PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

On Methods for the Continuous (Photographic) and Quasi-Continuous Registration of the Diurnal Curve of the Temperature of the Animal Body

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Phil. Trans. R. Soc. Lond. B 1909 **200**, 219-240
doi: 10.1098/rstb.1909.0006

VI. *On Methods for the Continuous (Photographic) and Quasi-Continuous Registration of the Diurnal Curve of the Temperature of the Animal Body.*

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(Received June 15,—Read June 18, 1908.)

[PLATES 20 AND 21.]

INTRODUCTION.

SINCE the days of Hippocrates, the attention of physicians has been directed to the importance of the changes in temperature of the human body in reference to the phenomena of disease. Long before the great Scottish physician, WILLIAM CULLEN, had in his Nosology defined the "Pyrexiæ" as diseases characterised by the following symptoms, others had drawn attention to the relations of increased temperature to certain morbid processes. CULLEN defined the febrile diseases as follows :—

"Post horrorem, pulsus frequens, *calor major*, plurimæ functiones læsæ, viribus corporis, præsertim artuum, imminutis."

In this luminous definition CULLEN had crystallised, as it were, the ideas which had been uttered in the seventeenth century by SANCTORIUS, later in the eighteenth century by BOERHAAVE, and his distinguished commentator, VAN SWIETEN.

It was SANCTORIUS, the author of the 'Medicina Statica' (1561–1636),* the predecessor of the investigators of the phenomena of Nutrition of to-day, of the VOITS, the RUBNERS, of the ZUNTZES, the ATWATERS, who first insisted on the determination of the temperature of the animal body as being one of its most important constants, but it is only when we come to the great Dutch physician, BOERHAAVE (1668–1738),† that we find the thermometer referred to as an actual aid to diagnosis. "Calor febrilis thermoscopio externus sensu ægri et rubore urinæ internus cognoscitur," and his famous commentator, VAN SWIETEN,‡ though not contradicting the false dictum that an increase in the pulse rate constitutes the *essence* of fever, asserts that observations of the temperature taken by the hand are inconclusive :—

"Omnium ergo certissima mensura habetur per thermoscopia, qualia hodie pulcherrima habentur, et portalia quidem, fahrenheitiana dicta a primo inventore :

* Ars Sanctorii Sanctorii, 'De Statica Medicina,' Venet., 1614.

† BOERHAAVE, 'Aphorismi de cognoscendis et curandis morbis,' Lugd. Batav., MDCCXXII, Aph. 673.

‡ GERARDI VAN SWIETEN, 'Commentaria in Hermanni Boerhaave Aphorismos,' Lugd. Batav., MDCCXLV, tom. secundus, p. 287.

accuratissima imprimis illa sunt quæ argentum vivum loco alterius cujuscunque liquidi continent. Tali thermometro, prius mensuratur calor hominis sani et plerumque in indice affixo ille gradus notatus est: deinde hoc cognito, si idem thermometrum a febricitante ægro manu teneatur, vel bulbus ejus ori immitatur, vel nudo pectori aut sub axillis applicetur per aliquot minuta horæ, apparebit pro varia altitudine ascendentis argenti vivi, quantum calor febrilis excedat naturalem et sanum calorem."

After BOERHAAVE, DE HAEN (1704–1776),* a great clinical teacher in Vienna, devoted his attention in a very special manner to the use of thermometry in disease, and, whilst recognising that fever is usually associated with a rise in the pulse rate, he employed extensively the thermometer in the study of the Pyrexiæ. DE HAEN was one of the first to study the temperature of healthy persons of various ages, and clearly expressed his opinion as to the value of thermometry both in prognosis and diagnosis; he was acquainted with the rise of temperature during febrile rigors, and with the habitual evening exacerbations of the temperature in fevers and the remission which is commonly observed in the morning.

But England did not at that time lag far behind Germany in this line of research, for we find CHARLES MARTIN publishing, about the year 1740, the first accurate observations on the temperature in healthy men and animals in his monograph, entitled "De animalium calore."† An observation of quite peculiar interest, as throwing the first light on the marvellous power of accommodation for changes of temperature which is possessed by warm-blooded animals, but very specially by man, was published by BLAGDEN in the 'Philosophical Transactions' for the year 1775,‡ when he demonstrated the constancy of the temperature of healthy men when placed in rooms heated to the temperature of the boiling-point of water; observations supplemented by those of JOHN HUNTER, who, also in the 'Philosophical Transactions' in the years almost immediately following BLAGDEN'S discovery, pointed out how animals possess the power of resisting external cold because of their capacity to produce heat enough to counterbalance the loss.§

In a cursory review of the first path-breaking researches on the temperature of the animal body, and avoiding a large amount of work, much of which led to fallacious results in reference to the mechanism by which heat is developed in the animal body, I have to refer to interesting observations made by Sir BENJAMIN BRODIE‖ between the years 1811 and 1837, in which he pointed out the influence

* ANTONII DE HAEN, 'Ratio Medendi,' Lugd. Batav., MDCCLXI. *Vide* 'De supputando calore corporis humani,' T. I, cap. xix, p. 118.

† CHARLES MARTIN. The author has not been able to see a copy of this paper.

‡ C. BLAGDEN, F.R.S., 'Experiments and Observations in an Heated Room,' 'Phil. Trans.,' vol. 65 (1775), pp. 111 and 484.

§ JOHN HUNTER, F.R.S., 'Of the Heat of Animals and Vegetables,' 'Phil. Trans.,' vol. 58 (1778), p. 7.

‖ Sir B. BRODIE, Bart., 'Physiological Researches, collected and reprinted from the Philosophical Transactions,' Lond., 1851.

of certain lesions of the nervous system upon the temperature of the body; to the observations of that distinguished physician, PIORRY, who, in his 'Traité de Diagnostique,'* published in 1838, pointed out the value of the thermometer in the study of disease, and who quotes the weighty sentence of the physicist, BIOT:—"Lorsqu'on voit tant de résultats obtenus par le seul secours d'un peu de mercure enfermé dans un tube de verre, et qu'on songe qu'un morceau de fer suspendu sur un pivot a fait découvrir le nouveau monde, on conçoit que rien de ce qui peut aggrandir et perfectionner les sens de l'homme, ne doit être pris en légère considération."

Amongst the observations on the temperature of the human body in health and in disease, under varying conditions of climate, which were published between 1844 and 1850, were those of one known to many of us still alive, Dr. JOHN DAVY, the younger brother of the great Sir HUMPHRY. These observations, which were published in his collected 'Physiological Researches,'† treat, *inter alia*, of a subject of special importance in reference to the present paper, namely, the diurnal fluctuations (see vol. 1, p. 168), the influence of active and passive movements, of the amount of food consumed, of the influence of tropical climates, as contrasted with those of the temperate zone.

But, unquestionably, the modern study of medical thermometry began, as has been pointed out by WUNDERLICH in his classical work "On the Temperature in Diseases," of which a translation was published by the New Sydenham Society in the year 1871, in Germany with, in the first instance, the observations of the great TRAUBE on the effect of digitalis on the temperature in febrile diseases, and which appeared in the 'Annalen der Charité,' in the years 1850 and 1851, and which were followed in 1851 by BÄRENSPRUNG's classical work, entitled 'Untersuchungen über die Temperaturverhältnisse des Fötus, und des erwachsenen Menschen im gesunden und kranken Zustande,'‡ and which marked the commencement of the really accurate observations of the phenomena of disease which, in so far as a mercurial thermometer can be employed, have been carried down to the present day for the great good of medicine and our knowledge of disease. No one, however, contributed in so important a manner to the systematic study of medical thermometry as WUNDERLICH, in the work to which I have already made reference. Two names must, however, be mentioned very particularly in connection with researches concerning the regulation of the temperature and its diurnal variations in the human body: I refer, in the first place, to LIEBERMEISTER, who, in the 'Deutsche Klinik' of 1859, published his observations, entitled "Die Regulirung der Wärmebildung bei Thieren von constanter Temperatur," a monograph which was followed in the following year by two

* PIORRY, 'Traité de Diagnostique et de Semiologie,' vol. 3, p. 28 *et seq.*

† JOHN DAVY, M.D., F.R.S., 'Researches Physiological and Anatomical,' in two volumes, Lond., 1839.

‡ BÄRENSPRUNG, see 'Muller's Archiv' for 1851 (p. 126) and for 1852 (p. 217).

papers in REICHERT'S 'Archives' (1860 and 1861), entitled "Physiologische Untersuchungen über die quantitätiven Veränderungen der Wärmeproduction," and in 1875 by his classical work, entitled 'Handbuch der Pathologie und Therapie des Fiebers.' The second investigator, whose death we deplored but a few months ago, was Professor THEODOR JÜRGENSEN, of Kiel, who, in 1873, gathered the results of the researches, which he had published in preceding years, in a monograph entitled 'Die Körperwärme des Gesunden Menschen.'*

In this monograph JÜRGENSEN for the first time took up in a serious manner the study of the diurnal variations in the curve of the temperature of man. His observations were carried out with mercurial thermometers, of which one was graduated in divisions of 0°·2 C., but allowing 0°·1 to be estimated, the other being divided into divisions of 0·1 of a degree. The thermometers were introduced 5 cm. high into the rectum, and allowed to remain *in situ* during varying periods, extending in one case to six days, the reading of the height of the mercurial column being carried out by nurses who had for years been in the habit of reading clinical thermometers.

JÜRGENSEN arrived at the conclusion, which in its main features has been confirmed by all subsequent observers, that the diurnal changes in the temperature of man, which in a state of health are comprised within limits which rarely exceed 1°·0 C., or at most 1°·5 C., may be expressed by the statement that this period of 24 hours is, in reference to temperature, divided into two periods, one of rising and comparatively high temperature, the second of falling and low temperature. Approximately it may be said that these two periods correspond to day and night. The 24-hourly *minimum* occurs, according to JÜRGENSEN, between the hours of 2 and 8 A.M., whilst the 24-hourly *maximum* occurs between 4 and 9 P.M. Subsequent researches by no means absolutely confirm the details of the original work of JÜRGENSEN, it being probable that the *minimum* occurs, *as a rule*, between 5 and 7 in the morning, and that the *maximum* is, in the majority of healthy persons, between 3 and 4 in the afternoon. The latter estimate represents the results of the majority of French observers, and is in accordance with my own experience, though unquestionably there are cases in which the maximum temperature, in health, may occur as late as 6 or even as late as 9 P.M.

In relation to this question of the great regularity of the diurnal curve of the temperature of man, and the marvellous powers which the animal, and particularly the human, organism possesses of regulating its temperature, I cannot do better, in this place, than quote the highly philosophical and accurate remarks bearing on the subject which we owe to WUNDERLICH.†

* Leipzig, Verlag von F. C. W. VOGEL, 1873.

† *Op. cit.*, p. 83.

"Since the temperature of the human body can only be considered as the result of continual production and losses of heat, of varying amounts, it appears a very remarkable fact that the sum total* should always remain so nearly the same (under the operation of so many, and doubtless every moment changing processes and influences) that the internal temperature varies by little more than a degree Centigrade."

"What LAVOISIER has said of the body-weight—'Quelle quantité d'aliments que l'on prenne, le même individu revient tous les jours après la révolution des 24 heures au même poids à peu près qu'il avait la veille, pourvu qu'il soit d'une forte santé, que sa digestion se fasse bien, qu'il ne s'engraisse pas, qu'il ne soit pas dans un état de croissance, et qu'il évite les excès,' may be said with still greater propriety of the temperature of the body."

It must strike all who have read the remarks which I have made on JÜRGENSEN'S painstaking observations, how coarse was the method employed and how great were its inherent errors. To keep a rigid glass thermometer for 24 hours, and in one case as long as six days, permanently in the rectum, would necessarily produce local congestion and irritation, which would materially falsify the observations; that such results actually occurred from time to time is frankly admitted by JÜRGENSEN. But there is a further observation to be made, viz., that the error due to the constantly varying personal equation of the weary nurses who, through the long night, had to take readings of the thermometer every five minutes, must have been very great indeed.

It is only fair and just to the memory of JÜRGENSEN to say, however, that at the commencement of his monograph occurs the following suggestive sentence :—

"Das wissenchaftliche Ideal für Beobachtungen, welche den Verlauf der Körperwärme innerhalb einer gewissen Zeit feststellen wollen, ist die Anwendung einer Methode, welche eine fortlaufende graphische Aufzeichnung durch selbstregistrirende Apparate möglich macht. Um diesem vorläufig nicht erreichbaren Ziele möglichst nahe zu kommen, muss man sich über die Fragen klar zu werden suchen, wie oft, wie viel, wo gemessen werden soll. Denn das womit erledigt sich dadurch, dass für längere Versuchsreihen am Menschen nur das Thermometer als Instrument möglich ist." †

The careful and detailed study of all the work done since the earlier observations of JÜRGENSEN and others on the diurnal variations of the temperature of man shows in the clearest possible manner that it can only be by the introduction of automatic and extraordinarily sensitive methods of registration that the wonderfully

* To be accurate, WUNDERLICH should have said, instead of "the sum total," "*the numbers representing the mean temperature of the body*," seeing that in spite of a constant mean temperature, the energy evolved by the body and the actual amount of heat produced in it, as expressed in calories, may vary within exceedingly wide limits.—A. G.

† JÜRGENSEN, *op. cit.*, Erstes Capitel, "Methode."

interesting problem of the diurnal variations in the animal temperature and their relation to *mean time*, as well as to other conditions probably affecting it, could be attacked and solved. It is to the discussion of such methods, which have formed the subject of severe and continuous study during the last three years, that the present paper is mainly devoted, the results of the extensive and systematic observations as applied to the body of man and the lower animals, both in health and disease, being reserved for future communications by myself or by others who shall succeed me, for the work is great and arduous, and will demand time, and means, and opportunities, such as it will be difficult to realise in England.

I wish to state *in limine* that the research upon which I have been engaged is one which is concerned with the determination of the variations in, and the distribution of, the *temperature* of the animal body, and is to be clearly distinguished from such investigations as those of RUBNER, and particularly of ATWATER and BENEDICT, which are concerned with the study of the total amount of heat produced in the organism under various conditions of alimentation, of work, etc., investigations which have attained a precision which has rarely been equalled, and scarcely ever surpassed, in any department of physical science.*

It was ever since the time when I was quite young, and was engaged in physical researches under the direction of Professor PETER GUTHRIE TAIT, that I conceived the intense longing to develop a thermo-electric method of observing the variations in the temperature of the animal body. Already, in the year 1834, BECQUEREL and BRESCHET had made use of thermo-electric couples composed of copper—steel to investigate the temperature of the cavity of the mouth and of certain of the tissues and internal organs of the human body and some of the lower animals. In certain of his researches, BECQUEREL employed a thermostat devised by M. SOREL, which enabled him to keep one of the couples at a temperature which remained constant to within 0°·1 C. Later, he placed the constant temperature junction in the mouth by the side of a delicate mercurial thermometer; the other couple, which was provided with a sharp needle-point, was, when necessary, thrust through the living tissues to be investigated, *e.g.*, the biceps of a man, the iron—copper junction being central, and lying in the exact situation in which it was desired to determine the temperature. Obviously, the iron ends of the two couples were connected together by iron wire, whilst the copper ends were connected by copper wires, with the terminals of as perfect a low-resistance astatic galvanometer as was at that time available. By this method BECQUEREL and BRESCHET made valuable observations of importance to

* It is impossible, or rather beyond the scope of the present paper, to quote *all* the papers in which the work of ATWATER and BENEDICT is recorded. The best general view of their work is, perhaps, to be obtained in the fine monograph entitled 'A Respiration Calorimeter with Appliances for the Direct Determination of Oxygen,' by W. O. ATWATER and F. G. BENEDICT, Washington, D.C. Published by the Carnegie Institution of Washington, 1905. This account was written by Professor BENEDICT subsequent to the retirement of the late Professor ATWATER.

physiologists.* DUTROCHET, modifying the form of the couples, employed the method with great advantage in the investigation of the development of heat in plants.† Employing thermo-electric couples in connection with the WIEDEMANN galvanometer, HELMHOLTZ was afterwards enabled to prove the development of heat during simple muscular contractions and tetanic contractions in the separated, but still living, muscles of frogs, and thermo-electric methods in which, however, beautifully constructed thermopiles were employed, and not simple couples, were adopted by HEIDENHAIN and by FICK in the study of the heat produced by the contracting muscle of the frog and the relation which it bore to the work done under varying conditions.

The thermopile was employed by LOMBARD, of Geneva, in the investigation of the temperature of the surface of the head during intellectual work, and he believed that he had obtained results of some importance. His method has, however, been considered valueless, and it may be said, generally, that a thermopile is absolutely unsuited to the exact measurement of the absolute temperature of the surface of the animal body, or even to comparative measurements, unless within exceedingly short intervals of time, because of the practical impossibility of maintaining the cool end of the pile at a constant temperature.

When, more than three years ago, I determined to carry out the strivings of my youth, and to work out a method of automatic registration of the curve of the temperature of man, I discussed, theoretically, the comparative advantages which would be presented by the method of electrical resistance thermometers on the system of automatic registration so splendidly worked out by Professor CALLENDAR, and a thermo-electric method, and I decided in favour of the latter. I may say that the motive which urged me to make the sacrifices of all kinds which this research has involved, was the intense desire to study for the first time, and in an elaborate manner, the normal curve of the temperature of man, and thereafter, in the first instance, the changes which that curve exhibits during the very earliest stages of pulmonary consumption and of surgical tuberculosis, when the organism is the prey of the tubercle bacillus alone and not yet subject to a "mixed infection"; for I had, by long-continued observations carried out with the clinical thermometer, ascertained the utter want of precision and insight which at present prevails in reference to the very earliest stages of phthisis, when physical signs are yet almost, or completely, in abeyance, and when the cough, the anæmia, the loss of flesh, and slight temperature abnormalities are the only guides the physician has to rely upon. The conditions under which an automatic method of registering the differences in the

* BECQUEREL, 'Annales de Chimie et de Physique,' 2nd série, vol. 19, p. 113; also BECQUEREL, 'Traité expérimental de l'Electricité et du Magnétisme, et de leurs Rapports avec les Phénomènes Naturels.' Refer to vol. 4, Chap. II, "De la Mesure des Températures des Parties Intérieures des Corps Organisés."

† DUTROCHET, 'Annales des Sciences Naturelles,' 2nd série, Botanique, vol. 13, p. 5.

E.M.F. of thermo-couples could be carried out, had completely changed since the days when I worked with TAIT. The discovery of the moving coil type of galvanometer, which we associate with the name of D'ARSONVAL, but which had been initiated by the beautiful syphon-recorder of Lord KELVIN, had, to my mind, absolutely simplified the solution of the problem. Given a galvanometer practically uninfluenced by all changes in the surrounding magnetic field, and at the same time possessed of great delicacy under the conditions of the special investigation; given, besides, an extremely perfect photographic recorder; and, thirdly, given a thermostat more perfect than had ever been constructed, which should be able to maintain a thermo-couple during days and weeks at a temperature not varying more than 0°·02 C.; fourthly, given thermo-couples of sufficient delicacy, and of which one set should be so arranged as to constitute respectively very perfect surface and deep thermometers, and it appeared to me that the problem must be definitely solved. The results of my work have verified my predictions.

Before discussing the methods which I have to bring before the Royal Society, I have to refer to the exceedingly interesting work done by Professor BENEDICT and Dr. JOHN FERGUSON SNELL* on the quasi-continuous registration of the temperature of the human body by means of a resistance thermometer.

The method essentially consisted in an admirably contrived and pliable resistance thermometer, which could be introduced into the rectum and cause no irritation. The wire used in constructing this thermometer was copper wire, of 0·08 mm. diameter, covered with a double layer of silk, and having a resistance of about 20 ohms. This was enclosed in a tube of pure silver, 30 mm. long and 50 mm. in diameter. The Wheatstone's bridge, which, in connection with the d'Arsonval galvanometer, was employed to measure the changes in temperature, permitted of readings being directly made to an accuracy of 0°·01 C. The method was in no sense automatic, but at intervals of four minutes the observer closed the circuit, and determined the extent of the first swing of the galvanometer, which was noted. The method is essentially a ballistic method, and appears to me to be open to two objections: firstly, that it in no way eliminates the personal element of fatigue affecting the observer, who is engaged in making observations during the whole night; and, secondly, that in spite of the perfection of the mercury key employed in closing the circuit, it is almost impossible to conceive of the time of closure being always so precise as to eliminate the error arising from heating the one arm of the Wheatstone's bridge. Admitting, as I do, that Professor BENEDICT'S observations possess a very much higher value than any which preceded them, I still think that his method left the problem of the automatic registration of the temperature of man

* Professor Dr. FRANCIS GANO BENEDICT and Dr. JOHN FERGUSON SNELL, "Eine neue Methode um Körpertemperaturen zu messen," 'Pflüger's Archiv,' vol. 88 (1902), pp. 492–500: "Körpertemperatur Schwankungen mit besonderer Rücksicht auf den Einfluss welchen die Umkehrung der täglichen Lebensgewohnheit beim Menschen ausübt," 'Pflüger's Archiv,' vol. 90 (1902), pp. 33–72.

unsolved, and that, considering the changes in instrumental conditions which it has been possible to introduce within the last fifty years, thermo-electric methods offer paramount advantages for such researches as those on which I am engaged.

I.—On the Method of Absolutely Continuous Photographic Registration of the Curve of the Temperature of Man.

In describing the method which I have adopted, I shall briefly, but still with sufficient detail, give an account of the various parts of the apparatus which I have employed under the following heads:—

1. The Thermostat and its Regulator;
2. The Thermo-couples, *i.e.*, the Electrical Thermometers employed, and the Leads;
3. The Automatic Photographic Recorder.

1. *The Thermostat.*

During the last few years the construction of thermostats, in which the temperature is kept very constant, has been remarkably developed, thanks especially to the work of Professor Ostwald, of Leipzig, and to Herr Fritz Köhler, the Universitäts-Mechaniker, of Leipzig. It is in great part due to Herr Köhler that I succeeded in procuring a thermostat which, I believe, possesses an efficiency very much greater than that of any similar instrument yet constructed, and which has allowed me to keep one of my thermo-couples (we shall call it the constant temperature couple) at a temperature which had not varied more than 1/100° during 12 or 15 days at a time. This thermostat, which has a capacity of 50 litres of water, is constructed in the following manner:—It possesses double copper walls between the intervals of which Kieselguhr has been firmly packed; external to the outer copper wall is a thick layer of felt, surrounding which is a mantle of polished aluminium. The thermostat possesses a beautifully fitting cover of copper, two layers of copper enclosing an air space. This cover is pierced so as to allow centrally of the adjustment of a turbine stirrer, which is kept in extremely rapid rotation by an electric motor. Another aperture permits of the introduction and maintenance of an excessively perfect Toluol Regulator. The thermostat is heated by six small luminous gas burners, with mica chimneys, the supply of gas to these burners being controlled by the toluol regulator. In fig. 1 is indicated *schematically* the thermostat with the first form of toluol regulator which I employed, and in which the expansion or contraction of toluol made or closed a circuit which, through an electro-magnetic arrangement, controlled the flow of gas to the burners. Whilst all the burners are lighted on the occasion of first raising the 50 litres of water to the temperature required (± 36°·5 C.), when this temperature has been reached, and the regulator is in proper action, all the burners, with the exception of one, are extinguished. The space beneath the thermostat, and in which the burners are placed, is surrounded by a circular cylindrical wall of aluminium lined with asbestos. The water employed to fill the thermostat was sterilised distilled water, and I made the interesting observation that when the turbine regulator was continuously at work, rotating at the rate of several hundred revolutions per minute, the water remained absolutely clear during many weeks, and was doubtless still sterile. In fig. 2 is shown a photograph of the thermostat with its motor.

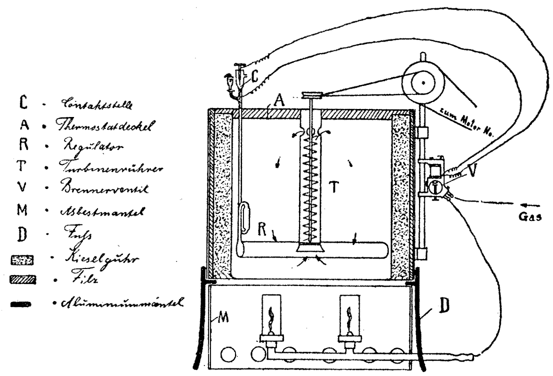

FIG. 1.

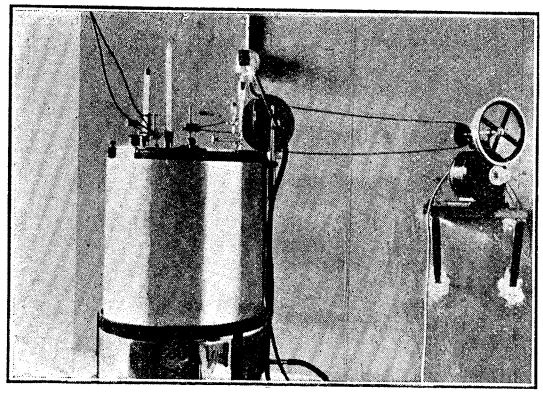

FIG. 2.

In the course of my work, I had occasion to discard the original toluol regulator, which I found unsatisfactory for long-continued work, mainly, no doubt, in consequence of the oxidation of the mercury by the sparks which passed when the current was made and broken. I substituted for it the truly admirable toluol regulator, which we owe to Dr. LOWRY. But I have modified this instrument in such a manner as to make it even more valuable than it previously was. In the original Lowry Regulator, as in regulators generally, the gas supplied to the regulators enters through a glass tube, which passes through a cork or a stopper of indiarubber. The glass tube is provided with an exceedingly small hole, which acts as a bye-pass to the gas when the lower end of the glass tube is in contact with the mercury of the regulator; a side tube is connected to the burners. For the stopper, I substituted a well worked steel cap, in the centre of which was a screw, into which fitted a screwed steel tube, with a very minute opening at the end, and provided near its lower end with an exceedingly minute bye-pass. By rotating the screw surmounting the tube, I was able to adjust, with the utmost accuracy, the level of the lower end of the steel tube so that it was absolutely central, and corresponded to the centre of the meniscus of the mercury, rising and falling as the toluol expanded or contracted. I found it advisable always to adjust approximately the height of the mercury in the toluol regulator to be used to that of the temperature of the thermostat, before commencing a new series of experiments. In order to aid the action of the regulator, I interposed in the course of the gas supply one of Wisnegg's gas regulators, which is essentially a small gasometer provided with two gauges, one of which indicates the oscillations of pressure as the gas enters, and the other the oscillations as the gas leaves the gasometer. In addition to the apertures in the lid of the thermostat for the turbine-stirrer and the toluol regulator, there were three placed side by side, lined with vulcanite, and which were adjusted for the introduction and maintenance of (a) standard mercurial thermometers; (b) the "fixed temperature" couple. I have employed two thermometers for reading the temperature of the water of the thermostats, two thermostats being employed when standardising the couples during this research. The first of the above thermometers is divided directly into fiftieths of a degree Centigrade; the second, which has served during the actual work of observation, is divided into hundredths of a degree Centigrade. Both these thermometers have been controlled by the Königliche Reichsanstalt of Berlin, and possess tables of corrections. The height of the mercury in these thermometers was read by means of FRITZ KÖHLER'S magnifying arrangement, which is shown in the drawing of the thermostat (fig. 2), all error due to parallax being avoided.

The thermostats with the motor driving the "turbine" stirrers of each are shown in figs. 3 and 4.

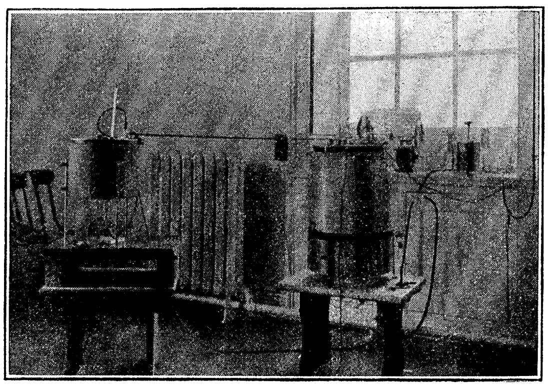

FIG. 3.

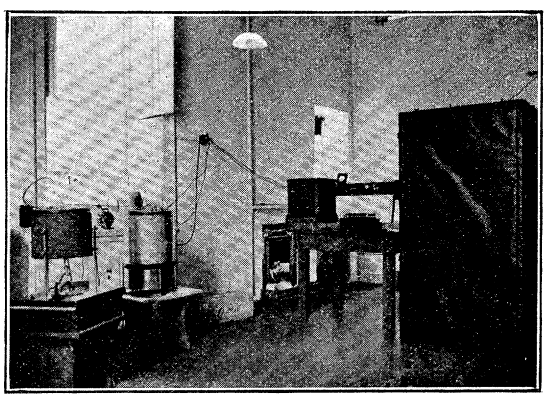

FIG. 4.

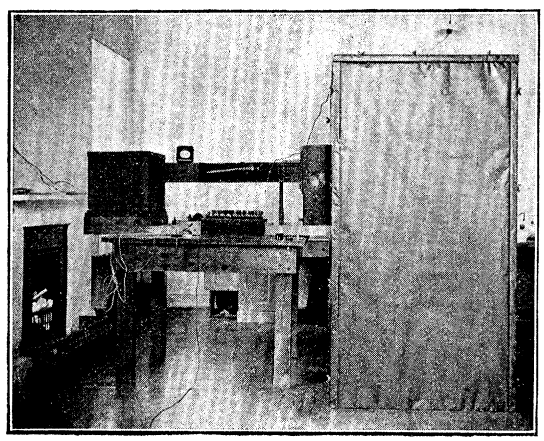

FIG. 4A.

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

2. *The Thermo-couples, i.e., the Electrical Thermometers employed, and the Leads.*

Before commencing actual work, and whilst discussing theoretically the conditions of my experiments, I determined that, whatever the nature of the couple employed, one of the elements of the couple must be copper, and before knowing how universally Cu-constantan couples had been adopted for technical purposes, I had decided that thermometers in which one element was Cu and the other the purest constantan available, would best suit me for the purpose. I have to acknowledge the great help which I received in the first instance in the construction of deep and surface thermo-electric thermometers from the firm of PHILIP HARRIS and Co., Ltd., of Birmingham. The constantan employed was placed at my disposal by BASS and SELBE, of Altena, Westphalen.

(1) *Surface Thermometers.*—The construction of my first surface thermometers is shown in the annexed diagram (fig. 5). The diagram shows a vulcanite body A, consisting of a disc, 4·3 cm. in diameter, and 0·9 cm. thick. The front face is convex and polished, the back is turned out 3·5 cm. by 0·6 cm., and the recess thus formed is screwed and fitted with a vulcanite cap B. This cap may be taken out for inspection. Through the body A pass a bar of constantan C, and a bar of copper D. These bars were made from pieces of constantan and Cu respectively, 5·6 cm. long

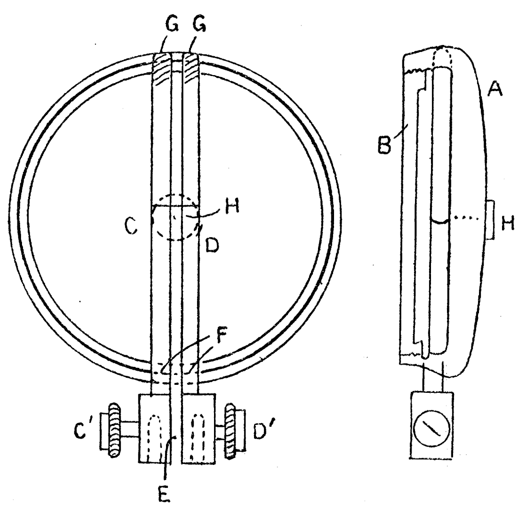

FIG. 5.

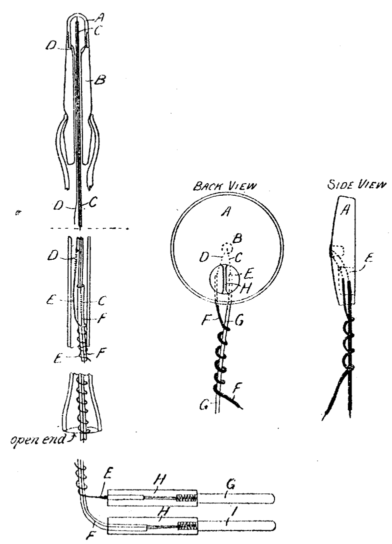

FIG. 6.

by 0·6 cm. thick. The parts which pass through the body are turned down to 0·5 cm. and screwed at the end for a distance of 0·6 cm. The thick end, which is 1 cm. long, is drilled up for a distance of 0·8 cm. to suit the flexible wire. This wire is clamped with screws of constantan and Cu C′ and D′. The sides of the bars opposite to the clamping screws C′, D′, are filed flush to the thinner part of the bar so as to allow the bars to lie close together without touching, as at E. Holes are drilled in the body at F to allow the bars to pass through easily, and again at G, into which the ends of the bars screw. The circular disc H is 0·5 cm. diameter, by 0·01 cm. thick, and is made of a half disc of constantan and a similar half disc of Cu hard soldered together. The weight is 0·017 gramme. On to this compound disc are soldered wires of constantan and Cu, which go through holes in the face of the vulcanite body. The wires are then bent over the bars of constantan and copper respectively and soldered.

My original conception had been that, in constructing the surface junction, I should provide as low a resistance as possible, and it was with this object that the half discs of Cu and constantan respectively, hard soldered together, were connected with actual bars of Cu and constantan. I found, however, by experience, that a surface-couple, constructed after such a plan, took a very long time before assuming the temperature of the body, and I ultimately modified the couple connecting the Cu and the constantan halves of the disc by Cu and constantan wires having a sensible resistance, the lag being thus greatly reduced. The later forms of junctions are shown in the two figures to the right in fig. 6. The surface thermometers were placed in the closed axilla, being maintained in position by a kind of truss arrangement which encircled the upper part of the thorax, and which could be enlarged or diminished in circumference so as to suit patients of different ages and sexes. This truss arrangement, with the surface thermometer and the leads passing from it, caused no inconvenience to the patient, who was, however, invariably kept in bed during the first preliminary observations. I had a number of these axillary thermometers, their total resistance varying between 0·45 and 0·61 ohm.

(2) *Thermometer for Introduction into one of the Cavities of the Body.*—The construction of the ultimate form of thermometer which I devised, for observations particularly of rectal temperature, is shown in the diagram to the left of fig. 6. At A is seen a small Cu cup, very heavily silver plated on its external surface. To the centre of the interior of this tiny cup is soldered a fine constantan wire (C), which is insulated by being surrounded by the very finest surgical drainage tube. At D a copper wire is soldered to the interior of the Cu cup, and is led up by the side of the constantan wire. Near D the silvered Cu cup is screwed into a small cylinder of vulcanite B. This is cemented into the cut end of a No. 8 soft elastic catheter. At a distance of some centimetres from the distal end of the thermometer the same constantan and Cu wires are soldered to stronger leads, which are carefully insulated. At the proximal end of the thermometer connections are made between the Cu and the constantan wires, and Cu and constantan leads, specially constructed according to my directions, and possessed of very low resistance. Experience has shown that this thermometer can be maintained *in situ* in the rectum without causing the very slightest irritation, the patient being, indeed, absolutely unaware of its presence. The resistance of the last and most perfect of my rectal thermometers was equal to 2·6 ohms.

The Leads.—These were specially constructed for me, and were composed of a large number of strands of Cu and of constantan wire respectively. They were 50 feet in length, and their total resistance was 12 ohms. The length of the leads permitted of my having my thermostats, the standard couple, and the great photographic recorder in one room, whilst the patient under observation was in an adjoining ward.

3. *The Automatic Photographic Recorder.*

I have, in the first place, to give expression to my indebtedness to the Cambridge Scientific Instrument Company, and in particular to Mr. HORACE DARWIN, F.R.S., and to Mr. R. S. WHIPPLE, for carrying out all my wishes in the construction of this splendid instrument, and devising certain mechanical devices which it would have been quite impossible for me to have designed.

The general view of the apparatus is shown in figs. 4 and 4A, while certain of the details of construction can be best studied in figs. 7, 8, and 9, and especially in the much reduced working drawing represented in fig. 10. Referring to fig. 8 we see the

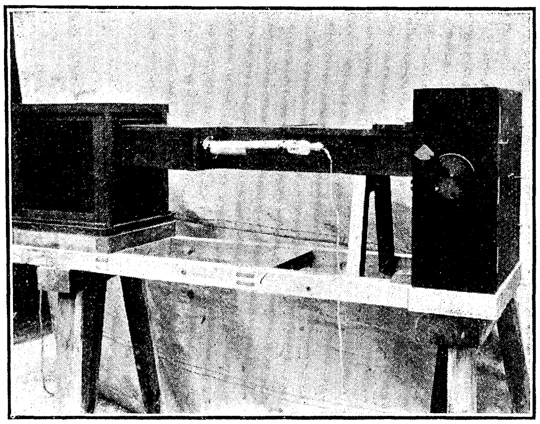

FIG. 7.

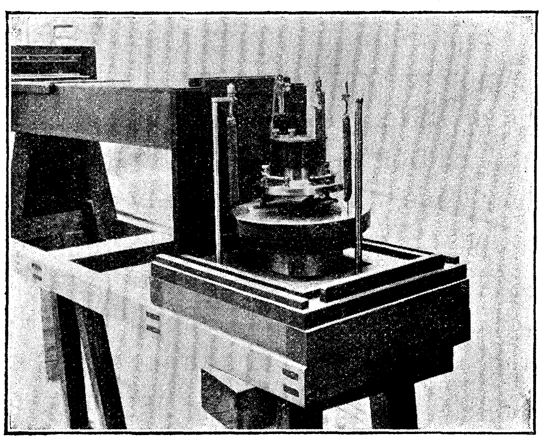

FIG. 8.

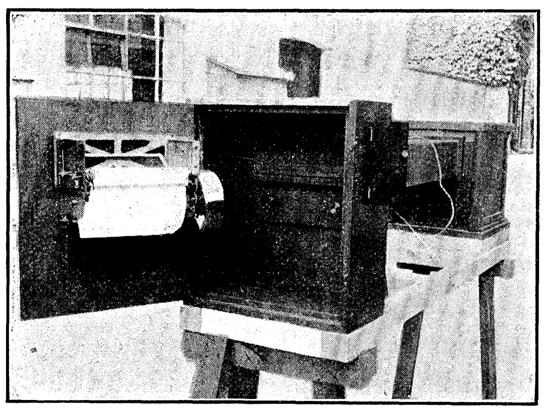

FIG. 9.

apparatus with the box enclosing the galvanometer removed. At the right-hand side of the photograph is seen the galvanometer of the Ayrton-Mather suspended coil type, made by the Cambridge Scientific Instrument Company, Ltd. Since these galvanometers are very susceptible to vibration, the one in my recorder is supported on a special anti-vibration stand. The wooden base of this stand is hung from three steel spiral springs; these springs absorb some of the vibrations which would otherwise be communicated directly to the galvanometer, and they are jacketed with cloth to damp out their oscillations. On the under side of this base is a closed circular vessel half filled with oil, and fitted with internal radial vanes fixed to the circumference and extending half-way towards the centre; any oscillation of the stand causes the oil to move relatively to the vessel, and the resistance to this movement causes the oscillations to rapidly diminish. Outside this vessel, on the bottom, there are two additional vanes, fixed at right angles to each other, and these dip into an open vessel filled with castor oil. The resistance of the galvanometer is 10·5 ohms, and the deflection is 12 mm. per micro-volt on the photographic paper, which is 116 cm. distant from the galvanometer mirror. The E.M.F. given by Cu-constantan junctions for a temperature difference of 1° C. is, in the mean, 40 micro-volts; if this E.M.F. were applied to the galvanometer terminals, the deflection would be 12 by 40 = 480 mm.; this is too sensitive an arrangement for working conditions, and a resistance is put in the galvanometer circuit to reduce the sensitivity to the required figure. If the circuit were composed entirely of Cu, an error would be introduced due to resistance variation with temperature (0·4 per cent. per 1° C.). Manganin has such a small temperature coefficient as to be practically negligible; its insertion in the circuit serves the further purpose of much reducing the error due to resistance changes; though the Cu does change 0·4 per cent. per 1° C., it is only a fraction of the whole resistance in circuit, consequently the percentage change on the total resistance is very small.

To avoid errors due to thermo-electric effects in other parts of the circuit than at the two main Cu-constantan junctions, it is advisable to have as few dissimilar metals as possible; for this reason the galvanometer terminals were made of Cu, and a Cu wire was run from the frame terminal up to the top of the suspension and attached there, thus eliminating any possible effect due to the brass carcase of the galvanometer.

The source of light is a Nernst lamp (see fig. 7). A diaphragm F is placed just in front of the lamp filament, and cuts off all the light except that which passes through a small slit 10 mm. long by 0·2 mm. wide, in this diaphragm. The light is projected down the lamp tube and falls upon the galvanometer mirror, and also upon a second mirror, which is fixed by the side of it (see fig. 10).

This second mirror can be tilted in either the vertical or horizontal plane by means of two small thumb screws, and the spot of light reflected from it can thus be adjusted to any position. The galvanometer mirror is brought into correct

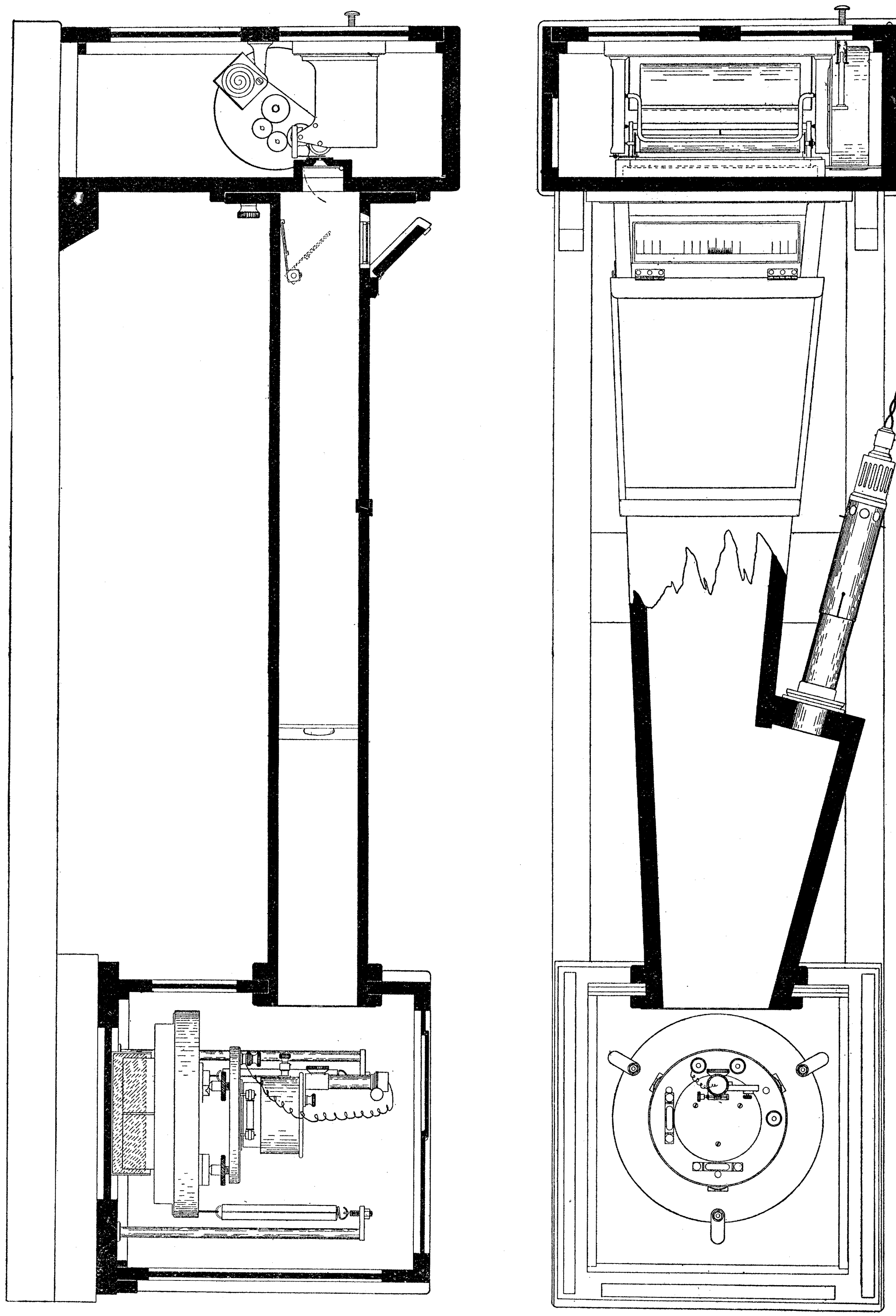

FIG. 10. — PHOTOGRAPHIC RECORDER Dr. GAMGEE'S. —

adjustment by means of a tangent screw, which controls the torsion on the strip carrying the suspended coil, and also by the three levelling screws.

Both these mirrors are concave, having a radius of 103 cm., and they are 10 mm. in diameter. When glass mirrors were used, silvered on the back, trouble was caused by the reflected image from the front of the glass; to avoid this trouble the mirrors ultimately used were of quartz, platinised on the front surface.*

These mirrors, when adjusted, throw the image of the slit in the diaphragm on the brass strip, showing it as a bright fine line; along this brass strip there is a narrow slit 0·5 mm. wide by 210 mm. long; this permits a small spot of light to pass through and fall upon the sensitised paper (see figs. 9 and 10).

In reference to the optical arrangements of my photographer recorder, I have to draw attention to the fact that, unlike most seismograph or magnetograph recorders, there is no cylindrical lens interposed in the path of the beams of light reflected from the mirrors of the galvanometer, but that the image of the slit in front of the Nernst lamp falls on the very narrow horizontal slit placed anterior to the plane of the recording surface. It is to the abolition of this cylindrical lens—an abolition rendered possible by the great luminosity of the Nernst lamp which was employed in the place of the usual and much feebler lamps used in seismographs and magnetographs—together with the substitution of finely worked platinised quartz lenses in the place of silvered glass lenses in the galvanometer, that I attribute the remarkable definition of the curves obtained by my recorder.

The recording paper is being continuously drawn over a roller, at the rate of 1 mm. per minute, by means of the needle points fitted in the middle of a roller, which is driven by the clock through the train of wheels.

The spot of light from the fixed mirror is adjusted to fall upon a small shutter. This shutter is moved gradually forward and then allowed to drop back, every half-hour, by means of a cam fitted on the end of the driving roller; when the shutter drops back, the spot of light falls upon the photographic paper. By this means, simultaneously with the temperature record, an intermittent line is obtained, which gives the time at any portion of the record. This line can also be used as a zero reference line, the distance of any point on the temperature curve from it being a measure of the temperature at that point.

It is important to give a ready means of examining the spots of light, for adjusting their position and for focussing. A plane mirror, mounted near the recording paper and movable by hand, deflects the beams of light upwards on to a translucent horizontal scale, where the spots of light can be examined. The dotted lines in fig. 10 show it in adjusting position, the full lines in working position, when the light passes over it to fall on the recording paper.

If it is desired to stop the clock, a knob is pressed in; this causes a small spring to touch the balance wheel of the escapement, thus stopping it; when the knob

* These mirrors were made by Hilger and Co., Ltd.

is released, the spring gives the balance wheel a small impulse and starts the clock again.

When the shutter is closed, the camera part of the recorder becomes a complete light-tight box, and, by removing the screws, this camera *may* be detached from the rest of the apparatus and taken to a dark-room, for inserting or removing the sensitised paper.

As a matter of fact, I found that it was practically impossible to detach this light-tight recording box (ot which the weight was 40 lbs.) without entirely deranging the whole adjustment of the apparatus, and I accordingly devised a small chamber, the walls of which were composed of ruby-red tissue, and which were impermeable to any but red rays, which permitted of the sensitised paper being introduced and removed from the apparatus (see figs. 4 and 4A, p. 229). After a run of, say, 24 hours, the roll of paper is removed, placed in light-tight paper, and taken to the dark-room for development. The paper which I employ in the photographic recorder is the seismograph paper supplied by the Kodak Company to all the seismograph stations in this country. It has a width of 200 mm. and a length of about 150 cm. Thanks to the explicit directions given to me by the scientific staff of the Kodak Company, I was enabled to develop all my curves, without a single exception, in an absolutely faultless manner.

My description of the various parts of the apparatus which I have devised and employed for the continuous photographic registration of the temperature of man will have made clear to the reader the manner in which my work has been carried out. A constantan-Cu couple is placed in a thermostat of practically absolutely constant temperature: the Cu terminal of this couple is connected with one terminal of the galvanometer by means of a Cu lead, whilst the constantan terminal is connected by a constantan flexible lead with the constantan half of the Cu-constantan electrical thermometer situated in the patient's axilla, mouth, or rectum. From the Cu element of this thermometer, by means of a flexible Cu-lead, the circuit is completed with the second Cu terminal of the galvanometer. In the path, which may be a very long one, however, of the circuit, there is placed a standard manganin resistance box, permitting of increasing or diminishing the resistance in the circuit and thus altering the amplitude of the oscillations of the galvanometer mirror according to the case which is being studied. (In figs. 4 and 4A, p. 229.) In addition, one or more keys are interpolated in the circuit. Thus, given the study of the rectal temperature of a healthy man, in whom the variations in temperature would presumably not exceed 1° C., resistances are intercalated which permit of 100 or even 120 mm. to correspond with 1° C. On the other hand, in the case of fever patients, in which the temperature may vary several degrees in 24 hours, such resistance must be introduced into the circuit as will permit of the whole excursion of the curve falling within a height of 200 mm.

It is not in the Royal Society, though it has in the past, and even in the recent past, listened to the actual results of medical and pathological observations of importance, that I should wish to enter in detail into the results of the actual observations which I have carried out by means of the method of automatic photographic registration which I have described, for, as is indicated by the title of this paper, I am dealing at present with methods rather than with results. I may, however, be permitted to point out and to illustrate by certain of the curves which I have obtained, that the method of photographic registration has revealed the fact that the temperature of the body in any given region is ceaselessly changing, and in a manner hitherto unsuspected, doubtless in consequence of constant changes in the activity of the great vaso-motor centre and its subordinates. These changes are much more strikingly seen in the curves of the diurnal changes in the rectal temperature of a healthy man, which are not reproduced in this paper, but which will be subsequently published.

II.—On the Method of Quasi-Continuous Registration of the Curve of the Temperature of Man, Employing the Patent Thread Recorder of Mr. Horace Darwin, F.R.S.

During the month which I spent in perfecting and adjusting the photographic recorder, almost constantly working in the rooms of the Cambridge Scientific Instrument Company, and prior to carrying out systematic observations in Addenbrooke's Hospital, I became intensely interested in the really beautiful instrument devised by Mr. Darwin for recording differences in temperature very much more considerable than those which form the subject of my studies—an instrument which may be used either as a recording ammeter or voltmeter, the amount of energy absorbed in the instrument being exceedingly small. The instrument, of which a general view is given in fig. 10, and of which the essential parts are schematically shown in fig. 11, consists of the following parts: firstly, of

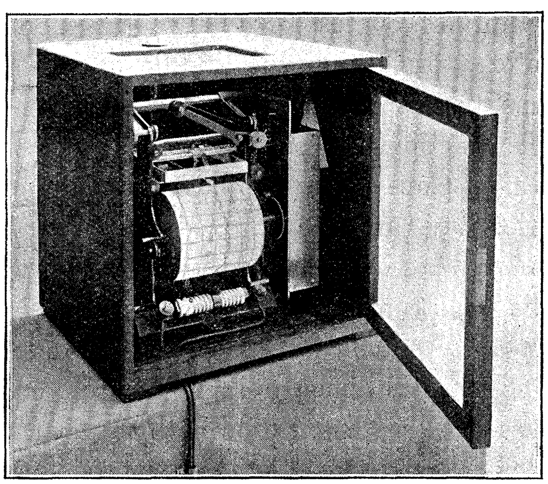

Fig. 11.

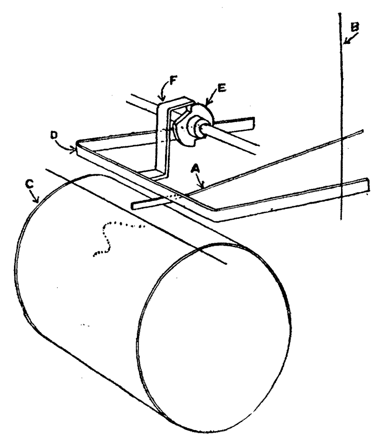

Fig. 12.

a d'Arsonval galvanometer (not shown in the photograph and diagram), of which (see fig. 11) the moving coil, instead of carrying a mirror, is provided with a pointer turning about its axis B and overhanging a drum C, the circumference of which is 180 mm., and which rotates once in 25 hours, or, by a simple change-speed arrangement, once in 2 hours 5 minutes. To the right-hand side of fig. 11 is seen a case enclosing a double clock. The lower of these clocks has for its function to drive the rotating cylinder. The upper, or so-called "slave-clock," has a much more arduous work to perform. "Between the pointer A and the drum C (*vide* 'schema,' fig. 12), an inked thread is stretched parallel to the axis of the drum, and at a short distance above its surface. (This endless thread is continuously being moved by the clock and, passing over an 'inking roller,' is kept sufficiently saturated with ink.) A presser-bar D is situated above the galvanometer pointer, and this bar is normally held free of the pointer by means of a cam E and its follower F. At regular intervals, normally of 60 seconds, the cam E makes a half-revolution, allowing the presser-bar D to fall upon the pointer A, and then raising it again to its normal height. As the presser-bar falls it depresses the pointer on to the drum, nipping the inked thread between the pointer and the paper. The pointer end of the galvanometer boom has an ivory knife-edge on its under side, which produces a dot upon the paper at the point of the intersection of the pointer and the thread, thus making a visible record of the instantaneous deflection of the galvanometer. The galvanometer pointer is hinged so that it can be depressed without bending the suspension. In the intervals between the production of the dots the galvanometer is, of course, free to take up its true deflection without frictional errors; as a dot is always produced where the thread and the pointer intersect, it will be obvious that, by suitable arrangements of the galvanometer coefficient, paper with rectangular co-ordinates of uniform scale can be used."

In the exceedingly capable catalogue on Technical Thermometry, published by the Cambridge Scientific Instrument Company, it is stated that a maximum sensitiveness of the said recorder with Cu-constantan couples for 1° C. = 3 mm. on the paper. As I was watching by the bedside of a patient in the middle of one night, the immense advantage which would accrue to hospitals and sanatoria, in which the study of disease is carried out in a truly scientific spirit, of possessing an ink recording galvanometer such as the thread recorder, in place of my very costly and delicate photographic recorder, struck me very forcibly, and it occurred to me that, by altering the resistance of the galvanometer, and much increasing the delicacy of suspension of the moving coil, a recording instrument would be obtained which, whilst writing its records in ink, would possess a delicacy between two and three times as great as that of our most delicate clinical thermometers, it being understood that all the arrangements which I have described in connection with my method of photographic registration, and which have reference to thermostats, couples, leads, etc., would remain the same. On discussing the matter the following afternoon with Mr. HORACE DARWIN, he entered warmly into my views, and by Wednesday of the following week the Scientific Instrument Company placed at my disposal a thread recorder which has absolutely fulfilled my predictions, and which has enabled most interesting curves to be recorded, both in the case of man in health and in disease. The recorder with which I worked enabled me, under the most propitious conditions of internal and external resistance, to obtain an excursion of 12 mm. per 1° C. The instrument is absolutely automatic; the roller over which the thread passes only requires to be inked once in six weeks, or once in two months, and both the cylinder and the "slave-clock" need only be wound once in 24 hours. Seeing the comparatively slow rate at which the cylinder clock rotates, the dots made by the galvanometer boom pressing upon the inked thread coalesce into a perfect curve.

It is my opinion that, whilst the system of continuous photographic registration which I have described constitutes the most perfect and the most delicate method of recording with absolute continuity the curve of the temperature of man, the thermo-electric method in connection with the thread recorder of Mr. HORACE DARWIN will be the practical instrument of clinical investigation.

Although, as I have stated, the present paper deals with methods, rather than with the results of their application, I think it advisable to illustrate the methods which I have devised and employed by adding to this paper and to the drawings which illustrate it:—

I. (See Plate 20.) A curve taken with the photographic recorder in a pathological case of great interest, and associated with great and continuous fever, in which an abdominal abscess (non-tubercular), of which I precisely diagnosed the locality, existed in a boy of 12 years. The case, unfortunately, proved fatal. The curve has been reduced by photography to exactly one-half its original dimensions. It exhibits, however, with great clearness the sensitiveness of the methods employed. The case being one of continuous though fluctuating high temperature, I arranged for a sensitiveness *much below* that which I employ in studying the axillary and rectal temperatures of healthy men. Still, it will be seen that an excursion of 21·2 mm. corresponded to 1° F., or 38 mm. to 1° C., *i.e.*, the sensitiveness of the arrangement being four times greater than that which can be attained by a fine clinical thermometer. I would further point out that whilst with the system of automatic continuous photographic registration the actual temperature at any time can be accurately determined, the maximum clinical thermometer, which is now invariably employed, if kept *in situ* 3, 5, or 10 minutes, in no sense furnishes an integration of the temperature during the period of observation, but merely records the highest temperature attained at an unknown time during the sojourn of the instrument in one of the cavities of, or in contact with the surface of, the animal body. I may add that observations made with clinical thermometers of peculiarly careful construction, divided into 0°·05 C., and tested at the National Physical Laboratory, have shown in the results which they furnished perfect agreement, so far as their indications permitted it, between the results obtained with them and those deduced from the study of the curves taken with the continuous photographic recorder.

II. A curve of my own temperature taken in the axilla with my thermo-electric arrangements and Mr. HORACE DARWIN'S thread recorder. (See Plate 21.)

III. The curve in a case of pneumonia, almost certainly of tubercular origin, taken with the thread recorder. (Plate 21.)

At 10 P.M., paracentesis of the left pleural cavity was performed to withdraw the greater part of a large effusion which had formed. The operation was followed by a rise in temperature from 104°·2 F. to about 105°·3, probably in great measure accounted for by the incessant coughing of the patient. At 1.25 a dose of the hospital "*linctus*," containing 12 drops of liq. morph. hydroch., was administered. The cough was almost at once relieved, and at 3.25 the patient fell asleep, when the temperature sank almost suddenly, as shown by the curve, to 100°·5. This curve, which represents all the temperature changes during 38 hours 30 minutes, illustrates admirably the value of the method of registration under discussion.

In conclusion, I wish to express the deep obligations which I owe to the Committee of Addenbrooke's Hospital, Cambridge, who during several months furnished me every opportunity of carrying out, in their fine hospital, the studies of which the results are incorporated in the present paper. I have, further, to express my indebtedness to the Regius Professor of Medicine, Sir CLIFFORD ALLBUTT, K.C.B., F.R.S., to Dr. LAURENCE HUMPHRY, F.R.C.P., and, indeed, to the whole staff of Addenbrooke's Hospital for the help which they gave me in my work, and the sympathetic interest which they manifested in it.

Lastly, I have to acknowledge the resourceful help given me, evening after evening, by Mr. F. W. BISSETT, at that time an assistant in the Testing Room of the Cambridge Scientific Instrument Company, and now an assistant in the Technical Department of the University of Sheffield.

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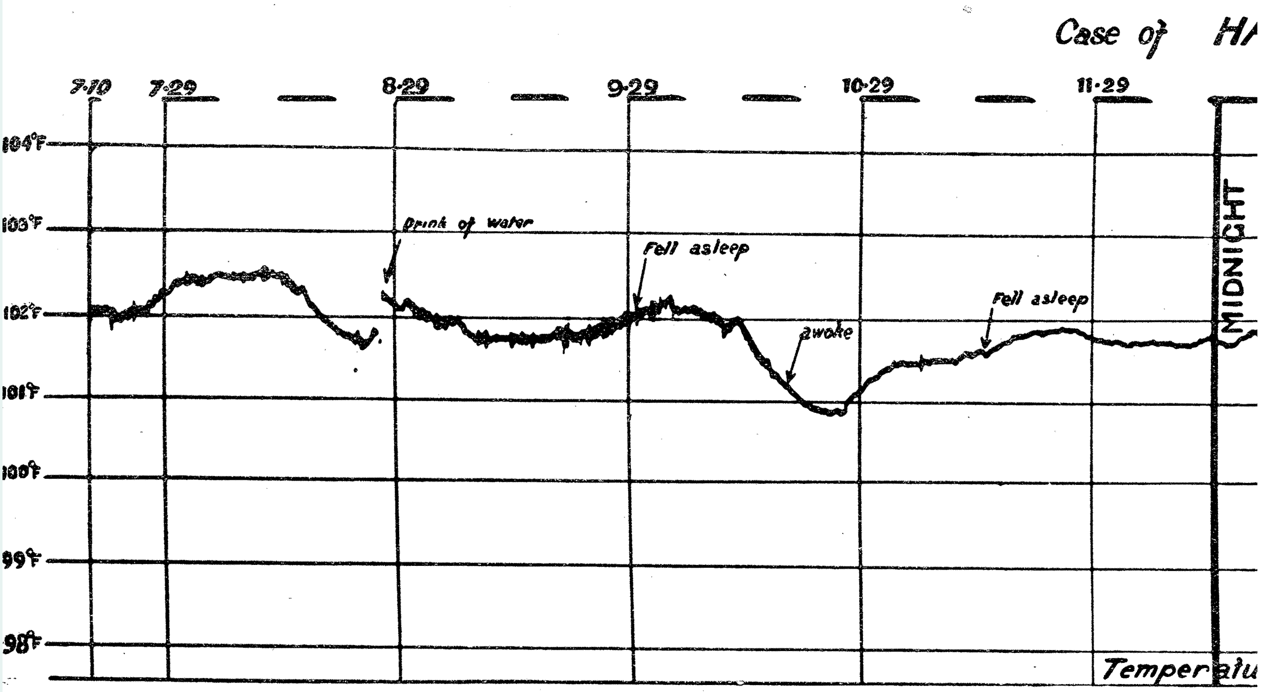

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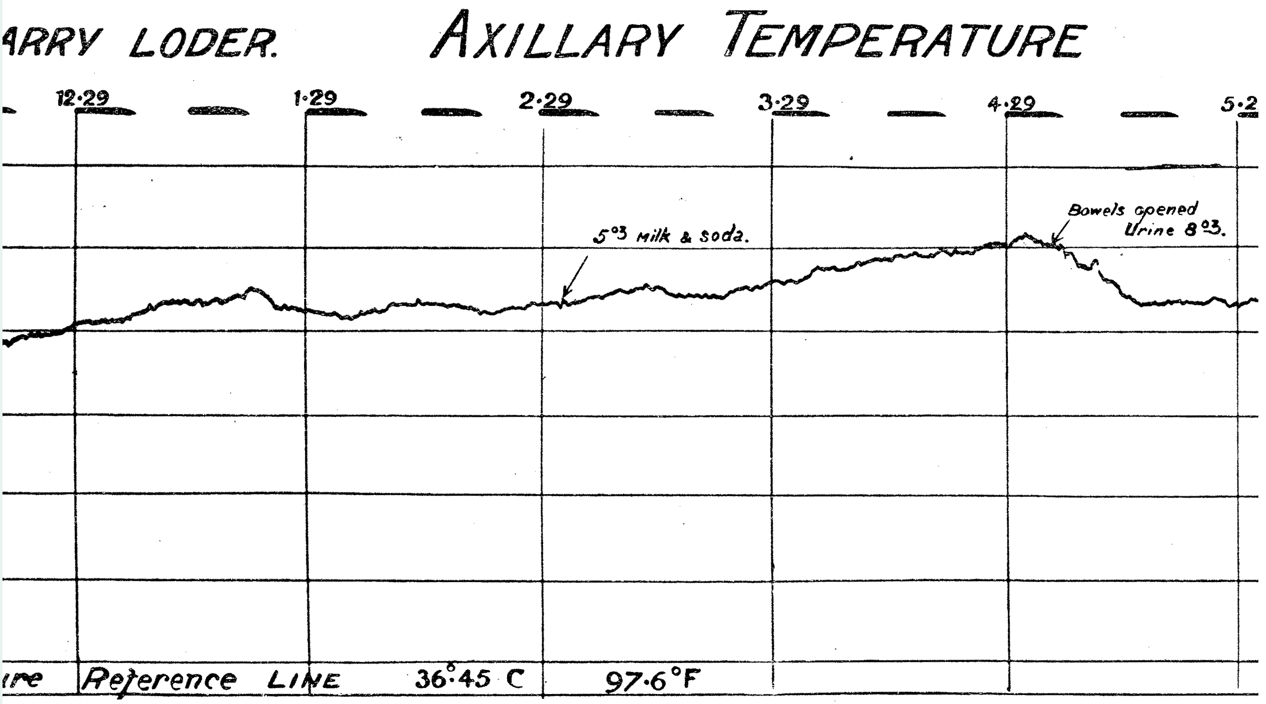

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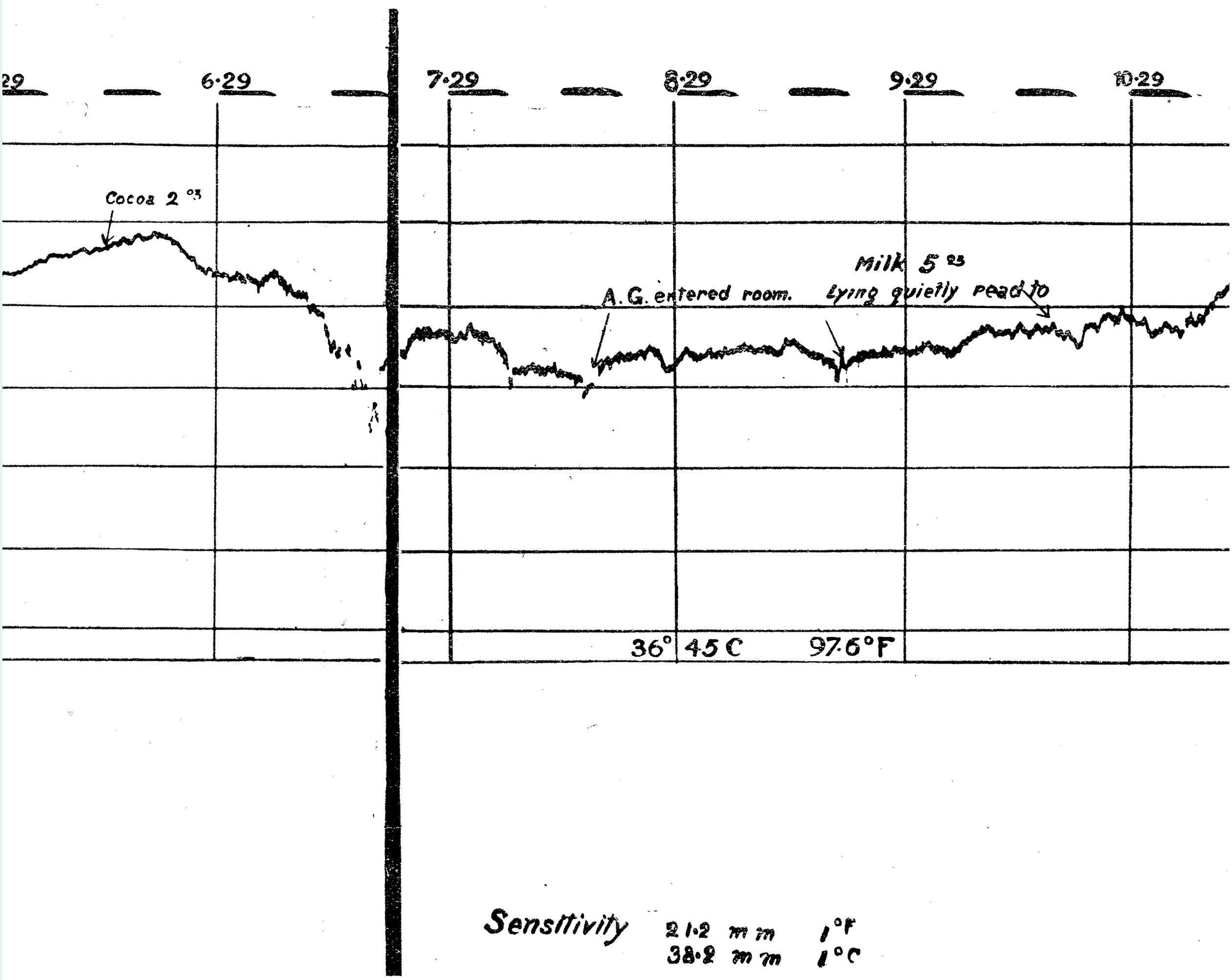

ntinuous Curve taken with the Photographic Recorder.

(Reduced by Photography to one-half original dimensions.)

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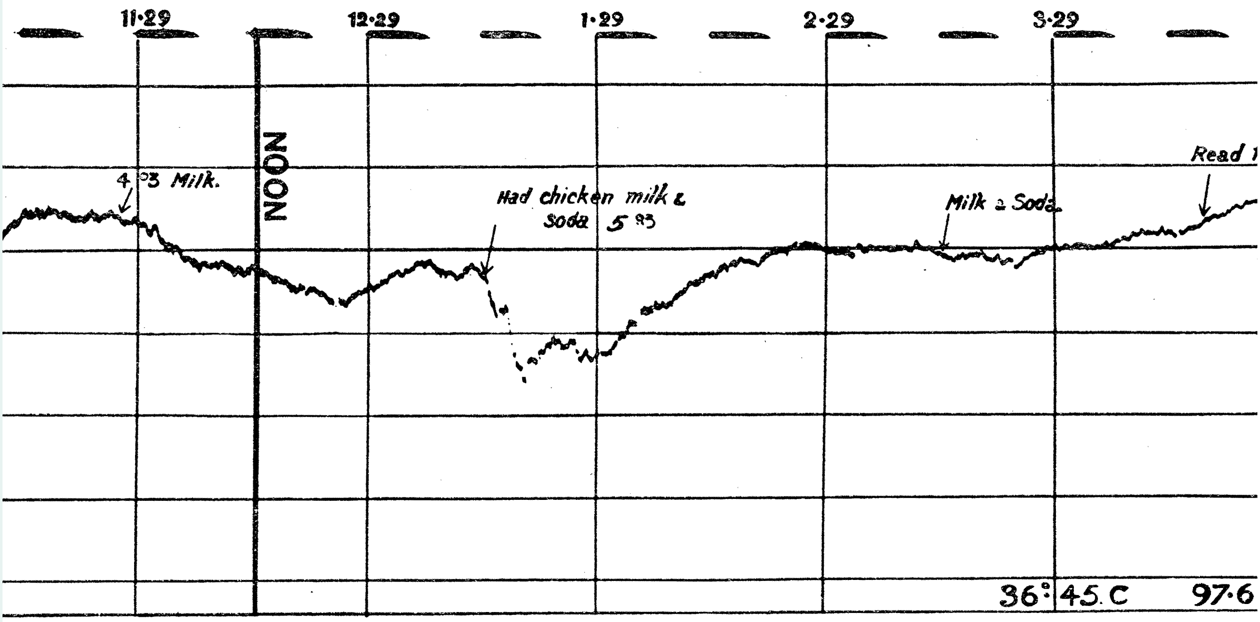

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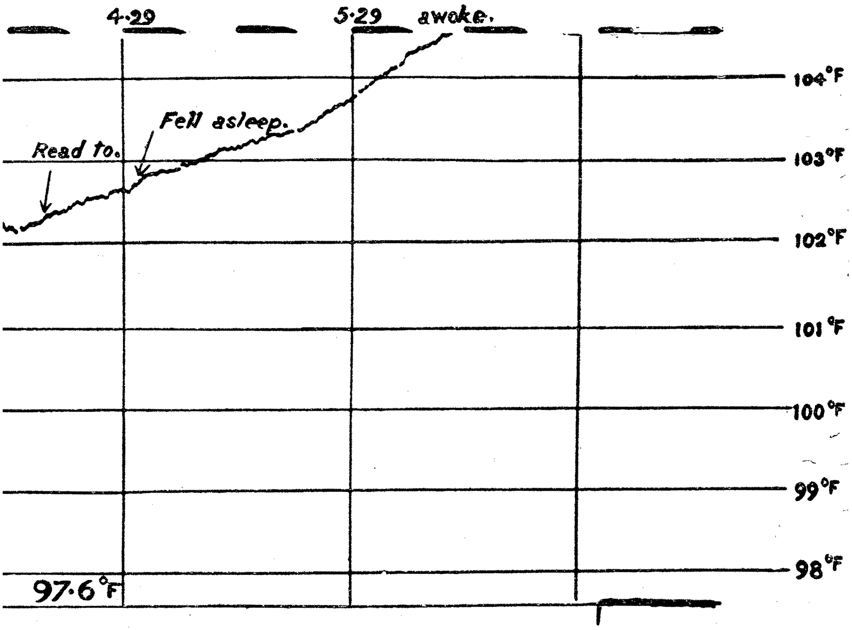

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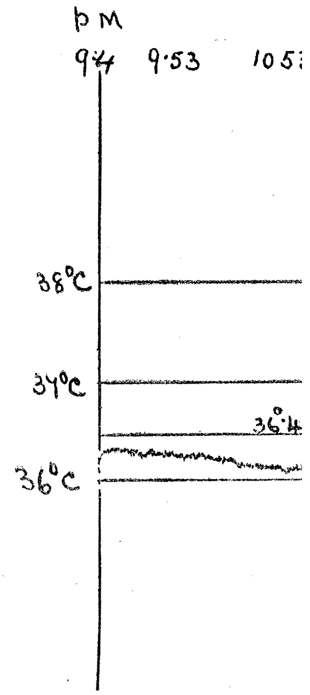

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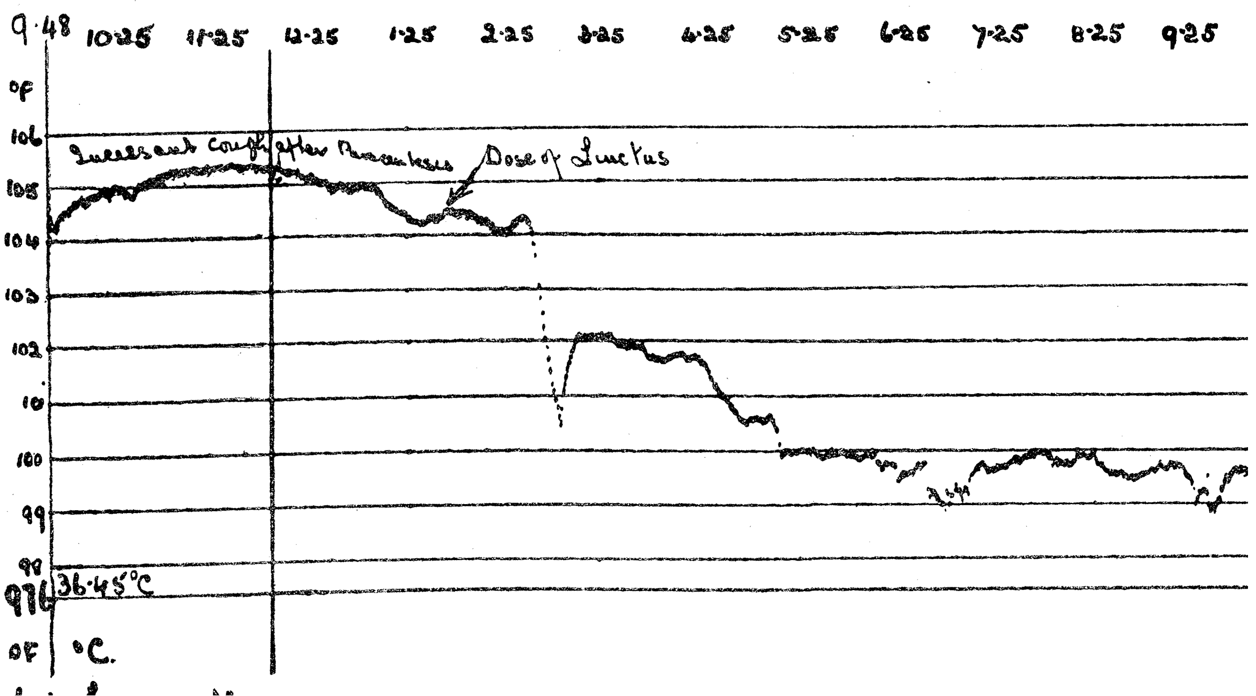

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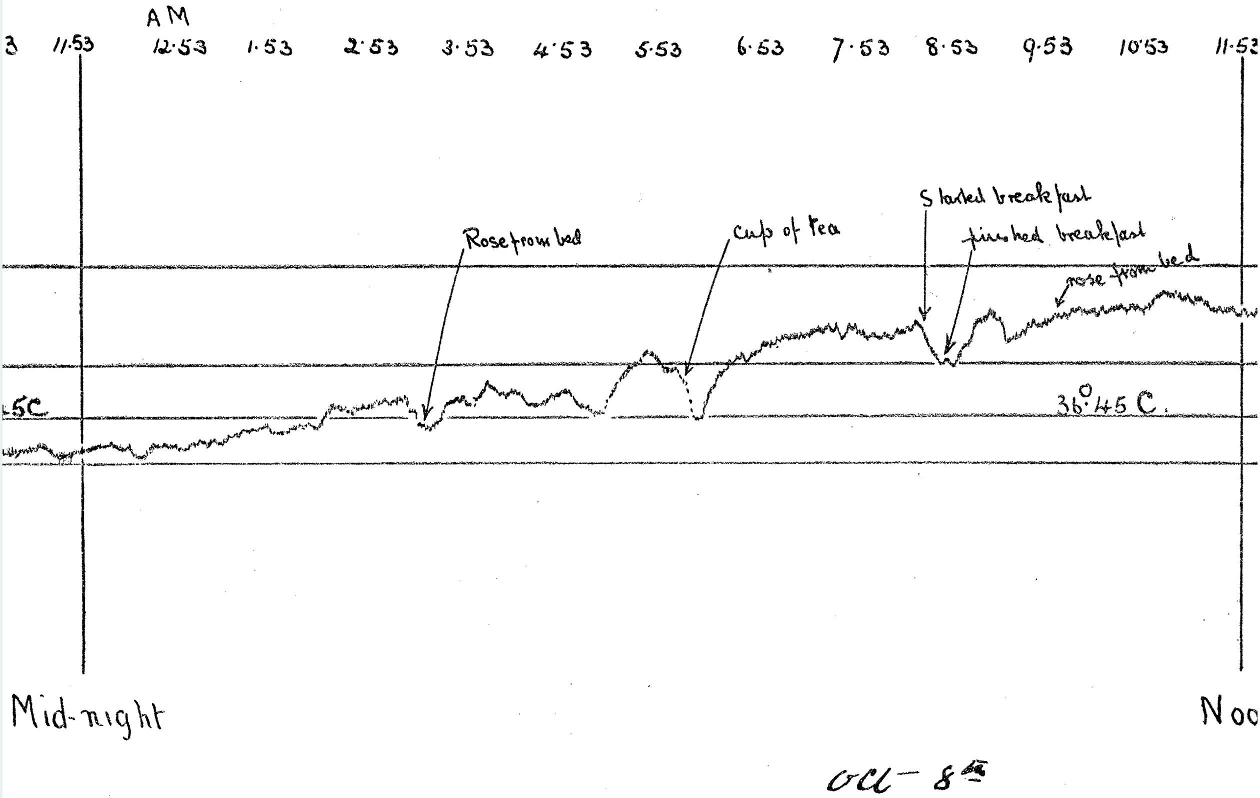
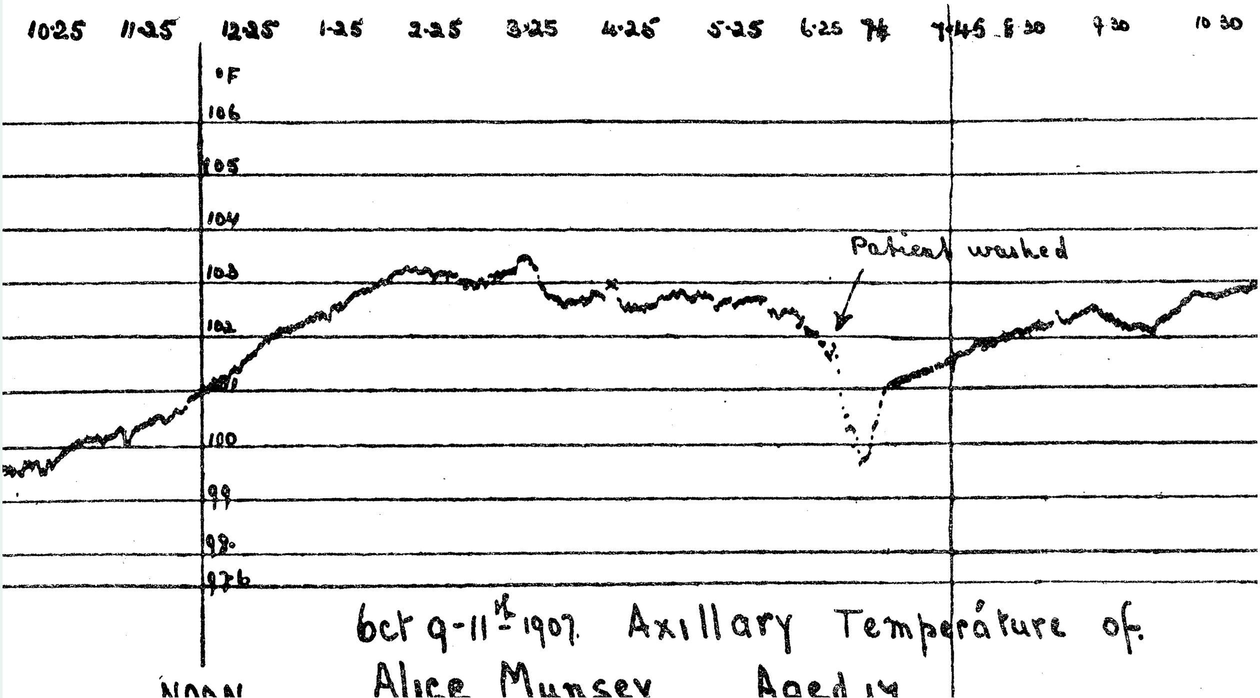
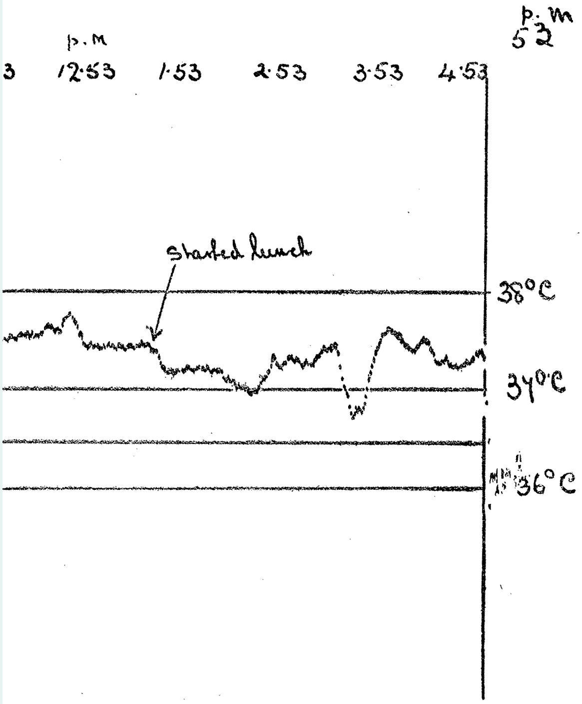


Curve of Axillary Temperature of A.G. (Thread Recorder).

(Original dimensions.)





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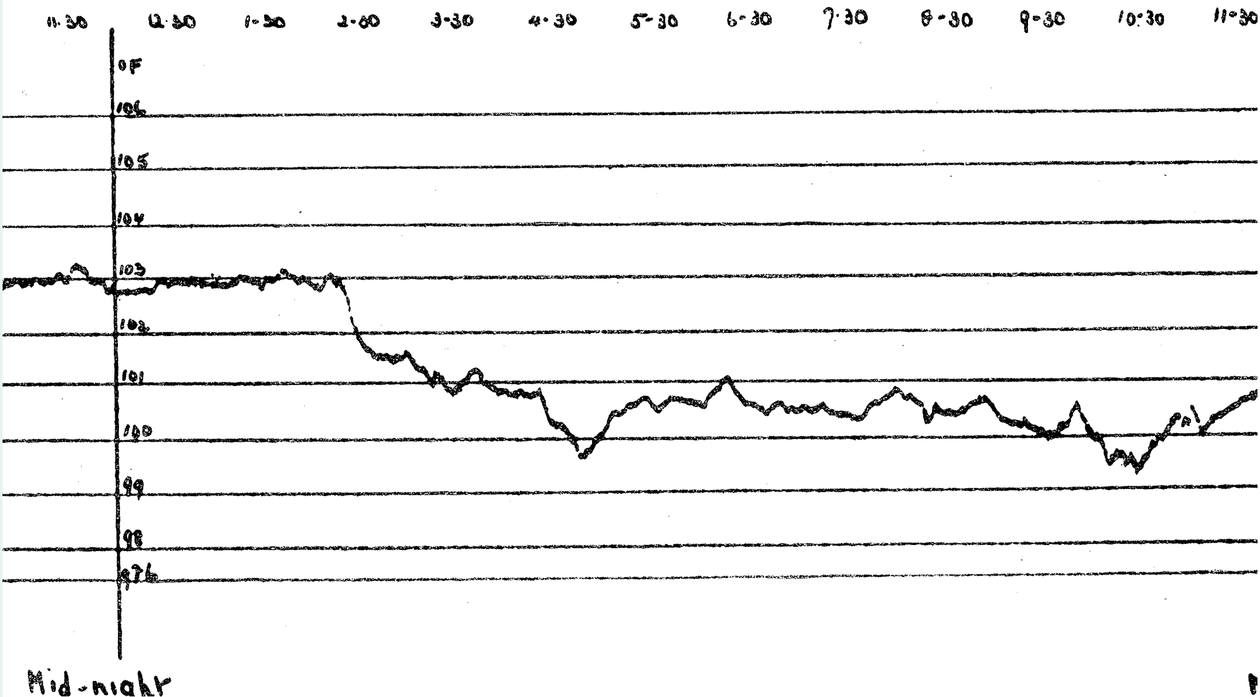
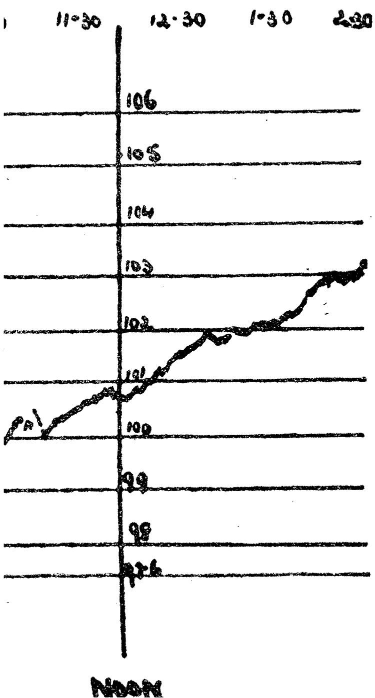




PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

Oct 9-11th 1907. Axillary Temperature of.
Alice Munsey. Aged 17.
Pneumonia with effusion

NOON
Oct 10th 1907.

Lower Half. (Taken with Thread Recorder.)

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

Noon
Oct 11th 1907.

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

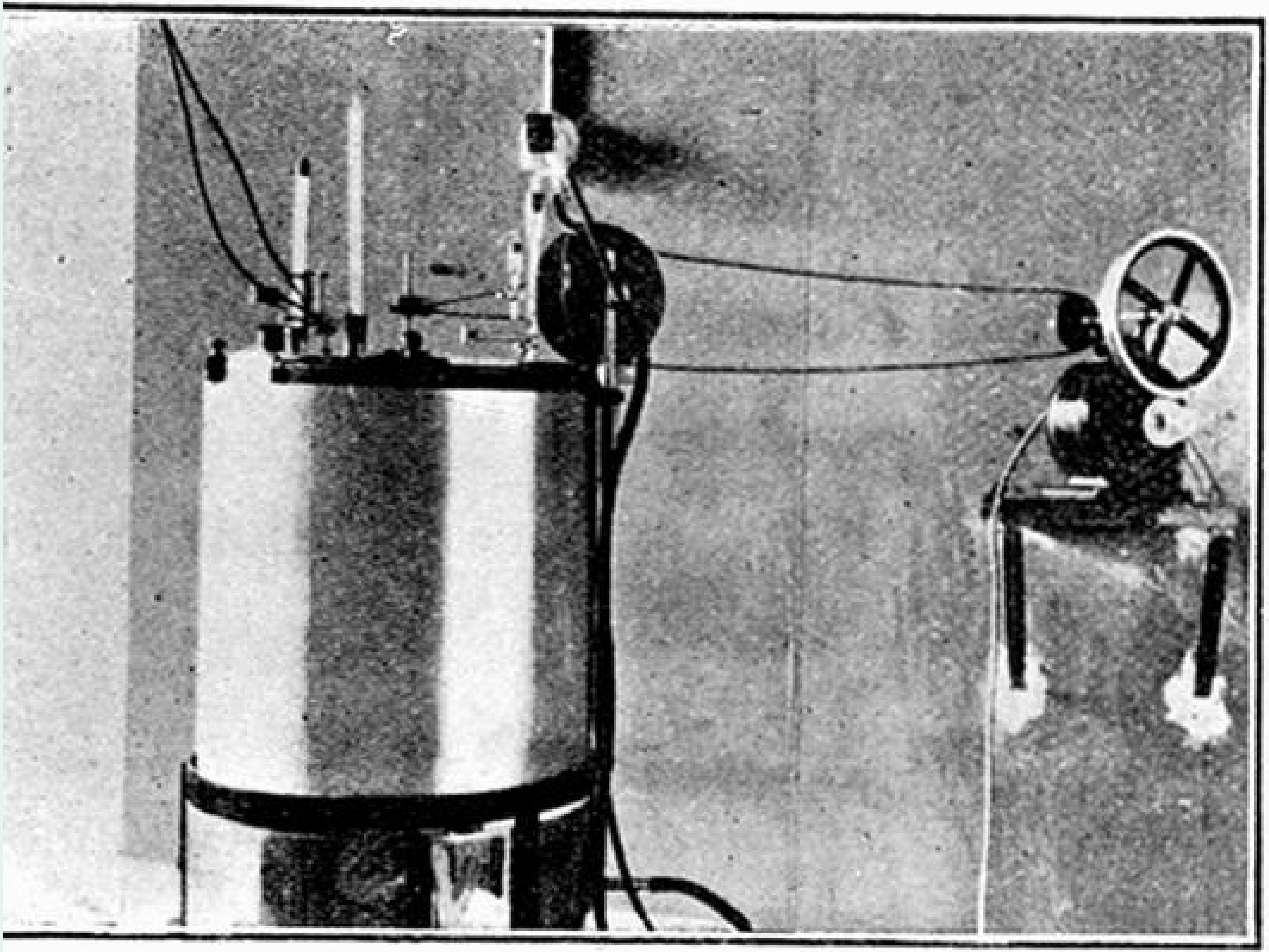


Fig. 2.

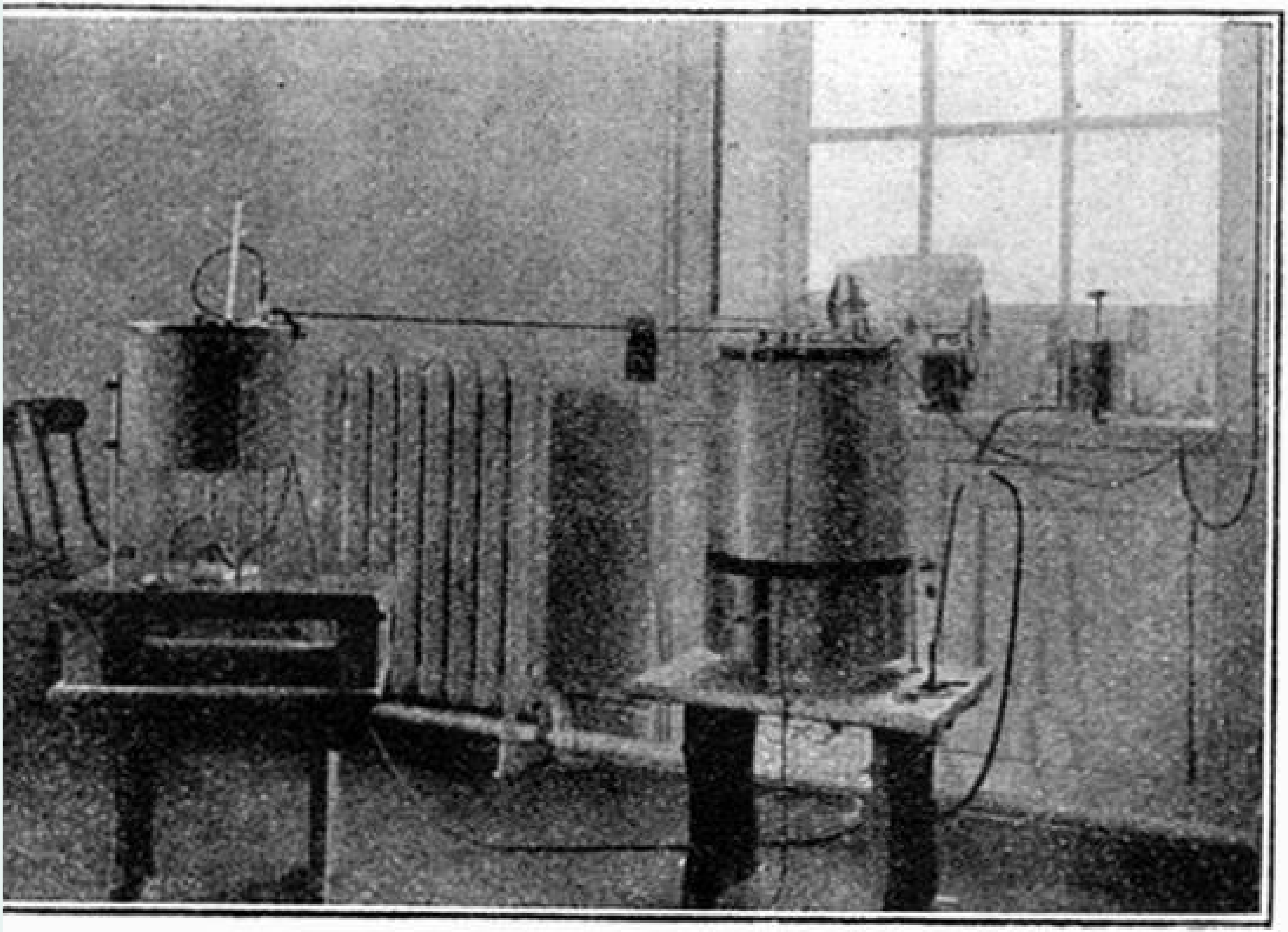


Fig. 3.

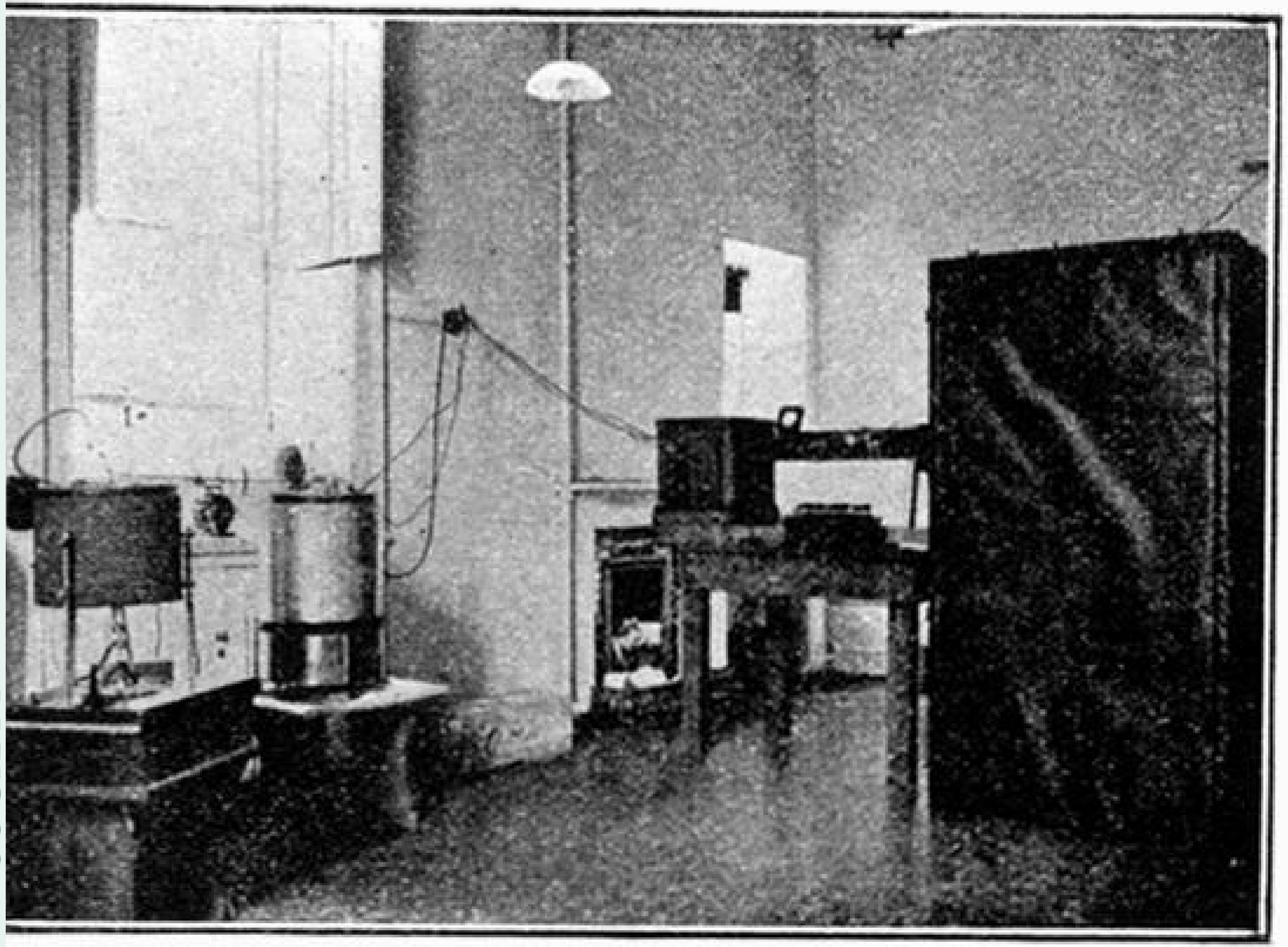


FIG. 4.

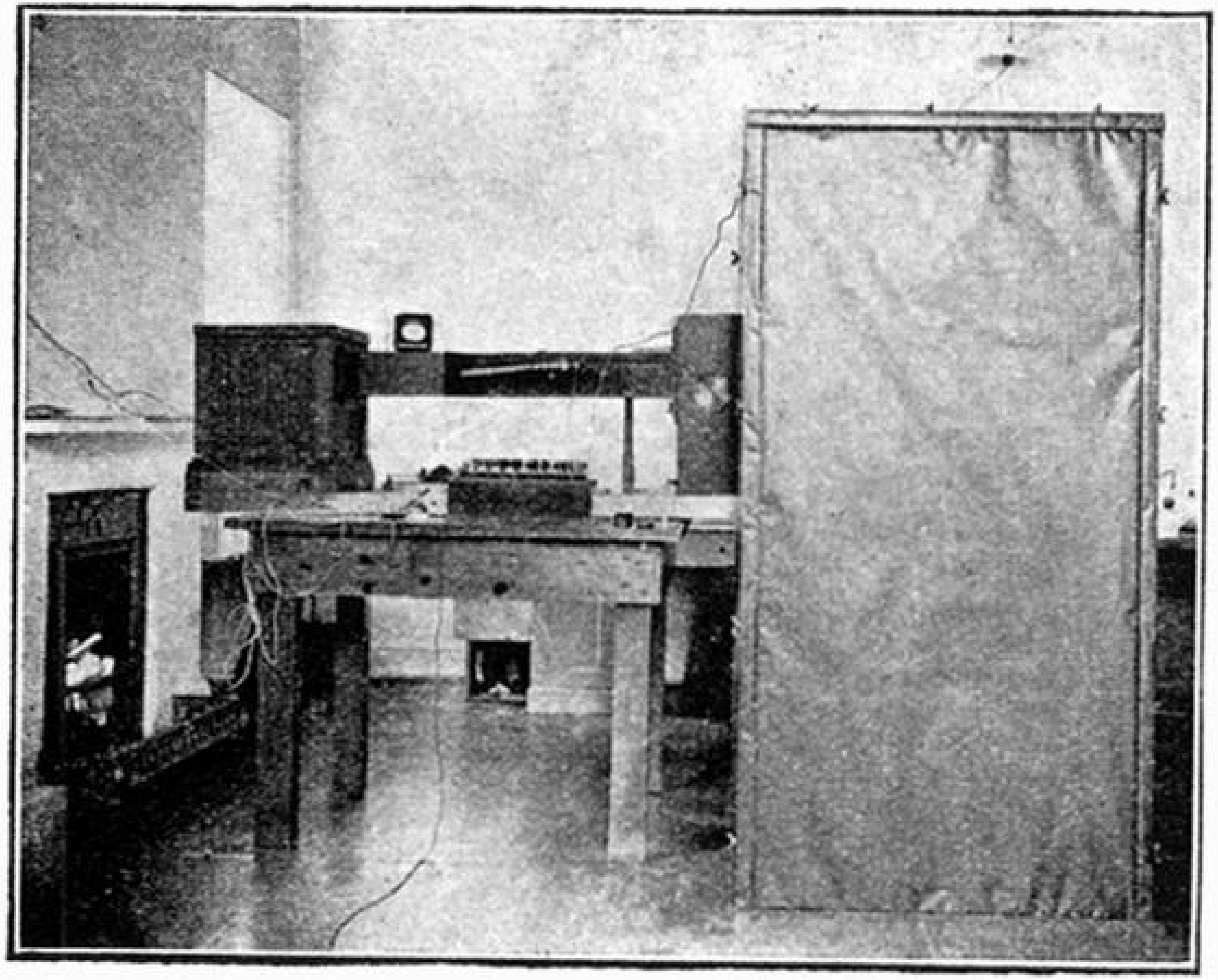


FIG. 4A.

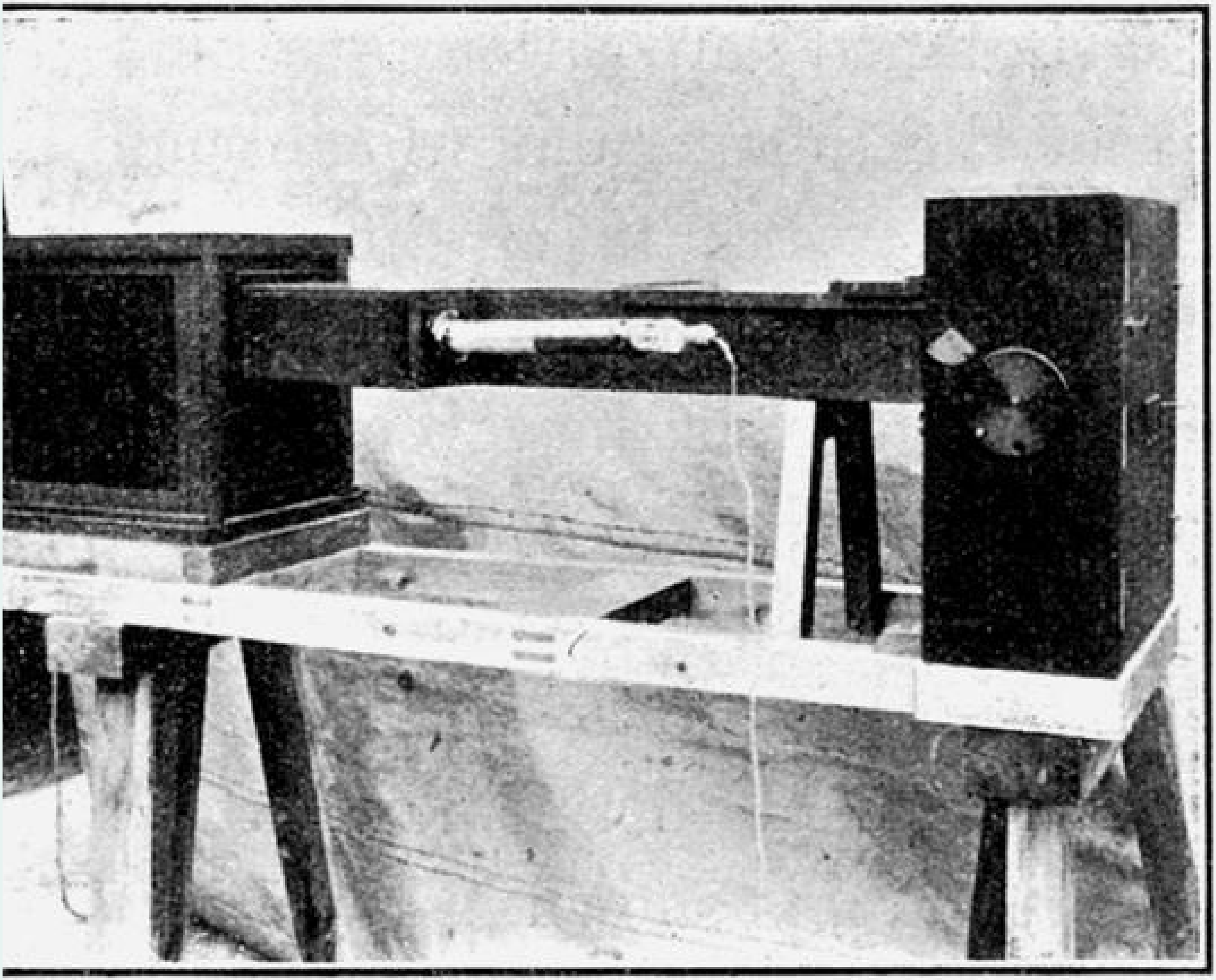


FIG. 7.

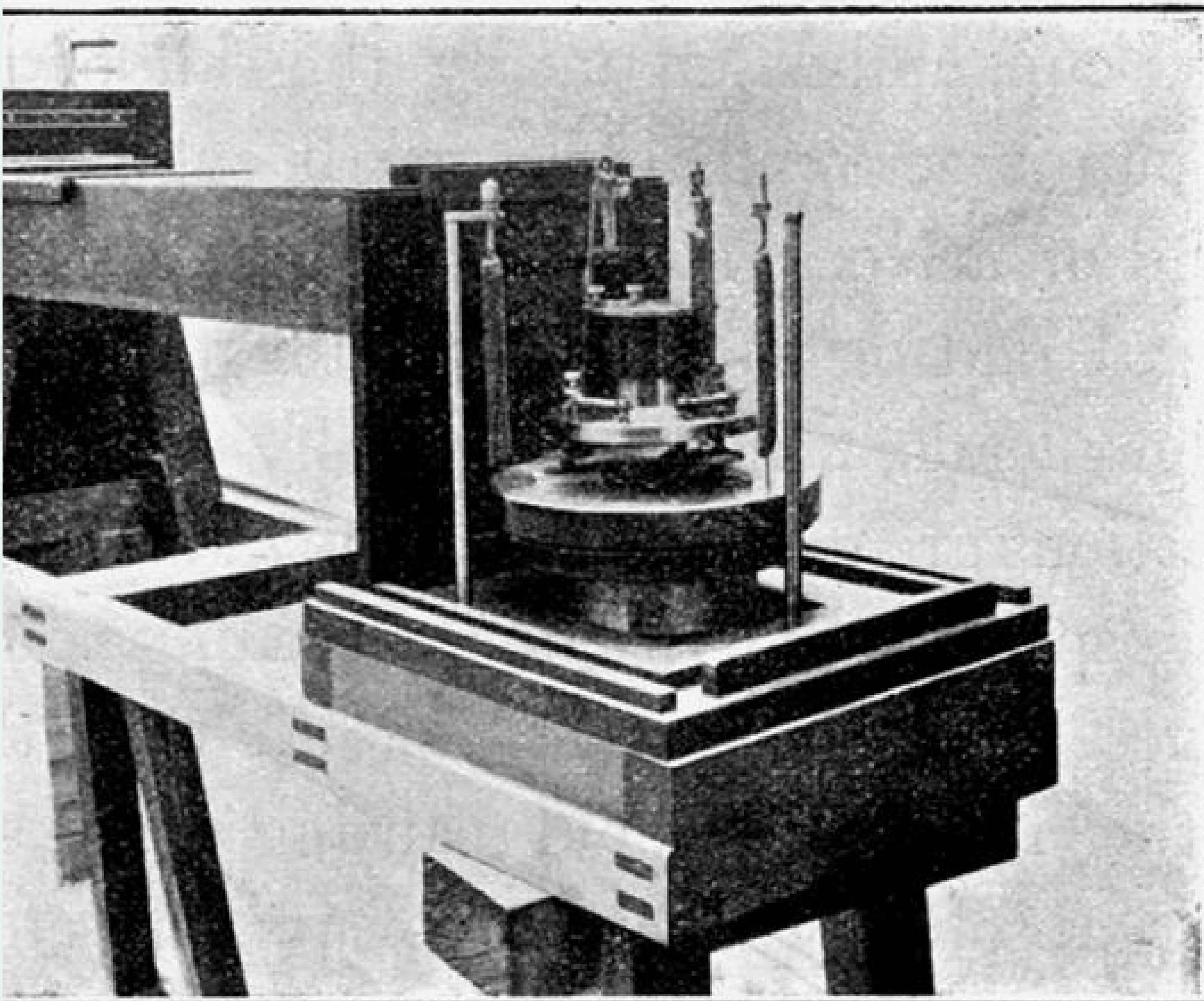


FIG. 8.

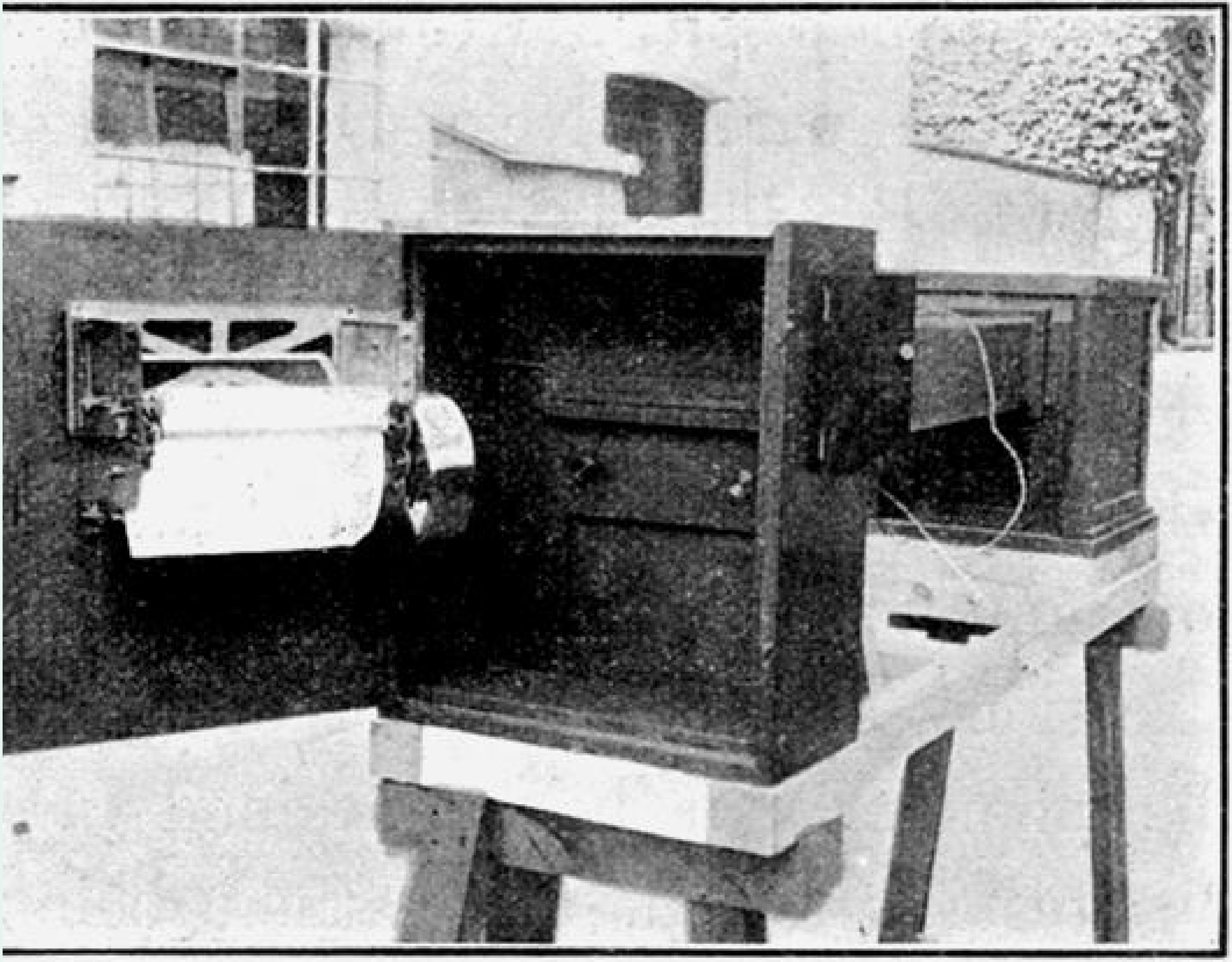


FIG. 9.

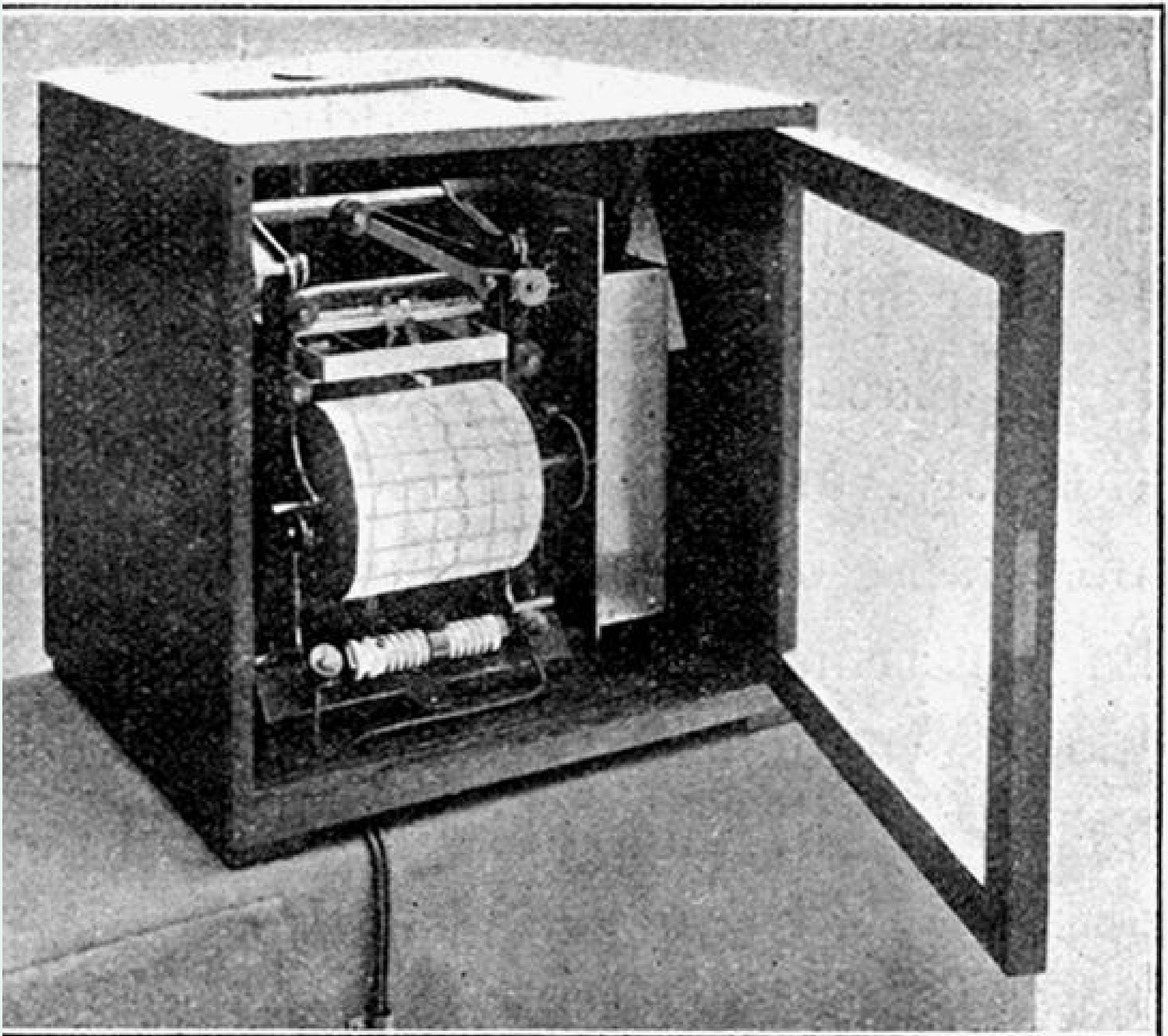
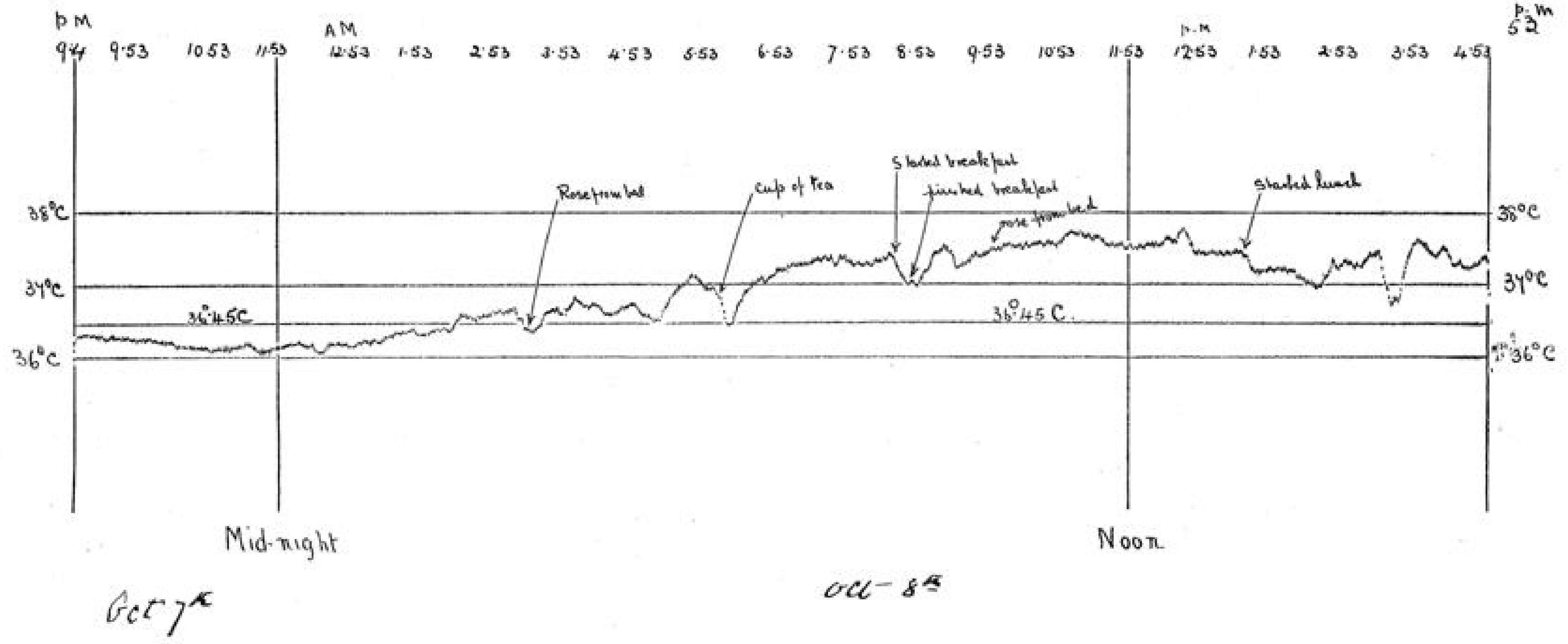


FIG. 11.

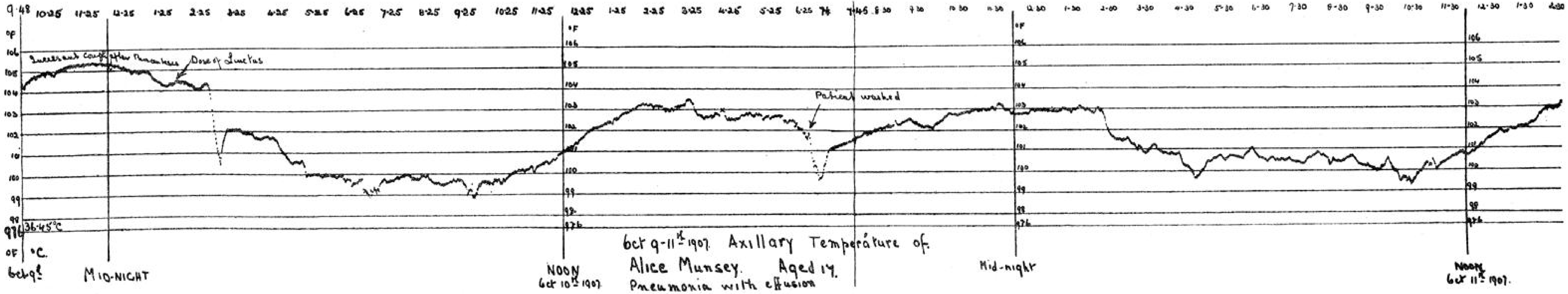
Continuous Curve taken with the Photographic Recorder.

(Reduced by Photography to one-half original dimensions.)



Curve of Axillary Temperature of A.G. (Thread Recorder).

(Original dimensions.)



Lower Half. (Taken with Thread Recorder.)