ANALYSIS OF WATERS FROM SEVERAL SPRINGS AT THE CALIFORNIA GEYSERS.

Contents per United States Gallon, Expressed in Grains.	Lemonade Spring, Temp. 103° F.	Witches' Caldron, Temp. 212° F.	Acid Spring, Temp. 140° F.	Alum Spring, Temp. 130° F.	Iron Geyser Creek, below Alum Spring, Temp. 96° F.	Spring on side of hill near river, Temp. 138° F.	Iron Spring north of hotel, Temp. 70° F.	Indian Spring (second), Temp. 101° F.	Mud Indian Spring, Temp. 100° F.	Spring little above Indian Spring, Temp. 105° F.	Hot sulphur water above bathhouse, Temp. 140° F.	Devil's Tea-Kettle, Temp. 212° F.
Potassium bisulphate	7.53	0.42	1.14									
Potassium sulphate	....	....	....	....	....	....	....	0.21				
Sodium bisulphate	53.91	39.82	9.62	5.14	....	....	....	....	17.12	....	....	98.16
Sodium sulphate	....	....	....	....	3.15	3.23	....	3.29	....	....	2.36	
Sodium carbonate	....	....	....	....	....	....	....	1.40				
Calcium sulphate	....	6.98	4.44	3.81	5.34	1.10	3.32	....	6.42	8.72	.65	4.36
Calcium carbonate	....	....	....	....	....	....	....	7.35				
Calcium silicate	....	....	....	....	....	10.18						
Calcium borate	....	....	....	....	....	....	....	....	....	....	6.62	
Magnesium sulphate	40.73	9.62	91.29	34.49	16.66	....	2.52	....	59.33	41.12	....	39.09
Magnesium carbonate	....	....	....	....	....	....	....	15.47				
Magnesium silicate	....	....	....	....	....	15.46						
Magnesium borate	....	....	....	....	....	....	....	....	....	....	17.31	
Iron sulphate	12.25	....	16.63	7.34	.08	.11	....	....	....	28.81	.16	
Iron carbonate	....	....	....	....	....	....	.12	.07				
Aluminum sulphate	32.02	2.04	20.62	63.82	....	.20	....	....	22.78	118.78	2.39	31.16
Alumina	....	.27	....	....	.89	....	.17	.18				
Free sulphuric acid	31.82	....	154.37	6.45	....	....	....	....	32.30	5.75	....	110.64
Hydrochloric acid	1.19											
Silicic acid	16.50	4.37	21.11	17.26	3.50	17.25	.99	5.42	12.25	18.08	8.63	12.83
Sulphureted hydrogen	Sat.	Sat.	Sat.	Sat.	Sat.	....	....	Sat.	Sat.	Sat.	Sat.	Sat.
Boric acid	....	....	Str.	Traces.	....	....	....	....	....	....	Str.	Traces.
Total	195.95	63.52	319.22	138.31	29.62	47.53	7.12	33.39	150.20	221.26	38.12	296.24

enterprise of our Western civilization, it may now be reached in a comfortable six-horse stage from the termini of the Cloverdale and Calistoga railroads over excellent mountain roads. It is a good plan to go by way of Cloverdale and come back by way of Calistoga, as all the grandeur and beauty of the surrounding country may thus be seen. The following entertaining account of a visit to the geysers is taken from Dr. Anderson's work:

"Leaving Cloverdale after luncheon, comfortably seated in our stage, with an experienced and accommodatingly communicative driver, who takes pleasure in pointing out the many objects of interest, we soon cross the Russian River and commence the ascent. The hills and mountains are robed in evergreen verdure of indigenous flora, gigantic oaks, and towering pines. Here and there the huge boulders and rocky cliffs stand out in bold relief, and as we wind up and around the mountain sides, with the Pluton River many hundred feet below, basking and smiling in the afternoon sun, and rippling along its moss-covered banks and bright-pebbled bottom, with here and there a miniature cascade and waterfall, we feel that words cannot describe the grandeur of the scenery. . . .

"As we gain in altitude the view becomes more and more extended, until our eyes leap with vivid interest from peak to peak and valley to valley for miles around, feasting upon the beauties of nature. Some two or three miles down the cañon, before we reach the geysers, our attention is called to the large white or yellowish-white banks across the cañon. They are known as sulphur banks, and consist of deposits of sulphur and cinnabar, with incrustations of salts of sodium, potassium, magnesium, sulphur, etc. . . . Near these sulphur banks are found the famous Indian Springs, at which Edwin Forrest camped for one season and was completely restored to health."

The waters are diuretic, laxative, and antacid, and are valuable in dyspepsia, torpidity of the liver and bowels, and in renal and cystic diseases. (See table for analysis.)

Near by are the real "Indian Mud Springs," which are highly extolled in the treatment of chronic rheumatism, gout, arthritis, and synovitis, and scrofulous and cutaneous contaminations. (See table.)

". . . After a few more horseshoe curves have been passed and several more magnificent landscapes have been mentally photographed on the brain, we reach the geyser resort. The many cosey cottages, the hotels and grounds, are situated in a leafy dell on the side of the mountain opposite the Geyser Cañon. The huge oaks and pines afford pleasant shade to the commodious verandas as we sit and enjoy the pure, dry, invigorating, and exhilarating mountain air and picturesque scenery which surround us on every side."

The geysers are wonderful and picturesque exhibitions of the nearly extinct volcanic forces slumbering beneath the romantic "Devil's Cañon." The region covers an area of about four hundred acres, most of the activity, however, being confined to the "Devil's" or "Geyser" cañon, comprising about sixty acres. Collectively, the springs, hot and cold, flow about one hundred thousand gallons daily.

From the foregoing analyses (see above) made by Prof. Thomas Price it will be observed that at the geysers can be found probably as great a variety of mineral waters as at any other place on the continent, or perhaps in the world. When the improvements now contemplated are carried out, the "geysers" will be one of the world's greatest sanatoriums.

There are other geysers in various parts of California, but they have not so far reached any great importance as health resorts. Near Litton's Station, in Sonoma County, some few miles from Geyserville, is a pleasant resort known as the "Geyser Spa" or "Soda Springs." The surrounding country is picturesque, and the climate mild and salubrious. A large number of people go to Geyser Spa every year. The waters are highly esteemed for their antacid, diuretic, and aperient properties. The following analysis was made by Dr. Winslow Anderson in 1888:

ONE UNITED STATES GALLON CONTAINS:

Solids.	Grains.
Sodium chloride	8.93
Sodium carbonate	4.97
Sodium bicarbonate	21.16
Sodium sulphate	2.60
Potassium carbonate	Trace.
Magnesium bicarbonate	9.03
Magnesium sulphate	1.14
Calcium carbonate	4.90
Ferrous carbonate	2.09
Silica	3.75
Organic matter	Trace.
Total solids	58.57

Carbonic acid gas, saturated.

A previous analysis made by Bauer and Price yielded results almost identical with Anderson's.

James K. Crook.

CALIFORNIA POPPY. See *Eschscholtzia.*

CALIFORNIA SELTZER SPRINGS. — Mendocino County, California. These springs are pleasantly located in the Coast Range, 12 miles from Cloverdale. The surroundings are picturesque, and the climate salubrious. There are comfortable accommodations for visitors.

On analysis the Seltzer Spring was found by Anderson to be composed as follows:

ONE UNITED STATES GALLON CONTAINS:

Solids.	Grains.
Sodium chloride	17.15
Sodium bicarbonate	53.00
Sodium carbonate	Trace.
Magnesium carbonate	44.60
Ferrous carbonate	Trace.
Calcium carbonate	72.40
Organic matter	Trace.
Silica	Trace.
Total solids	187.15
Free carbonic acid gas	18.00 cu. in.
Temperature of water	57° F.

The waters are sparkling and quite palatable. They have a diuretic and aperient action, and are beneficial in dyspepsia with acid eructations, constipation, acid states of the urine, cystitis, etc. They belong to the alkaline-carbonated class.

James K. Crook.

CALISAYA. See *Cinchona.*

CALISTOGA SPRINGS.—Napa County, California. These valuable springs are situated 9 miles south of Mount St. Helena. There are two sets of springs, one in the city of Calistoga and the other just outside the town. They are very similar in chemical composition. There were at one time an excellent hotel and many fine cottages at the springs, but since the fire in 1868, which destroyed the former and several of the latter, the resort has changed hands many times, and has been allowed to run down. It is said that the present proprietor contemplates fully restoring the once handsome resort.

The mineral springs number some twenty or more, and range in temperature from 75° to 186° F. They are used for drinking and bathing purposes, and have acquired considerable reputation. The following analysis of the water of one of the springs at Magnolia Hotel was made by Dr. Anderson:

ONE UNITED STATES GALLON CONTAINS:

Solids.	Grains.
Sodium chloride	20.76
Sodium carbonate	5.10
Sodium sulphate	1.75
Sodium iodide	.16
Potassium iodide	Trace.
Magnesium sulphate	2.90
Calcium chloride	5.57
Calcium sulphate	.63
Alumina	.47
Silica	4.55
Organic matter	Trace.
Total solids	41.89
Free sulphureted hydrogen gas	4.75 cu. in.
Temperature of water	95° F.

The following analysis shows the mineral ingredients of the Hot Swimming Pool on the grounds of the late Senator Stanford:

ONE UNITED STATES GALLON CONTAINS:

Solids.	Grains.
Sodium chloride	23.07
Sodium carbonate	2.19
Sodium sulphate	6.92
Sodium iodide	.73
Potassium iodide	.21
Potassium carbonate	.76
Magnesium sulphate	1.16
Magnesium chloride	.40
Calcium chloride	.96
Calcium sulphate	1.25
Ferrous protoxide	.45
Manganese	Trace.
Alumina	.27
Silica	3.61
Organic matter	Traces.
Total solids	41.98
Sulphureted hydrogen gas	6.30 cu. in.
Temperature of water	121.6° F.

The springs have gained considerable celebrity in obstinate cases of syphilitic contamination, rheumatism, etc.

James K. Crook.

CALLOSITAS.—(*Callus, Hardened Skin*).—SYNONYMS.—Callosity; Tyloma; Tylosis; Callus; Keratoma; (*Fr.*) Durillon.

DEFINITION.—A circumscribed thickening and welding of the horny layer produced by intermittent friction or pressure.

Callosities are congenital or acquired. The congenital callosities, however, are now usually discussed separately under the heading of Keratodermia or Tylosis Palmæ et Plantæ. The latter are diffuse or circumscribed keratomata, usually symmetrically distributed over the palms or soles, or over both, springing from an apparently normal skin or surrounded by a red areola. Arsenic from prolonged use often causes a similar condition.

Peculiar symmetrical horny hypertrophies are sometimes associated with certain neuroses or unknown constitutional conditions; these are often preceded by mild inflammatory symptoms. The so-called syphilitic keratodermias should probably be placed with the latter class. The term callosity is more properly applied to the acquired form, which is essentially a result of external irritation by friction, by *intermittent* pressure, or rarely by chemicals. *Continuous* pressure or friction causes active inflammatory reaction, either vesiculation, or pustulation, or sloughing. The result of this milder trauma is best seen upon the hands of mechanics, oarsmen, wood-choppers, and those whose occupations necessitate this irritation, as yellowish or yellowish-brown, circumscribed, round, or irregularly shaped flat or raised patches of thickened skin that are hard and resistant to the touch. They occur usually over the bony prominences or bursæ, and spring from apparently normal skin.

Callosities may occur upon any portion of the body subjected to the exciting factor. The feet, next to the hands, are most frequently affected, due to walking barefoot or to badly fitting shoes.

This thickening of the horny cells is an effort of nature to protect the more delicate underlying structures. Histologically there is probably no actual increase in the production of epithelial cells but a "welding" (Unna) together of the pre-existing horny cells by the friction, into a homogeneous horny mass; thus the cells normally thrown off are retained, producing an apparent increase and an actual thickening. Except in those cases in which the condition results from a more violent trauma, no marked inflammatory symptoms, aside from a slight dilatation of the vessels, are seen.

The acquired callosities can be differentiated from the keratodermias by the history and symmetry of the latter, though it must be remembered that in those who are particularly susceptible, very little friction may produce a marked callus.

The syphilitic conditions of the palms and soles usually begin in the centre and not over the bony prominences, spread peripherally, and at some points the horny layer is often split up or undermined.

The treatment of callosities is first to remove the cause, whatever that may be. To soften and remove the thickened horny layer salicylic acid is the remedy *par excellence.* It can be used in form of a plaster (10 to 20 per cent.) or in flexible collodion (ʒ ss.–℥ i.). Either should be applied for several days, when the affected part is immersed in very hot water for several minutes and the dead, macerated cells removed by gently scraping with a curette or dull knife blade. This procedure is repeated as often as necessary until the skin is reduced to its normal thickness, when a mild tar application will effectually complete the cure.

William A. Hardaway.

CALORIMETRY (L. *calor,* heat + Gr. *μέτρον,* measure) is the name applied to the process of measuring the heat given off from any body or substance; and a calorimeter is an instrument for making such measurement.

Animal calorimetry is determining the heat produced and the heat given off by an animal. This is accomplished either by indirect or by direct calorimetry, each of which will be described in its proper place. A respiration calorimeter is one which is so arranged as to allow the inspired and the expired air to be analyzed at the same time that direct calorimetric observations are made.

The unit of measure for heat in calorimetry is the *calorie.*[*] This is the amount of heat required to raise 1 gm. of distilled water 1° C.[†]

In work involving small amounts of heat this is commonly used, and is often spoken of as a small calorie.[‡] Another unit, often called simply "calorie," is the amount of heat required to raise 1 kgm. of water 1° C. This is called a large calorie (or sometimes a great calorie) to distinguish it from the small calorie. It is used when larger amounts of heat are to be measured. One large calorie =1,000 small calories. When the term "calorie" is used in connection with physiological experiments, the large calorie is generally meant. It will be so used in the present article. Other heat units in terms of different thermometer scales and different quantities of water were formerly employed in calorimetry, but their use is now being fast given up in favor of the calorie or large calorie —a change which is highly desirable for the sake of uniformity. In engineering the B. T. U. (British thermal unit) is still widely employed even in papers of unquestioned scientific standing. Its use in physiology was, for the most part, abandoned a decade or more ago.

In physics and in chemistry calorimeters are mostly used for determining the specific heats of different substances, for determining the heat of various combustions, and for determining the latent heat of fusion and of vaporization. It is not within the scope of the present article to discuss these methods or the instruments involved.

In the sciences more closely allied to medicine, calorimetry is used to study the phenomena of animal heat and its regulation in the healthy body—physiology; to study the same in fever—pathology; and to study the effect of drugs and poisons which influence body temperature—experimental pharmacology. The classic researches with the calorimeter in these fields will be discussed in the respective sections of this article, which for convenience of reference will be divided as follows:

§ 1. Introductory and historical.
§ 2. Indirect calorimetry.
§ 3. Direct calorimetry.
§ 4. Description of calorimeters employed in classical medical researches.
§ 5. Calorimetry in physiology.
§ 6. Calorimetry in pathology.
§ 7. Calorimetry in experimental pharmacology.

§ 1. INTRODUCTORY AND HISTORICAL.—Our modern conception of animal heat, viz., that it is produced by the slow oxidation of combustible materials in the body, first became possible with the establishment of our present theory of combustion, which dates back to the last quarter of the eighteenth century, and is dependent chiefly upon the brilliant researches and conclusions of Lavoisier (1772–94). Prior to that epoch, there was a perfect chaos of speculative theories regarding animal heat. Haller taught that this heat was produced by the friction of the blood in the heart and in the vessels; that every heart beat put the tissues on a stretch, that between the heart beats they rebounded by their own elasticity, and all these motions produced heat by friction. Summing up he says: "De cordis primo insito calore nulla dubitatio superest." Van Helmont attributed animal heat to a vital spirit. Descartes ascribed it to a fermentation of the blood in the cavities of the heart. Hamberger held that the heat of the body was comparable to the heat of a dunghill. All these theories had their followers at the time the combustion theory entered the field—the theory of Haller being, probably, the dominant one.

Animal heat soon came in for its share of investigation in connection with the general question of the origin of heat which was occupying the attention of investigators in England and in France at the epoch referred to.

The first calorimetric researches on animals were made by Crawford in Edinburgh, and an account of them was published (1779) in a pamphlet entitled "Experiments and Observations on Animal Heat and the Inflammation of Combustible Bodies, Being an Attempt to Resolve These Phenomena into a General Law of Nature." In this work Crawford clearly secures for himself and for England the priority in calorimetric observations on animal heat, and the title of his pamphlet, as well as the matter it contains, leaves no doubt as to his position in ascribing animal heat to an oxidation of combustible substances in the body.

Crawford's work has not received the recognition it deserves, and, even in English books, one occasionally sees the statement that Lavoisier was the first to use the calorimeter in experiments on animal heat. Lavoisier[*] had already, in 1777, from his analyses of expired air, published the fact that in the lungs the air lost oxygen and took up carbon dioxide; but his calorimetric observations were first published[†] in conjunction with Laplace in the year following the appearance of Crawford's pamphlet.

Unfortunately, Crawford used the nomenclature of the old phlogiston theory to which English scientists still clung, but he measured the heat given off by guinea-pigs, and he also analyzed the air they breathed during the experiment, and his conclusions, translated into the language of modern chemistry, may fairly be given as follows: Both CO_2 and H_2O are given off by the animal from its lungs. The blood brings back from the capillaries a combustible material for which the oxygen has a great affinity. The oxygen unites with this and produces heat which the blood distributes through the body. The heat is produced in the process by which the O is transformed into CO_2 or H_2O. "Animal heat seems to depend upon a process similar to a chemical elective attraction." Considering that the whole theory of chemical affinity was then in its infancy, one can hardly expect a more definite statement than this from a pioneer series of experiments.

It will be seen that Crawford places the seat of combustion in the blood in the lungs. In this he takes a view expressed by Lavoisier, two years before, although Lavoisier, contrary to the way he is generally quoted, clearly states the possibility that there may be only a gaseous exchange in the lungs, the true oxidation taking place farther back—a position now universally held to be the correct one.

§ 2. INDIRECT CALORIMETRY.—"Indirect calorimetry" is the name given to the method by which the heat produced and the heat given off from the body are not measured directly, but are calculated from the amount of oxygen used, and the amount of oxidized waste products given off from the body during a given period taken in connection with the body temperature. This method yields accurate results when the experiments are continued uninterruptedly for a considerable time—say twenty-four hours—and when cognizance is taken of the composition of the ingesta and of *all* the waste products thrown off by the lungs, skin, kidneys, and intestines, and the temperature of the body is also carefully recorded. In many experiments the observers have considered only part of the waste products, and the experiments have been of short duration—one hour or less. While such

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[*] It is interesting to note that among physicists and chemists one sometimes meets the spelling *calory* and the pronunciation *calóry* or *că'lory*. Among physiologists the original spelling *calorie* is retained (this statement is made after consulting all the available text-books of physiology), as is also the pronunciation *caloree'* in conformity with the spelling and older pronunciation. Lexicographers seem to prefer the spelling *calory*, but give both *calory* and *calorie* as correct.

[†] Since the specific heat of water varies at different temperatures, this would be more accurately stated as the amount of heat required to raise 1 gm. of water from 15° C. to 16° C. See Berthelot, "Thermochimie," Paris, 1897, vol. ii., p. 5.

[‡] When very minute quantities of heat are to be measured, the micro-calorie is sometimes used. A micro-calorie is .001 small calorie.

[*] "Mem. de l'Acad. des Sciences," 1777, p. 183.

[†] Op. cit., 1780, p. 355.

investigations may throw light on certain isolated points in connection with the chemical changes in the body, it must be said that any conclusions drawn from them, applying generally to the heat phenomena of the animal, are untrustworthy. This becomes apparent when we consider the nature of the chemical changes productive of heat which go on in the body.

The greatest amount of heat made in the body is produced by the oxidation of food, which is prepared for absorption by the digestion processes and then carried by the blood to the lymph which bathes the cells of the different tissues. These living cells then slowly burn the combustible parts of the food, and throw the waste products back into the lymph surrounding them, from which the said waste products are taken up by the blood and carried to different organs for removal—the excreting organ depending on the character of the waste. The food which is thus burned consists mostly of carbon, hydrogen, and nitrogen, with a certain amount of oxygen, but not enough to cause its complete combustion, so that to burn it, as is done in the cells, requires the use of a considerable quantity of the oxygen which we breathe. It must not be forgotten, however, that the oxygen in the food itself is just as potent as the oxygen we breathe for forming oxidized waste products. So it is clear that unless we know how much oxygen the food contains we cannot use the oxygen taken up in the lungs as an accurate measure of oxidation.

Again, it is a well-known law in chemistry that when a highly complex molecule breaks down into more stable ones, there is a certain amount of energy liberated, and this energy is apt to take the form of heat. Now the food contains a large number of these highly complex molecules which break down into simpler ones and give rise to heat. The oxygen in the food is in different combination in different kinds of food, and the same oxidized end-product of the breaking down of one food may represent a very different amount of heat from that which it represents in another. This has a direct bearing on the "heat equivalent" of different food-stuffs.

From the above it must be seen that a determination of part or even all the oxidized waste products will not give satisfactory data from which to calculate the heat produced in the body, if the waste products alone are taken into consideration.

Some experiments have been made in which calculations of the heat produced have been made only from the CO_2 excreted. It is true that of all the elements of the food whose oxidation gives rise to heat, carbon is the most important, and it is also true that CO_2 is the chief waste product of such oxidation. It must further be granted that the amount of CO_2 given off by the lungs forms a rough and general index to the total amount of oxidation in the body, but this method is unreliable as a quantitative measure of heat produced, chiefly for the following reasons:

(*a*) There is always more or less carbon in food which is not oxidized all the way down to CO_2, but stops at intermediate stages. The amount of carbon thus incompletely oxidized varies under different conditions which are not easy to control or to recognize. This partial oxidation gives rise to heat, and there is no CO_2 to show for it.

(*b*) The oxidation of the hydrogen in food gives H_2O as its end product. The amount of heat thus produced is considerable, and there is no CO_2 to show for it.

(*c*) The amount of CO_2 thrown off by the lungs depends to a large degree upon the depth of respiration, owing to changes in the partial pressure of CO_2 in the pulmonary alveoli. With shallow respiration an animal can store up a large quantity of CO_2 in the blood, and give this off if the respiration becomes deeper, so that for experiments of short duration a very considerable error may be introduced simply by the animal changing the depth of its breathing.

(*d*) The condition of an animal, with regard to food, has a profound influence on both the heat produced and the CO_2 excreted, but they do not vary quantitatively together. This is shown by the following table compiled by Rosenthal[*] from the experiments of Senator and Liebermeister:

Animal in Senator's experiments.	CALORIES OF HEAT PRODUCED PER HOUR.	
	Measured by calorimeter.	Calculated from CO_2.
Dog A, fasting	12.6	11.2
starving	10.9	10.24
during digestion	18.9	16.0
Dog B, fasting	16.5	14.1
during digestion	19.4	15.4
Dog C, fasting	16.9	10.24
starving	15.3	9.6
during digestion	22.0	12.2

It may be seen at a glance that the difference between the amount of heat measured directly by the calorimeter and the same value calculated from the CO_2 is considerable, and that this difference varies with the food. The figures in the table are for one hour only, so that the error for a day might be twenty-four times as great.

Indirect calorimetry becomes accurate only when a careful analysis is made and the temperature recorded of everything (food, drink, air, moisture, etc.) which enters the body (ingesta); and the same is done for everything which leaves the body (egesta). The difference between the potential energy of the ingesta and of the egesta will represent the energy which the body availed itself of, and temperature records of the body will show how much of this has taken the form of heat. Such observations are excessively laborious—far more so than direct calorimetry. When made in connection with direct calorimetry, however, they are exceedingly valuable, and to such experiments we owe one of the most important discoveries in modern science, viz.: that the human body obeys the law of the conservation of energy just like an inanimate machine—or, in other words, the fundamental laws of physics and chemistry dominate vital phenomena with all the rigor that they exercise in the inorganic world.[†]

Nearly all experimenters in the field of indirect calorimetry have employed modifications of the apparatus used by Regnault and Reiset,[‡] or by Voit,[§] in the classical researches of these authors. For an excellent *résumé* and criticism of this work, with references to original papers, the reader is referred to an article by Zuntz on "Respiratory Exchanges" in Hermann's "Handbuch der Physiologie," Leipsic, 1880, vol. iv., part 2, pp. 118–129.

§ 3. DIRECT CALORIMETRY.—Direct calorimetry consists in placing the body emitting heat in an appropriate apparatus (calorimeter) which will measure the amount of heat given off.

Two widely different classes of observations in the field of calorimetry are of interest to us in medicine. The one relates to the heat equivalent of foods, or, in other words, to determining the value of the different food-stuffs as energy-producers in the body; the other relates to the study of the animal body itself by means of the calorimeter.

Each class of researches demands different methods and different instruments. Those of the former class will be briefly touched upon here, while those of the latter will be more fully described.

The older method of determining the heat equivalent

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[*] Rosenthal, "Hermann's Handbuch der Physiologie," 1880, vol. iv., part ii., p. 374.

[†] To be strictly exact, it must be said that the experiments in question have come up to ninety-nine per cent. of absolute accuracy. Considering the complexity of the experiments and the probable error involved, this is sufficiently close to warrant the above statement. For a fuller discussion of this interesting question the reader is referred to Rubner, "Calorimetrische Methodik," Marburg, 1891; Rubner, "Die Quelle der thierischen Wärme," Zeitschrift für Biologie, 1893; Rosenthal, "Calorimetrische Untersuchungen," Arch. für Physiologie, 1894 and 1897; Atwater and Rosa, "A Respiration Calorimeter," etc., "Report of Storrs (Connecticut) Experiment Station," 1897; and Atwater and Rosa, and Rosa, "Physical Review," 1899 and 1900.

[‡] Regnault and Reiset, Ann. de chim. et de phys., 1849, (3), xxvi.

[§] Voit, Zeitsch. f. Biol., xiv., p. 122.

of a given food was to dry it carefully and then mix a known quantity of it with some chemical which would furnish oxygen, such as nitre or a mixture of potassium chlorate and manganese dioxide. This made a sort of gunpowder, which was detonated in a closed vessel surrounded by water, and the heat given off was measured by the rise in temperature of the water.

An improved method, suggested by Frankland, was first practically applied by Berthelot in a special calorimeter which he devised. This is known as the bomb calorimeter, and is made so as to contain the food to be investigated, with oxygen at a very high pressure (seven to twenty-five atmospheres). The food is ignited by means of a platinum spiral heated white hot by an electric current. Berthelot found that in such an atmosphere the food was completely oxidized. The bomb is immersed in water, and the heat given off is estimated from the rise in temperature of the water. There are many forms of calorimeters used for such determinations, but one of the two principles here outlined is at the bottom of all of them.

These methods give accurate and valuable results. They are applied not only to studying the heat equivalent of foods, but are also used to determine the heat equivalent of partially oxidized waste products from the body, such as urea. It must not be forgotten that we utilize only part of the potential energy of many of our foods, so that to rate the value of different foods as directly proportional to the figures in tables giving their heat equivalents would be a grave error. We are sufficiently acquainted with the metabolism of most of them to make a fair estimate of their true value as energy liberators in the body, but an adequate discussion of that question would be too voluminous to be attempted here.

Turning our attention now to the subject of direct calorimetric observations on animals, we may describe the process as follows: An animal is placed in one of the forms of calorimeter to be described in § 4, and the heat given off from the animal is determined in calories. This is known as the heat dissipated. If the temperature of the animal is the same on entering and on leaving the calorimeter, the heat produced must just equal the heat dissipated, for the animal brings out with his body just as much heat as he took in, and the heat dissipated while in the calorimeter must be exactly equal to what was produced there. If the temperature of the animal is higher on leaving than on entering the calorimeter, it shows that in addition to the heat dissipated and recorded by the calorimeter, there was an extra amount formed sufficient to raise the temperature of so much weight of animal so many degrees. In accordance with the laws of physics this extra amount may be found by the following formula:

$x = wdh$. In which—
x = the extra heat formed and not recorded by calorimeter.
w = weight of animal.
d = the difference in the animal's temperature between entering and leaving the calorimeter.
h = specific heat of animal's body.

The total heat produced is then found by adding the value of x to the amount of heat dissipated.

If the temperature of the animal falls while in the calorimeter, it shows that the heat dissipated and recorded by the calorimeter represents not only the heat actually produced by the animal while in the instrument, but also a certain amount of heat which is represented by the cooling down of so much weight of animal through so many degrees. In this case we must subtract the amount of heat found by the above formula from the amount of heat dissipated and recorded by the calorimeter, to get the true amount of heat produced during the time of the experiment.

Direct calorimetry furnishes the most reliable means of studying variations of heat production in the body, and by this method, and this method only, can we solve a number of interesting problems, notably those connected with fever. The temperature alone is a very unsafe guide. It has been shown over and over again, by direct experiment, that we may have high fever, while the animal or man is producing *less* heat than normal, and it has been shown, also, that certain antipyretics will lower the temperature while the production of heat in the body is far above the normal.

The temperature of the body depends upon two factors, and may be influenced by either of them separately or by both together. These factors are heat production and heat dissipation. In warm-blooded animals the balance is arranged so as to keep the temperature constant. If more heat is produced, for any reason, there is a corresponding increase in heat dissipation so that the temperature remains about the same. If more heat is dissipated more heat will be produced so as to keep the balance even and the temperature constant. If the balance is disturbed, as during fever, it is clear that we cannot tell in which factor the trouble lies by such an instrument as the thermometer, which only records the balance between them. These questions will be discussed more fully in the later sections of the article, and are only introduced here to show the importance of direct calorimetry in medicine.

Some of the objections urged against experiments of short duration in indirect calorimetry will also apply to direct calorimetry. The metabolism of the body is bewilderingly complex, and transient commotions produced by causes beyond the observer's perception may give results which would be totally inapplicable to calculation of averages, and which multiplied by the time sufficient to extend them to days would lead us to serious errors (see p. 559).

§ 4. DESCRIPTION OF CALORIMETERS EMPLOYED IN CLASSICAL MEDICAL RESEARCHES.—As the study of the heat equivalent of foods is usually taken up with chemistry rather than with medicine, and as the field is large enough to make a monograph by itself, it is deemed advisable to omit here a description of the apparatus and methods employed in this line of research. Those interested will find an excellent treatise on the subject in Atwater's "Methods and Results of Investigations on the Chemistry and Economy of Food" (U. S. Dept. of Agriculture, Bulletin No. 21, 1895).

The fundamental object of all calorimeters, for animals, is to register the amount of heat given off by the animal placed within them. This is done in different ways in different instruments, and the various kinds of calorimeters may be classified, according to the means used to measure the heat, as follows:

(*A*) Fusion (ice) calorimeters. In these the heat is made to melt some solid (usually ice), and the amount of heat is calculated from the quantity of the substance melted.

(*B*) Vaporization calorimeters. In these the heat is made to volatilize a liquid, and the amount of heat is measured by the quantity of liquid volatilized.

(*C*) Water calorimeters. In these the heat is taken up by water, and measured by different methods according to the instrument.

(*D*) Air calorimeters. In these the heat is taken up by air and measured by different methods, according to the instrument.

(*E*) Respiration calorimeters.

Each accurate calorimeter, whatever its form, must be calibrated. This is done by producing within it known quantities of heat, approximating those it will later be used to measure, and noting how accurately (and sometimes how rapidly) the calorimeter will register this heat. The known quantity of heat is usually produced by burning, within the calorimeter, a given quantity of hydrogen, alcohol, or some pure oil, or by passing an electric current of known strength through a coil of known resistance. The heat produced is calculated from the formula:

$$H = I^2 \times R \times k.$$

In which H = the heat produced, I = the strength of the current in amperes, R = the resistance of the wire in ohms, and k is a constant, which, to give the value in calories per hour = .864.

This is the latest and most accurate method, and serves admirably to give varying amounts of heat through the range in which the calorimeter would be called on to register the heat of animals, including man.

Class A: Fusion Calorimeters.—The only calorimeter of this class employed in animal calorimetry was the ice calorimeter of Lavoisier and Laplace.[*] It consisted of three metal cylinders, placed one within the other, with spaces between them. The animal (guinea-pig) was placed in the innermost cylinder, and the space between this and the middle cylinder was filled with ice, which was melted by the heat given off by the animal. The space between the middle cylinder and the outer cylinder was also packed with ice to prevent heat from the outside from reaching the ice in the space next the animal cylinder. The water from the ice melted by the animal was collected and weighed and the heat calculated by multiplying this weight by the latent heat of fusion.

This is a very accurate form of calorimeter, but it is not well adapted to animal experiments, as the animal is kept in surroundings of an abnormally low temperature, and this seriously affects its production and dissipation of heat. The researches of Lavoisier and Laplace are classical, in being the second to employ the calorimeter, and the first to give valuable results of extended observations which were stated in terms of the modern combustion theory. In these experiments the animal was furnished with air, and the O used and the CO_2 given off were determined.

Class B: Vaporization Calorimeters.—Calorimeters of this class were used by I. Rosenthal and by Neesen.[†]

I. Rosenthal[‡] devised a calorimeter in which he used a fluid with a boiling point near that of the ordinary room temperature, or a fluid with a boiling point a few degrees below the normal temperature of the animal. The fluids which he recommends are acetic aldehyde, CH_3CHO, with a boiling point of 21° C., and ethyl ether, $(C_2H_5)_2O$, with a boiling point of 34.9° C.

The calorimeter consisted of an inner cylinder, in which the animal was placed, and an outer cylinder containing the liquid to be volatilized. The whole was surrounded by a water bath kept carefully at the temperature of the boiling point of the liquid in the outer cylinder. Thus no heat could either be gained or lost by the liquid in the outer cylinder except such as came from the animal in the inner cylinder. The heat from this source was all spent in volatilizing the aldehyde or the ether, and from the quantity thus volatilized the amount of heat given off by the animal could be determined. By filling the outer cylinder with ice the instrument could be used as an ice calorimeter, and thus, as Rosenthal pointed out, according to the material used the heat dissipated could be determined for temperatures of 34.9°, 21°, or 0° C. by the same apparatus. This calorimeter, as constructed, could be used only for small animals, such as mice, or for isolated organs, such as muscles.

Class C: Water Calorimeters.—The water calorimeter was the first employed in animal calorimetry (see account of Crawford's researches, § 1). From that time (1778) to the present it has been the favorite form. After Crawford it was used in the classical researches on animal heat by Despretz,[§] and by Dulong,[‖] and on fever by Senator,[¶] and by Wood.[**]

In its simplest form, a water calorimeter consists of a tank containing a definite amount of water into which is plunged a water-tight metal box containing the animal. The animal is supplied with air by tubes entering and leaving the box. The heat given off by the animal raises the temperature of the water, and, knowing the weight of the water and the increase in temperature, the amount of heat thus given off can be calculated in calories. In text-books, the calorimeter of Dulong is generally described, but in the present article the Reichert calorimeter is chosen as a type of this class. This instrument combines all the simplicity of the older forms with the accuracy and convenience of modern improvements. It has been used by Reichert[*] in his researches on animal heat, on fever, and on drugs.

The calorimeter consists of a metal box *A*, for the animal, and a larger metal box surrounding the box *A*, the space between the two metal boxes being filled with water. The whole is enclosed in a wooden box, the space between the outer metal box and the wooden box being filled with shavings *SH*, to prevent the radiation of heat. At the right of the figure is an opening from the exterior into the box *A*. This is for putting in and taking out the animal. During the experiment it is closed by a wooden plug fastened with clamps to the wooden box. The tubes *EN* and *EX* are for the entrance and exit of air, and each is furnished with a thermometer as shown in the figure. Another thermometer, *CT*, registers the temperature of the water. *S* is a stirrer to mix the water thoroughly so as to be sure that the temperature recorded is the temperature of the whole mass of water. The arrows show the direction of the air current through the animal box.

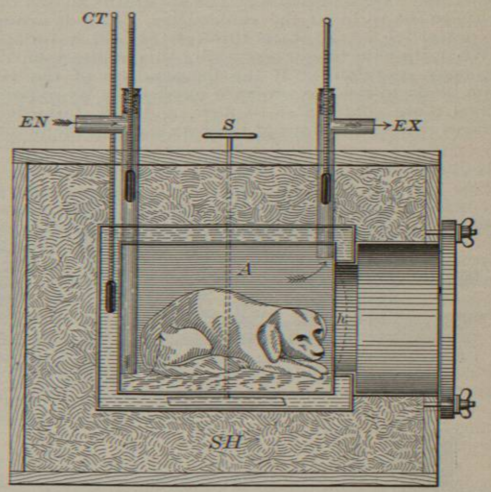

FIG. 1073.—Reichert's Water Calorimeter.

Ott[†] devised a water calorimeter of sufficient size to take a man. The inner chamber, to receive the patient, was cylindrical in form, and the air, as it was drawn from this chamber, passed through a lead pipe coiled in the water and thus gave off its heat to the water. The water was slowly stirred by a mixer driven by an electric motor.

D'Arsonval's compensating calorimeter, of constant temperature, is another form of water calorimeter, although the principle involved in the measurement of heat is different from that of the calorimeter last described.[‡]

This instrument is shown in Fig. 1074. It consists of two cylinders, of thick copper, enclosing a space between

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[*] Lavoisier and Laplace, "Mémoires de l'Academie," Paris, 1780, p. 369.

[†] See Richet's "Dictionnaire de Physiologie," Paris, 1897, vol. ii., p. 405. The writer was unable to find a reference to Neesen's original article.

[‡] I. Rosenthal, Arch. für Physiol., 1878.

[§] Despretz, Ann. de chim. et de phys., 1824, vol. xxiv., p. 337.

[‖] Dulong, Ann. de chim. et de phys., 1843, p. 140. In 1822, the Paris Academy offered a prize for the best experimental researches on animal heat. Despretz and Dulong were competitors and Despretz won. The work of the two was contemporaneous, but Dulong's paper was not published until 1843, after his death.

[¶] Senator, "Untersuchungen über den fieberhaften Process," Berlin, 1873.

[**] Wood, "Smithsonian Contributions to Knowledge," No. 357.

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[*] Reichert, University Med. Mag., 1890, vol. ii., p. 173, and "American Text-Book of Physiology," 1896, p. 586.

[†] Ott, New York Med. Journ., 1889, vol. xlix., p. 343; also Journ. Nerv. and Ment. Dis., 1890, vol. xvii., p. 348.

[‡] D'Arsonval, Arch. de Physiol., 1890, p. 612.

them. Through this space run two spirals of metal tubing like the worm of a still. These spirals are shown in cross-section in the figure. One of these spirals connects the inner chamber of the calorimeter with the outside air. The air is aspirated through the calorimeter, passing in by a tube on the left, as shown by the arrow in the figure, and out, by the spiral, to the exterior. In passing through the spiral it gives up its heat to the petroleum with which the space between the cylinders is filled. The other spiral opens, at both its ends, on the exterior. It conducts a stream of cold water which is made to flow through it. The space between the copper cylinders, enclosing the spirals, is filled with petroleum because of its mobility. When the heat of the animal warms this petroleum it expands, and exerts pressure on the apparatus shown in the figure to the right of the calorimeter. This is arranged to control the flow of water through the cold-water spiral.

When the calorimeter is working this makes a sensitive, automatic regulator. If the temperature of the petroleum tends to rise the pressure exerted by its expansion causes more cold water to flow, and this immediately reduces the temperature of the petroleum to the point for which the instrument is set. (For a description of this regulator in detail, see *Arch. de Physiol.*, 1890, p. 614.) The cold water is furnished from a tank, and is made to enter the calorimeter at a known temperature. A tank filled with ice furnishing water at 0° C. is the arrangement recommended. The temperature of the water on entering the calorimeter, the temperature on leaving it, and the amount of water passed through being known, the amount of heat given off by the animal can easily be calculated in calories. It is found by experience that the water leaves the spiral through the petroleum at the temperature of the petroleum, and when this is kept at the room temperature, as it should be, the amount of heat given off by the animal is directly proportional to the amount of cold water required to keep the temperature of the petroleum constant. If, therefore, the amount of cold water flowing through the spiral be recorded continuously throughout the experiment, we can not only calculate the total amount of heat given off by the animal, from the beginning to the end of the experiment, but we can tell whether there was any variation in the rate at which this heat was given off, by finding, from the record, the variations in the rate with which water flowed through the spiral.

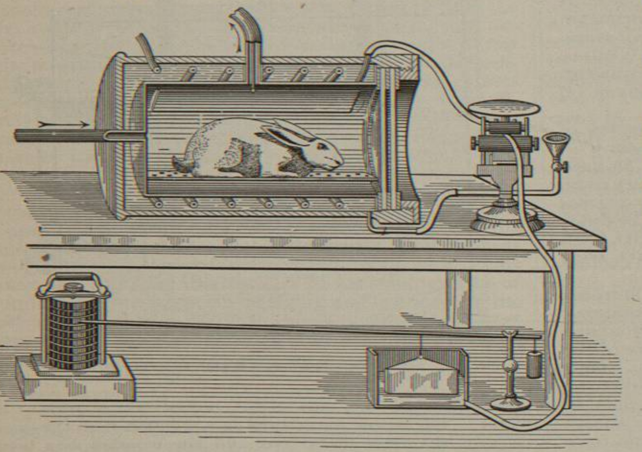

FIG. 1074.—D'Arsonval's Compensating Calorimeter of Constant Temperature.

A simple form of apparatus for registering the flow through the spiral is shown in the figure as placed on the floor under the table. It consists of a cylinder (shown in section in the figure) which receives the outflow from the spiral. On the surface of the water is a float which rises as the water in the cylinder rises. This float is attached to a lever which has on its short arm a counterpoise weight for the float, while the long arm is made to write on a cylinder driven by clockwork. Since the rise of the lever is directly proportional to the amount of water flowing through the spiral, and since this is directly proportional to the heat given off by the animal, it follows that the ordinates of the curve written by the lever will be directly proportional to the heat which we wish to measure. The abscissas will be in terms of time, and will be proportional to the speed of the drum. By regulating the length of the lever and the speed of the drum a curve may be obtained which can be read in terms of calories for any convenient unit of time, minutes, hours, days, etc., without further calculation. A more elaborate recording apparatus with electrical contacts is figured and described by D'Arsonval (*Arch. de Physiol.*, 1890, p. 616). The same author has described a more convenient but less accurate calorimeter based on a modification of the one just described (*op. cit.*, p. 620).

One of the most recent, as well as one of the most elaborate and perfect water calorimeters, is that of Atwater and Rosa.[*]

In this calorimeter experiments, lasting several days, have been conducted on man.

The principle involved is practically the same as that of D'Arsonval's compensating calorimeter (Fig. 1074); the heat being removed by coils of pipe carrying cold water through the chamber where the man is placed. For a full description of this instrument and methods employed, the reader is referred to the original papers. A more condensed description of the apparatus is given under the head of Respiration Calorimeters at the end of this section.

Calorimetry by Baths. The study of heat phenomena in animals by baths has found a place in medical literature chiefly through the classical researches of Liebermeister,[†] and his pupils Kernig, Hattwig, and Gildemeister.

The method here employed was to place the patient in baths of different temperatures, and to calculate the production of heat from the gain or loss of heat by the patient and by the water under different conditions. This procedure presents certain crudities and sources of error which have been pointed out by nearly every special investigator in the field, but it has lately been defended by Lefevre,[‡] who employed it in some experiments of his own. The researches of Lefevre are of interest in showing some interesting points as to the rapidity with which the heat-regulating mechanism adjusts itself when the patient is placed in a cold bath. They also show that this mechanism is neither as sensitive nor as efficient in an ape as it is in man, but they fail to convince one that the method is trustworthy for obtaining absolute values of heat dissipated or produced. Most of his observations were of short duration—five to twenty minutes.

Leyden[§] employed the bath method in his researches on fever which are classical. In his experiments a part of the body, usually a leg, was immersed in water in an apparatus somewhat resembling a plethysmograph, and the heat given off to the water measured. In many of Lefevre's experiments the patient was placed in a sitz bath and only part of the body covered by water.

Class D: Air Calorimeters.—The first air calorimeter was used by Scharling.[‖] This consisted of a closed box placed in a room of constant temperature. When a man was put in the box, the temperature of the air in the box rose, and from this rise the heat given off by the man was calculated. A calorimeter of practically the same principle was used in the early experiments of Vogel, of Sapalsky and Klebs, and of Hirn; and in the later researches of Kaufman,[*] who speaks of it as simple and precise.

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[*] Atwater and Rosa, "Report of Storrs (Connecticut) Experiment Station," 1897; also Atwater and Rosa, and Rosa, "Physical Review," 1899 and 1900.

[†] Liebermeister, Deutsches Arch. f. klin. Med., v., pp. 217–234; x., pp. 89 and 420; also "Handb. d. Path. u. Therap. des Fiebers," Leipzig, 1875, p. 197.

[‡] Lefevre, Comptes rendus, Soc. de Biol., 1894–96.

[§] Leyden, Deutsches Arch. f. klin. Med., v., p. 273.

[‖] Scharling, Journ. f. practische Chemie, 1849, vol. xlviii., p. 435.

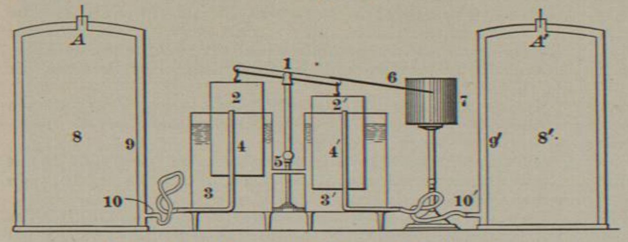

FIG. 1075.—D'Arsonval's Differential Calorimeter.

In most of the later forms of air calorimeters, the principle of measuring the heat by a rise of temperature of the air has been discarded, and the expansion of air caused by the heat given off from the animal has been used as an index. This gives a more convenient and more delicate method of measurement.

One of the simplest calorimeters constructed on this principle is the siphon calorimeter of Richet.[†] This consists of two double-walled hemispheres of metal, fitting upon each other so as to make a globe. They are connected by a hinge, so that the upper hemisphere may be thrown back like the lid of a box. When closed they are fastened by an ordinary clasp. The air space between the two walls of each hemisphere is connected by a tube with a large bottle of water, arranged like a wash bottle, in such a way that when the air between the walls of the hemispheres expands it forces out a volume of water equal to the expansion of the air. When an animal is placed in the globular box formed by the two hemispheres, the heat given off by the animal causes the air to expand in the way just described. This expansion is measured by the amount of water forced out of the bottle, and the amount of heat given off by the animal is thus determined.

U. Mosso[‡] used a calorimeter constructed on the principle of the above. The water, forced out of the bottle, passes into a balanced recipient after the manner of the registering apparatus of Mosso's plethysmograph. This is an ideal arrangement, for a continuous graphic record can thus be kept of the rate of heat dissipation throughout the experiment, and if for any reason the animal should absorb heat, instead of giving it off, this would be recorded as well.

Differential Air Calorimeters. The principle involved in differential air calorimeters is to have one closed air space affected by the heat of an animal, while another similar air space is kept at a constant temperature. These air spaces are connected with an appropriate recording apparatus, and the heat given off by the animal is calculated from the difference in expansion of the two.

The simplest form of differential air calorimeter is D'Arsonval's[§] compensating differential calorimeter, shown in Fig. 1075.

This instrument consists of two calorimeter chambers 8 and 8′. Each of these chambers has a double wall enclosing an air space, 9 and 9′. These air spaces are connected by a rubber tube, 10 and 10′, with the registering apparatus. This consists of a lever balance, 1, from each arm of which is suspended a cylinder, 2 and 2′, closed at the top, the lower end dipping into tanks of fluid, 3 and 3′. These tanks are connected by a tube, 5, so that the level of liquid is the same in each. The tubes, 4 and 4′, rise above the surface of the liquid. When the air in the space 9 or 9′ expands it passes into the cylinder 2 or 2′ respectively, and buoys this cylinder up, thus raising the arm of the lever 1. To one arm of the lever is attached a straw, 6, terminating in a writing point which records on a cylinder, 7. This cylinder moves by clockwork, and can be made to go so slowly that continuous records of a day or a week may be obtained.

When an animal is introduced into one of the calorimeter chambers, 8 or 8′, the heat given off causes the air in 9 or 9′ to expand, and this expansion is registered as above described. The empty calorimeter chamber is under exactly the same conditions except for the presence of the animal, and registers on the opposite arm of the lever, thus giving a *compensating* effect for the instrument minus the animal. The curve recorded is due to the *difference* which is produced by the animal, and is independent of barometric changes, room temperature, etc.

This instrument is classical and is often referred to. It is theoretically excellent, but it possesses practical disadvantages which render it unfit for accurate scientific research, as the writer has found from personal experience (see also D'Arsonval, *Arch. de Physiol.*, 1890, pp. 787 and 789).

The most complete and accurate air calorimeters are those of Rubner[*] and of Rosenthal.[†] These eminent investigators have spent years in perfecting their respective instruments, and each, notably that of Rubner, has been used in extensive and valuable researches. These calorimeters are too elaborate to be described in detail here. A complete description of the latest improvements will be found in the original papers of Rubner and Rosenthal referred to above.

The fundamental principle of these two calorimeters is the same. Each consists of two closed air spaces, one of which is warmed by the heat from the animal, while the other is immersed in a bath which is kept at a constant temperature by an automatic regulator. Rubner measures the expansion of the air by an apparatus similar in principle to that employed by D'Arsonval and shown in Fig. 1075. Rosenthal connects the two air spaces, respectively, with a U-manometer, which will respond at once to any difference of pressure on the two sides. Connected with the air space on one side, there is an ingenious piston arrangement by which air can be forced in, so as to make the pressure on the two sides of the manometer equal. This is driven by an electrical device which is set in motion the moment the liquid in the manometer changes level. The amount of pressure thus exerted is registered automatically, so that a complete graphic record may be kept of how much pressure was necessary to equalize exactly the pressure exerted by the air expanded by the heat from the animal, and thus this heat may be calculated.

Haldane White and Washburn[‡] have described a compensating differential air calorimeter in which the animal is placed in one side while a hydrogen flame is kept burning in the other. The enclosed air spaces of the two sides are connected with the opposite arms of a manometer. The hydrogen flame is so regulated that it shall give off exactly as much heat as the animal, as shown by the liquid in the two branches of the manometer remaining at the same level. The amount of hydrogen burned is estimated and the heat produced by the flame calculated. This exactly equals the amount given off by the animal, since the heat produced in each calorimeter chamber is the same.

Anemo-Calorimeter of D'Arsonval.[§] Most of the calo-

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[*] Kaufman, Comptes rendus, Soc. de Biol., 1896, p. 201.

[†] Richet, Comptes rendus, Soc. de Biol., 1884, pp. 707–715; also Arch. de Physiol., 1885, vol. vi., p. 237.

[‡] Mosso, Arch. Ital. de Biol., 1890, vol. xiii., pp. 467–471.

[§] D'Arsonval, Arch. de Physiol., 1890, p. 785.

[*] Rubner, "Calorimetrische Methodik," Marburg, 1891; also "Die Quelle der thierischen Wärme," Zeitsch. f. Biol., vol. xxx., 1893–94, pp. 73–142.

[†] Rosenthal, "Calorimetrische Untersuchungen," Arch. f. Physiol., 1897, pp. 170–209.

[‡] Journ. of Physiol., 1894, vol. xvi., p. 127.

[§] D'Arsonval, Arch. de Physiol., 1891, p. 364.