

- I. Blocking Nerve Impulses Set up in Strychninized and Normal Frogs.
- II. A comparison of Cranial and Artificially Aroused Impulses under the Influence of Nerve Blocks.

Two Theses submitted to the department of Physiology of the University of Kansas in partial fulfillment of the requirements for the Degree of Master of Arts.

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accepted
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The question of what causes a block in nerve tissue is still open for investigation, and will remain so until some method has been discovered by means of which we can determine what takes place in the nerve tissue itself when a block is secured, and until a definite understanding of nerve conduction or nerve irritability has been obtained. Are enzymes activated at the point of block, do coagulation electrons or ions accumulate to counteract the stimulus or conducting power and thus block the impulses that pass through the nerves, must be determined before much progress can be made in this work. I hope that this paper and previously published articles on nerve conduction may prove of value to some future experimenters in the solution of this difficult question.

Within recent years a number of articles have appeared incorporating different methods for inhibiting nerve conduction. They have taught us that Mechanical (¹compression), Chemical (²MgSO₄, ³Cocaine) or thermal (⁴Freezing) applications have similar effects upon nerve conductivity. However, little has been done with the electrical block, probably, because it is considered more as a stimulus than as a block. ⁵Schenck, ⁶Pflücker and ⁷Fröhlich used the electric block to shut out cranial impulses of the vagus nerve and then abandoned it. ³Hyde also used electricity to block impulses. However, she did not employ the tripolar method but paralysed the nerve by means of a strong interrupted current. The object of my experiments is to invest-

igate the practical value of the tripolar block upon impulses caused by different kinds of stimuli and to compare its efficiency with the block caused by other methods. It is assumed, when using ²MgSO₄, ³Cocaine, and ¹Compression as a block that the afferent impulses are blocked long before the efferent impulses. It is interesting therefore to ascertain whether this was true when employing the electrical block,

The tripolar method has been used as a stimulating current by many scientists, ⁸Achilles, ⁹Danilewsky, ¹⁰Schaternikow and ¹¹Werigo. As early as 1870 ¹²Filehne introduced the tripolar method into electrotherapeutics. He employed it as a stimulating method and not as a means of decreasing irritability or conduction of nerve impulses.

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- b. Herman: Handbuch der physiologie 1879 11 p 95.
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- d. Zederbaum: Archiv für Anatomie und Physiologie 1883 p 161.
- e. Efron: Archiv für die gesammte Physiologie 1885 XXXVI p 469.
- f. Calugareanu: Journal de Physiologie et de Pathologie 1901 pp393-413.
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- h. Bethe: Allgemeine Anatomie und Physiologie des Nervensystems 1903 - 248.

1. Semenoff: Archiv für Physiologie 1903, c. p 182.
2. Melzer & Auer. Amer. Journ. of Physiol. 1906, Vol. XVI. No. II.
3. Hyde. Amer. Journ. of Physiol. 1906, Vol. XVI. No. III, p 368.
4. a. Tait: Quat. Journ. of Exp. Physiol. 1908, Vol. I, No. 1 p 79.
Proc. Phys. Soc. Journ. of Physiol. 1906, Vol. XXXIV.
Zeitschr f Algem. Physiol. 1908, Vol. VIII.
- b. Boycott: Eng. Journ. of Physiol. 1902, Vol. XXVII, pp. 488 No. 6.
- c. Pictet: Reone Scientifique, 1893, 52.
- d. Hewell: Text : 910 p 116
- e. Gad: Arch. f Phisiol 1880 S 1.
5. Schenck: Pflügers Archiv. 1905 Bd. 106 haft 8 & 9, S 368.
6. Pflücker: Pflügers Archiv. 1905 Bd 106 haft 8 & 9 S 372
7. Fröhlich: Pflügers Archiv. 1906 Bd. 113 haft 7 & 8, S.433
Pflügers Archiv 1906 Bd. 113 haft 7 & 8, S.418
8. Achelis: Pflügers Arch. 1905, Bd. 106 haft 8 & 9.
9. Danilesky: Zentralbl f Physiologie 1895 Bd. 9.
10. Schaternickow: Zentralbl. f d Med. Missensch 1895 Bd. 26.
11. Werigo : Pflügers Arch. Bd. 66.
12. Filehne: Deutsches Arch. f Med. 1870 Bd. 7.

⁵Schenck in watching ⁸Achilles perform his experiments with the tripolar electric stimulating method, noticed that under certain conditions the irritability or nerve conduction was decreased so that no contraction of the muscle resulted upon stimulation of the nerve. From these observations he published his ⁴paper substantiating his theory given in one of his previous ⁵papers.

⁶Ludwig Pflücker, upon Schenck's suggestion, employed this method to block the cranial impulses in the vagus. ⁷Fröhlich in 1906 renewed the value of this block and employed it as one of his blocks for blocking impulses in both warm and cold blooded animals and he also corroborated Pflücker's work in excluding the vagus impulses. since the publication of his paper, as far as I have been able to ascertain, no further investigations have been made with this block.

5. Schenck: A. Pflügers Archiv 1905 Bd.106 haft 8&9 S 368.
b. Pflügers Archiv 1905 Bd. 100 S 337.
6. Pflücker: Pflügers Archiv 1905 Bd. 106 haft 8 & 9.
7. Fröhlich: Pflügers Arch. 1906 Bd. 113 haft 7&8 S 433.
Pflügers Arch. 1906 Bd. 113 haft 7&8 S 418.
8. Acheles: Pflügers Arch. 1905 Bd. 106 haft 8 & 9.

Stimulating Current.

My experiments were performed on frogs of the specie *Rana pipiens* and with Hall's combination frog board, fitted with an

insulating glass plate.

For the stimulating current I used a standard Harvard inductorium, graduated in 1/16 inches. The primary coil was connected through a du Bois Reymond key and one Leclanché cell of 1.2 voltage. Unless otherwise stated the stimulus was a faradic current. Very small insulated platinum electrodes were used in the secondary circuit when the nerve was stimulated directly and simple platinum electrodes when stimulating the foot for strychnine reflexes. In a few of the experiments a resistance was introduced in the secondary current as a control. Resistances varying from 4000 to 225,000 ohms were interpolated through a resistance box or a ground glass plate with lead pencil lines. In most of my later experiments I omitted the resistances because they proved unnecessary.

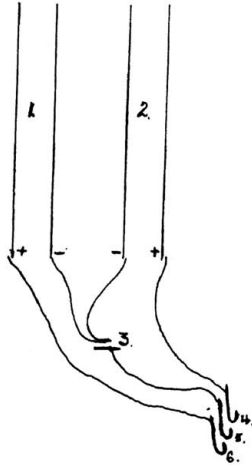
A signal circuit to mark the point at which the nerve was stimulated and where back circuit was closed and opened was also employed. A single mark was made when stimulating, many marks when the block circuit was closed and two marks when the block circuit was opened.

Block Current.

⁷Fröhlich's method of connecting the nonpolarizing electrodes to nerve was used except that the zephyr fibres were moistened in normal salt solution instead of Ringer's Solution. The three polarized electrodes were placed in the circuit so that the middle one was joined to the two negative poles and each outer electrode to each of the positive poles, of the batteries. Consequently the middle electrode always carried twice the volt-

of either of the outer positive electrodes.

Diagram.



1 & 2 Leclanché cells

Zinc plate

Carbon plate

3. Du Bois Reymond key, connecting the negative posts from the two cells leading to the middle boot.

4 & 6 Positive boots of equal strength.

5 Negative boot, Strength equal to both positive boots.

One of six different groupings of voltages was used in these experiments, namely:

(1.4)² (2.8)² (4)² (10.3)² (12.8)² Volts.

2 cells 4 cells 6 cells 12 cells 18 cells.

The voltage (1.4)² or (2.8)² does not mean 1.4 volts squared, 2.8 volts squared but is a brief method of writing (2 x 1.4) volts or (2 x 2.8) volts. As the strength of the cells may vary from day to day, their voltage was tested with a voltmeter before each experiment. This must be done to make sure that both positive boots are of equal strength.

Since most nerves in frogs are short, split zephyr fibres, kept moist with an isotonic salt solution, connected the boots to the nerve. This is the point of difference between the

⁵Schenck ⁶Pflücker method in which the nerve was placed direct-

ly on the boots, and ⁷ Fröhlich's method in which the wollen fibres were moistened with Ringers solution and my method.

5. Schenck: (a) Pflügers Archiv 1905, Bd. 106 haft 8 & 9
S 368.

(b) Pflügers Archiv 1905, Bd 100 S 337.

6. Pflücker: Pflügers Archiv 1905 Bd 106 haft 8 & 9.

7. Fröhlich: Pflügers Arch. 1906 Bd 113 haft 7&8 S 433
Pflügers Arch. 1906 Bd 113 haft 7 & 8 S 418

A. Minimal Electrical Block for impulses set up by an electrical stimulus.

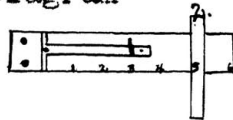
The object of this series of experiments was to determine the strength of current required to block a weak electrical stimulus which causes a contraction.

The frog was pithed or put under ether anaesthesia then fastened to the frogboard. The gastrocnemius tendon was exposed and fastened to a lever. The urostyle was next removed and the sciatic nerve exposed as far as the spinal cord and insulated from the surrounding tissue, either by means of a double rubber dam or a glass plate. The split zephyr fibres were folded around the nerve as close to the muscle as possible in order to place the stimulating electrodes outside of the anelectrotonic area. Great care was taken to place the fibres equally distant from the middle one ($1/2$ cm is the best distance) and not to have any moisture between the zephyr fibres. In a few cases the last electrode or the one next to the muscle was placed on the gastrocnemius muscle instead of on the nerve. This proved also to be efficient block. The bipolar method was also tried

but the tripolar was found more efficient.

The insulated stimulating electrodes were then placed on the nerve as far as possible from the block electrodes without stretching or pressing the nerve. The stimulating current was the weakest possible in every case, which would cause tetanus and a maximal contraction of the muscle, which was found to be in the majority of cases without a resistance in the secondary coil, when the latter was 5 inches from the primary coil.

Diagram



1. Primary coil
2. Secondary coil.

*From a large series of experiments it was ascertained that a strong tetanic contraction of the muscle resulting from faradic stimulation instantly ceased the moment, and during the whole time, that the block circuit was closed. The instant that the block circuit was broken a contraction resulted upon again stimulating the sciatic nerve. While the nerve muscle preparation was fresh a large voltage was required in the block circuit. Usually $(10.3)^2$ Volts, in a few cases $(4.2)^2$ Volts were sufficient, but in some as much as $(12.8)^2$ Volts were necessary. See Plate I Curve 1 a & b. The block was often efficient for stronger stimuli, even when the secondary was 2 inches and in many cases 1 inch from the primary coil. Therefore, it is evident that the inhibited block was often efficient for maximal electrical stimuli. As a control to prove the efficiency of the block liquid air and a freezing mixture of NaCl and Ice were used for freezing and also $MgSO_4$ and Cocaine were used to narcotize the nerve in a few of the experiments.

I. B. Liquid Air.

*When a fibre of absorbent cotton dipped in liquid air was applied to the intact nerve, the muscle contractions due to electrical stimuli were shut out in every case and remained so as long as the nerve was frozen, as soon as the nerve was no longer frozen the contractions again reappeared. As long as the nerve remained intact, this procedure could be repeated an indefinite number of times without much injury to the conductivity of nerve impulses. Plate I Curve 3 a. But when the nerve was cut and then frozen or cut after it had been frozen the muscles would not, strange to say, again respond to electrical stimuli until the stimulating electrodes were moved beyond the previously frozen part of the nerve. Plat I Curve 3 b.

*I. C. NaCl & Ice.

To ascertain whether liquid air was peculiar in causing the death of the nerve when cut, a control with a freezing mixture was made. NaCl and Ice were placed in a glass tube. This tube was then carefully placed on the nerve. With this block the results were the same as those obtained with the liquid air block. Plate I Curve 4.

The efficiency of the tripolar electric block was also compared with that of the cocaine and $MgSO_4$ blocks. The time required to produce the cocaine and $MgSO_4$ blocks was very long often from 25 to 45 minutes. In no case in my experiments did the nerve return quite to normal even after waiting from $1/2$ to $3/4$ of an hour. The stimulating current in every case was strengthened by moving the secondary coil $1/6$ to $1/8$ inches nearer the primary coil, showing a decrease in irritability or

Table of general results of a large series of experiments.

* Efferent Impulses. Sciatic nerve cut + Stim.

Frog No.	Block current in Volts.	Strength of Stimuli. Far. Sec. from Prim.	Distance of Stim. from Block.	Resistance.	Observation	Condition of Nerve.	Curve.
30	(2x1.4) Volts.	4 1/2 inches.	2 inches.	0	No Block	Cut.	
30	(2x2.8) Volts	"	"	"	No Block	"	
30	(2x4) "	"	"	"	No Block	"	
30	(2x6.4) "	"	"	"	No Block	"	
30	(2x10.3) "	"	"	"	Block	"	Plate I Curve 1a.

* Efferent Impulses. Sciatic nerve. Stim.

Frog No.	Block current in Volts.	Strength of Stimuli Faradic Sec. from Prim.	Distance of Stim. from Block.	Resistance	Condition of Nerve.	Observation	Curve.
31	(2x1.4) Volts.	5 1/2 inches from Prim.	1 1/4 inches	0	Intact.	No Block	
31	(2x2.8) "	"	"	"	"	" "	
31	(2x4) "	"	"	"	"	" "	
31	(2x6.4) Volts	"	"	"	"	" "	
31	(2x10.3) "	"	"	"	"	Block	Plate I Curve 1b & 2c.

+ Efferent Impulses. Liquid Air.

Frog No.	Block	Strength of Stim. Faradic	Distance of Stim. from Block	Resistance	Dist. of Block from Muscle	Condition of Nerve	Observation	Curve	Remarks.
31	Liquid Air.	Sec. 2 1/2 inches from Prim.	1/4 inch	0	1 1/2 inch.	Intact.	Block	Plate I Curve 1	Blocked 22 Times.
31	Liquid Air	" "	" "	"	" "	Cut.	Block	Plate I Curve 2	Blocked Once. Nerve Dead.

+ Efferent Impulses. Freezing Solution.

Frog No.	Block	Strength of Stim. Faradic	Distance of Stim. from Block	Resist.	Dist. of Block from Muscle	Condition of Nerve.	Observation	Curve	Remarks.
32	NaCl + Ice	Sec. 2 inches from Prim.	1/4 inch	4088	1 1/2 inch.	Intact.	Block.	Plate I Curve 1	Blocked 2 or More Times.
32	NaCl + Ice	" "	" "	"	" "	Cut.	Block.	" "	Blocked Once. Nerve Dead.

conductivity in nerve tissue even 45 min. after the block was removed. This is not so with the electrical. The nerve whether intact or cut retains its normal functions whether blocked once or many times, unless the stimulating current is so strong that it paralyses the ³ nerve completely. Plate I Curve 2

*††† See Table.

3. Hyde--Amer. Journ. of Physiol. 1906 Vol. XVI No. III p 36

In this series of experiments the efferent impulses caused by direct electrical stimulation of the nerve were blocked, without apparent injury by the tripolar method, and with but slight injury by either liquid air or a freezing mixture and with more or less injury by cocaine or $Mg SO_4$. However, section of the nerve after freezing causes a destruction that is avoided by the other methods. In the next series of experiments I shall show that reflex efferent impulses caused by stimulating the opposite foot can also be blocked.

II

Strychnine reflex. Reflex Afferent and Efferent Impulses.

With ² $MgSO_4$ and ³Cocaine it was discovered that the afferent impulses were blocked 10 to 15 minutes sooner than the efferent. With pressure the afferent were blocked with much less pressure than the efferent. Can the afferent impulses be blocked with a weaker current than the efferent? Can strychnine tetanus be blocked? These were some of the questions that were investigated with the strychnine frog.

II. A. Strychnine Tetanus.

The frog was weighed. It was then put under light anaes-

thetic and prepared for the experiment exactly as in No. I and then for each 15 gms. of body weight one minim of a 0.1 % Strychnine sulphate solution was injected into the dorsal lymph sac. Strychnine tetanus soon resulted which was blocked with a strong electrical block $(10.6)^2$ Volts. In a few cases $(4.2)^2$ volts blocked them immediately and during the whole interval of time that the block current was introduced.

II. B. Efferent Impulses.

Without disturbing the block electrode and stimulating the opposite foot either electrically or mechanically a reflex response resulted which was blocked when the block circuit was closed. This was blocking reflex efferent impulses. Usually a strong block of $(10.6)^2$ volts was required, but occasionally $(4.2)^2$ volts would block them. Plate II Curve 2 a b c & g #III

In a few cases the forelegs were stimulated instead of the opposite hind leg. The block was so efficient when the block circuit was closed that the fore legs could be severed without producing the usual reflex. In ever case $(10.3)^2$ volts was required to block these impulses. When the block circuit was opened a prick or touch on the forelegs before they were cut, would cause intense contractions. Plate II Curve 3 a b c d.

II. C. Afferent impulses.

The zephyr fibres were next placed on the leg opposite to the one attached to the recording lever. When the leg was stimulated either by touching its skin with a pencil point or minimal electrical stimulation a reflex contraction resulted in the other leg but if now the block circuit was closed and the foot stimulated again with the same strength of stimulus no con-

traction resulted. No muscle of the body except those in the stimulated foot contracted. This was blocking afferent impulses. These impulses were blocked with a much weaker current. In almost every case $(1.4)^2$ or $(1.3)^2$ volts proved efficient. These results show that the afferent impulses are blocked with a much weaker current than are the efferent, and in both cases it results at the instant that the key in the block circuit is closed, and at the instant that the block switch is opened the block disappears. There were no marked variations in my results. The afferent impulses never required a block stronger than $(4.1)^2$ while the efferent were only blocked a few times with the same voltage.

Plate II Curve 1 & 2 a b c d e f # II.

When the sciatic nerve was stimulated directly, either by a weak interrupted or make and break current instead of stimulating the skin of the foot, the result was the same as above described and the same kind of a curve was obtained. Plate II Curve 2. a b c d e f g.

II. D. Liquid Air, NaCl & Ice.

As a control for the efficiency of the electrical block I repeated experiment II a & c on a strychninized frog but used liquid air and also a freezing solution instead of the electrical block. I applied them exactly in the same way as described above (page) and blocked both strychnine tetanus and afferent and efferent impulses. The time required for the functions of nerve conduction to return after freezing was from 1/2 to 1 hour. Curve similar to Plate II Curve 4 b efferent.

II. E. Galvanometer.

It may be questioned whether part of all of the impulses

Resume of a large series of Experiments with Strychninized Frog.

Efferent Impulses. #II

Frog No	Block Current in Volts.	Strength of Stim. Farad	Region Stimulated	Observation	Curve.
23.	(2x14) Volts.	Sec. 1 5/8 inches from Primary.	Skin of * opposite foot.	No Block	Plate II C. 2d #III
"	(2x2.8) "	"	"	" "	" " C 2c #III
"	(2x4.2) "	"	"	" "	" " C 2b #III
"	(2x10.6) "	"	"	Block	" " C 2a #III

Afferent Impulses. #II

Frog No	Block Current in Volts.	Strength of Stim. Farad	Region Stimulated	Observation	Curve.
23	(2x14) Volts.	Sec. 1 5/8 inch. from Prim.	Skin of Op Foot	Block	Plate II C. 2d ref. #II
"	(2x2.8) "	"	"	"	" " C 2c 2e #II
"	(2x4.2) "	"	"	"	" " C 2b x 1 #II
"	(2x10.4) "	"	"	"	" " C 2a #II

Frog No	Block Current in Volts.	Strength of Stim. Mechanical	Region * Stimulated.	Observations	Curve.
23.	(2x14) Volts.	Touched Frog with Pencil Point.	Skin of opposite foot.	No Block.	Plate II C. 2d. #II
"	(2x2.8) "	"	"	" "	" " C 2c. #II
"	(2x4.2) "	"	"	" "	" " C 2b. #II
"	(2x10.6) "	"	"	Block.	" " C 2a. #II

Frog No	Block Current in Volts.	Strength of Stim. Mechanical	Region + Stimulated	Observation	Curve.
23.	(2x14) Volts.	Touched opposite foot with pencil.	Skin of opposite foot.	Block.	Plate II C. 2d. #II
"	(2x2.8) "	"	"	"	" " C 2c #II
"	(2x4.2) "	"	"	"	" " C 2b #II
"	(2x10.4) "	"	"	"	" " C 2a #II

Frog No	Block	Strength of Stim.	Region * Stim.	Observations	Curve
33.	Liquid Air	Sec. 2 inches from Prim.	Opposite foot.	Block.	Plate II C. 4b

Frog No	Block	Strength of Stim.	Region + Stim.	Observation	Curve.
33.	Liquid Air	Sec. 2 inches from Prim.	Opposite Foot.	Block.	Plate II C. 4a.

Frog No	Block.	Strength of Stim.	Region Stim. *	Observation	Curve
35	NaCl + Ice	Sec. 2 inches from Prim.	Opposite Foot.	Block.	Plate II Curve 4b

Frog No	Block	Strength of Stim.	Region Stim. +	Observation	Curve
35	NaCl + Ice	Sec. 2 inches from Prim.	Opposite Foot	Block.	Plate II C. 4b

Cutting off Foot.

Frog No	Block Current in Volts.	Mech. Stim. of Forefoot	Cut.	Observation	Curve.
23	(2x10.6) Volts	Left.	Left foot.	Block	Plate II C. 2b
"	" "	Right.	Right foot.	"	" " C 2c

Frog No	Block	Strength of Stim.	Region Stim. +	Observation	Curve

* Foot opposite to the attached lever. Front feet were also Stimulated.

+ Block + Stim were on same Foot. Opposite Foot attached to Lever.

† Foot was first pricked and then block circuit closed and Foot cut off.

are blocked after electrical stimulation even when no contraction results, because possibly they may not be strong enough to cause a contraction. To ascertain if that were true galvanometric readings were taken. It was found that when a block was obtained no deflection of the galvanometer occurred. When there was no block a deflection was sure to result. This shows that no impulses passed the block.

From these observations there can be no doubt that the efferent and the afferent impulses set up by means of electricity or any other kind of a stimulus can be blocked. The efficiency of the tripolar block can scarcely be disputed. In every case a block resulted either by a weaker or stronger block current depending upon the condition of the frog. The efficiency of this block is by far superior to that produced by other methods.

1. Because the time required is merely the time taken to close the key. At the instant that the key is closed a block is produced and lasts as long as the key remains closed. It is not only a block for the minimal stimuli, but also for stimuli which would cause prolonged tetanic contractions. At the instant that the key is opened the block disappears and the nerve irritability and nerve conductivity is immediately restored. It differs in this respect from $MgSO_4$ and cocaine which require about an hour for the effects to wear off. It is superior to freezing which appears only after several minutes and requires as many, if not more, before irritability and conductivity is restored.

2. If the nerve is cut and then frozen or if the nerve is frozen and then cut, the conductivity of the nerve impulses is

lost. It seldom returns even after an hour. When the nerve is cut the electrical block on the other hand produces no apparent damage. It can be employed many times without injury to the nerve. Why the nerve degenerates when cut and frozen is still open for investigation. No explanation can be given here.

3. Both afferent and efferent impulses can be blocked, but the efferent require a much stronger block current than the afferent.

Summary--

1. Nerve impulses produced by electrical or other kinds of stimuli can be blocked by the tripolar electrical block.

2. The minimal strength of current required to block the efferent impulses varies with the condition of the frog $(10.3)^2$ volts as a rule proved efficient.

3. In the cut or intact nerves the block acts similarly.

4. Strychnine tetanus can be blocked.

5. Afferent and efferent impulses set up by an electrical or mechanical stimulation of the foot in strychnine frogs can be blocked.

6. The afferent impulses are cut out by a much smaller voltage $(1.4)^2$ to $(2.8)^2$ volts, whereas the efferent require from $(10.3)^2$ to $(12.8)^2$ volts.

7. The foreleg can be severed without causing a contraction or electrical variation in the leg to which the block is applied.

8. The electrical tripolar block is the most efficient, and superior to any of the others investigated in that it excludes all impulses and leaves the tissues unaltered in function.

It is possible that it may be of practical and valuable aid in surgery or for experimental purposes.

I wish to thank Dr. Ida H. Hyde for suggesting the subject of these investigations and for her assistance and instruction during my experiments.

Explanation of Curves.

Unless otherwise stated S. = stimulation B = Block circuit closed B^o = Block circuit open. $(10.3)^2 = (10.3 \times 2)$ volts, $(6.4)^2 = (6.4 \times 2)$, $(4)^2 = (2 \times 4)$, $(2.8)^2 = (2 \times 2.8)$ and $(1.4)^2$ volts. R. = resistance. Curves are read from left to right with drum moving at the rate of 1 inch in 15 seconds.

Efferent Block.

Plate I. Curve 1 a. This is an example of numerous duplicate curves obtained. Here the minimal stimulus was secondary coil 4 1/2 inches from primary coil. R = 0. and a block current of $(10.3)^2$ volts was required. Nerve was cut.

Plate I. Curve 1 b. Contractions and block with and without a resistance. # 1 4000 ohms resistance was used in the experiment, in # 2 no resistance was employed. The secondary coil was 2 1/2 inches from the primary coil. Nerve intact. Block $(10.3)^2$ volts.

Plate I. Curve 2. Contraction from the right leg of frog # 35. A block of $(10.3)^2$ volts was employed. Stimulating current was secondary coil 4 1/2 inches from the primary coil and a resistance of 4000 ohms. Block was sufficient to shut out the impulses caused by electrical stimulation even when the secondary coil was 2 1/2 inches from the primary coil. However,

the nerve shows signs of paralysis since it did not return to normal instantly, but did a few seconds later.

Plate I. Curve 3 a. Nerve intact. Nerve was frozen with liquid air. The stimulating electrodes were $1 \frac{1}{4}$ inches from muscle. The freezing block was applied $\frac{1}{4}$ inch from the stimulating electrodes. The strength of the stimulating current was secondary coil $2 \frac{1}{2}$ inches from the primary coil. S = Stimulation. F = Duration and time of liquid air application. This shows the time taken to freeze and the time required for the nerve's irritability or conductivity to return.

Plate I. Curve 3 b. 22 curves such as Curve 3 a were taken before this curve. The sciatic was cut and apparently dead, as no response could be obtained from the muscle upon stimulation of the nerve. The stimulating electrodes were then moved beyond the place where the nerve had been frozen. Upon stimulation of the nerve a contraction resulted, but when the nerve was again frozen and then stimulated no response could be obtained until a stimulating electrodes were again moved beyond the frozen part. S = same strength as Curve 3 a.

Plate I. Curve 4 F NaCl & Ice. S Same strength as curve 3 a. This curve is similar to curve 3 b. It also shows the effect of cutting the sciatic nerve.

Explanation of Curves Strychnine: Frog.

Curves read from left to right. S = Stimulation B = Block circuit closed B^o = Block circuit open. R = Resistance $(1.4)^2 = (1.4 \times 2)$ volts.

Plate II Curve 1. This shows increased irritability in which the afferent impulses required $(4.2)^2$ volts to block. S = Secondary coil 1 inch from the primary coil. R = 0.

Plate II Curves 2 a,b,c,d, # II afferent impulses. # III efferent impulses. Block current in (a) was $(10.6)^2$ volts, (b) $(4)^2$, (c) $(2.8)^2$ and in (d) $(1.4)^2$ volts. Stimulating current was secondary coil $1 \frac{5}{8}$ inches from the primary coil. (a) Efferent impulse blocked (d) afferent impulse blocked. Similar curves were obtained upon mechanical stimulation and stimulation of the sciatic with make and break ^{or faradic} current.

Plate II Curves 2 e,f and g. # II Afferent # III efferent. These curves show in f the afferent impulse blocked with $(1.4)^2$ volts in (e) the afferent impulses blocked with $(2.8)^2$ volts. In 2 g $(12.8)^2$ volts were required to shut out the impulses. S = secondary coil 2 inches from the primary coil. The irritability of the frog can be judged easily from the tetanic curves.

Plate II Curve 3 a. Here the right forearm was stimulated and a block of $(4.2)^2$ volts was placed on the sciatic nerve. This was not sufficient to block the impulses. S = secondary coil $1 \frac{5}{8}$ in from primary coil.

Plate II Curve 3 b & c. The right and left forelegs were stimulated and the efferent impulses in left hind leg were blocked with $(10.6)^2$ volts. S = Secondary coil $1 \frac{5}{8}$ inches from the primary coil.

Plate II Curve 3 d. With open block still remaining on the sciatic nerve of the left hind leg. The left leg was stimulated by pricking it with the points of a pair of scissors.

Then the block circuit was closed and the left forefoot was cut off. No contraction resulted in the leg that contained the block. The small rise in the curve was due to the mechanical pull of the contracting muscles ^{of the body and} of the opposite leg. In the same curve the right foot was cut off in the same way.

Curve 4 a & b Freezing Solution NaCl & Ice.

S = Stimulation. Secondary coil 2 inches from the primary coil. F = The point at which the freezing solution was applied. F° = Freezing solution removed. (a) Afferent impulses shut out. This shows that nerve became normal again 3 1/4 min. after the removal of the block. (b) efferent impulses were shut out. This curve shows the irritability of the frog and thus the raggedness of the curve is due largely to the mechanical pull of the lever, due to the contraction of the muscles of the body. Nerve became normal in 8 3/4 min. after freezing block was removed. Similar curves were obtained for liquid air.

A Comparison of Cranial and Artificially Aroused
Impulses under the Influence of Nerve Blocks.

Charles M. Gruber

June 1912.

A Comparison of Cranial and Artificially Aroused Impulses under the Influence of Nerve Blocks.

In my former ¹ paper conclusive evidences were given that impulses aroused by artificial stimuli in a frog's sciatic nerve can be suppressed by the tripolar electrical block or liquid air. And at the same time it was proved that the afferent impulses could be blocked with a weaker current than the efferent impulses. In this article I shall show: that cerebral impulses as well as those artificially produced can be blocked, and discuss the relative strength of block current required for each; and that there are both afferent and efferent fibres in the phrenic nerve.

At the suggestion of Dr. C. S. Sherrington, several years ago Dr. Hyde began experimenting with the phrenic nerve. At her request I have repeated and completed her work. I take this opportunity to thank her for suggesting this question and for her assistance. As far as I have been able to ascertain no one has blocked the phrenic nerve impulses electrically. ² Schenck ³ Pflücker and ⁴ Fröhlich shut out the impulses of the vagus by means of electrotonus, but no attempt was made to determine the relative strength of current required for this and for impulses set up artificially.

1. Gruber:
2. Schenck: Pflügers Archiv 1905 - Bd. 106 haft 8 & 9, S 368.
3. Pflücker: Pflügers Archiv 1905 - Bd. 106 haft 8 & 9 S 372.
4. Fröhlich : Pflügers Archiv 1906 Bd. 113 haft 7 & 8 S 433.

The question as to whether the phrenic is a mixed nerve has
been investigated by Schreiber, Henle, Pøeter, Schwalbe,
Falot, Landois, Aurep and Cybulski, Mislawski, Luria,
Baglioné and Deason & Robb. I wish to corroborate some of
their results and by a new method show the presence of afferent
and efferent fibres in this nerve.

These experiments were conducted on rabbits, narcotized
with chloral hydrate. The rabbits were not fed the day preced-
ing the experiment. Under these conditions much less time was
required for the drug to take effect. For each kilo of body
weight $3/4$ grammes of chloral hydrate was injected subcutaneous-
ly in a 50 % solution which was found sufficient to cause deep
narcosis in less than $1/2$ hour. When the animal was under the
influence of the drug, it was fastened on an animal table, pro-
vided with a warm stage, with a modified cyon rabbit holder. The
phrenic nerves were then exposed in the neck, insulated from all
the surrounding tissue, and kept warm with Ringer's solution.
The slips were exposed according to Head's method and also kept
warm with ringer's solution. The cartilage with its attached
muscle slips was cut from the bone, and along the median line so
that each muscle slip was left attached to half of the ensiform
cartilage. The latter were then fastened with small hooks to
separate recording levers through a series of pullies. This is
similar to Head's method except that no buttons were used in
giving the muscle slips an artificial attachment. These levers
registered diaphragmatic and thoracic contractions, while a
third lever was attached to the thorax and registered purely
thoracic movements. The curves thus obtained could be readily

distinguished from each other.

The stimulating and block currents were the same as those used in my previous experiments and therefore need no further explanation. However, it may be said that the nerve was stimulated with small insulated platinum electrodes with the weakest possible current. The secondary coil was 5 1/8 inches from the primary, which was practically at right angles. Even so an appreciable contraction resulted. The diaphragm was stimulated with practically the same weak current the secondary coil usually 5 inches from the primary.

5. Schreiber: Pflugers Archiv. 1883 Bd XXXI S 577.
6. Henle : Handbuch der Nervenlehre des Menschen 1879, S 521.
7. Peter : Archives Generales 1871 XVII.
8. Schwalbe : Lehrbuch der Neurologie, Erlangen 1881.
9. Falot : Montpellier Medical Mai 1866 ref. Virchow Hirsch, 1866.
10. Landeis Page 214.
11. Aurep and Cybulski: Pflugers Archiv. 1884 Bd XXXII p 243.
12. Mislawsky : Centralblatt 1901 Bd XV No. 17 p 481.
13. Luria : Journal de Physiologie et de Pathologie Generale 1901 Vol. 3, p 818.
14. Baglieni: Centralblatt 1902 Vol. XVI No. 23, p. 1.
15. Deason & Rebb: American Jour. of Physiol. 1911 Bd XXVIII p 57.
16. Head: Eng. Jour. of Physiol. 1889. Vol. X. p. 1.
1. Gruber.

Stimulation.--

At the beginning of each experiment the efficiency of the slips was always tested with a weak current. Small insulated platinum electrodes were then placed on the phrenic, avoiding compression or stretching of the nerve. Upon stimulating with a very weak current a contraction of the slip on the same side resulted as long as the stimulus acted. The electrodes were then applied to the 1st branch and then to the 2nd. In every case a large inspiratory phase of the same side of the diaphragm was obtained. In a few cases when stimulating the phrenic or its branches, a reflex contraction on the opposite side resulted when closing the circuit, and in a few cases when circuit was broken. This reflex, no doubt, was inhibited later by the larger contraction and stronger stimulus of the side stimulated. Plate I. Curves 1. a, b & c and 2. a.

Cerebral impulses blocked.

The block electrodes were then placed on the phrenic nerve, arranging the split zephyr fibres as outlined in my former ¹ paper. It was found that when the block circuit was closed, the muscle slips did not contract. (2.8)² volts were sufficient except in one case when (1.4)² volts blocked the cranial impulses. Plate II. Curve 4. a.

1. Gruber.

When the first or second branch of the phrenic was stimulated with a very weak faradic current (coil almost at right angles, secondary 5 1/8 inches from the primary) a contraction resulted. But as soon as the block circuit was closed,

and then stimulated under the same conditions, no contraction was obtained. It was found that when a block was obtained for cerebral impulses, it was also efficient for impulses set up by a very weak electrical current. Plate II. Curve 4. a. In one case, only, did this fail, when the cranial impulses were shut out with $(1.4)^2$ volts, this was not sufficient to block the weakest electrical stimulus.

Liquid Air.

As a control for blocking cranial impulses liquid air was employed. A fibre of absorbent cotton was dipped in liquid air and then applied to the nerve. This, in every case, shut out the cranial impulses as well as the impulses aroused by electrical stimulation, but failed to do so, when the area was no longer frozen. Plate II Curve 3 b.

Afferent fibres.

I, too, found the phrenic to be a mixed nerve. When the nerve or its branches were stimulated, in many cases a contraction of the opposite side resulted, at the closing of the current which reflex, no doubt, was later inhibited by the stronger contraction and stimulus of the side stimulated. Plate I. Curves 1 a, 1 c & 2 a. When the motor impulses were blocked and the phrenic stimulated centrally to the block, there was obtained a change in rate and amplitude of the respiratory movements of the opposite side as indicated by the curves secured, from the slip. Plate I, Curve 3 a. The same thing was found true when the phrenic was cut and the central end stimulated. Stimulation of the *peritoneum*, with intact phrenic is followed by a change of rate and force of contraction on both sides of the

diaphragm. This, however, may be due to afferent impulses from other nerves to the respiratory centre. Plate II, Curve 5.

Summary.

1. Cranial impulses in the phrenic as well as impulses set up artificially can be blocked by the tripolar block and liquid air.

2. With but one exception, the same strength of block was required for cranial as for impulses set up by very weak electrical stimuli. The minimal block was $(2.8)^2$ volts.

3. The phrenic nerve is a mixed nerve containing both afferent and efferent fibres. This was definitely proved by stimulating the nerves centrally to block and thus causing a change in the rate and force of contraction of the opposite ~~slip~~ slip of the diaphragm.

Explanation of Curves.

All curves read from left to right. The upper curve is obtained from the right slip, the lower from the left slip. The middle curve is that of the thorax. The down stroke in the upper and lower curves is inspiration, in the middle one, expiration. The up stroke in the upper and lower expiration. In the normal animal when the middle lever went up the other two went down and when the middle lever went down the other two went up.

Plate I, Curve 1 a # 9. Stimulation of the right phrenic. S = secondary coil 5 inches from the primary. In this curve a reflex contraction can be seen on opposite side. Inspiratory phase.

Plate I, Curve 1 b # 10. Stimulation of the 1st branch of the right phrenic. S = Secondary coil 5 inches from Primary.

Plate I Curve 1 c # 11. Stimulation of the 2nd branch of the right phrenic. S = secondary coil 5 inches from the primary. Also a reflex at break on opposite side.

Plate I, Curve 2 a # 10. Stim^{ulation} of 1st branch of right phrenic showing a reflex contraction on opposite curve. S = Secondary coil was 5 inches from the primary. # 9 Stimulation of right phrenic.

Plate I, Curve 3 a. # 9. stimulation of right phrenic, secondary coil 5 inches from primary. F = Liquid air freeze. S = Stimulation of phrenic. secondary over primary. This shows a change in force and rate of contractions on the opposite side.

Plate II, Curve 4. # 28. = Blocking of cranial impulses with block (0.3)² volts. 280 = Block out # 10. = Stimulation of first branch of right phrenic with secondary coil 5 1/8 inches from

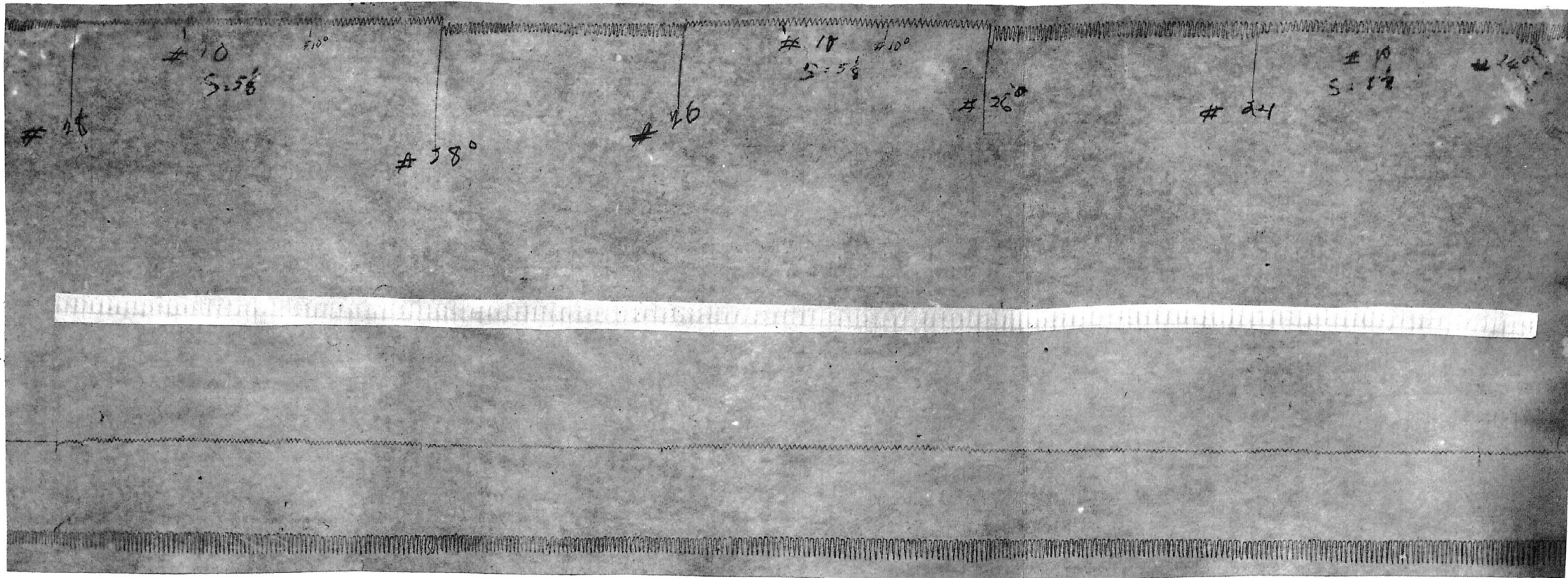
primary. # 26 = Block (4)² volts. 26^o = Block circuit broken.

24 = Block current (2.8)² volts 24^o = Block out. # 22 = Block current strength of (1.4)² volts. This as may be seen was neither strong enough to block the cranial nor the weak electrical.

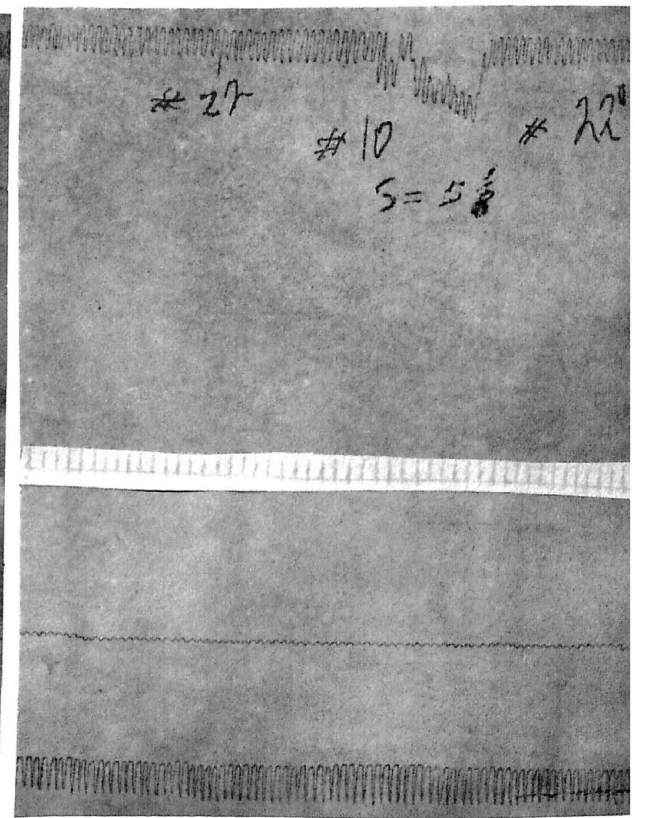
Plate II. Curve 3b F = Left phrenic was frozen and shut out the normal impulses. Only passive curves remain

Plate II. Curve 5 # 4. = Stimulation of the peritoneum of the left side of the body. #4^o = Stimulus removed. This shows a change in both curves. #5 = Stimulation of the peritoneum of the right side of the body. 5^o = stimulus removed. This also shows a change in the curve on both sides of the diaphragm. This current was weak Secondary 4 1/2 inches from the primary.

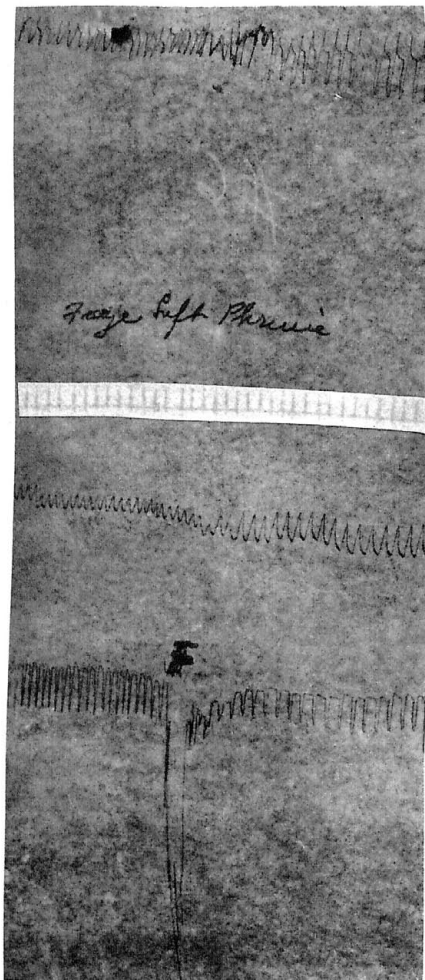
Plate II.



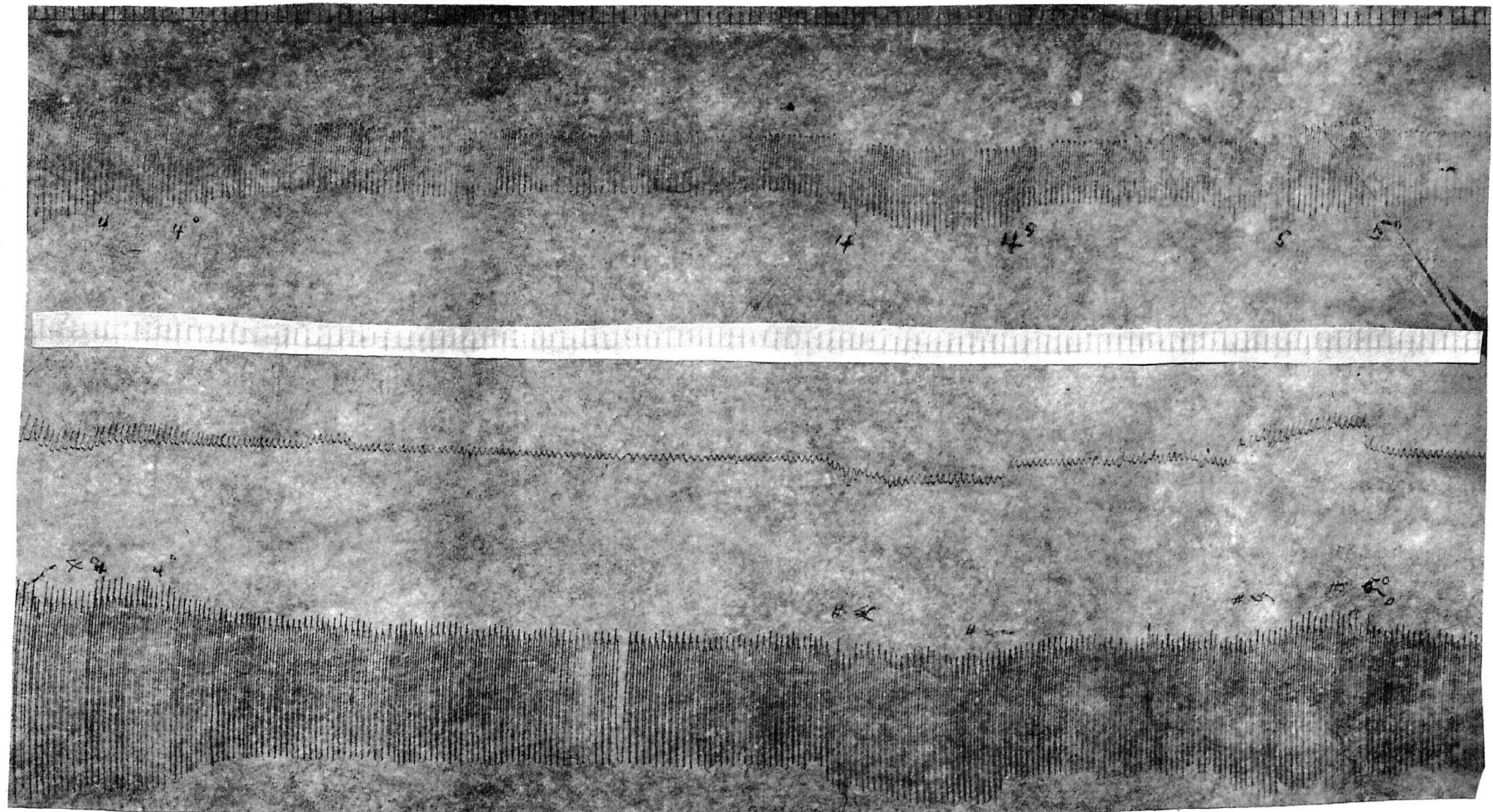
Curve 4.a.



Curve 4.



Curve 3b.



Curve 5.