AN EXPERIMENTAL ENQUIRY INTO THE NATURE OF THE OBJECTIVE CAUSE OF SENSATION.

BY JOHN B. HAYCRAFT, M.B., B.SC., F.R.S.E.

Professor of Physiology, Mason College, Birmingham.

THE present lecture, recently read before the Birmingham Philosophical Society, is an extension of a short communication to the Royal Society of Edinburgh,¹ and includes an account of some experiments conducted in my laboratory in the Mason College, together with a discussion of some general psychological problems.

If a stimulus, say a rapidly interrupted electrical current, be applied to the body for a definite period of time, it will of course produce a sensation; but that sensation will not coincide in time with the stimulus that produces it. In the first place, the sensation will not commence as soon as the stimulus is applied, and secondly, it will continue after the withdrawal of the stimulus. In the first part of this paper we shall discuss this non-coincidence in point of time between duration of the sensation and the stimulus.

The sensations have their seat in the brain, and the impressions require a definite time before they can reach this part of the body, situated as it is in so central a position.

FIG. 1.

Let A, Fig. 1, represent a particle (cell) at the surface of the body which is stimulated; B, a nerve passing from it towards a sensitive particle (cell) C in the brain. A definite time

¹ Proceedings R.S.E., 1883, p. 246. Abstracted in "BRAIN," April 1884, p. 141.

must elapse before A is excited by a stimulus, and the impulse thus set up has time to travel along the nerve B and throw into excitement the cell C. A nervous impulse travels no faster than some forty yards in a second, and from this factor alone—allowing three feet for the average length of a nerve path—the sensation will be delayed one-fortieth of a second.

But the sensation remains after the stimulus has been withdrawn. If I pin a small patch of red paper near the edge of this wheel, and then cause it to revolve, you will observe that the red patch moves round, then it appears to elongate, and finally, as the speed of rotation increases to some ten or fifteen revolutions per second, it is seen in the form of a complete red ring. You will remember, too, that in the firework known as the "Catherine Wheel," one part alone is alight, yet, when it revolves, one sees a ring of flame.

What is the explanation of this? At any given instant the patch of red or the coloured flame is at one spot only; how is it seen as if it were at all points of the circle in which it moves? This is very easily explained, for the sensation produced by the patch remains after the latter has moved away, and if we suppose that the patch starts from a certain point and revolves so rapidly that it comes back to that same point in a period of time less than the time that the sensation remains, we shall be sensible of a continuous ring.

This may be demonstrated in another and perhaps a more conclusive way. I will attach the patch of red to a steel spring, which can be caused to vibrate. I will now set the spring in such a manner that it will appear five times during each second above this screen, disappearing five times below and behind it. You are now conscious of a flickering sensation, but on altering the spring, so that it may vibrate ten times instead of five, the red patch appears continuously in front of the eye. The red object is, however, being continually withdrawn from view for periods of one-twentieth of a second. The sensation must, therefore, persist for this time.

In the case of hearing, Helmholtz found that when the "beats" follow one another at the rate of twenty or thirty a second, they cease to produce individual impressions, fusing

into a jarring grating, rough sound, which may be heard even when 130 beats affect the ear during the same interval.¹

Physiologists tell us, that in the case of tactile sensibility no less than 1,400 impressions must stimulate the finger tip before they become fused. This statement is or is not correct, according to our interpretation of the word "fused." If it is meant that then, for the first time, they cease to produce individually a sensation, it certainly is not true. At most it is a very superficial description of what may with care be observed. Touch this revolving toothed wheel. On turning it very slowly, each little tooth will be felt in its turn, and will be recognised by a separate feeling of impact.

Increase somewhat the speed of rotation and it will be no longer possible to recognise each separate impact, but a sensation will be produced which we call "roughness." Rotate more rapidly, and the wheel will feel of a finer and finer roughness, until, when 1,400 teeth are brought in contact with the finger tip during the period of a second, it will feel like a rotating smooth wheel producing merely a shearing or displacement of a portion of the skin touched.

There are, then, *three* periods. In the first, we can distinguish in consciousness each individual impact and the gap which separates it from the next impression. In the second, they have lost their individual character and produce a sensation—"roughness." In the third this feeling changes into that of smoothness.

These periods are not sharply demarcated one from another, yet one may state approximately in one's own experience where one begins and the other ends. In my own case impacts as rapid as forty per second are recognised as distinct; forty to 1,500 produce roughness, and above that number a sensation results similar to that produced by a rotating smooth wheel. The number forty is probably too high. With very strained attention, I sometimes fancy I can distinguish as many impacts in a second. Perhaps it would be safer to put it down at thirty.

These numbers were determined by allowing a vibrating

¹ "The Sense of Tone, as a Physical Basis for the Theory of Music." Eng. Trans., p. 253. In English works Helmholtz has been generally misquoted. He never says that 130 beats may be heard individually in a second.

steel rod to strike the finger tip. Its pitch could be varied at will by weighting it or by altering its length, and could exactly be determined by arranging it so as to write on a smoked cylinder revolving at a known speed.

We can see, from the results of this experiment, striking analogies between the sense of touch and the senses of sight and hearing. In the case of the red object attached to the steel spring, in the case of the beats, which are intermittent sounds, and in the case of the revolving toothed wheel, we find that on increasing the frequency of the stimulus the sensations pass through three distinct stages. In each case the slowly intermitting stimuli are formulated separately in consciousness, each is followed by a period of rest, and then another is felt. Such slow periodic stimuli may be productive of great pleasure.

FIG. 2.

Slow beats may produce considerable artistic effect; the ticking of a watch and the "passes" of a hand over the skin may induce hypnotism. Slow intermittent stimuli are pleasurable and soothing—instance the rhythm of poetry and the rocking of a cradle.

Let the line A indicate the time of application of a slowly intermitting stimulus. The line A' shows the duration of the resulting sensation. The two lines are arranged in vertical series. When they rise above the abscissal line, they indicate respectively that at that point the stimulus is being applied or the sensation felt. On striking below the abscissal line, the stimulus is being withdrawn in A, and the sensation ceases to

be felt in A'. These lines indicate in a graphic way the condition of things in this first stage; two sensations being separated one from another by a period of rest—the curve descends below the abscissal line

When, however, the frequency of the stimulation is increased, so that they are no longer individually felt, you obtain a continuous sensation, which varies periodically at first in its intensity, and indeed in the first part of this stage we may be conscious of this variation. This may be graphically represented (B and B'). The curve B represents the stimuli which are seen to follow one another more closely. In B' the sensations have not time to disappear before the result of the next stimulus follows on.

The sensations are now as unpleasant as those produced by slow intermission are pleasant in their nature. Few things are more annoying than the flickering of a gas jet. Helmholtz has shown, that the cause of dissonance in music occurring when certain notes are sounded together is caused by the *rapid* beats they produce. When this wheel revolves so that thirty or forty teeth touch the finger tip, you remark that it feels rough, a term standing for a sensation or idea which is not of a pleasant kind. Thus we say "a rough fellow," meaning thereby a man whose activities are not of an agreeable nature. In the case of touch, and also of hearing, this second stage is much prolonged, being still of a disagreeable nature, although the sensation is absolutely continuous.

In the third stage the sensation is also continuous, and is not to be distinguished from a stimulus constantly applied.

Why stimuli, differing only in their frequency of application, should produce such different effects on the organism we cannot say. This question is, to a certain extent, out of the range of present experimental inquiry, and its consideration must therefore be postponed. It is enough that we can state this general psychological law, which applies to senses such as touch, sight, and hearing, where the sensations coincide pretty exactly in time with the stimuli which produce them, but not for the senses of temperature, taste, and smell, where the limits of the sensations are very diffuse. "Slowly intermitting stimuli are followed by slowly intermittent

sensations, which intermittence is pleasurable, provided the stimulus itself be not of a disagreeable nature. Increase the frequency, and the sensations become fused into a disagreeable rough sensation; and finally, in the third stage, they produce a continuous smooth sensation, not to be distinguished in quality from the same stimulus constantly applied." It is a curious fact, that in tactile sensibility the same sensation is produced, whether a single portion of the skin be stimulated in rapid succession, or a stimulus be rapidly applied to a series of sensory surfaces, one after the other. Roughness is produced, whether you place your finger against a revolving wheel, or draw the smooth edge of a knife, held vertically, along the front of the finger. In all cases it is combined with tickling, if the stimulation be very light. Hold a tuning-fork, set in vibration, against the lip; it tickles intolerably; draw a pin along the lip, and the same feeling is produced. Of course you are aware of the difference between the two, because the location is different. Both produce tickling. In one case this is associated with contact at one spot, in the other with contact shifting along the lip. The feeling of tickling and of roughness seems, then, to be produced whenever a series of nerve impulses, following one another in rapid succession, reach the sensorium, no matter whether they all came from one sensory point, or each one from a different sensory surface.

As no experiments, so far as I am aware, have been conducted upon the coincidence in time between the stimuli and sensations in the sense of temperature, I undertook a series, a portion of which I will now describe.

Touch this iron ball, which is a good conductor of heat, and you will be conscious at once of a sense of impact, but only after a very appreciable interval will you feel that it is cold. On withdrawing the hand the sensation of cold remains for some time. Obviously, the coincidence in time is not so exact in the sense of temperature as in touch. For more exact study of these phenomena I have used a very simple piece of apparatus. A long and slowly vibrating rod, 3ft. to 4ft. long, was fixed to an iron vice, and to its free end a glass bottle was attached. To this was fitted a cork, through which passed an

iron rod. The bottle was filled with a mixture of ice and salt, which cooled the rod in its whole length. The vibrating rod brought the cooled rod periodically upon the finger tip; it was held there for half a second, or long enough for it to be felt as a cold body, and then allowed to swing back. It was found that if the iron was brought periodically in contact with the finger, each time after the lapse of a second a continuous and uniform sensation of cold was produced; if after a second and a-half, each impact was associated with a *separate* sensation of cold. The sensation remains for more than a second after withdrawal of the stimulus, but not for so long as a second and a-half. As will be presently shown, the same results are not obtained when other parts of the body are stimulated.

Sensations of cold and heat, as well as of impact, result from stimuli applied to the surface of the skin. Remove this, and the subjacent bones and muscles are found insensible to these stimuli. Now the skin is a large and extensive tissue, and microscopical sections taken from various parts show considerable differences. Some parts are more richly supplied with nerves than others, and these are regions where sensation is acute. In many places the horny outer layer, into which the nerves do not pass, is very thick, and it may be developed into protecting structures, such as nails and hairs. The experiments on tactile and thermal sensibilities, recorded in this paper, have been made with the skin of the finger tip. Let us extend the enquiry, and examine other parts of the skin. It is well known that all parts of this tissue are not equally sensitive to touch. The skin of the finger tip and the front of the hand can be stimulated by the impact of a lighter body than will affect the skin of the back of the hand. Again, the skin of the front of the arm is more sensitive than that of the dorsal surface, and still more so than the skin covering the shoulders. Together with this difference in actual sensibility, the brain is unable to localise impacts which affect the less sensitive parts so exactly as those which affect the more sensitive parts. If the points of a pair of compasses, less than one millimetre apart, touch the finger tip, they may be distinguished one from the other, but over the skin of the

back they may be held over an inch apart, and yet give rise to only one impression. This difference, not to be discussed here, is due (partially, no doubt) to the arrangements of the peripheral nerves. What I propose to discuss is, whether the non-coincidence in time between the stimulus and the sensations varies with the sensibility and powers of localisation of the surface.

If a rod, vibrating some twenty times a second, be held to the finger tip or lips, sensations of distinct impacts may be felt. Allow the rod to vibrate upon a surface less sensitive, say the skin over the sternum, and the impacts are individualised almost as before. I should mention that inasmuch as the skin is less sensitive, the amplitude of the vibration and force of the impacts must be increased. There is little difference then, in this respect between the more sensitive and less sensitive parts. On experimenting with the toothed wheel applied to the sternum, it is impossible to obtain the finely rough sensations with rapid rotation which could be felt by the finger tip. This is probably due to the less sensitive nature of the surface, and the impossibility of pressing the wheel upon the skin in order to compensate for this without producing at the same time injury to the surface. We see, then, that in less sensitive parts the sensation coincides in time almost as exactly with an applied stimulus as in the case of the more sensitive parts, whereas the space-localisations are so different.

Let us now extend our observations on the sense of temperature to other parts of the body. Apply after intervals of a second a good conductor—say an iron ball—to the skin of the bare arm; distinct sensations will be recognised on each application, whereas a continuous and unbroken sensation is produced on touching the ball in the same manner with the finger tip. This is not due to the fact that the arm is usually protected, and in consequence might be conceived as less inured to cold, for the same obtains with the skin covering the forehead and lips. The difference is partly due to variations in the thickness of the epidermis—a bad conductor—which separates the body touched from the nerves situated in the lower layers of the skin. The corneous fingers of a working-

man allow but slow conduction and a sensation is perceived only after a lapse of two or perhaps three seconds.

In our study of the senses of hearing, sight, and touch, I have shown that we are able to perceive twenty or thirty sensations in a second, and, but one, or at most two, sensations of cold or heat may be felt. We find that the sensations of taste and smell, like those of temperature, spread over a longer period of time, and are not sharply limited in duration.

Herbert Spencer, in his "Principles of Psychology" (vol. i., p. 169), calls attention to this difference, distinguishing between peripherally initiated feelings caused by internal disturbances—some of which he says are extremely indefinite, and few or none definite in a high degree—and feelings caused by external disturbances which are mostly related quite closely alike by co-existence and sequence. He illustrates this by the fact, that our states of consciousness in connection with vision and hearing are more sharply limited in time and space than those in connection with smell and taste, and, still more, hunger.

Now, discarding the fact that when considered developmentally, the retina at any rate is far more internal than the mouth or nose, the former being really a portion of the brain, the latter puckering in of the surface, I would suggest that the all-important factor producing this difference is not anything in the brain, nor in the nature of the feelings themselves, as Herbert Spencer seems to me to indicate, but in the nature and arrangements of the end organs. If the point of a pin impinges upon the finger tip, the epithelium is depressed, and at the same time the nerves of tactile sensibility are stimulated, and on withdrawing the pin they are in a condition of rest. Also in the ear, the sound vibrations travelling rapidly into the internal ear cause the structures there (the basilar membrane and rods of Corti) to vibrate, and—as we are aware from our knowledge of the action of one vibrating body upon another—they do this very rapidly.

Far otherwise with the senses of smell and taste. When odorous particles pass into the olfactory or upper part of the nasal cavity—in which the nerves of smell are placed—it is by diffusion from the lower or respiratory part of the nose. If

the breath be held, and a piece of incense paper be burnt in front of the face, some time may elapse before the scent is perceived, because the odorous particles have in fact to diffuse into a closed sac, slowly increasing in numbers. If, on the other hand, the experimenter "sniffs" the air, the stimulus will be more rapidly perceived, because a large number of odorous particles are carried rapidly through the lower chamber of the nose, inducing out-currents from the upper chamber, which consequently becomes immediately filled by these. In like manner, the closed sac has to get rid of odorous particles from within it by this same slow process of diffusion, before the odour ceases to be felt. The application and removal of the stimulus is then a gradual process. The feeling produced is therefore gradual in coming on and slowly passes off.

In the case of the sense of taste, the same holds true. Substances held in solution are alone tasted; the tongue is covered with a layer of mucin derived from mucous and salivary glands, and the nerves are not superficial but embedded in the epithelial covering. It will be easily understood that in this case also the accession of a sensation must, from the nature of the stimulus, and the position of the end-organ, be gradual in its production and slow in passing off, and therefore not strictly limited in time. The watery solution has to mix in the first place with the mucin covering the tongue, before it can reach the end-organs situated in the epithelium.

In the case of hunger again, the limitations in time are due entirely to a condition of things other than mental. The fulness of the alimentary canal is associated with a feeling of comfort, and when no food is present there with a feeling of hunger; and as there is every conceivable transition between a condition of full stomach and an empty one, so the passage of the one sensation into the other must pass through innumerable transition states.

If it be needed, another example may be mentioned in the case of the cold body applied to the horny tip of the finger, and to the thin skin covering the sides. The nerve-endings are stimulated by the addition or withdrawal of heat from the

nerves of the skin. This is gradual, and does not correspond to the application of the cold body to the surface because of the horny epithelial covering. Where this covering is thin, the limitation in time of the sensation is more definite than where it is thick; and could we apply the cold body directly to the nerve end-organ, the limits would then be very sharply defined. Cover the hand with a glove, and the limits would be very ill-defined indeed.

Sufficient evidence has, I think, been adduced to show that where the limits of a sensation are not well defined in time, we may conclude that this is not due to anything in the nature of the sensorium, but depends upon the way the external energy is changed into nerve energy in the terminal end-organ.

Let me define a sensation as the result of a transformation of the energy travelling along a nerve of sensation from without, into the energy manifested by the nerve cell to which it passes. We have, I insist, no reason to doubt, that if that nerve energy travelled twenty times a second along a nerve of smell, of taste, hearing, or of sight, we should be conscious of twenty separate sensations in each case.

That such a transmission is impossible in every case we know, but it is due to the fact, that in these cases the nerve cannot be stimulated from without so frequently.

A theory advanced, that quality in sensation depends for its objective cause upon the "frequency" of the vibration of the stimulus which produces it.

The air may be caused to vibrate at infinitely long or infinitely short periods, and at all intervening rates. If I pull this long steel band which is fixed to an iron vice and then let it go, it will vibrate and set the air in motion. It is now vibrating some ten times a second, but, although the amplitude is very great, you hear no sound. Shorten the band, increasing therefore its frequency of vibration, and you hear a low deeply-pitched note. Continue to shorten, and the note becomes higher, and higher, and at last you can hear nothing at all. We see that here, at any rate, the different sensations you were conscious of depended upon the frequency of vibra-

tion of the air set in motion by the vibrating steel band. The steel band—and the same applies to other sounding bodies—not only vibrates as a whole, but also in parts, so that the air is moving in rather a complex manner. We have the movement of the air corresponding to the movement of the band, as a whole producing what is called the fundamental tone; and in addition, movements corresponding to vibrations of parts of the band, and producing the “harmonic tones.”

Now, the sensory quality which distinguishes one instrument from another—the difference say in the “sound” of a string stretched upon the sounding-box of a guitar, and another attached to that of a violin—depends upon a difference which these boxes produce in the number and strength of these harmonics; upon, in fact, the intensification of certain frequencies. The multitudinous sensations of the Concert Hall or Opera are produced by immense numbers of little waves, varying infinitely in periodicity, falling upon and stimulating the ear.

Much the same may be said of sight. A something called “Ether” may be thrown into vibrations, and these cause the sensations light and colour when they fall upon the retina. When a ray of light is passed through a prism, the vibrations of which it is composed are separated out in a scale called the spectrum. At one end, in the region of the ultra-red, we have slow vibrations. Like the very slow vibrations of the steel band, they produce no sensation. Higher in the scale where the rapidity is greater (some 481 billions per second) a sensation called red is produced. As we pass higher in the scale, the sensation changes into orange, then into yellow, green, blue, and last of all violet. Where still more rapid vibrations are found, namely in the region ultra-violet, no sensation—again the analogy with the steel band is seen—is produced. We see here again, that it is frequency or rapidity of vibration which determines the quality of the produced sensation.

For the last few years I have held as probable, that much the same holds for the senses of taste and smell, believing that just as a certain vibration will produce, say, a sensation of colour or of sound, so the periodicity of the vibrating particle given off from the scented rose, or of the molecule in solution,

will determine the sensation of smell or taste produced. This is now removed from the field of mere speculation, and one may look forward to a time, perhaps not far distant, when in a more advanced state of molecular physics one may be able actually to determine the rate of vibration of even complex substances; a time when the arrangement of a bouquet or menu may be as scientific as thorough-bass.

Professor William Ramsay, in a very valuable communication to "Nature" (June 22nd, 1882), has brought forward, I think, some very important facts as to the objective cause of smell. He finds that gases of very small molecular weight, and therefore of high pitch, are incapable, like the ultra-violet rays and the very rapid vibrations of the steel band, of producing a sensation. All the simple gases, and many of the compound ones, are odourless; in fact, a gas must have a molecular weight fifteen times as great as that of hydrogen, in order that it may be smelt. He has studied certain chemical series, for example hydrocarbons, such as the paraffins and olefines, which increase regularly in molecular weight. The lightest have no smell, but passing up the series odours may be perceived, which vary in quality, and increase as a rule in strength. There are many other points in this paper which show analogies between smell on the one hand, and sight and hearing on the other. It seems difficult, however, to find examples of very heavy gases which, like the ultra-red vibrations, produce no sensation at all.

I have myself been working at the sense of taste, and have been already able to arrange many familiar tastes in a scale or series, associating them in each case with definite molecular vibrations. The subject is not, however, so complete as I should wish, and I have postponed its publication.

I have been also able to arrive at similar conclusions in respect to touch. Let me ask you, Mr. President, once more to touch this revolving toothed wheel. I turn it very slowly, and you feel each separate tooth. Increase its rapidity they fuse into a sense of "roughness," and as I continue to increase the speed you pass through every possible degree of sensation from a coarse to a fine roughness, and finally, it is rough no more. We have here, in fact, quality of sensation depending

upon frequency of impact. There are a hundred grades of sensation intermediate between a very coarse and a very fine roughness. These are not grades of quantity, but of quality.

It is true, certainly, that there may be a difference in quantity, but that is because on rapidly rotating the wheel we cannot *press* the finger against it without fear of injury. It is equally true with many sound instruments. On increasing the revolutions of a syren the music is at first low and voluminous, then it becomes higher and less voluminous, but more intense. The higher notes of a piano are weaker than the lower ones.

A moment's consideration will suffice to show, that this "roughness" is as much a sensation; with qualitative variations, as taste and smell. It is incorrect to say that it is a sensation of intermittent stimulation, although it is a sensation *produced by* intermittent stimulation, which is quite another thing. From our very earliest infancy the objective cause of the sensation has been known to us, yet at first it must have been gained entirely by experience, which without the assistance of the eye would have been very difficult. We can no more be said to be conscious of 1000 impacts in a second of a toothed wheel, than of 256 vibrations of a wire when the lower C on the piano is sounded. In both cases we have definite sensations, and in both cases we have been able to associate these with their objective causes. A practised musician on hearing a note sounded might name it, and tell the period of the string that produced it. After long experience with the sense of touch, after careful attention to the sensations, after careful experiment conducted to find the exact frequency of impact producing these, it would also be possible to say of a given sensation, that it is produced by so many impacts per second.

It may further be objected, that an intermittent impact is not the same as a vibrating stimulus. In one case the skin is stimulated for a certain time, and then it is stimulated no longer, whereas when a sonorous vibration stimulates the organ of Corti it is thrown into periodic movement, alternating in direction, and without a break in its continuity. This difference is more apparent than real. A child upon a swing may be kept in motion in either of two ways. In the first case,

by a force applied, say by means of the hand, which shall adapt itself in every way to the pendulum action of the swing, varying in the direction of its application and increasing in amount as the lowest point is reached. This represents one vibration producing another. The vibrating arm causes the swing to vibrate. Or secondly, the swing might be set or kept in motion by short pushes, synchronous with the period of the swing. This, of course, represents an intermittent force producing a vibration. We see, then, that although the toothed wheel is applied periodically, and is not in itself a vibration, it may produce a vibration of the skin. Indeed, as the skin has "mass," this must be the case. In all cases, it is the vibration of the sensory surface which is transformed into nerve impulse, it matters not how this is produced. It need only finally be added that it is possible to stimulate the skin with true mechanical vibrations, which produce the same effect on the nervous system as the toothed wheel. Instead of the ordinary toothed wheel, use a grooved wheel, the border being regularly curved. Apply the finger to its border, or place a vertical metal spring, fixed at one end to the vice, between it and the finger, so that on revolving it pushes the spring alternately forwards and backwards. In this case the motion will be a true vibration. We have then in touch, as in sight, hearing, taste, and smell, not only quantitative variations, but in addition a *scale*, each part of which is quantitatively different from the rest.

There is yet another sense, that of temperature. Its study in this connection is most interesting.

Lord Bacon anticipated some of the results of the Dynamical Theory when he stated his belief, that heat was a kind of motion or agitation of the particles of matter. The ultimate particles of gases, liquids, and solids are probably in constant periodic movement, and these movements may be transformed into nerve impulses. As in the other senses, certain specific structures are necessary for this transformation; they are found in the skin. Bring a live coal near the hand; its particles are in a state of great agitation; it induces similar motions in the skin, and these are transformed into nerve impulses, which, passing to the brain, produce a sensation—

"heat." If we stop to consider for a moment the various heat sensations of which we are conscious, we are struck with this very curious fact, that there is an entire absence of *quality* in this sensation. We may have in the other senses different qualities and kinds of sensation, and these may, in addition, vary in amount or quantity. There is nothing in the sense of temperature which corresponds with pitch in music, or colour in sight. We have "more heat" or "less heat," but it is always of the same kind. We cannot distinguish the heat of a hot potato from that of a piece of iron at the same temperature.

We must not be deceived by the terms "hot" and "cold." These are not qualities, but two quantities relative to the body temperature. In the same way we have light and darkness, sound and silence. Just as darkness may be less light, so cold is less heat—indeed the darkness, by common experience, may after a time become relatively light, and the cold may become relatively warm when afterwards compared with super-added sensations. Pass from a light into a dark room; you can see nothing. In a few minutes you become sensible of light. Plunge your hand into tepid water after warming it in front of the fire, and it feels cold. Now place the hand in ice-cold water, and then into the tepid fluid, and the latter feels quite warm.

There is, then, nothing of the nature of a qualitative difference in our sense of temperature, and curiously enough there is nothing which, according to our theory for the production of quality in other senses, would produce quality in this.

Physicists tell us, that when a body gains in temperature its molecules continue to vibrate at the *same rate or frequency*, increasing only in *amplitude*. When the skin is heated, from whatever source, its molecules do not vibrate either more quickly or more slowly than before. We have, then, objectively no difference in frequency of vibration, and subjectively no difference in quality.

The experiments of Kirchoff and Balfour Stewart tend to show, that at very high temperatures certain "partial" vibrations become more pronounced, but before these temperatures

could be reached the skin would be entirely charred. These temperatures are therefore outside the range of our enquiry.

Returning once more to the study of tactile sensibility, the usefulness of a sensation will depend upon two things. In the first place, it will depend on the extent of the scale of quality which is present, and in the second upon the smallness of the difference of quality that we are able to appreciate. In sound we have some eight or nine octaves, which can produce sensations; and towards the middle of the scale a practised musician is said to be able to distinguish two notes one-sixtieth of a tone apart. In sight we have barely an octave, yet within this small scale we are very sensitive to minute intervals. How about the sense of touch? Taking twenty-five for the lowest number in the sense of roughness, and 1,500 as the highest, we have nearly six octaves; more than in sight, but not so many as in sound.

FIG. 3.

Within this scale what differences can we discern? To investigate this question I have constructed the following instrument, which may be called the "touch-board."

It consists of a series of steel bands radiating from a centre, and bounded by two concentric arcs. These are fastened by their edges to a board, and are kept "taut" by wires passing to metal pins. On the right-hand side the interval between the bands is one centimetre, but to the left it is only half a centimetre. On drawing the forefingers of the two hands across the bands with the same velocity and placed at both extremities, the right-hand finger will be stimulated twice as often during the same time as the left, giving a difference which may be compared with the musical octave. Intervening points—not shown in the cut—are placed on the board, corresponding to thirds, fourths, &c., down to a quarter of a

tone. In practising with this instrument the operator must be blindfold, and another person should be present in order to reverse the position of the touch-board. This is absolutely necessary, for the imagination has much power in this kind of experimentation. In my own case it is perfectly easy, without a previous experimental course, to distinguish the intervals down to a semitone. I do not think I am more sensitive to roughness—differences—than others who use their fingers. No doubt those engaged in many trades, where there is constant testing of the roughness of materials, could distinguish smaller intervals. In the case of the blind, too, this sense is of great importance. I have not yet tried a blind person with the touch-board, but I should expect, that in this case very small intervals indeed could be detected.

In music, we find that small intervals are not distinguished so readily in some parts of the scale as in others. Thus towards the extreme upper limit, one may be unable to distinguish two notes a semitone apart. It is the same with touch. If the hands are drawn very rapidly across the board, the smaller interval cannot be made out. Towards the extreme upper limit I am able, however, to distinguish an interval of a third.

The sense of roughness, to which so little attention has been given, is yet of great importance. It has qualitative variations, almost as great as the musical scale; and the sensations are definite, and may be distinguished fairly sharply one from another. It is by this sense of roughness that we learn much of the nature of the external universe. By it we distinguish the roughened border of a file, the granularity of a surface, and the texture of a fabric. Its study has not engrossed the minds of physiologists and psychologists, because of the prevalent idea that it is merely an intermittent sensation, resulting from intermittent stimulation. This we have shown not to be the case.

Let us turn to the larger question, namely, that quality of sensation is objectively determined by frequency of stimulation. In the senses of sight and hearing this is undoubtedly the case. I mentioned that strong evidence has lately been brought forward in favour of smell, and some experiments of my own on taste tend towards the same result. In touch, too, we have

a curious example of a sense where subjective quality evidently depends upon objective frequency of impact. A curious negative proof is furnished in the case of temperature. Here we cannot be said to have any subjective quality at all—merely a sense of quantity. On studying objective temperature we find that the molecules of bodies, when heated to different temperatures, do not vibrate at different rates, but only at different amplitudes. Here we have no variations in objective frequency, and no variations in subjective quality.