HALLOCK

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VOICE PRODUCTION AND ANALYSIS

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BY

PROF. WILLIAM HALLOCK

AND

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The fact that the study of voice production requires a knowledge of acoustics as well as of anatomy, lead us to unite our forces in what we agreed should be an impartial experimental research. The following articles which appeared in the "Looker-On" during the summer of 1896, give approximately the present state of our investigation; the final presentation of our results may differ in form and in details, but will not in the broad and general principles set forth.

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VOICE PRODUCTION AND ANALYSIS.

By Prof. Wm. Hallock.

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Thousands of persons whose voices naturally are pleasant, sweet, acceptable, find, as the result of training, of learning to sing, that their voices are ruined. The result of their efforts is ability to perform all sorts of vocal gymnastics. They have the trill and tremolo and arpeggio and many other accomplishments. Their singing, however, has no heart, no soul. The voice is merely the wreck of its former self, and the vocal organs are irreparably damaged.

This result of the present methods of voice-culture is all the more remarkable when it is remembered that other physical training, if properly conducted, does not injure the bodily organs. Any one by gymnastics can be made a better athlete than he is naturally. A person who is taught to play the piano may not always develop into an artist. The muscular exercise required by such training does not, however, result in cramped fingers or in loss of sensation. Why, then, do the present methods of instruction in vocal music result so frequently in irretrievable injury to the voice and vocal organs? To answer this question, not empirically, but scientifically, is the purpose of this series of articles.

Must we not admit that something is wrong in the method of training these vocal shipwrecks? And since these results follow most all of the "methods" as applied by various teachers, is not the inference justified that, even if the correct method lurks somewhere amid this mass of error, it is not sufficiently understood nor strictly and definitely applied? Joseph Henry once said that if the fundamental law of the universe were told to us this minute, it would undoubtedly be too simple for us to understand or to apply immediately. We shall revert to this subject later on.

After some personal experience with a ruined voice, and considerable study of the mechanism of the vocal apparatus, one of us (Dr. Muckey) was led to make some scientific investigations of the problem involved in the satisfactory production of a correct tone. This necessarily included the question of the strict scientific definition of a tone accepted as artistically correct. The other part of the research then becomes the study of the conditions which enable a singer to produce the nearest possible approximation to such a tone. In this first article is discussed the means of tone analysis and tone modification. In later articles will be considered the question of the proper use of the vocal mechanism. In conclusion a *résumé* of the results of our work on voice-analysis will be given.

Resonance is the keystone of our work. It is at once our tool and the object upon which we labor. For our purpose resonance may be defined as the re-enforcement of a tone by a quantity of more or less confined air, the inherent rate of vibration of which is identical with that of the tone re-enforced. Such a quantity of air receiving successive impulses from the vibrating object comes into vibration itself, thus giving to the surrounding air a much greater amplitude of vibration and consequently greater intensity and carrying power of the tone. The jew's-harp is an excellent illustration. In it the mouth cavity re-enforces the tones of the little tongue. In fact the size of the cavity in this case, selecting its own pitch from the complexity of sounds produced by the harp, and so re-enforcing it, makes it the characteristic tone, which varies with the size and shape of the mouth cavity. To a lesser extent do the cavities of the mouth and nose act selectively upon the tones produced by the vocal cords, thus modifying the *klang-tint* (*Timbre*, *klang-farbe*) of the tone, as in articulation, but never determining the characteristic pitch (fundamental), which is entirely controlled in the larynx. This point will be more fully explained in the second article, when the management of the vocal cords is treated.

Fig. 1 is a section through the head and neck, showing the location of the parts essential to our study. Many of the parts will be readily recognized. One is at once struck with the great size of the cavity of the nose and upper pharynx, even as compared with that of the mouth. The soft palate (12) acts as a door between these two resonators. When it is drawn back and closed (as in Fig. 2), it cuts off the upper cavity entirely, leaving only the mouth available, for it is impossible for air-waves in the mouth to set the air in the nose in motion through either the bony roof of the mouth, or the flesh of the soft palate. The vocal cords are attached in front to the middle of the thyroid cartilage (Fig. 1 No. 6), and, at the back, to the arytenoid cartilages (No. 14), which sit upon the rear upper part of the cricoid cartilage (No. 17). No. 17 sits directly upon the top of the windpipe. The sound-waves from the cords pass out, under and behind, the epiglottis (No. 13); thence past the soft palate (No. 12), either into the nasal cavity and out the nostrils or over the tongue, under the hard palate (No. 11) and roof of the mouth, and out between the teeth and lips. Nos. 2, 3, 4, are the turbinated bones which bulge out into the nose cavity, breaking it up into narrow passages, which is also done by the septum, or partition, which divides the nasal cavity into a right and left half. This irregularity and complexity of the spaces and passages enable the nasal cavity to lend

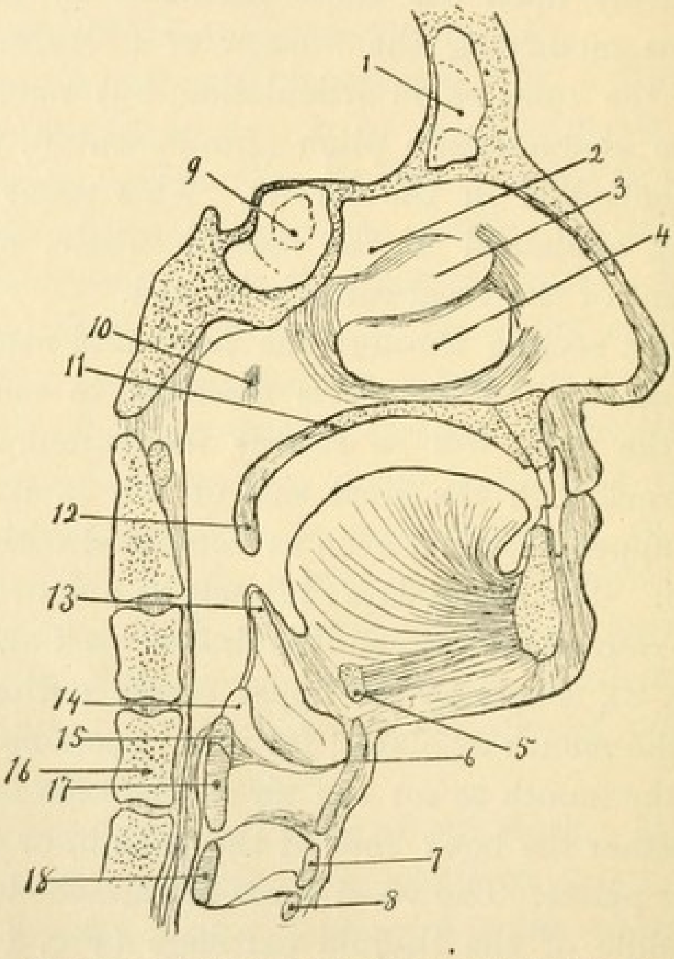


FIG. 1.—Vertical section of the head to show location and relative size of the resonance cavities. 1. Frontal sinus; 2, 3, and 4. Turbinated bones; 5. Hyoid bone; 6. Thyroid cartilage; 17. Cricoid cartilage; 7 and 18. Top ring of the trachea; 9. Sphenoidal sinus; 10. Entrance to the eustachian tube ; 11. Hard palate; 12. Soft palate; 13. Epiglottis; 14. Arytenoid cartilage; 15. Arytenoideus muscle; 16. Vertebra.

resonant re-enforcement to a much greater range of tones than if it were regular and simple. This is a fact of fundamental importance in the discussion of *klang-tint* and articulation, to be treated in another article. No. 10 is the entrance to the eustachian tube, leading to the inner ear. No. 9 is the sphenoidal sinus, and No. 1 is the frontal sinus. It is sometimes urged that these cavities, together with the antra, aid in resonance, but it is practically impossible, since at best their openings are small, and they are usually closed entirely, as is the

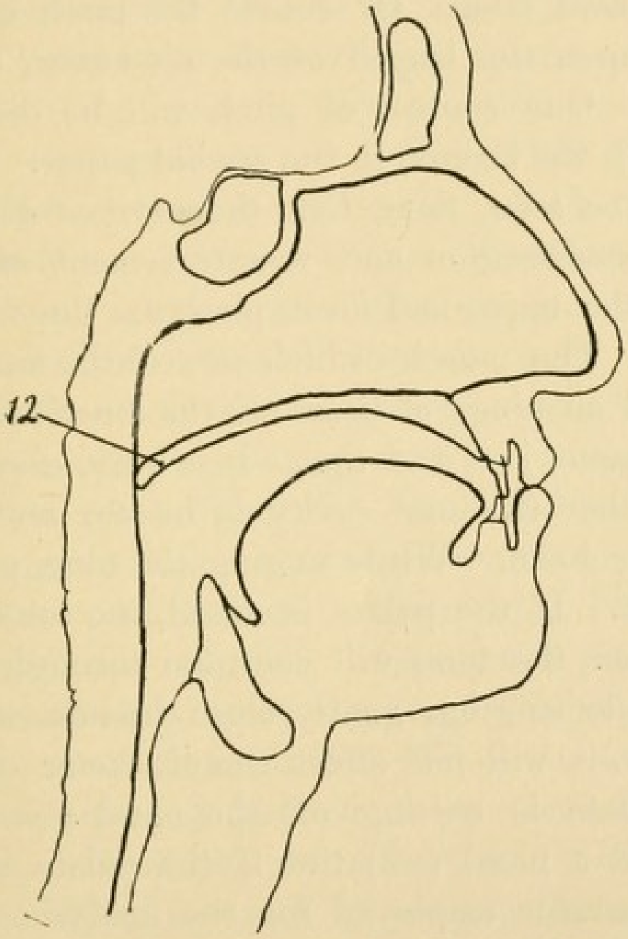


FIG. 2.—Vertical section of the head similar to Fig. 1, but showing how raising the soft palate, 12, and closing the passage diminish the space available for resonant re-enforcement by cutting off the large cavity of the upper pharynx and nose.

cavity of the inner ear. A closed cavity can not re-enforce a tone. This statement applies also to the cavities below the vocal cords; that is, the "chest cavities." Vibrations of the air in them may take place, and possibly may exert some influence on the cords, but they cannot aid in the resonant re-enforcement of the tone. The intensity, or carrying power, of a tone depends upon the "height" of the air-waves, and may be obtained by increased activity of the source of sound (of the cords) or by resonant re-enforcement. The former method strains the cords and exhausts the breath; the latter requires no effort, only the correct use of our resonance cavities, as will be shown later. Of course the pitch of the tone depends upon the length of the air-waves, or rate of vibration. Our control of pitch will be discussed, together with the larynx, in the second paper.

It will be seen, then, that the cavities available for resonant modification and re-enforcement of tone are those of the upper and lower pharynx, the mouth, and the nose. The muscles which control the size, arrangement, and openings of these are the muscles of the soft palate, tongue, jaw, and lips. It is quite easy to determine whether the nose cavity is in use and the soft palate door down. While singing the tone, gently close the mouth. If the palate is closed, the tone will stop; if it is open, the tone will continue through the nose. Again, while singing, gently close the nose with thumb and finger, it will not affect the character of the tone if the palate is cutting off the nasal resonance, but will give it a nasal (*sic*) tint if the palate is down.

The apparatus employed for the analysis of tone is practically that devised and used by König and Helmholtz, but with some essential modifications. It depends upon resonance; that is, upon the fact that a hollow sphere with a circular opening, about one-fourth to one-sixth the diameter of the hollow sphere, will re-enforce one pitch, and one only. Its air can normally vibrate at that rate, and at no other. The pitch of the tone which such a "resonator" will pick out depends upon the diameter of the sphere and that of the opening. Fig. 3 shows a section of such a resonator, as made by König.

B is the opening with a slight lip, with which it is tuned. C is a slight conical extension at the back, opposite to B. If this extension is put into the ear it will be found that all sounds are heard faintly, except those of the pitch to which the resonator is tuned, and this is greatly re-enforced. With sets of such resonators one is in a position to determine, by listening, whether a given tone is present in any complex sound. This method is very accurate and delicate, but very inconvenient. König devised a better way of observing what the resonators are doing. We have, however, decidedly modified König's apparatus. The resonators A (Fig. 3) are so mounted in a plank P that the point C is flush with the back. A block, H, screwed upon the back of P, has a conical hole conaxial with the resonators, into which fits the conical plug G. The inner end of G is hollowed out to leave a small cavity D, over which a thin membrane of rubber is stretched. The latter is bound around the end of G. Gas enters the cavity D by the tube E, escaping by the central tube, and burning in the small flame at F. When the tone of this resonator is sounded, the air in A responds (that is, it vibrates), making the drum-head at D vibrate, thus causing the little flame at F to jump at the same rate as the vibrations of the tone. Looking simply at the flame we see little change, since its jumps are so rapid, 128 to 1024 per second, that the eye fails to distinguish them. If, however, we observe the flame in a moving mirror each jump will appear in a different place, and hence be visible. A stationary flame viewed in such a rotating mirror appears as a line of light; a jumping flame appears like the teeth of a saw, the distance between the teeth depending upon the relation of the rapidity of motion of the flame to that of the mirror. Similarly, if the image of such a flame fall upon a moving photographic plate, the trace developed will be a true report as to the state of rest or agitation of the flame. Such are the principles and devices underlying the apparatus shown in Figs. 4 and 5. Fig. 4 is the front view, showing the eight resonators of various sizes, and the rotating mirror, and a few of the small flames, and the camera at the back. In Fig. 5 are seen the "manometric capsules" with their connecting tubes and little flames. A spherical resonator stands upon its mouth on the corner of the table, and our standard fork with its cylindrical resonator stands upon the stool. A device at the back of the camera enables us to move the photographic plate across an opening through which fall the images of the flames. This gives a record of the report of each flame and its resonator, upon any tone produced in front of them. Fig. 6 is such a record when a certain voice was singing a (as in father), upon the pitch of our standard fork, which is 128 vibrations per second, or about "bass C." The number of vibrations that the fundamental or characteristic tone or pitch of a string, bears to the rate of its overtones, harmonics, or upper partials, is the ratio of 1 to 2, 3, 4, 5, 6, etc. Hence our resonators are tuned to bass C, and its first seven overtones, whose rates of vibrations and approximate pitches are given below.

Fundamental,		128	vib. per sec.,	about	bass C
1st overtone		256	"	"	middle C
2d	"	384	"	"	" G
3d	"	512	"	"	treble C
4th	"	640	"	"	" E
5th	"	768	"	"	" G
6th	"	896	"	"	" B*b*
7th	"	1024	"	"	high C

The number of points in the lines in Fig. 6 are proportional to the above numbers; that is, to 1, 2, 3, 4, etc. If any one of these tones had been absent, there would have been no points in its line. The above series of overtones of a string were adopted because they are the overtones in the voice, and, moreover, as will be made evident in the second paper, because the vocal apparatus is a stringed instrument, both in theory and practice. Thus an instrument has been obtained which can analyze certain complex sounds. It is our purpose to discuss the results obtained with it in investigating voices of all degrees of merit, from our own to those of the de Részkes'. These results manifest the effects of resonance upon carrying power, upon *klang-tint* (timbre), and upon articulation.

It will, however, be necessary first to discuss the vibrations of strings, reeds, and membranes, and the possible operations of our vocal mechanism, and the laws which govern them. This will form the subject of the second paper.

(*To be continued in September number.*)

VOICE PRODUCTION AND ANALYSIS.

BY PROF. WM. HALLOCK.

DR. FLOYD S. MUCKEY.

II.

IN the present paper we discuss the behavior of vibrating strings, reeds, etc., and apply the conclusions directly to the explanation of the mechanism of Voice Production. In a later article the results obtained in our photographic analysis of various voices, especially those of noted singers, will be considered.

If we examine a string attached at each end and vibrating, we shall find that three factors control the rate of vibration—in other words, the pitch of the tone emitted. These factors are the length, weight, and tension of the string. The rate of vibration of a string is inversely proportional to the length of the string—*i.e.*, a string of half the length of another will vibrate twice as fast, and hence will give the octave. The rate is proportional to the square root of the stretching force. If we wish to raise the pitch of a string to the octave by increased tension, we must put upon it not twice, but four times, the stretching force. The rate is inversely proportional to the weight of the string. A string of half the weight would give the octave, other things being equal. It will be shown later that the larynx contains the means for varying these three factors. The *klang-tint* (timbre) of the tone produced by a string depends upon the number and relative strength of the overtones, or harmonics, or upper partials. The mathematical theory, as well as the experimental results, show that these overtones form a series whose rates of vibration, together with that of the fundamental or pitch tone, are proportional to the natural numbers 1, 2, 3, etc. For every vibration of the fundamental there are two in the first overtone, three in the second, and so on. Note well that these are in harmony with the fundamental and each other, at least to No. 6, then also 8, 10, and 12.

There are several very satisfactory ways of showing how a string divides up into segments when vibrating to its various overtones. Fig. 1 gives a series of photographs of a vibrating string taken by Prof. W. L. Robb, and kindly given for use here. Photograph marked A shows the string swinging, as it does when giving its "fundamental" or pitch tone. This is its slowest rate, and consequently produces its lowest-pitched tone. It will be seen that the string moves as a whole from one side to the other in a very simple motion. A string vibrating in this way would give a pure or simple tone. A "pure tone" is one which is produced by one single rate of vibration, as a tuning-fork with its resonator. This is the definition universally adopted in the science of acoustics. It might be well for writers upon music to conform to this usage and not call a tone by Melba "pure," when they mean smooth or fine or pleasing, and when the fundamental has at least three or four overtones with it. B shows the same string as A, only now vibrating to the first overtone, the octave, twice as rapidly, having a "node," or point of rest, in the center, and two segments. One readily sees that the effective length in B is one-half that in A. In C we have the second overtone the fifth above the octave, with two nodes and three segments, and with one-third the effective length of A. D is the third overtone, the double octave, with three nodes and four segments. E is a photograph of the same string vibrating so as to give several overtones at once. It is not known at present which overtones are active in E.

If now we turn our attention to the case of a vibrating reed or rod, fastened at one end and free at the other, we find its pitch controlled by its length, thickness, and elasticity. The ratios of the rate of vibration of the fundamental to its overtones are about as 1 to 6¼ to 7, and to the squares of the odd numbers, 3^2, 5^2, etc. Note well in this connection that there are five overtones in a string before we come to the first overtone of the reed; also that none of the overtones of the reed are in simple harmony with either the fundamental or with each other; also that their pitch varies with the varying form of the reed.

In the case of disks and membranes there are no harmonious overtones. In fact, Helmholtz classes reeds (rods), disks, and membranes as sources of sound "with inharmonic overtones."

Musical instruments and voices differ from each other in *klang-tint*; that is to say, in the relation of the number, pitch, and intensity of the overtones to the fundamental. It is this relation that makes one piano "tin panny," and another rich and melodious; that makes one voice strident and disagreeable, another sweet and full of feeling. A pure tone cannot be varied except in intensity. Its character remains the same. A lip organ pipe or a flute cannot give the rich, full tone of the violin, because it is practically a pure tone. In articulation the different vowel sounds are entirely due to this variation of *klang-tint*. This will be shown very clearly in the photographs with the last article.

The *klang-tint* of instruments is controlled in various ways, according to the method of tone production. For example, in the piano the main factors are the length and weight of the string, the hardness and shape of the hammer, the sharpness of the blow, and the distance of the point struck from the end of the string. To these may be added the resonant qualities of the frame and sounding-board. But when the piano is finished, its tone, its *klang-tint*, is determined; the performer can do very little to change the *klang-tint* of a tone without at the same time varying its intensity.

The enormous superiority of a good violin over a poor one lies in the resonant properties of the wood, and the cavity and openings. That which gives to the violin its greatest flexibility of tone, and enables it, better than any other instrument, to give voice to the feeling of the composer and performer, is the opportunity it offers the player of producing tones the most varied, from harsh discord to the sweetest melody. This is done by the manner in which the string is bowed, and the distance from the bridge to the bow. It is the bowing that distinguishes the tones of a Wilhelmj from those of the tyro. In spite of all this the source of the power of the violin lies in the fact that the string when properly controlled has the most overtones and the most harmonic.

The only tone source which equals, and indeed excels, the violin in flexibility is the human voice. We must now seek to discover the causes of this marvelous power.

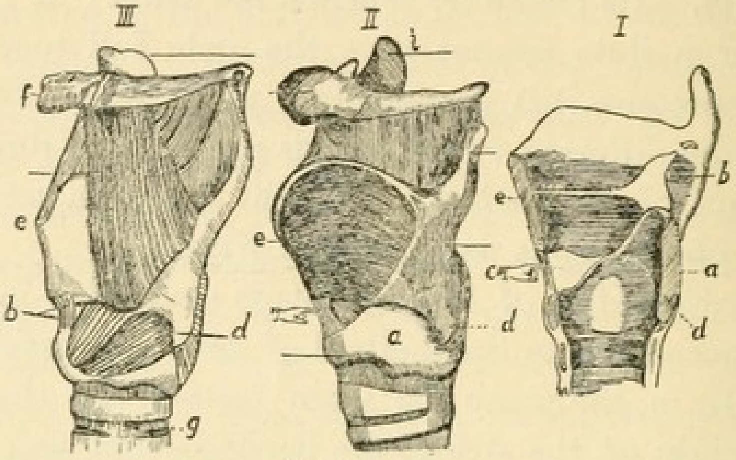


Fig 2.

Fig. 2 shows three views of the larynx: I, a section vertical from front to back; II, the left side of the cartilages; III, the left side with some of the muscles. *e* is the large thyroid cartilage, the front point of which forms the "Adam's apple," just behind which is the front attachment of the vocal cords. This cartilage is hinged upon the cricoid, *a*, by two projecting horns *d*. Upon the back, top part of the cricoid sit the two arytenoid cartilages *b*, which form the rear attachment of the vocal cords. The thyroid is held in place by muscles running up to the soft palate and head, and down to the collar-bone. When the muscles *h* are contracted, the front edge of the cricoid is drawn up, closing the niche *c*, and tilting on the hinge *d*. The back top of the cricoid, with the arytenoids, is thereby carried backward, lengthening the cords slightly and stretching them more tightly. The muscles *h*, which thus control the tension of the vocal cords, are "intrinsic" and "involuntary"—*i.e.*, they are not directly controlled by the will. *g* is the top of the windpipe; *f* is the hyoid

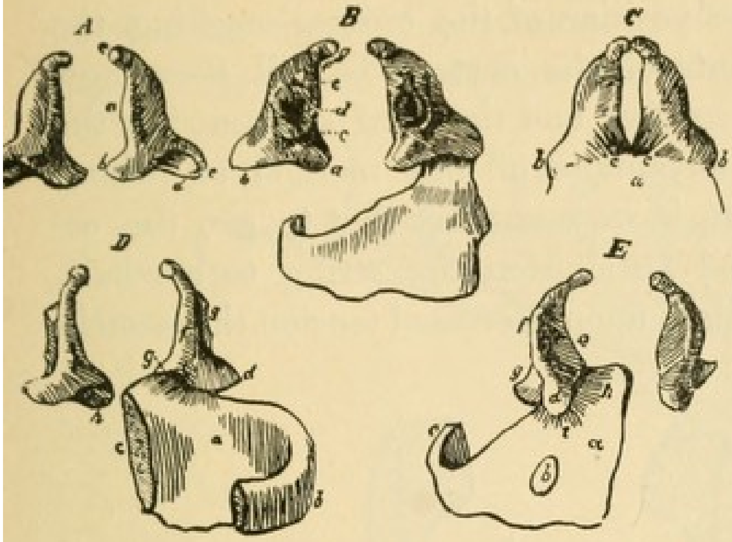


Fig 3.

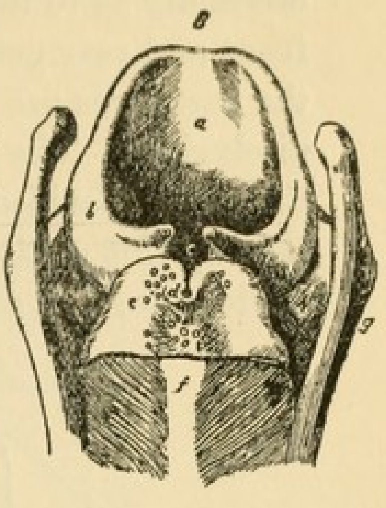


Fig 4.

bone, and *i* is the top of the epiglottis. Fig. 3 gives various views of the arytenoids upon the cricoid. Fig. 4 is a view of the larynx from the back. Fig. 5 shows four photographs of the vocal cords, looking down upon them. The front attachment is out of sight at the bottom of the pictures, being covered by the epiglottis; *l* is the cords themselves, with the apparent slit, *k*, between them; at the back, *bb* are the arytenoid cartilages. The "vocal muscle" is attached to the outside of the arytenoid cartilage at a point near *n*. It extends forward through the thick part of the cord and is attached near the cord to the front of the thyroid. When these muscles are contracted they cause the arytenoids to rotate around a point near *bb*, throwing the forward ends, *o*, inward toward each other. This rotation of the arytenoids results in a shortening of the effective length of the cords and a consequent raising of the pitch. In I and II the person is singing low G, and the whole length of the cord is in vibration. III shows the position when the octave G (bass clef) is sung, and IV when G (middle G) is the note. A comparison of II, III, and IV, especially as to the position of the crosses marking the front and rear points of the arytenoids, will show how the cartilages are rotated and the cord shortened as the pitch rises. The advantage of this method of raising the pitch is evident, if we remember that to get the octave by this method we shorten the string to one-half, while if we rely solely upon increased tension the stretch-

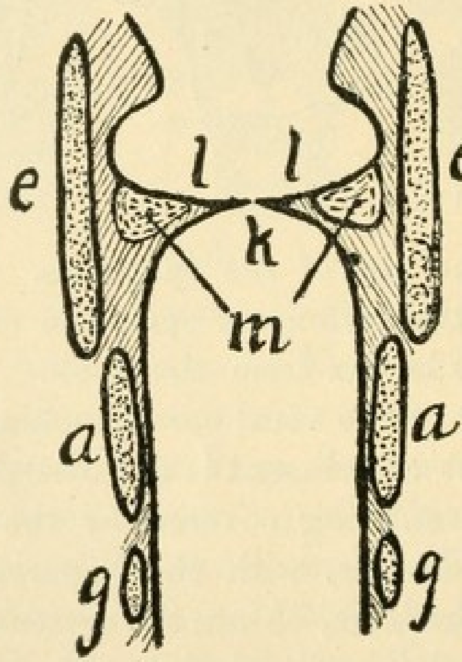


Figure 6.

ing force must be increased fourfold. Fig. 6 shows a section at right angles to *l*, Fig. 2, and hence to the cords. *a* is the cricoid and *e* the thyroid cartilage; *l*, *l*, are the vocal cords forming the slit, *k*; *m* shows a section of the vocal muscle in each cord. In proportion as this muscle is drawn tighter and tighter, it holds more and more of the cord still, finally allowing only the extreme edge of the cord to vibrate. This secondary action of this muscle results in a lessening of the weight of the vibrating part of the cord, thus tending also to raise the pitch of the tone. The muscles which control the arytenoid cartilages are intrinsic and involuntary.

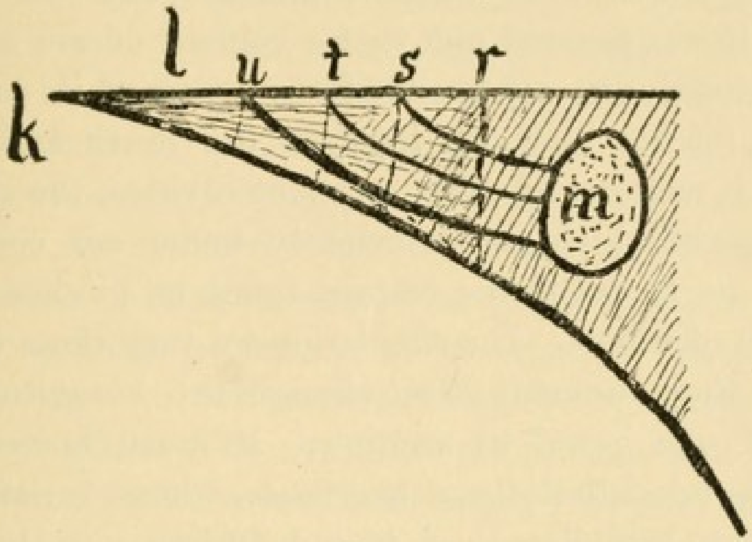


Figure 7.

Fig. 7 is a schematic representation of the vocal cord, showing the location of the vocal muscle *m*, and how it sends its fibers into the body of the cord. When *m* is uncontracted, or but slightly so, the cord may vibrate from the edge as far back as *r*, but as *m* is tightened more and more it holds the vocal cord first as far as *s*, then *t*, and finally for the highest notes (IV, Fig. 5) only the part between *u* and the edge *k* is allowed to vibrate, giving thus a much lighter string and thus helping to get a high pitch with a minimum of tension.

It will be seen that we have in the larynx the means for controlling the three factors which determine the pitch of a string—length, tension, and weight. Moreover, the tuning mechanism of a reed, plate, or membrane is lacking. Actual analysis shows the overtones of the vocal cords to belong to the series of a string, and not to that of a reed, plate, or membrane. We are thus forced to the conclusion that, both in its action and in its resulting tone, the larynx is a string instrument. The *klang-tint* of the voice is not controlled as it is in any other instrument; in fact, it would be almost impossible to so control it mechanically. In the first article it was pointed out that a volume of air more or less inclosed can act to reënforce a tone of its own particular pitch. Now we have, in the lower and upper pharynx, mouth, and nose, resonant cavities, the size and openings of which are sufficiently under our control to enable us to reënforce certain tones or pitches at the expense of others. In articulation we vary these cavities so that their resonant effect changes the *klang-tint* from that of one vowel to another. It must, however, be borne in mind that these overtones, whose variation enables us to articulate, and to put feeling into the voice, are originated *in the cords themselves*, and that they are modified only as to their relative *intensity* by the resonant cavities above. Any other origin of the overtones is absolutely incompatible, as well with theory as with observed facts. Another fact that must be accepted is that the only resonance available, either for reënforcement or modification, is the resonance of the air in the above cavities. Any vibrations that may occur in the air in the chest are useless for reënforcement, since the cavity is closed, and a closed cavity cannot reënforce a tone. Resonance from the spine, jaw, or muscle is simply ridiculous. These are often referred to as "valuable sounding-boards." Bone is 48.6 per cent. water, and the other structures are from 75 per cent. to 90 per cent. water. Imagine the tones of a piano with water-logged sounding-board! Let any one take an ordinary tuning-fork, and, striking it, press the shank upon a board, and hear the tone-sound. Then, striking it again, try to get a similar reënforcement by pressing the shank upon his friend's skull or spine or cheek or neck. If he tries it upon himself he may get a slight reënforcement, but we do not sing for our own ears.

We must then conclude that since the intrinsic muscles are ample for the control of pitch they should be left free to do that, and not be overpowered by the extrinsic, voluntary, interfering muscles of the palate and tongue, whose duty it is to control the *klang-tint* of the tone; *i.e.*, to articulate and to give expression. The two systems of muscles should be as independent as the bellows and the performer on an organ. The intrinsic muscles can and will satisfactorily control pitch, if not interfered with. The extrinsic muscles can and will articulate if they have not been applied to the improper function of controlling pitch. Voice-Production and articulation must be independent.

The following article, which will appear in the next number, will be devoted to an examination of the results of an analysis of voices, with special reference to the method of Voice-Production. The effects of improper use of the resonance cavities, and of the interfering muscles of the soft palate and tongue, will be described. The way in which these defects may be corrected will be indicated.

(*To be continued.*)

VOICE PRODUCTION AND ANALYSIS.

By Prof. Wm. Hallock.
Dr. Floyd S. Muckey.

III.

In the two articles which have already appeared, we endeavored to set forth some of the principles of acoustics and anatomy which are involved in scientifically correct voice production. We shall now attempt to apply the principles, and illustrate their effect upon the character of the tone produced. It will be well at first to use one voice as a type to show variations due to method and articulation, and then show where the same peculiarities are present in other voices.

In the estimation of a great number of teachers and pupils, carrying power is the great thing in a voice, it must be able to fill the large auditorium with a full tone whose pitch shall be readily recognized, even a *piano* tone must carry to the back rows, and top gallery. To do this a tone must have "fundamental" and plenty of it. The fundamental must do the heavy work, it must be the backbone of the whole tone. Those who will not admit that carrying power is the *summum bonum* hold that the really desirable thing is the quality of the tone, the *timbre*, the *klang tint.* This quality is due to the relative intensity and number of the overtones which are present with the pitch tone or fundamental. It would seem natural that a tone to be well rounded and "symmetrical" should have a firm, strong fundamental with the overtones well developed, but their relative strength diminishing as they rise in pitch in the series. Such a tone is well represented in Fig. 1, which is an *ä*, as in f*a*ther, in the voice which has been most studied. It will be seen that as the pitch rises the serrated effect is less pronounced, that is, the strength of the overtones becomes less; yet a careful count of the negative shows that for one wave in the first line (fundamental), there are two in the second (first overtone), three in the third (second overtone), and so on, to eight in the top line, which is the limit of our apparatus. Compare Fig. 1 with Fig. 2 which is the same vowel by the same voice, except that here the palate is raised and the production is forced, giving a rough hard tone. It will be seen that the overtones are stronger than the fundamental. The tone is top-heavy. Also note that number four is so overpoweringly strong that it forces its rate through 5, 6, 7, and 8, and drowns them out if they are present. Fig. 3, is another voice, *ä* as in m*a*rble, this tone is overwhelmingly strong in 3, with little or no fundamental, and nothing above 3, and yet this is the favorite tone of a great authority on voice production. It is much too strong in the middle, and weak at each end. Fig. 4 is still another *ä*, much too strong in 5.

As to the effects of articulation upon the tone, one only needs to compare Fig. 1, *ä*, Fig. 5, *ā* as in l*a*te, Fig. 6, *ee* as in m*ee*t, Fig. 7, *o* as in n*o*, Fig. 8, *oo* as in f*oo*d, to see that it is the overtones which determine the vowel. It must be said, however, that in Figs. 5 to 8 the fundamental should be stronger for a good tone with carrying power.

A great many people have been kind enough to permit us to make such photographic record of their tones.

Although the first effect was to bring out, in its finest details, the extreme complexity of the subject, still, as evidence accumulated, it emphasized, even more forcibly, the essential but distinct parts played by the fundamental and overtones in moulding a tone.

In spite of the fatigue and rush of the close of the Metropolitan Opera season, most of the greatest artists kindly consented to sing a few tones into our inartistic apparatus, and enable us to put the final test to our idea as to what constitutes a good tone. It must be remembered that these artists acted under unaccustomed difficulties. It is not for them to sing a simple tone into a box. Their forte is to thrill an audience. Moreover the depth of the serrations must be compared in each photograph by itself. Because, had the singer produced a louder tone or nearer to the apparatus, all the serrations would have been more pronounced ; for example, we can draw only a very poor conclusion as to the strength of a voice from our photograph, but we can judge its character. In order to see the waves in the fundamental clearly, the picture should be looked at obliquely. In the ladies' voices the difficulty is still greater because singing an octave higher than our fundamental, the apparatus can record only three overtones, and at that time only recorded two, numbers 2, 4, 6 and 8 in the male series. As the pitch of the fundamental rises, the number of accompanying overtones decreases, so that the highest soprano or falsetto tones are nearly "pure." In Fig. 9, we have Nordica's *ä* with its strong fundamental and its well marked overtones. Her *ee* in Fig. 10, is characterized by that same powerful fundamental, indeed it must doubtless be admitted that she has a truly great voice.

Fig. 11, is a photograph of Scalchi's voice. It will be seen that her *ä* is not quite so symmetrical as Fig. 9, being a little stronger in 2 and weaker in 3. This is much better than to have 3 stronger than 2.

The brilliancy of Calvé's voice may be accounted for possibly by the strength of 3 in her *ä* Fig. 12.

The remainder of the figures are as follows:

Fig. 13. Jean de Rezké *ä*		all of these tones are characterized by a relatively very strong fundamental.
Fig. 14. do.	*ee*	
Fig. 15. Eduard de Rezké *ä*		
Fig. 16. do.	*ee*	
Fig. 17. Arimondi *ä*		these tones seem a little forced, the fundamental is not strong enough.
Fig. 18. Cremonini *ä*		
Fig. 19. Ancona *ä*		

A careful comparative study of the above will develop certain individual characteristics, but we believe will also manifest the presence of a good strong backbone to the tone in its fundamental, together with a comparatively symmetrical supply of overtones to give fulness and flexibility.

The conclusion which we draw from these examples may be briefly stated. The above characteristics of a good desirable tone, with quality and carrying power not forced, can best be obtained by a use of the vocal mechanism which shall give to the larynx entire control of pitch by the intrinsic, involuntary muscles, leaving the *klang tint* or articulation, to the extrinsic, voluntary muscles of the pharynx, mouth, etc. One must always bear in mind the all important part played by resonant reënforcement in the mouth and nose cavities.

How can all this be done? The soft palate is the telltale. Take a small mirror, seat yourself with your back to a window or a lamp. So hold the mirror that the light is reflected into the mouth at the same time that you see the interior of the mouth reflected in the mirror. Study carefully the appearance of the mouth and pharynx when all the muscles are relaxed, then produce a tone without disturbing this general position of rest.

When this is easy for low tones, run up the scale, never permitting *any* motion of the soft palate or pharynx. When one can sing up and down the scale with the soft palate and pharynx stationary, it is pretty certain that the extrinsic muscles are not interfering with the action of the intrinsic. It must be remembered that this exercise is intended to train the intrinsic muscles in the complete control of pitch, independent of any action of the extrinsic muscles. After this is accomplished, a proper use of the extrinsic muscles and resonance cavities will give the tone its desired quality.

It is well to hold the nose, once in a while, to see if the tone is really coming out through the nasal resonators. Do not be discouraged and conclude it is impossible. It is being done by many, and with excellent results.

We have endeavored to express our beliefs upon this complex subject, and the reasons therefore. Our one object is to arrive at the truth. If we are in error, the sooner we know it the better. Hence we are glad to hear the other side, and to discuss the question.

If we succeed in lessening the number of voices wrecked by false methods, we have accomplished our purpose and shall feel amply rewarded.

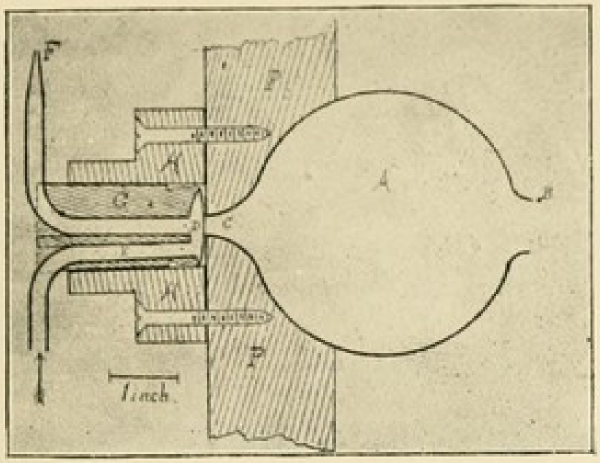


FIG. 3, p. 6.—Section of resonator and its manometric capsule. A. Resonator. B. Mouth of resonator where air-waves enter. C. Small extension through which the air-waves strike upon the rubber drum between D and C. D. Space behind the drum to which the gas enters through the tube E, and from which the gas passes out and burns at F. G. Wooden plug carrying gas tubes and hollowed out to form the space D. The rubber is stretched and tied over the end of G. H. Block to hold G. P. Plank on which the whole is mounted.

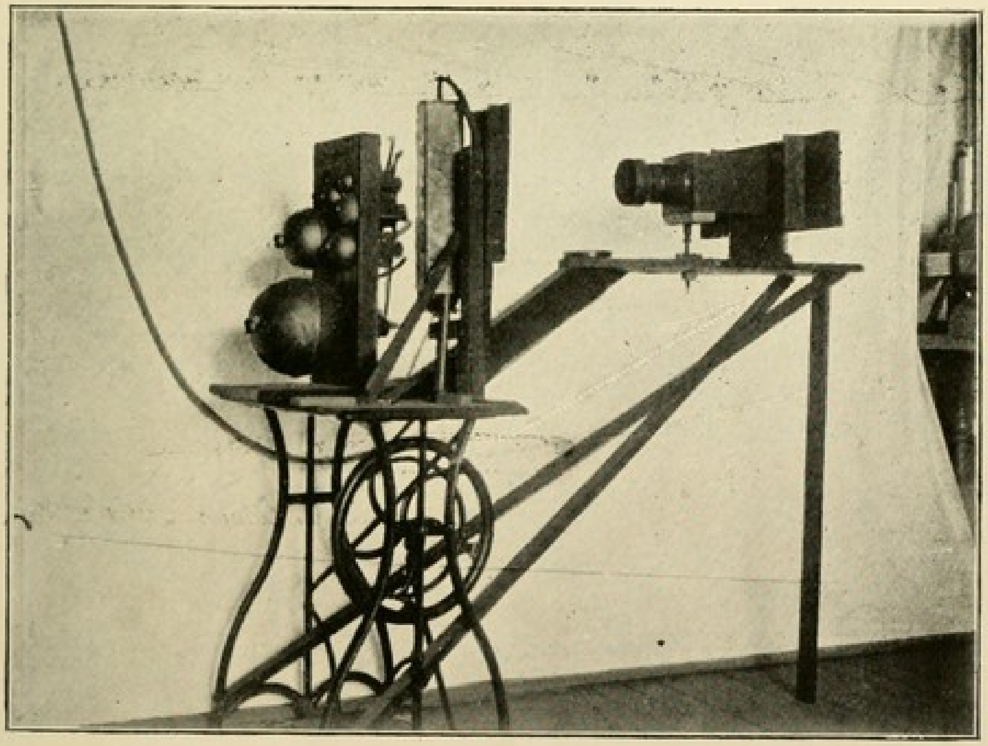


FIG. 4, p. 8.—General view of the apparatus showing the resonators, the rotating mirror and the camera at the back.

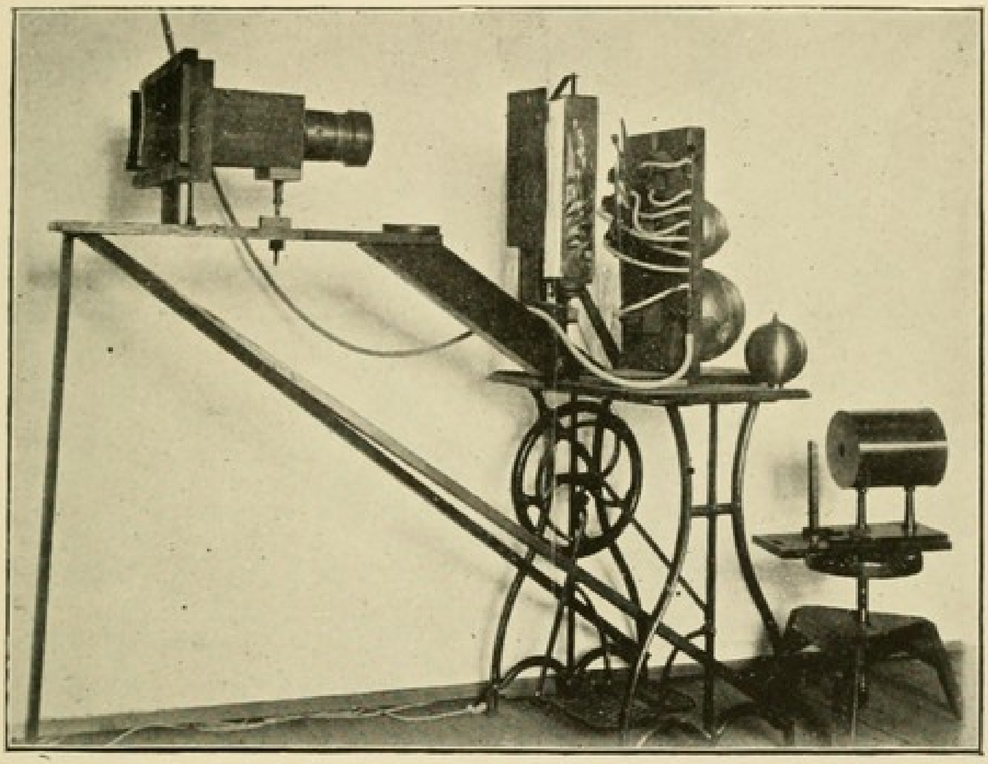


FIG. 5, p. 8.—General view showing the capsules and their attachments, the flames reflected in the mirror, and the sliding plate-holder at the back of the camera. A spherical resonator stands on the corner of the table and our standard tuning fork with its cylindrical resonator is on the low stool.

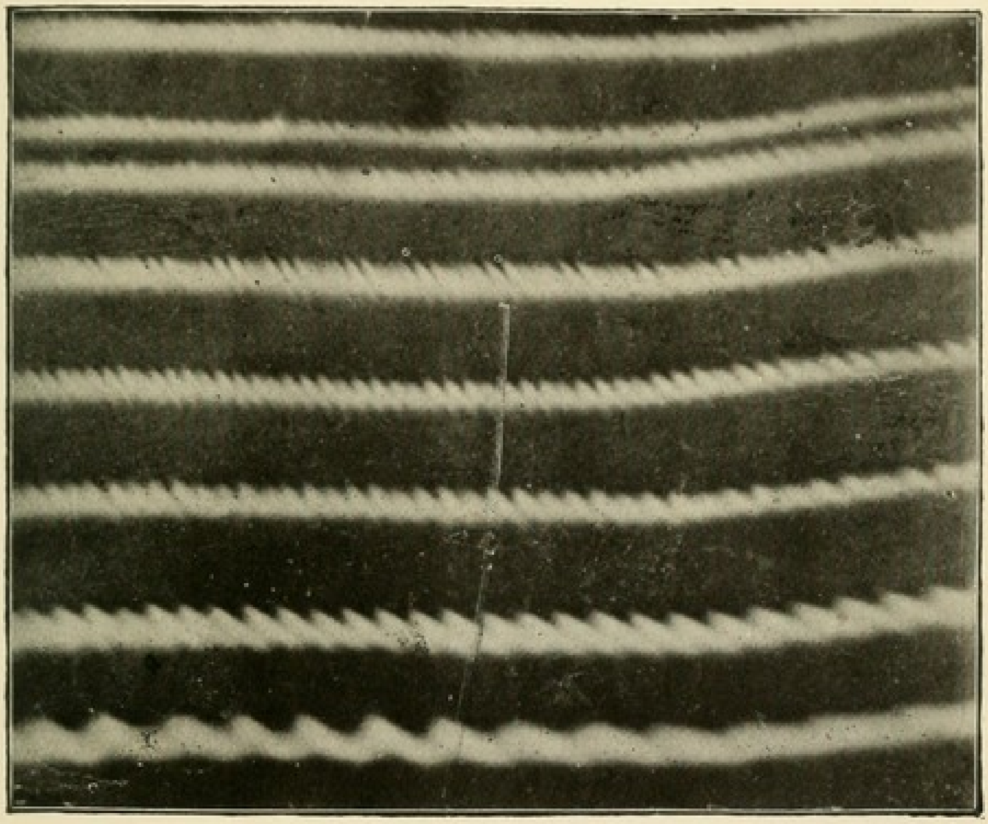


FIG. 6, p. 8.—Photograph of the motion of the flames while singing the vowel ä as in father. The lower line is the fundamental, and the others are the 1st, 2d, 3d, etc., overtones in the order of their pitch. One wave of the fundamental corresponds to two in the first overtone, three in the second, four in the third and so on.

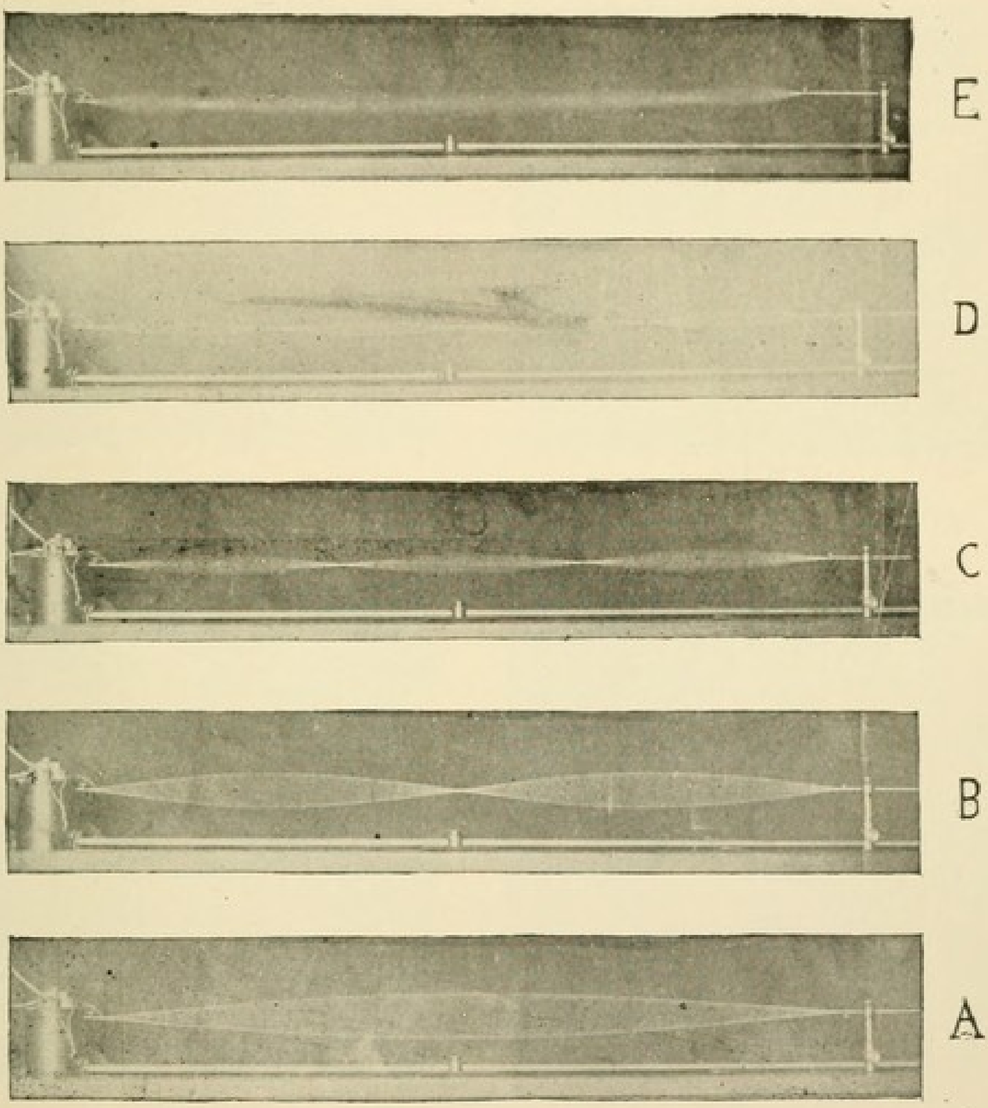


Fig. 1, p. 178.

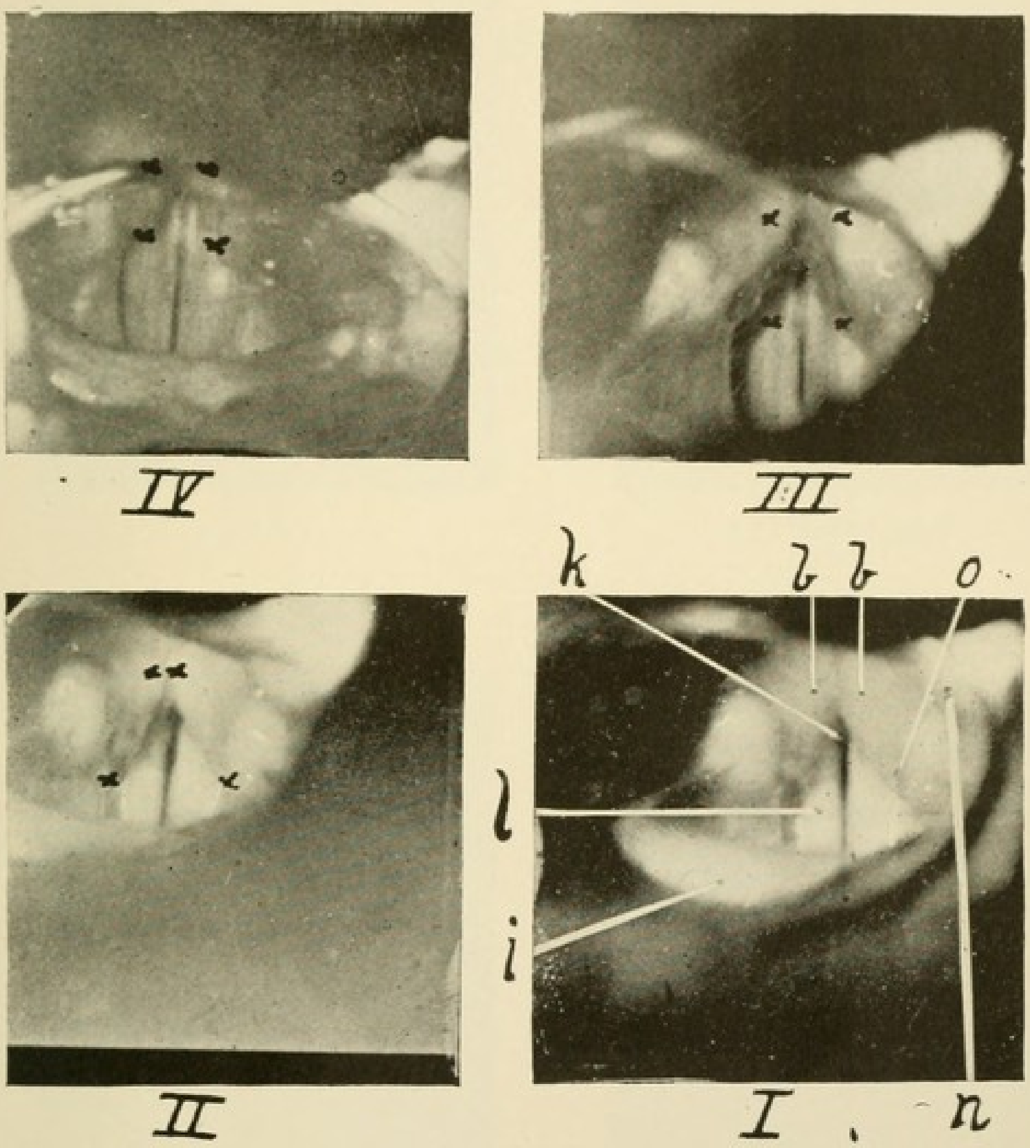


Fig. 5, p. 182.

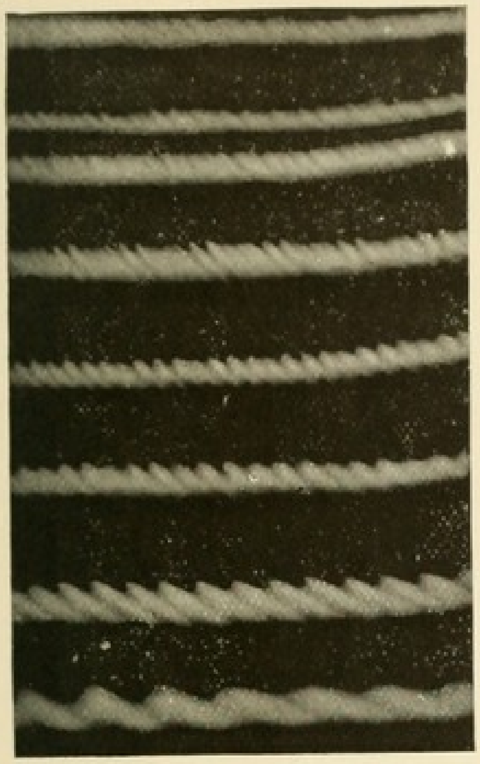


Fig. 1, Art. III.

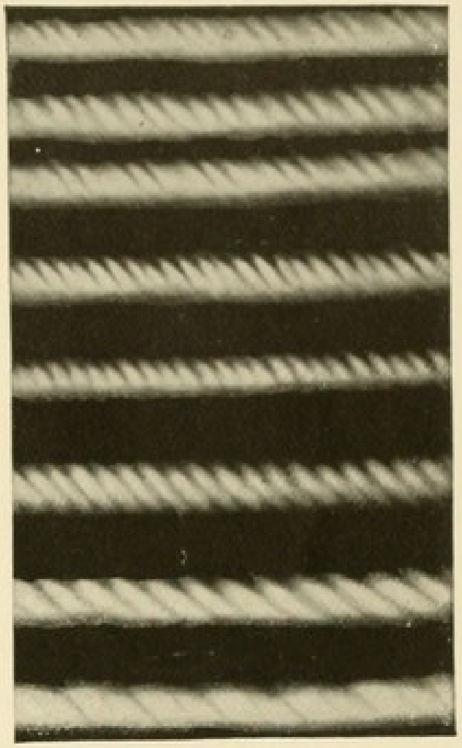


Fig. 2, Art. III.

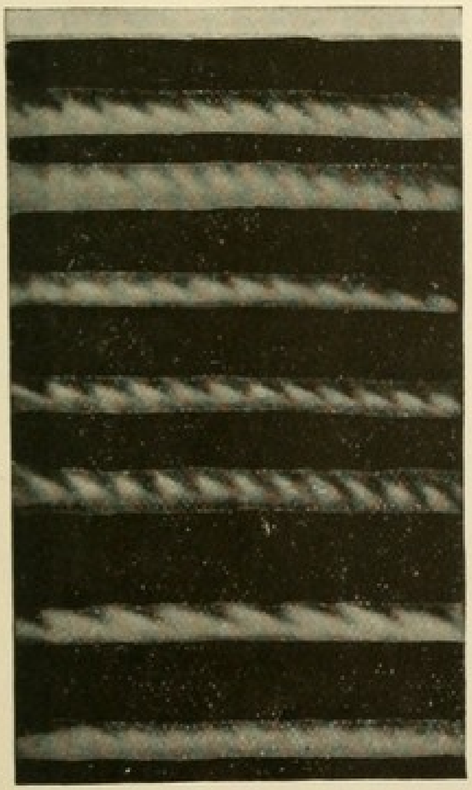
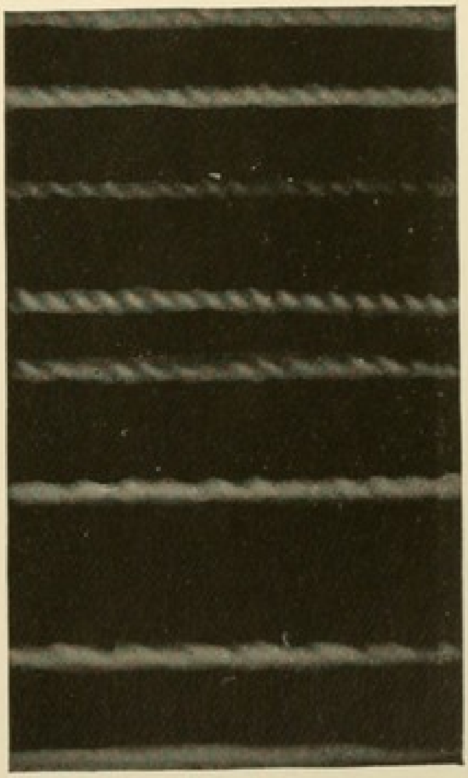


Fig. 3, Art. III.



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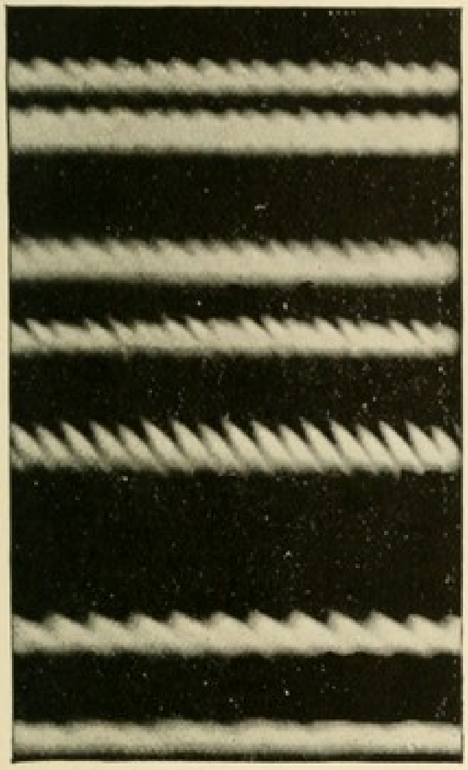


FIG. 5, ART. III.

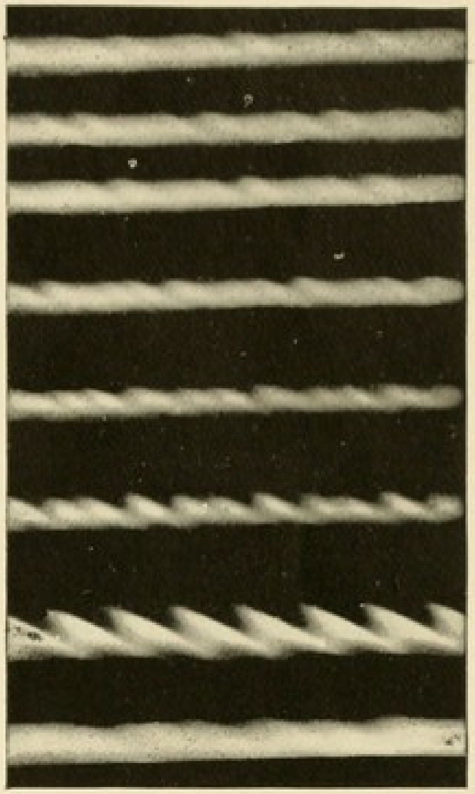


FIG. 6, ART. III.

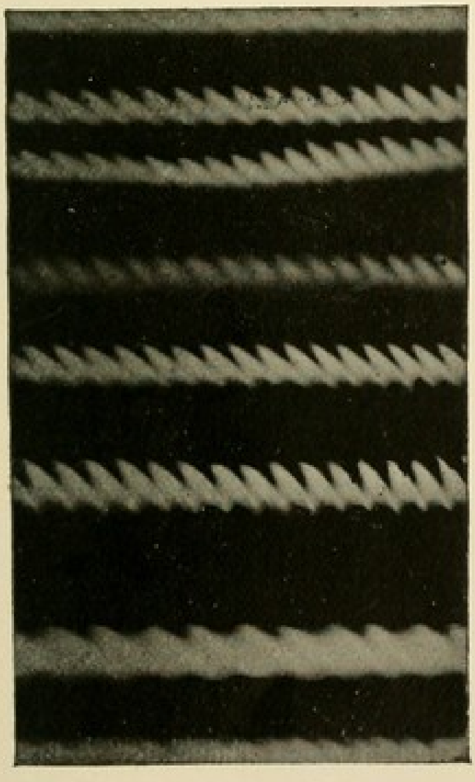


FIG. 7, ART. III.

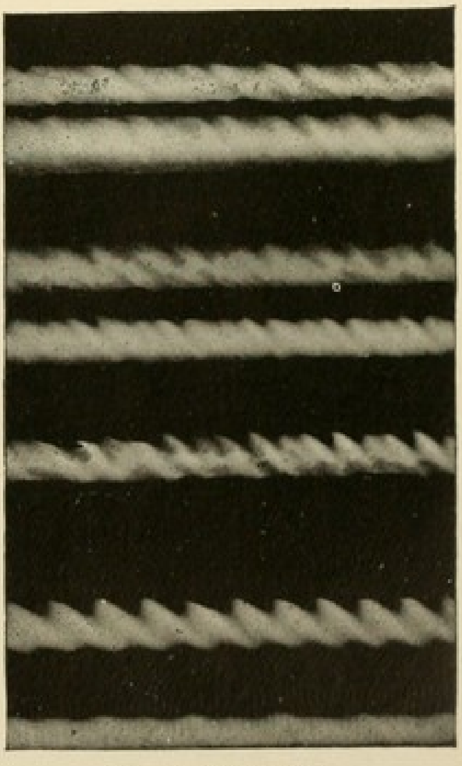


FIG. 8, ART. III.

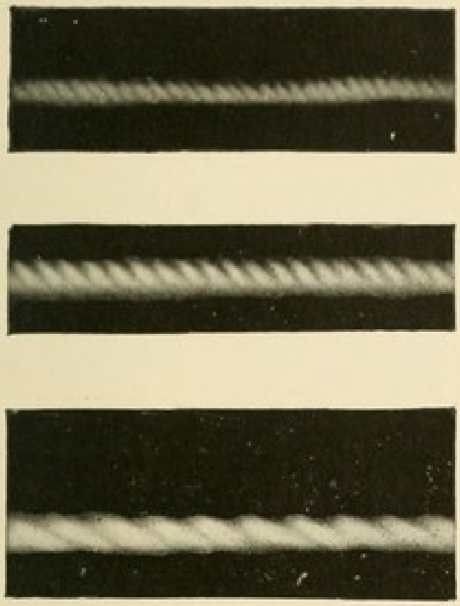
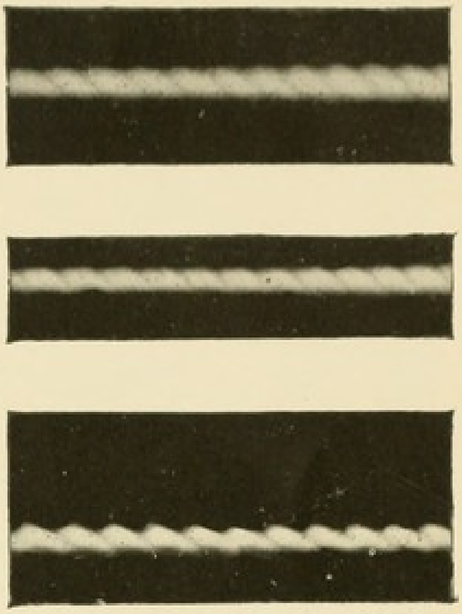


Fig. 9, Art. III.



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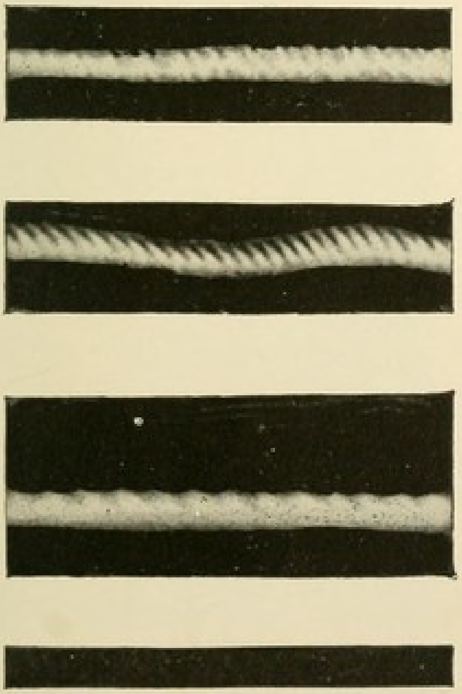

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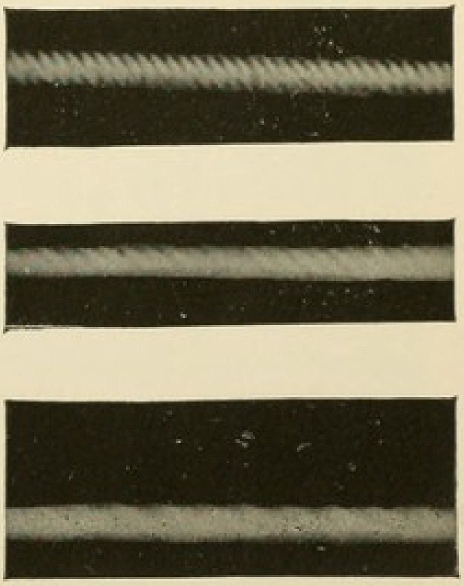
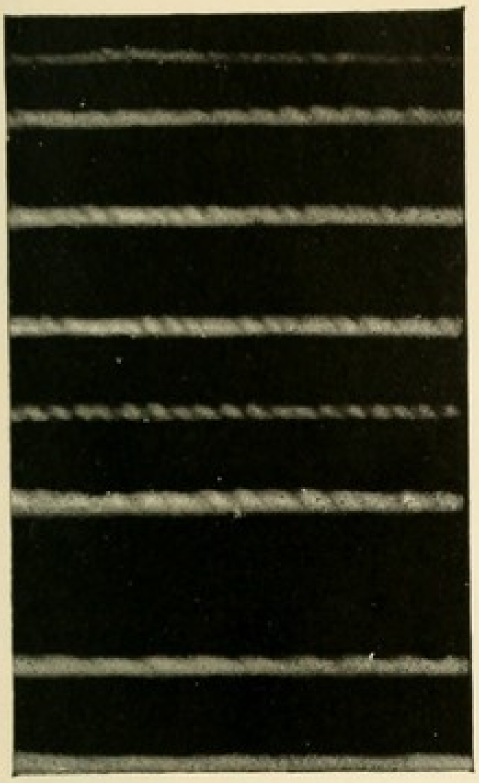


Fig. 12, Art. III.



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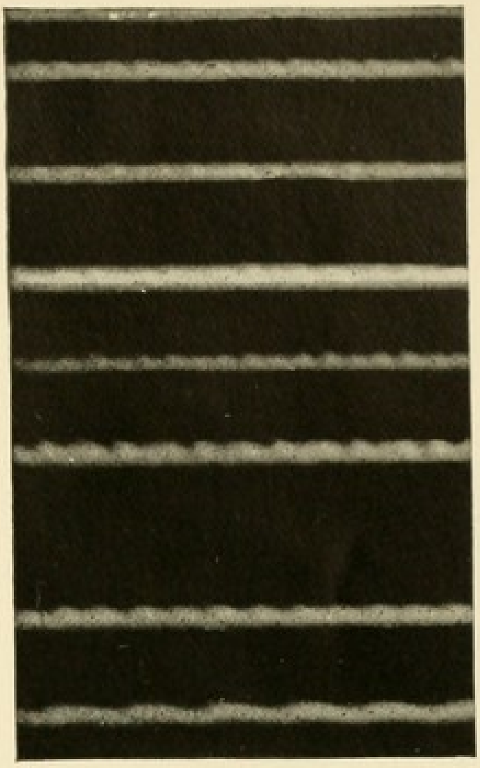

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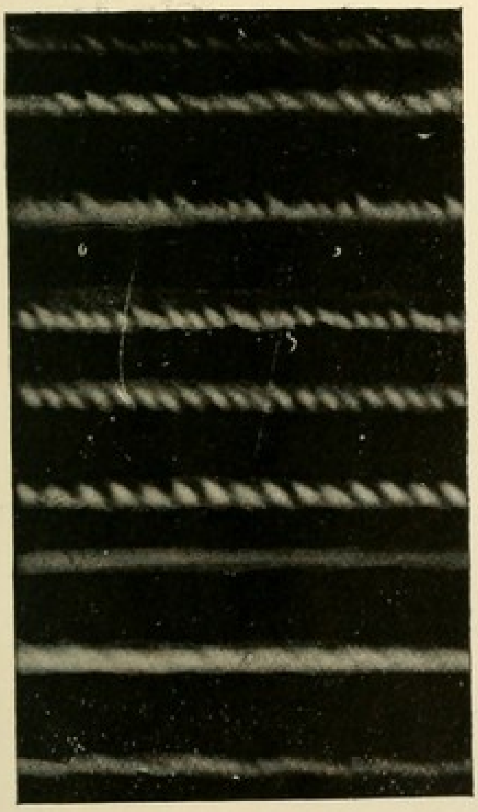

Fig. 15, Art. III.

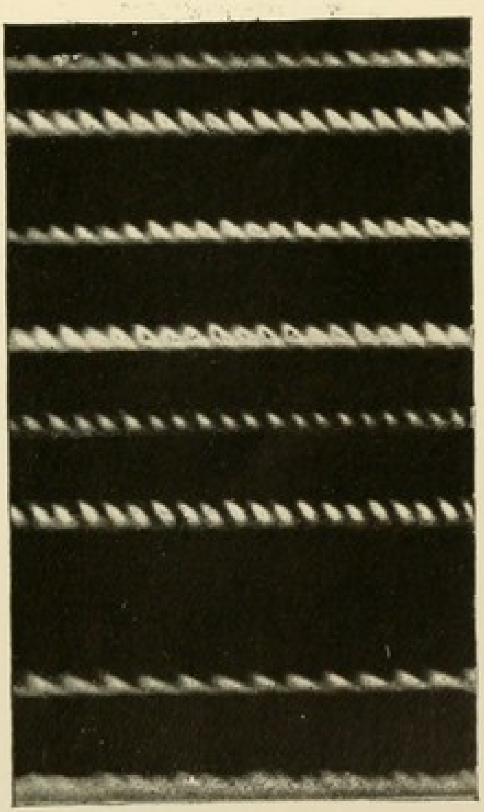

Fig. 16, Art. III.

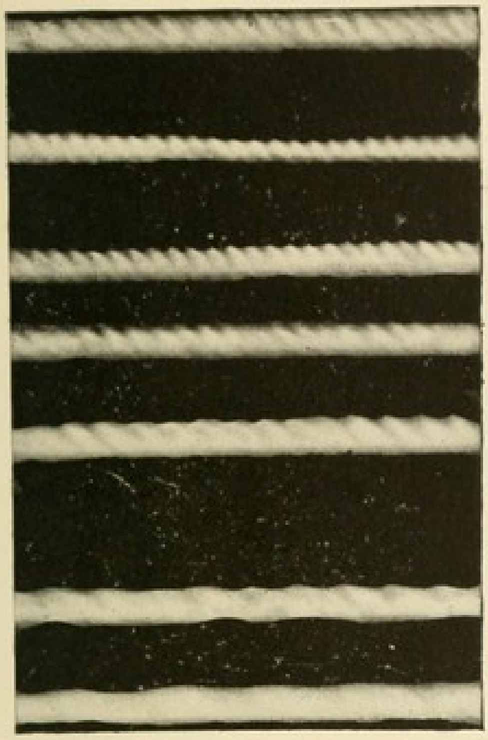

Fig. 17, Art. III.

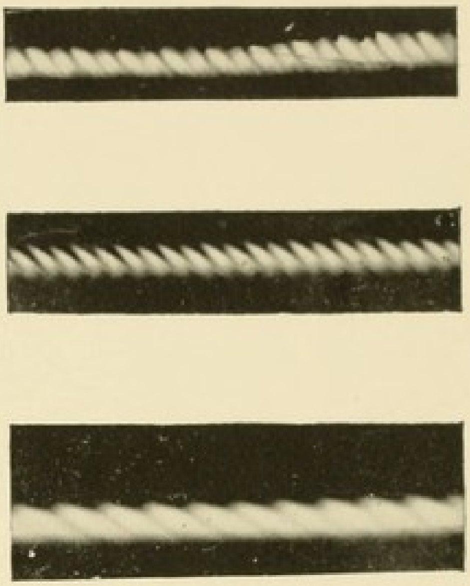

Fig. 18, Art. III.

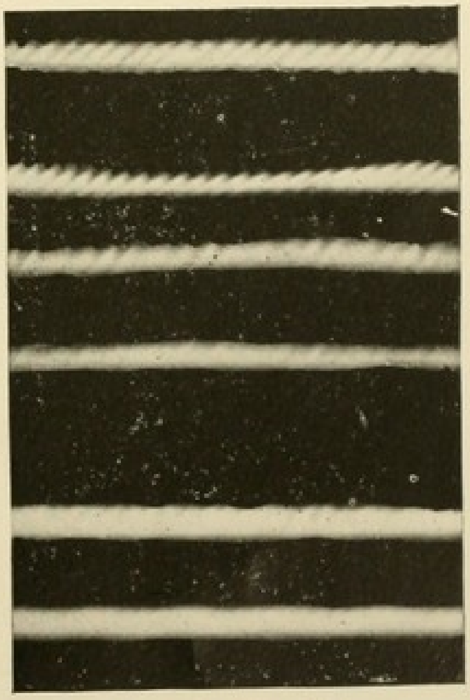

Fig. 19, Art. III.