perature, and adopting that of the fusing-point of the metal as determined by Balfour Stewart, we get

From A	.....	14·1948 at	−38°·85 C.
„ B	.....	14·1920 „	„
„ C	.....	14·1929 „	„

and, as a final mean of these three, 14·1932 *as the number representing the density of solid mercury at its fusing-point as referred to water at 4° C. taken as unity.* I think this result (which, it will be seen, differs considerably from the figures hitherto quoted) may be fairly accepted with confidence.

In these experiments most of the weighings were made by Adjunct Professor Dunnington, and the freezing-mixtures were managed, at no small cost of personal discomfort, by Messrs. Bryan and Memminger, students in this Laboratory. To these gentlemen my thanks are due.

IV. "The Automatic Action of the Sphincter Ani." By W. R. Gowers, M.D., Assistant Physician to University College Hospital. Communicated by J. S. Burdon Sanderson, M.D., F.R.S., Jodrell Professor of Human Physiology in University College, London. Received February 24, 1877.

The observations described in the following paper had for their object the determination of the form of the reflex or automatic action of the sphincter ani of man when voluntary power over it is lost. This reflex action is believed, from the researches of Masius*, to depend on an "ano-spinal centre," situated in the lumbar enlargement of the spinal cord, controlled in health by higher (encephalic) centres. It appears, however, to be very uniform in its character in various conditions, the most conspicuous common character of which is the entire loss of voluntary power.

The larger number of observations were made on a man who, by a violent fall on the sacrum, had apparently injured the posterior roots of all the sacral nerves and both roots of the lowest sacral nerves. A depression existed over the lower part of the sacrum. Sensibility to touch and pain was lost in all parts supplied by branches from the sacral plexus, the limitation being exact. There was no muscular paralysis or loss of nutrition except in the levator ani, the sphincter ani, and the sphincter vesicæ, all of which were paralyzed to the will. The anus and the mucous membrane of the rectum were quite insensitive. There was no evidence of any injury to the spinal cord; with this, indeed, the symptoms were incompatible. It would thus appear that the only lesion was a division of the direct communication between the sphincter

* Bull. de l'Académie Royale de Belgique, 1867, t. xxiv. p. 312, and Journal de l'Anatomie et Physiologie, 1868, p. 197.

and the cord. Other observations were made on two patients with paraplegia, due probably to disease of the dorsal region of the spinal cord, in whom there was reason to believe that the lumbar enlargement of the cord was free from material damage. In each case there was not the slightest voluntary power to retain the contents of the rectum. It was found that in each the condition of the sphincter was essentially the same, and that it was in a state of high reflex activity. The most uniform results were obtained in the case of injury to the sacral nerves. Finally these results were compared with those obtained by the same method when voluntary power was intact.

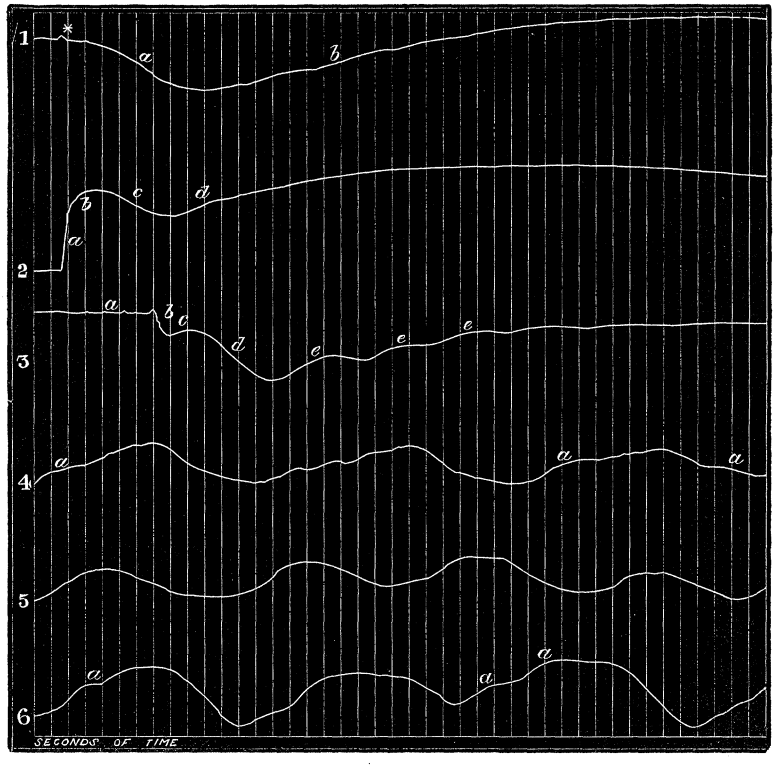
The instrument employed was a small cylinder of thin india-rubber, supported at each end on a wooden plug, the anterior extremity of which was conical, to facilitate its introduction. The chamber within communicated by means of a flexible tube with the cavity of a tympanum provided with a writing lever, by which the variations in the pressure were recorded on a revolving drum (Marey's cardiograph). A small metal tube passed through the middle of the cylinder, by which air could be injected into the rectum without disturbing the instrument. A smaller instrument, the rubber cylinder of which was only one inch in length, was used to ascertain the effect produced by different portions of the lower end of the bowel.

The first fact ascertained was that in each case, although the incontinence of fæces was complete, the sphincter was habitually in a state of continuous, slightly varying contraction. That this tonic state was not due to the presence of the instrument within the anus is shown from the fact that it existed before the introduction of the instrument, and that any irritation of the anus, as by movement of the instrument, produced a well-defined effect of a different character. The same tonic contraction is shown in every tracing obtained. After a disturbance caused by the introduction of the instrument was over, the pressure continued nearly the same throughout, being marked only by a few very slight and irregular variations.

This continuous contraction was, however, inhibited by any irritation applied to the mucous membrane of the rectum. Such an irritation was readily effected by the injection of a small quantity of air into the rectum. The result of such an injection is shown in the tracing (fig. 1). A rapid fall in pressure occurred (*a*), due to the relaxation of the sphincter, which was in some cases so complete that the instrument fell out. After a brief period of complete relaxation, contraction occurred, at first slight, and then slowly increasing, indicated by the rise of the lever (*b*), until the original pressure was attained. In most cases the rise was to a higher point than the original pressure, and a subsequent slight fall occurred until the initial pressure was reached.

When the irritation was produced by a solid body, a slight brief increase in the contraction preceded the relaxation of the sphincter. This

was seen, for instance, when the wooden head of the instrument was pressed down upon the sphincter. The most ready way in which the effect was produced was by making the patient cough. This initial contraction was also very marked on the irritation produced by the introduction of the instrument, the invariable effect being the succession of changes of pressure which are shown in the tracing (fig. 2). The vertical rise (*a*) is the effect of the pressure of the sphincter to which the instrument is suddenly exposed on its introduction; the top of this line represents the amount of pressure exerted by the sphincter before the introduction of the instrument. This is followed by a slight rise (*b*), succeeded by a considerable and rather quick fall (*c*), which fall is again succeeded by a rise (*d*) to a point a little higher than that from which the lever fell, as in the effect of the injection of air.



In the slow rise after this inhibition there was often an indication of a tendency to rhythmical action. In some tracings, especially those which show the effect of a cough, this is very distinct (fig. 3). The slight fall (*b*) immediately after the cough is the result of the movement of the instrument lessening the extent to which it is compressed by the

sphincter. The lower end of this line represents, therefore, the degree of the previous contraction of the sphincter, and corresponds to the top of the line (*a*) in fig. 1. The slight initial rise (*c*) precedes a considerable fall (*d*), and is succeeded by a slow rise, in which there are secondary waves of rhythmical variation (*e e e*). No such variation could be traced in the continuous contraction which followed.

Goltz* observed that in dogs, after division of the dorsal cord, a rhythmical action was caused by the presence within the sphincter of any foreign body. In man it does not appear that the presence of an unirritating foreign body within the anus, provided it is kept still, constitutes stimulation or excites any reflex action. No rhythmical variations were, as a rule, observed in the tonic contraction. In one case of disease of the dorsal spinal cord, however, the mere presence of the instrument caused sometimes a lengthened inhibition, at the end of which some rhythmical contraction occurred. But it was found that, in every case, the continuous injection of a jet of air into the rectum developed, very uniformly, a rhythmical action. The rapid fall which occurred immediately after the commencement of the injection was succeeded by a rather quick rise, followed by another fall, and then a corresponding rise, and so on in successive alternations. Thus a continuous series of nearly uniform curves was obtained (figs. 4, 5, 6). The height reached by the lever in these variations was in some instances the same as that of its continuous contraction, but in other cases it was less high. The cause of the rhythmical variation appeared to be, in part at least, the alternating accumulation of the air within and its escape from the rectum during the contraction and relaxation of the sphincter, the accumulation causing the inhibition of the sphincter, which permitted the escape of air. A difference noticeable in the form of these curves will be considered in speaking of their duration.

In some instances the rhythmical action was long in being developed, the first effect of the continuous injection being a complete inhibition of considerable length, succeeded by the intermitting contractions.

Goltz observed that a powerful sensory impression on the hind legs of a dog inhibited the rhythmical contractions of the sphincter. In the case of injury to the sacral nerves no such inhibition could be obtained by strong faradic stimulation of the skin of the lower part of the abdomen, on which sensation was intact.

The effects of a voluntary effort, a sigh, and a cough were observed to ascertain if there was any consentaneous contraction of the sphincter; but none could be observed.

Careful measurements were made of the duration of the several events in the reflex action above described.

On every form of stimulation it was found that a period elapsed after the commencement of the stimulation before there was any change in

* Pflüger's Archiv, vol. viii. 1874, p. 479.

the degree of contraction. After an injection of air, as nearly instantaneous as could be, the latent period amounted on one occasion to 1·3 second. After a cough it varied from ·8 to 1·2 second, the average of five measurements being just 1 second. The latent period after the introduction of the instrument, before the initial rise, varied from 1 to 1·5 second.

The initial rise, when it occurred, was very uniform in its duration. After the cough it varied from 1·1 to 1·5 second; four out of six measurements were exactly 1·5 second. After the introduction of the instrument, the initial rise, in four measurements, lasted 1·3, 1·5, 1·5, and 2 seconds respectively, the mean of the whole being very nearly 1·5 second. In the cases of disease of the cord the initial rise after the introduction of the instrument was rather longer, lasting 2 seconds.

The duration of the subsequent fall varied considerably. After the introduction of the instrument it varied from 3 to 4·5 seconds, three out of five observations being exactly 4 seconds. After a cough the fall occupied from 3·5 to 5·5 seconds. The mean of all the measurements of the fall caused by the mechanical stimulation of the instrument (on cough and introduction) was 4·2 seconds. It was found that the more considerable the fall the longer was its duration. Thus a slight fall caused by traction on the instrument (not included in the above average) lasted just 3 seconds. The initial rise did not exhibit this relation; in the last case it lasted 1·5 second, while the period of latent stimulation was exactly 1 second. In the case of disease of the cord the duration of the fall was 5 or 6 seconds.

The subsequent rise always occupied a much longer period than the preceding fall, varying in duration from 10 to 17 seconds. Only in one instance was it less than 10 seconds, and in that the rise was imperfect and was succeeded by a second fall. The mean of thirteen measurements of the rise after all forms of stimulation, in the case of injury to the nerves, was 13·5 seconds. In the case of disease of the cord it was somewhat longer, varying from 17 to 30 seconds.

The rhythmical variations which in some cases occurred during the rise (fig. 3) were from 4 to 4·5 seconds in duration, and, in the case of injury to the sacral nerves, were very uniform. As there was no corresponding variation in the stimulation, they must be regarded as the expression of a spontaneous rhythm in the action of the sphincter.

The length of the rhythmical contractions which resulted from a continuous injection of air varied considerably, and, as already mentioned, the form of the curves obtained also varied. Some (in each case) were of considerable length, lasting from 12 to 17 seconds. In these the fall was much steeper than the rise (figs. 4 and 6). These curves resembled in this the curve which was obtained on any sudden stimulation, and appeared to be merely a series of such curves, resulting from the intermitting inhibition consequent on the alternate accumulation and escape

of air. But on some occasions curves were obtained of a different form and shorter duration (fig. 5). The descent corresponded in inclination with the ascent. The duration of each period in the rhythm was nearly 9 seconds. It is to be noted that this is just double the length of the spontaneous rhythmical variations in the case of the rise after the mechanical stimulation by a cough &c. These more regular curves would appear, then, from their curve and duration, to be the more direct effect of the tendency on the part of the sphincter to rhythmical action under the influence of the continuous stimulation*.

The longest complete inhibition under a continuous injection of air lasted 30 seconds. It is evident that this might easily have been mistaken for permanent relaxation.

A comparison of these results with the action of the sphincter ani under normal conditions corroborated the conclusion which Masius and Goltz drew from their observation upon dogs, that the reflex action and tendency to rhythmical variations is modified and controlled by the higher encephalic centre. No variation in the uniform contraction of the sphincter resulted from either the introduction of the instrument or from its movement by a cough. Inhibition of contraction could, however, be readily produced by an injection of air into the rectum. No initial rise was observed under any circumstances: the inhibition continued during the whole period of a short injection of air, and on the cessation of the injection the pressure quickly rose to its original height. The duration of the several parts of the action differed little from that observed in the other cases. A latent period of 1·5 second was succeeded by a fall of 5 seconds' duration, a period of complete inhibition of 6 seconds, and a subsequent rise which occupied 11 seconds.

As far as could be ascertained, the internal sphincter was alone concerned in this reflex action. The external sphincter appeared to be in each case relaxed.

In the case of injury to the sacral nerves the direct communication between the sphincter and the cord must have been interrupted; the reflex action, if from the cord, can only have taken place through the sympathetic nerves. It is a point for future investigation, suggested by certain points of resemblance between the reflex action of the sphincter and that of the uterus, the intestine, and the heart, whether its action is

* The immediate cause of the intermitting inhibition, no doubt, was in each case the intermitting rectal stimulation; but the greater uniformity of ascent and descent, the resemblance in form of these causes to those which were undoubtedly spontaneous, suggests that the tendency to rhythmical relaxation determined the time and form of its occurrence in this case (fig. 5), whereas the longer curves, with steeper fall, were determined more directly by the reflex inhibitory impressions. It is to be noted that the latter often exhibited small secondary waves (as in fig. 6, *a a*), resembling the spontaneous waves (fig. 3, *e e*) in their uniform curve; while the regular waves (as in fig. 4) never exhibited these smaller waves of ultimate rhythm, as they might be called.

entirely dependent on the ano-spinal centre in the cord, and also by what mechanism the encephalic centre exerts its influence.

I would, however, draw especial attention to the points of resemblance between this reflex action of the internal sphincter and that of the middle coat of the intestine in peristaltic action, which suggest the probability that the action of the sphincter, apart from the will, is under the control of a similiar mechanism, and is indeed only, so to speak, a concentrated and more specialized instance of the action of the transverse fibres of the intestine. The action of the intestine, as well as that of the sphincter, is under central control, being inhibited by the vagus, intensified by the splanchnics. The deliberate character of the reflex action of the sphincter resembles closely the deliberate character of the intestinal reflex.

Increased intestinal contraction, like that of the sphincter, is excited most readily by irritation of the mucous membrane. Moreover Goltz believed that in dogs the muscular coat of the rectum participated in the rhythmical contraction which he observed in the sphincter; and my own observations have shown that the reflex action I have described is not confined to the thickened extremity of the bowel, but can be obtained in a modified form as high as two inches from the lower extremity.

The power of reflex action which is possessed by the whole internal sphincter must be possessed by each bundle of muscular fibres of which it is composed. As the sphincter may be regarded as an aggregation of bundles of fibres, such as are contained in the transverse muscular coat of the intestine, so the latter may be regarded as a serial arrangement of the bundles of which the internal sphincter is composed. An action of each bundle of fibres so arranged, such as we have seen to occur in the sphincter as a whole, must result in peristalsis, in the movement of a contained and stimulating body along the intestine. If each bundle of fibres passes through the same series of successive contractions and relaxations as the sphincter ani, then the curve traced by the action of the latter will represent not merely the condition of one bundle of fibres in successive intervals of time, but also the condition of successive bundles at the same time, and two such curves in apposition will represent a diagrammatic longitudinal section of the intestinal wall. The effect, therefore, of the presence in the intestine of a mass of fæces or other contents would be to cause, first, in the moderately contracted intestinal wall in front of it, an increased contraction, the effect of which would be to prevent the diffusion of the contents along the intestine (which would materially interfere with their movement); secondly, complete relaxation of the next portion of the intestinal wall into which the contents of the intestine could pass; and thirdly, a strong contraction behind, sustained, and moving on the stimulating body, as the initial contraction gave place to relaxation. The process would no doubt be materially modified by the contraction of the longitudinal fibres of the bowel, which would prevent the undue distension of the relaxed portion, and thus assist

the transmission onwards both of the contents of the bowel and of the resulting stimulation. The contraction of these longitudinal fibres would also mask the details of the process to external observation. The intermitting contractions of the sphincter under a continuous stimulation may represent the successive waves of peristaltic action when the intestinal contents are abundant. It is further to be noted that the presence of the instrument in the anus, after the effect of its introduction had passed off, was the source of no stimulation, just as contents may be at rest within the bowel, and if they are not moved, and do not irritate the mucous membrane, may excite no peristaltic action.

EXPLANATION OF TRACINGS.

Fig. 1. Effect on contraction of sphincter of the injection into the rectum of a small quantity of air at *. *a*, fall in pressure due to the inhibition of the contraction; *b*, rise due to the slowly returning contraction.

Fig. 2. Effect of the introduction of the instrument. *a*, sudden rise of lever at moment of introduction, due to the exposure of the instrument to the pressure of the sphincter (the top of this line represents the degree of previous contraction); *b*, initial rise due to increased contraction; *c*, fall from partial inhibition; *d*, subsequent contraction, rising to a greater degree than the initial contraction, and subsequently falling slightly.

Fig. 3. Effect of cough. *a*, pressure of tonic contraction of sphincter (the slight irregularities are due to pulse-waves); *b*, fall in pressure, due to the movement of the instrument by the cough; *c*, initial contraction; *d*, relaxation of inhibited sphincter; *e*, *e*, *e*, rhythmical variations in subsequent rise.

Figs. 4, 5, 6. Rhythmical variation in contraction of sphincter under the influence of a continuous injection of air into the rectum. *a*, *a*, *a*, waves of secondary rhythm.

Figs. 1, 2, 3, 4, & 6 are from the case of injury to the sacral nerves. Fig. 5 is from a case of disease of the dorsal region of the spinal cord.

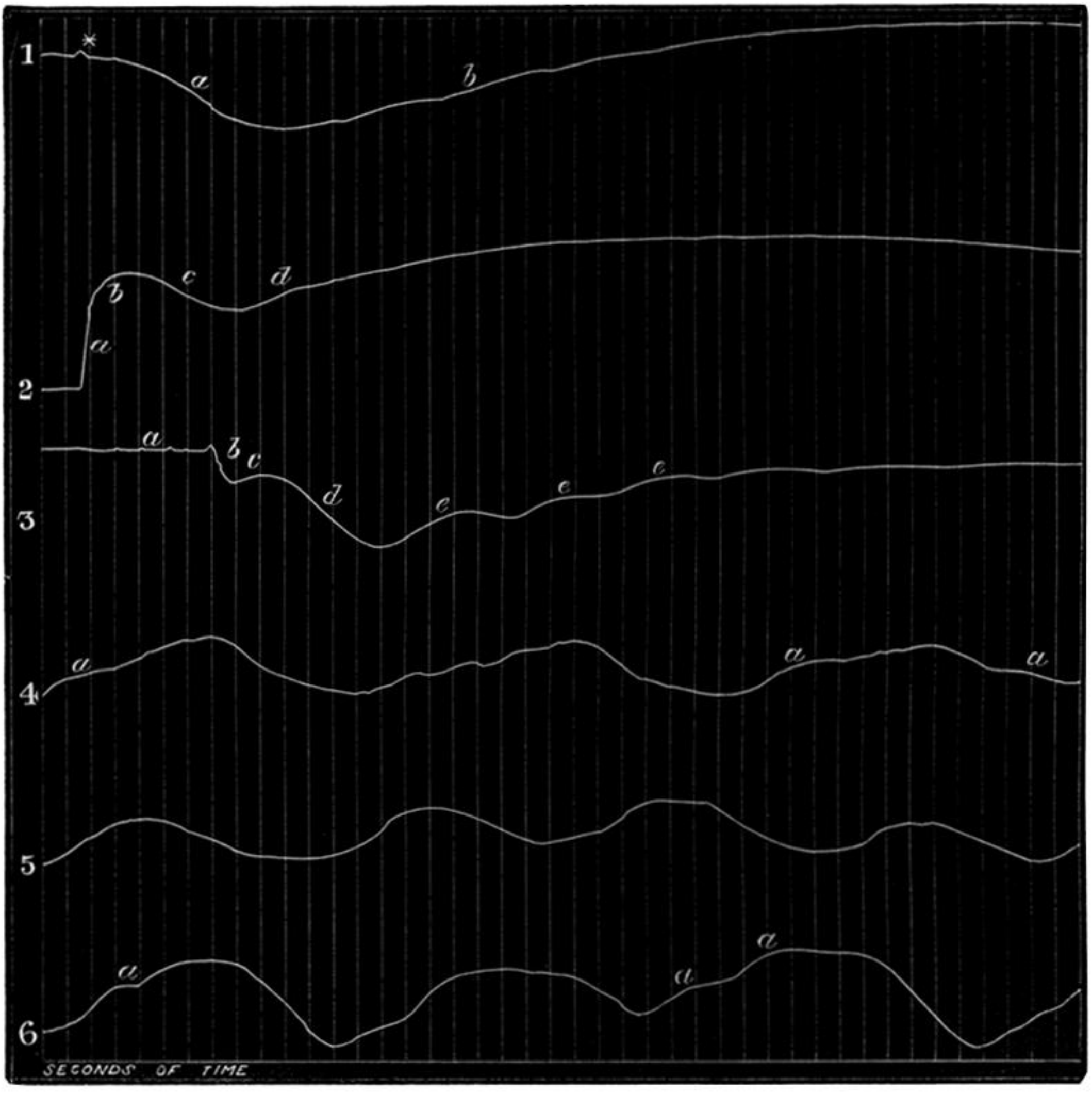
The vertical lines represent seconds of time.

V. "Description of the Process of Verifying Thermometers at the Kew Observatory." By Francis Galton, F.R.S. Received March 1, 1877.

It may be of interest to describe the method recently adopted at the Kew Observatory of verifying thermometers by comparison at different temperatures with a standard instrument, since a large proportion of the various thermometrical determinations made by English physicists are dependent for their accuracy upon that of the verifications at Kew. Many thousands of thermometers have already been verified by the apparatus about to be described.

Up to the year 1875 the apparatus for this purpose at the Kew Observatory was of the rudest character.

It was simply a glass jar $9\frac{1}{2}$ inches wide and 18 inches deep, filled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