC	—	—	,,	18	82	—	—	100	—	—	—
121–220	225	48	1	20	10x10-4/cc	60	28	4	8	72	16	12	—
121–180	150	38	6	,,	,,	35	20	—	45	55	10	35	—
141–210	175	34	9	,,	,,	76	24	—	—	72	20	8	—
121–210	200	31	12	,,	,,	60	28	—	12	56	12	32	—
131–210	150	2	225	500	,,	60	7	—	33	No narcosis			

Table 4 Specific movement of *I. melanotus* during different reactions in relation to different impulse frequencies.

Water temperature: 15°C — Nature of current: Rectangular impulse

Size group in mm.	No of fishes	Impluse frequency/sec	Impluse duration : ms	Pause duration ms	Conductivity of water :	% of specific movement of fish during galvanotaxis				% of specific movement of fish during galvanonarcosis			
						Anodic	Cathodic	Oscillo-tactic	Unspecific	Anodic	Cathodic	Oscillo-tactic	Unspecific
161–200	82	38	6	20	2x10-4/cc	33	20	7	40	—	20	80	—
171–200	64	34	9	20	,,	20	20	—	60	14	20	66	—
171–200	64	26	18	20	,,	40	28	—	32	—	6	6	56
171–200	64	25	20	20	,,	100	—	—	—	80	—	—	20
171–200	68	34	9	20	10x10-4/cc	20	40	10	30	10	20	14	56
161–200	82	31	12	20	,,	33	33	14	20	27	20	33	20
171–200	65	26	18	20	,,	20	38	14	28	14	51	7	28
171–200	65	25	20	20	,,	56	14	—	30	44	28	—	28

S. irideus in impulse D. C. of square wave form showed reduced anodic reaction both during galvanotaxis and galvanonarcosis in impulse frequencies both higher and lower than 82/ second irrespective of conductivity of water (table 2). Using impulse D. C. of rectangular wave shape the optimum impulse frequency for anodic reactions was found to be 34/ second in *S. irideus* of 111 to 210 mm irrespective of conductivity of waters (table-3). Reduced anodic effect was observed in impulse frequencies both higher and lower than 34/ second.

I.melanotus of 171 to 200 mm exhibited 100% anodic galvanotaxis and 80% anodic galvanonarcosis in water having conductivity of $2x10^{-4}$/cc with impulse frequency of 25/ second having impulse duration of 20 ms and pause duration of 20 ms (table 4). The anodic reaction decreased with rise of impulse frequency. With the increase in conductivity of water to 10×10^{-4}/ cc *I. melanotus* exhibited greater anodic reaction in impulse frequency of 25/ second.

Anodic effect of fish was obtained with impulse current of sudden increase and gradual decrease. The duration of each shock was 2 ms. Small fishes gave best results in 20 shocks/ second while larger fish moved to positive pole with 2 shocks/ second. (Kreutzer and Peglow, 1949). 84% of *G. aculeatus* showed anodic galvanotaxis and galvanonarcosis with impulse frequency of 65/second in water conductivity of 2×10^{-4}/ cc (table-5) and the anodic effect decreased with the increase in impulse frequency.

The optimum anodic effect of *T. tinca* of 191-240 mm during galvanotaxis and galvanonarcosis was observed in impulse frequency of 78/ second irrespective of conductivity of water in impulse D. C. of square wave form (table-6). The anodic reaction decreased with the rise of impulse frequency.

The optimum impulse frequency for anodic reaction of *S. fario* of 81-90 mm was found to be 73/ second with impulse duration of 7.2 ms and pause duration of 6.4 ms in water having conductivity of $2x10^{-4}$/cc when 80% of fish moved to anode during galvanotaxis and 100% during galvanonarcosis. The anodic reaction of the fish was reduced in other impulse frequencies (table-7). In higher conductivity of 10×10^{-4}/ cc also 100% of the fish showed anodic galvanotaxis and narcosis in impulse frequency of 73/ second, when impulse D. C. of square wave form was used.

Narcotizing pulse threshold values were 80, 50, 30, 100 and 40/ second for *S. irideus*, *C. carpio*, *I. melanotus*, *G. aculeatus* and *T. tinca* respectively. In the present series of experiments impulse, D. C. of rectangular wave form and square wave form were used. Narcotizing pulse thresholds for *S. irideus*, *C. Carpio* *G. aculeatus*, *T. tinca* and *S. fario* were 82, 78, 65, 78 and 73/ second respectively in water having conductivity $2x10^{-4}$/ cc. In higher conductivity of water the value of norcotising pulse threshold remained unchanged. With impulse D. C. of rectangular wave form the narcotising pulse threshold for *S. irideus*, *C. carpio* and *I. melanotus* were 34, 25 and 25/ second respectively irrespective of conductivity of water. Though the narcotising pulse thresholds for *S. irideus* and *C. carpio* were different in impulse D.C. of square wave form and rectangular wave form, the % of anodic effect of fishes during galvanotaxis and galvanonarcosis were more in impulse D. C. of square wave form (tables 2, 3 and 8).

Though the narcotizing pulse threshold for anodic reaction of *S. fario* was found

Table 5 Specific movement of *G. aculeatus* during different reactions in relation to different impulse frequencies

Water temperature: 16°C
Nature of current: Impulse D. C. of square wave form Conductivity of water: $2x10^{-4}$/ per C. C.

Size group in mm.	No. of fishes	Impulse frequency/sec	Impulse duration : ms	Pause duration ms	% of specific movement of fish during galvanotaxis				% of specific movement of fish during galvanonarcosis			
					Anodic	Cathodic	Oscillo-tactic	Unspecific	Anodic	Cathodic	Oscillo-tactic	Unspecific
37–54	25	82	5	7.2	32	56	12	—	68	8	24	—
37–52	25	78	5.7	7.2	36	52	12	—	60	28	12	—
39–52	25	76	6	7.2	32	44	24	—	72	16	12	—
40–52	25	73	7.2	6.4	52	44	4	—	52	48	—	—
39–53	25	69	7.2	7.2	68	28	4	—	56	32	12	—
38–54	25	66	8	7.2	60	32	8	—	52	28	20	—
36–34	25	65	7.2	8.2	84	12	4	—	34	12	4	—

Table 6 Specific movement of *T. tinca* during different reactions in relation to different impulse frequencies.

Water temperature:15°C Nature of current: Impulse D. C. of square wave form

Size group in mm.	No. of fishes	Impluse frequency/sec	Impulse duration : ms	Pause duration: ms	Conductivity of water :	% of specific movement of fish during galvanotaxis				% of specific movement of fish during galvanonarcosis			
						Anodic	Cathdic	Oscillo-tactic	Unspecific	Anodic	Cathodic	Oscillo-tactic	Unspecific
191–240	104	82	5	7.2	$2x10^{-4}$/cc	60	40	—	—	60	27	13	—
191–240	102	78	6	7.2	,,	72	28	—	—	86	14	—	—
191–240	84	82	5	7.2	$10x10^{-4}$/cc	65	28	7	—	93	7	—	—
191–240	86	78	6	7.2	,,	100	—	—	—	100	—	—	—

Table 7 Specific movement of *S. fario* during different reactions in relation to different impulse frequencies

Water temperature: 16°C. Nature of current: Impulse D. C. of square wave form.

Size group in mm	No of fishes	Impulse frequency per sec.	Impulse duration ms	Pause duration ms.	Conductivity of water	% of specific movement of fish during galvanotaxis				% of specific movement of fish during galvanonarcosis			
						Anodic	Cathodic	Oscillo-tactic	Unspe-cific	Anodic	Cathodic	Oscillo-tactic	Unspe-cific
81–90	25	82	5	7.2	2x10-4/cc	24	76	—	—	64	28	8	—
81–90	35	78	5.7	7.2	-do-	68	24	8	—	80	12	8	—
81–90	35	76	6	7.2	-do-	68	28	4	—	96	4	—	—
81–90	45	73	7.2	6.4	-do-	80	20	—	—	100	—	—	—
81–90	25	69	7.2	7.2	-do-	76	24	—	—	84	16	—	—
81–90	35	66	8	7.2	-do-	52	48	—	—	84	16	—	—
81–90	25	65	7.2	8.2	-do-	56	32	12	—	84	16	—	—
81–90	25	73	7.2	6.4	10x10-4/cc	100	—	—	—	100	—	—	—
81–90	25	69	7.2	7.2	-do-	96	—	4	—	96	4	—	—

Tabls 8 Specific movement of *C. carpio* during different reactions in relation to different types of current

Water temperature: 15°C

Size group in mm.	No. of fishes	Nature of current	Impluse frequency/sec	Impulse duration : ms	Pause duration: ms	Conductivity of water:	% of specific movement of fish during galvanotaxis				% of specific movement of fish during galvanonarcosis			
							Anodic	Cathodic	Oscillo-tactic	Unspe-cific	Anodic	Catho-dic	Oscillo-tactic	Unspe-cific
91–250	45	Rectangular impulse from pantostat.	34	9	20	2x10-4/cc	16	40	8	36	80	—	4	16
91–250	46	-do-	25	20	20	-do-	—	96	—	4	56	20	4	20
91–250	46	-do-	34	9	20	10x10-4/cc	15	30	15	40	80	—	10	10
91–250	48	-do-	25	20	20	-do-	12	56	—	32	90	10	—	—
91–130	80	square wave	82	5	7.2	2x10-4/cc	30	56	14	—	79	14	7	—
91–120	62	-do-	78	5.7	7.2	-do-	100	—	—	—	100	—	—	—
91–130	92	-do-	82	5	7.2	10x10-4/cc	58	28	14	—	100	—	—	—
101–130	60	-do-	78	5.7	7.2	-do-	100	—	—	—	100	—	—	—
101–130	64	-do-	76	6	7.2	-do-	80	20	—	—	72	—	28	—

Table 9 Specific movement of *S. fario* during different reactions in relation to the position of fish body in electrical field.

Water temperature: 14°C Nature of current: Impulse D. C. of square wave form Impulse frequency: 73/Sec
Conductivity of water : 2x10–4/cc Impulse duration : 7.2 ms
Pause duration : 6.4 ms

Size group in mm	No. of fishes	% of specific movements of fish during galvanotaxis						% of specific movements of fish during galvanonarcosis					
		Position of body axis to field lines	Direction of fish head to electrod	Anodic	Cathodic	Oscillo-tactic	Unspe-cific	Position of body axis to field lines	Direction of fish head to electrode	Anodic	Cathodic	Oscillo-tactic	Unspe-cific
81–90	28	Parallel	To anode	100	—	—	—	Parallel	To anode	100	—	—	—
81–90	30	Parpendi-cular.	—	70	13	12	—	Perpendi-cular	—	60	—	40	—
81–90	35	45°	To cathode	40	60	—	—	45°	To cathode	34	66	—	—
81–90	25	Parallel	To cathode	20	80	—	—	Parallel	To cathode	60	—	40	—

Table 10 Specific movement of *S. fario* during different reactions in relation to the position of fish body in electrical field

Water temperature: 15°C
Conductivity of water: 2x10–4/cc Nature of current: Impulse D. C. of square wave form Impulse frequency: 37/sec.
Impulse duration: 7.2 ms
Pause duration: 6.4 ms

Size group in mm	No. of fishes	% of specific movemont of fish during galvanotaxis						% of specific movement of fish during galvanonarcosis					
		Position of body axis to field lines	Direction of fish head to electrode	Anodic	Cathodic	Oscillo-tactic	Unspe-cific	Position of body axis to field lines	Direction of fish head to electrode	Anodic	Cathodic	Oscillo-tactic	Unspe-cific
131–175	35	Parallel	To anode	100	—	—	—	Parallel	To anode	100	—	—	—
131–175	30	-do-	To cathode	50	50	—	—	,,	To cathode	34	66	—	—
131–175	25	30°	To anode	100	—	—	—	10°	To anode	100	—	—	—
131–175	25	40°	,,	,,	—	—	—	30°	,,	,,	—	—	—
131–175	35	45°	,,	,,	—	—	—	45°	,,	,,	—	—	—
131–175	35	45°	To cathode	,,	—	—	—	45°	To cathode	50	50	—	—
131–175	35	60°	To anode	,,	—	—	—	65°	,,	—	100	—	—
131–175	30	65°	,,	,,	—	—	—	70°	To anode	100	—	—	—
131–175	30	70°	,,	,,	—	—	—	Perpendi-cular	—	56	38	6	—
131–175	25	Perpendi-cular	—	75	20	5	—	—	—	—	—	—	—

to be 73/ second with impulse duration of 7.2 ms and pause duration of 6.4 ms, yet fishes were not found to react 100% anodically during galvanotaxis (table-7). 20% of fishes moved to cathode during galvanotaxis. This may possibly be explained by the position of fish body in relation to field lines during galvanotaxis. Experiments with *S. fario* in present studies indicated that fishes exhibited 100% anodic reaction during galvanotaxis and galvanonarcosis when they lay parallel to current direction with heads towards the anode. 80% of fishes moved towards the cathode when heads were pointed towards the cathode even if they lay parallel to current direction during galvanotaxis. The transversal escape movement (Oscillotactic) occurred when the fish body was perpendicular to the flow of current during galvanotaxis (table-9).

S. fario of 131–175 mm in an impulse frequency of 73/ second of square wave form showed 100% anodic galvanotaxis when their body axis lay parallel to direction of current with heads towards anode. When heading towards cathode 50% of fishes moved to anode and 50% to the cathode. Varying the position of body axis to field lines from 30° to 70° also 100% of fishes reacted anodically (table-10.) Only when the fish body was perpendicular to current direction, 75% of fishes moved to anode and 20% to cathode. 5% of fishes exhibited transverse escape movement.

Studies were made with beheaded *S. irideus* of various size groups in electrical field using an impulse D. C. of square wave form having frequency of 82/ second and impulse duration of 5ms and pause duration of 7.2 ms. With the rise of threshold current density, 100% of the decapitated fishes moved towards the anode with vibration of the trunk so long as the trunk had power to move,

Table 11 Movements of beheaded trunk of *S. irideus* in electrical field in relation to its position to field lines

Impulse frequency: 82/Sec Nature of current: Impulse D. C. of square wave form
Impulse duration: 5 ms Conductivity of water: 2×10^{-4}/cc
Pause duration: 7.2 ms Water temperature: 15°C

Current density of the field in δ per Sq mm.	Size groups in mm	No. of fishes tested	Position of body axis to field lines	Direction of beheaded trunk to electrode	% of specific movement of beheaded trunk			
					Anodic	Cathodic	Oscillotactic	Unspecific
0.500	131–135	4	Parallel	To anode	100	—	—	—
0.567	136–140	5	Perpendicular	—	—	—	60	40
0.513	141–145	6	-do-	—	—	—	80	20
0.356	151–155	5	Parallel	To anode	100	—	—	—
0.320	156–160	4	45°	-do-	,,	—	—	—
,,	161–165	4	Parallel	-do-	,,	—	—	—
0.356	166–170	4	45°	To anode	,,	—	—	—
0.346	171–175	4	Parallel	-do-	,,	—	—	—
0.415	171–175	4	45°	-do-	,,	—	—	—
0.460	171–175	5	Perpendicular	—	—	—	60	40

when they were placed in parallel or 45° angle to the lines of current conduction of the electrical field. When the beheaded trunks were placed at right angles to the current direction, feeble unspecific escape movements were observed (table-11).

Conclusion

Different species of fish react differently to varying pulse rates. The narcotizing pulse limit of *S. irideus*, *C. carpio*, *G. aculeatus*, *T. tinca* and *S. fario* were 82, 78, 65, 78 and 73 respectively in impulse D. C. of square wave form irrespective of conductivity of water. With impulse D. C. of rectangular wave form best anodic effects during galvanotaxis and galvanonarcosis were observed in frequencies of 34, 25 and 25 in case of S. *irideus*, *C. carpio* and *I. melanotus* both in lower and higher conductivities of water. Increased anodic reactions were observed in impulse D. C. of square wave form when threshold values of narcotizing impulses were used. Conductivity of water did not have any effect on narcotizing pulse limit required for different varieties of fishes. The temperature of water played an important role on anodic movement of fishes during galvanotaxis and galvanonarcosis. 89 to 100% of anodic effect was observed in fishes in water temperature between 11° and 17°C and reduced anodic effect at 3 to 6°C. Increased anodic effect of fishes was observed when the fish remained parallel or making an angle of up to 70° with lines of current conduction. But the fish at right angles to direction of current flow exhibited escape movement in the field when the threshold value for galvanotaxis was reached in the same frequency. Decapitated *S. irideus* showed the movement of the trunk like the total organism towards the anode as long as the trunk was able to move when put in an electrical field parallel to line of current conduction establishing the anodic reaction of fish by reflex action and not by certain organ of sense. A feeble escape movement was observed when placing the beheaded trunk at right angles to the direction of flow of current.

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