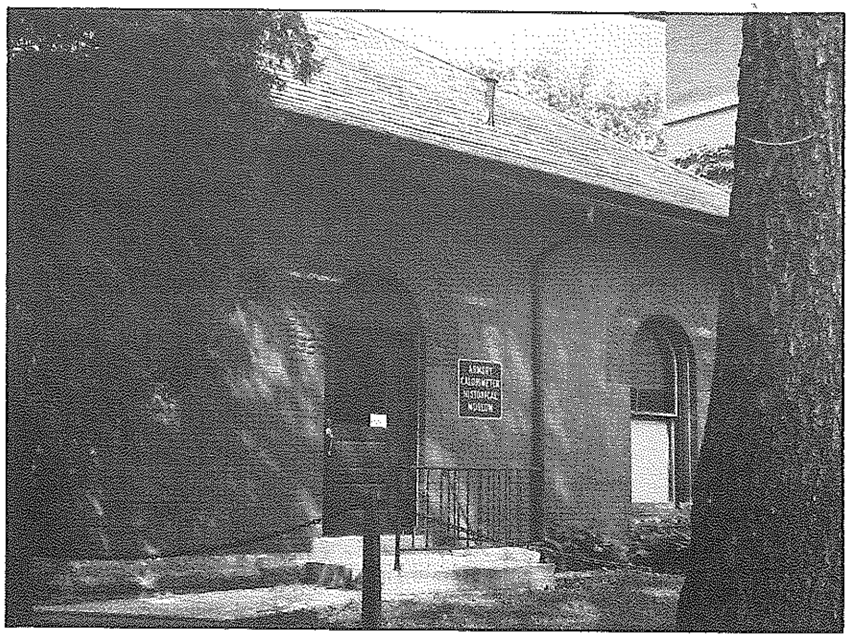
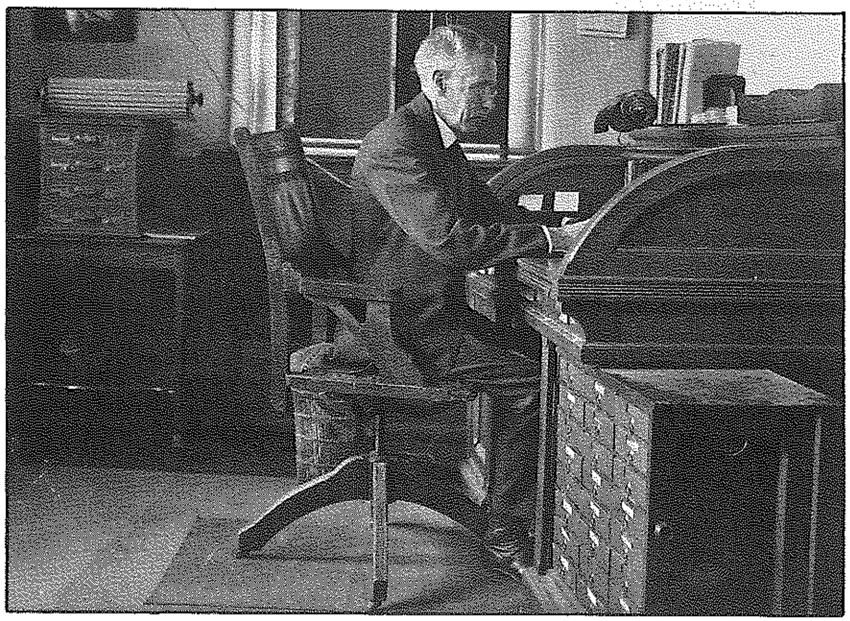


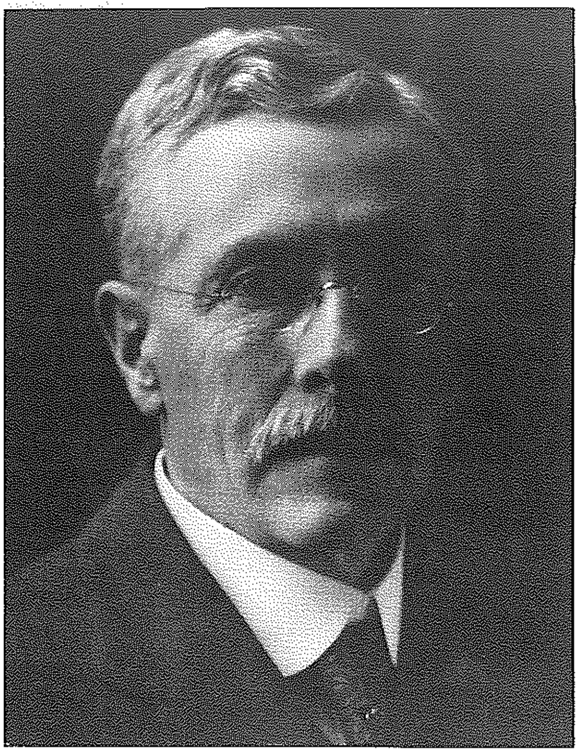
This small laboratory, constructed at the turn of the century, houses the famous respiration calorimeter. The laboratory has been preserved virtually intact as a museum and memorial to pioneers in animal nutrition research at Penn State.



Dr. Armsby at his desk in the respiration calorimeter laboratory where he spent much of the final 14 years of his life. His writings and understandings of animal nutrition and energy metabolism are as authoritative today as when first elucidated more than half a century ago.

The Respiration Calorimeter

A description of the construction and operation of the Respiration Calorimeter for the larger farm animals at The Pennsylvania State College



Henry Prentiss Armsby
(1853-1921)

THE PENNSYLVANIA STATE COLLEGE
School of Agriculture and Experiment Station

Bulletin 302 November 1933

Varga

A Tribute to Agricultural Research

The Armsby Respiration Calorimeter, located on the University Park Campus of The Pennsylvania State University, is truly the birthplace of animal nutrition studies in America.

Dr. Henry Prentiss Armsby, Director of the Agricultural Experiment Station, received permission in 1898 from Penn State trustees to construct and equip this unique laboratory for his historic experiments in energy metabolism of farm animals.

The first experiment, conducted in 1902, attracted the attention of scientists through the United States and in Europe. For more than half a century, the calorimeter contributed valuable research findings in animal and human nutrition to the state, nation and world.

It is remarkable in this age of sophisticated research facilities to find a turn-of-the-century laboratory virtually intact as a reminder of this country's agricultural research heritage.

The College of Agriculture Alumni Association allocated funds in 1970 to restore and preserve the calorimeter as a museum and memorial to Penn State pioneers in animal nutrition research.

Staff members and faculty of the Department of Animal Science, along with retired Penn State scientists who conducted actual experiments in this laboratory, have contributed greatly to the restoration.

We owe a debt of gratitude to the Agriculture Alumni Association and members of the Armsby Calorimeter Museum Committee who have spearheaded this project. Men like Dr. Raymond W. Swift, former head of the department of animal nutrition, have provided invaluable assistance.

Reprinted copies of this 1933 Experiment Station Bulletin have been made available in limited numbers to Museum visitors who have a special interest in energy metabolism and the operation of the respiration calorimeter.

Facsimile reproduction,
July 1974

J. M. Beattie, Dean
College of Agriculture

The Respiration Calorimeter*

A description of the Respiration Calorimeter for the larger farm animals at The Pennsylvania State College

WINFRED W. BRAMAN**

FOR SOME YEARS prior to 1898, Dr. H. P. Armsby, who was at that time Director of the Pennsylvania Agricultural Experiment Station, had been deeply interested in the nutrition of farm animals. In 1882 he had published his book "Manual of Cattle Feeding." Realizing the inadequacy of the prevalent methods of investigation in animal nutrition, he decided that more thorough studies should be made, and therefore sought to enlist the support of the United States Department of Agriculture in a cooperative program of highly scientific nutritional research at The Pennsylvania State College.

As a result, in the spring of 1898, the United States Department of Agriculture proposed to the Pennsylvania State College Agricultural Experiment Station that the latter undertake such work in cooperation with the Bureau of Animal Industry of the United States Department of Agriculture. The trustees of The Pennsylvania State College accepted the proposal, which provided for the payment of the larger part of the cost of the special apparatus required in the contemplated studies, and also a minor portion of the current expenses of the work—the Experiment Station to house the apparatus, to supply heat, light and power, and to contribute the use of animals, feeds and laboratory facilities.

In undertaking this project Doctor Armsby continued to serve as Director of the Pennsylvania State College Agricultural Experiment Station, and in addition was commissioned, by the Government, as Expert in Animal Nutrition, in the Bureau of Animal Industry of the United States Department of Agriculture. Under these joint auspices, therefore, was undertaken the first exhaustive study to be made in this country of the nutrition of farm animals by means of a respiration calorimeter.

In the summer of 1898 Doctor Armsby spent some time in Europe studying various existing apparatus for respiration calorimetric research, but found none superior to the respiration calorimeter at Middletown, Connecticut, which had been devised by Atwater and Rosa for experiments on man.

The general principle of this comparatively small American calorimeter was therefore adopted; the task of adapting the details to the requirements of work with large farm animals was undertaken; and in the autumn of 1898 the trustees of The Pennsylvania State College authorized the construction of a small building for housing the apparatus (Fig. 1).

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* Publication authorized November 16, 1933.

**Acknowledgment is made to Director E. B. Forbes and J. A. Fries for suggestions and criticisms.

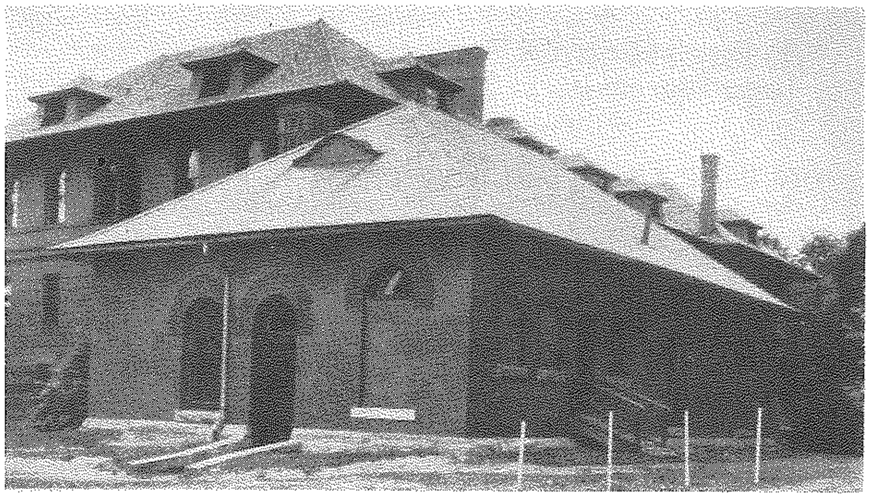

FIG. 1. RESPIRATION CALORIMETER BUILDING, THE PENNSYLVANIA STATE COLLEGE

In the building of this respiration calorimeter there were associated with Doctor Armsby, L. Thornton Osmond, Professor of Physics in the College, as consulting physicist, and J. August Fries, of the Pennsylvania Agricultural Experiment Station, who was given immediate charge of construction.

The building of the calorimeter was necessarily time-consuming, since it involved much work of a technical nature. The first experiment with an animal was made early in 1902. The cost of the apparatus, and the small brick building to house it, was approximately $20,000.

In 1907 this research interest was constituted an independent department, under the title of the Institute of Animal Nutrition. Doctor Armsby became Director of the Institute and relinquished his position with the School of Agriculture and Experiment Station. The Institute was continued in the relation stated until July 1, 1933, when it was constituted a department of the Agricultural Experiment Station.

Doctor Armsby died in October, 1921. Professor J. A. Fries, continued the work, as Acting Director, until September, 1922, when Dr. E. B. Forbes, the present director, assumed charge.

The Bureau of Animal Industry of the United States Department of Agriculture continued until July 1, 1920, to bear a minor portion of the current expense of the experiments. In 1922 a grant was received from the Bureau of Dairy Industry, of the United States Department of Agriculture, for a special study of the energy requirements of milk production. At the present time the Institute of Animal Nutrition is supported from the same funds as are the other departments of the Agricultural Experiment Station.

The Purpose of the Respiration Calorimeter

The purpose of the respiration calorimeter is to make possible an accurate measurement of the balance between nutritive income and outgo—the income being feed, water and oxygen, and the usual factors of outgo being the excreta—solid, liquid and gaseous—and the heat produced. During lactation milk is accounted for as a factor of outgo. The difference between the nutrient income and outgo, obviously, is that part of the income which is retained by the animal.

For the measurement of this nutritive balance the calorimeter is so designed as to inclose the animal in a room which is air-tight, in the sense that no air enters except for the ventilating current which is drawn through this room, and at the same time is measured, by a calibrated pump.

In order that the results may represent normal conditions the animal is maintained in comfort, free to stand, lie and rise at will; and receives feed and water in the manner to which it is accustomed.

The products of respiration, and the heat produced, are removed and measured; the liquid and solid excreta are collected for chemical analysis in receptacles provided, inside the calorimeter but below the floor on which the animal stands; and the calorimeter is so constructed and operated that no heat is gained or lost by radiation through the walls of the apparatus.

In the respiration calorimetric work with cattle, at this Institute, a unit period of experimentation is ordinarily 28 days, during the first 25 of which the animal is kept at the Nutrition Experiment Barn, which is equipped for digestion work. Only the last three days are devoted to the calorimetric study, the calorimeter being located in a separate building.

In order that the quantities of excreta and of heat produced and measured during the calorimetric period shall accurately relate to the feed given, it is necessary that the animal be subjected to a preliminary feeding period of 10 days, on the experimental ration. Then follows an 18-day digestion period during which the solid and liquid excreta are accounted for, and during the last 3 days of which the gaseous excreta and the heat production are also measured, in the calorimeter. The quantity of heat produced differs with conditions, but is equivalent to approximately 40 per cent of the gross energy of the feed when the animal is receiving twice the maintenance requirement.

The Nutrition Experiment Barn

The Nutrition Experiment Barn is a small 3-story structure serving mainly as an accessory to the calorimetric equipment. The main floor of this barn is equipped with digestion stalls. The floor below provides for the reception and collection of the excreta from the digestion stalls above—and for a heating plant; while the uppermost story contains machinery for the cutting and grinding of feed, and a magnetic separator for removing iron from the feed; also there is space for the mixing and weighing of feeds, and there are bins for feed storage.

During the 18-day digestion period the animal, if a male, wears a harness with accessory equipment providing for the collection of the urine. This harness is also worn during the 3-day experiment in the respiration calorimeter. The harness consists of a surcingle from which a heavy strap passes along the back of the animal, and ends in a light-weight crupper, covered with soft rubber tubing. The urine is received in a rubber-and-fabric funnel suspended beneath the animal by four leather straps (Fig. 2).

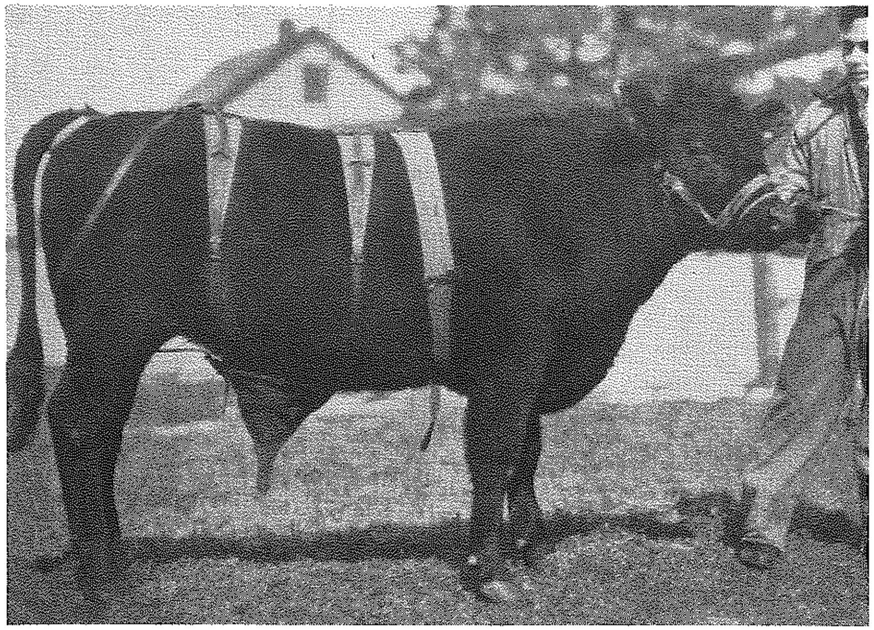

FIG. 2. STEER WEARING HARNESS USED IN THE DIGESTION STALL AND IN THE RESPIRATION CALORIMETER

The funnel terminates in a hose coupling, to which is attached a pure gum rubber tube about one inch in diameter. This tube passes through a hole in the floor of the stall, and conducts the urine to a receptacle in the space beneath the floor. The tube is weighted, to take up the slack when the animal lies down. The lower end fits loosely into an opening in the removable cover of a tin-coated copper can.

The feces are collected by means of a metal-lined hopper into which they are directed by a rubberized canvas apron, and are conducted into a galvanized iron box in the space beneath the floor. The apron is held fast at its lower edge by a light iron rod which passes through a stitched fold in the fabric and then through the sides of the hopper frame. The upper edge of the apron carries, in a stitched fold, a ¼-inch iron pipe. A stitched fold at each side of the apron carries a light chain which is attached by snaps to the iron pipe in the upper edge of the apron, and to screw-eyes in the frame of the hopper, below.

The upper edge of the apron is held against the rear of the animal by means of a system of cords, pulleys, window weights and springs, so ar-

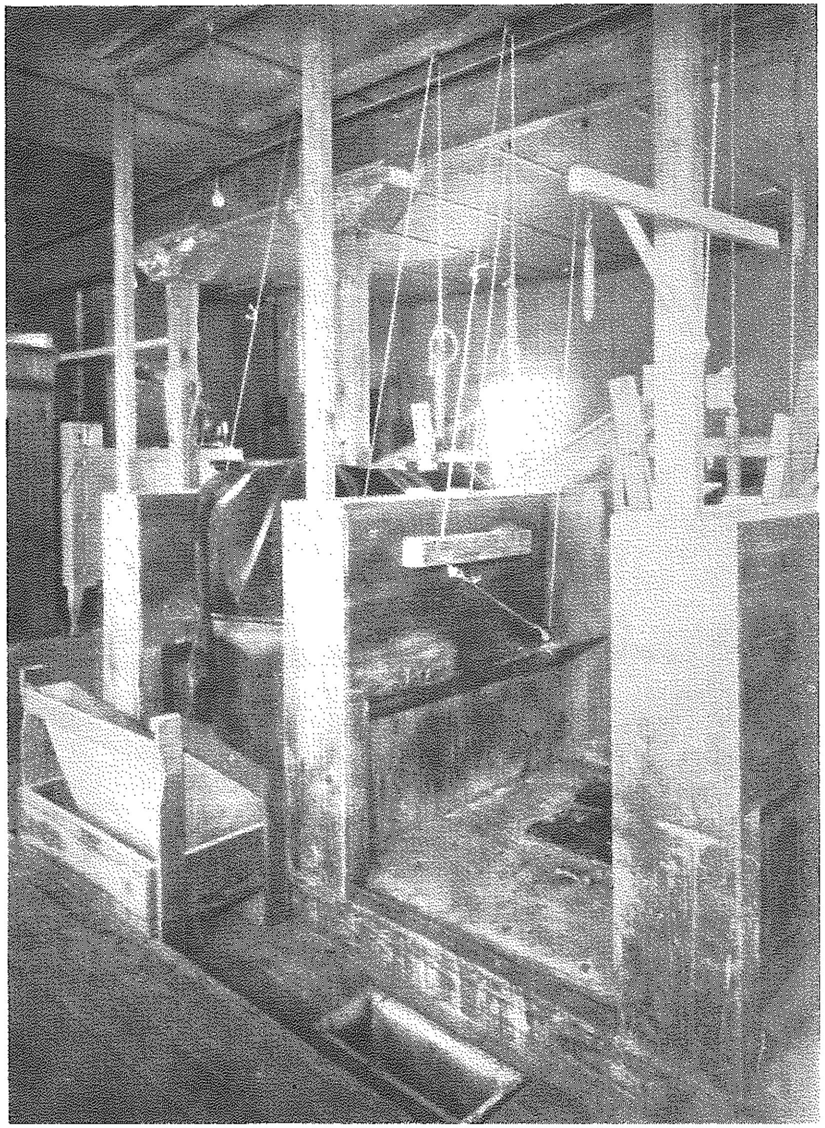

FIG. 3. DIGESTION STALLS IN NUTRITION EXPERIMENT BARN

ranged as to keep the apron in place, regardless of the position of the animal, as it stands, and to draw the edge of the apron forward, under the animal, when it lies down.

Fig. 3 shows a vacant digestion stall, and another stall containing a steer, with accessory equipment for excreta collection.

This hopper and apron arrangement for feces collection during the digestion period at the Nutrition Experiment Barn is also utilized, with certain changes of detail, during the 3-day experiment in the respiration calorimeter.

The Respiration Calorimeter Building

A substantial brick building was constructed especially for the respiration calorimeter and its accessory apparatus. The walls are built with

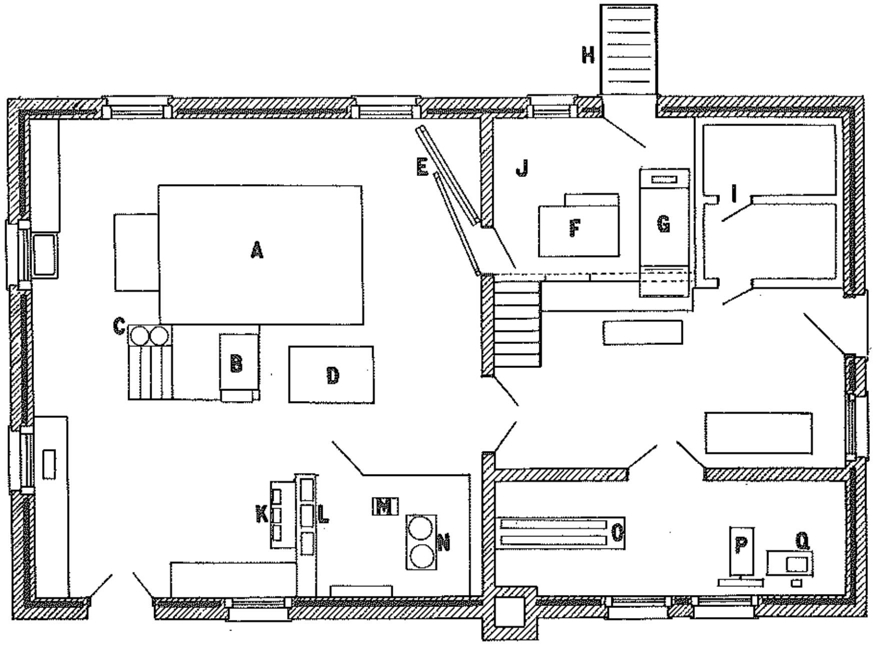

FIG. 4. GROUND PLAN OF RESPIRATION CALORIMETER BUILDING

A. Respiration calorimeter
B. Observer's table
C. Water meters for measuring absorber water
D. Brine tank for cooling absorber water
E. Bridge for entering chamber, folded back
F. Bullock scales
G. Digestion stall
H. Runway for entrance of animal
I. Cold storage rooms
J. Raised platform
K. Blowers for drawing samples through absorption tubes
L. Rack for absorption tubes, with air meters on top
M. Spirometer
N. Meter pump
O. Electrically heated combustion furnaces
P. Ammonia compressor
Q. Motor for operating compressor

an air-space, and the windows are provided with double sash. This construction minimizes the effects of the weather on the inside temperature, a condition essential to the satisfactory operation of the calorimeter.

Fig. 4 gives the floor plan of the building, and shows the location of apparatus. The floor is of cement, and the rooms have a height of 15 feet, the dividing walls being of brick. In the smallest room is a 7½ H. P. motor which operates a 5-ton ammonia compressor. In this room, also, are two special electric furnaces for oxidizing combustible gases in the ventilating air current, a two-H. P. motor for operating the meter pump, and a transformer to produce direct electric current.

In a room of intermediate size are two cold storage compartments, a work bench and tool cabinet, table (for weighing), and storage shelves. In a part of this room an elevated floor has been built, at a height of four and one-half feet, to provide for a digestion stall (with space beneath for excreta collection), a bullock scale, and for the convenient access of the animal to the calorimeter. One door opens from this raised floor to a runway by means of which the animal enters the building. From this floor another door opens on the level of the inner chamber floor of the calorimeter, in the adjoining room, thus permitting the animal to walk across a movable bridge into the calorimeter.

In the largest room (30 by 32 feet) is the respiration calorimeter. Partitioned off in one corner of this room is the so-called pump-house, in which are the meter pump, a special spirometer, and the meters and absorption trains used in the sampling of the air current.

In the attic of this building are tanks for supplying water, at constant pressure, to the heat-absorber system inside the calorimeter; and also equipment for freezing the greater part of the moisture out of the air which goes to the calorimeter chamber.

Construction of the Respiration Calorimeter

This calorimeter is a Pettenkofer, or open-circuit, apparatus, the inner chamber being 10 feet 4 inches long, 8 feet high, and 6 feet wide, surrounded by three double walls, one of metal and two of wood, with air-spaces both within and between these walls.

While its construction is similar in principle to the apparatus of Atwater and Rosa, important modifications in detail were required to adapt it for use with large animals. Thus, this calorimeter was made three times the size of the one at Middletown, Conn. Large, triple, swinging doors were made for the entrance of the animal. Special air-locks with separate doors to the outside were devised for the introduction of feed and the removal of excreta. A special device was installed for watering the animal. Changes in detail were made necessary by the fact that the animal could not, as in the case of man, aid in the experiments. Furthermore, means had to be devised for the measurement of the combustible gases produced by ruminating animals.

Detailed cross-sections of the respiration calorimeter are shown in Figs. 5 and 6. The door frames, H and I, are of heavy oak, as also are

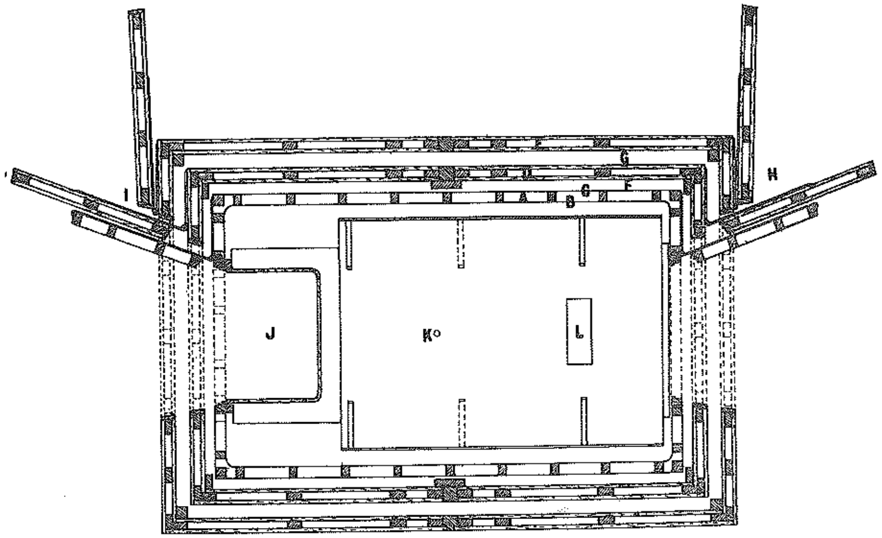

FIG. 5. HORIZONTAL CROSS-SECTION OF RESPIRATION CALORIMETER

A, the double metal wall of the chamber, consisting of an airtight inner wall, B, of heavy copper sheets, soldered together, and an airtight outer wall, C, of sheet zinc, carried on a framework of 2″ x 3″ lumber; D and E, double wooden walls, inclosing dead air spaces, and rendered airtight by the use of building paper. Between the walls A, D and E are the inner and outer air spaces, F and G, which serve an essential function of the calorimeter; H, the hinged entrance doors; I, the doors to the feedbox air-lock, J; K, the opening in the stall platform for the urine tube; and L, the opening for the feces hopper. The outer finish of the calorimeter is of beaded partition lumber.

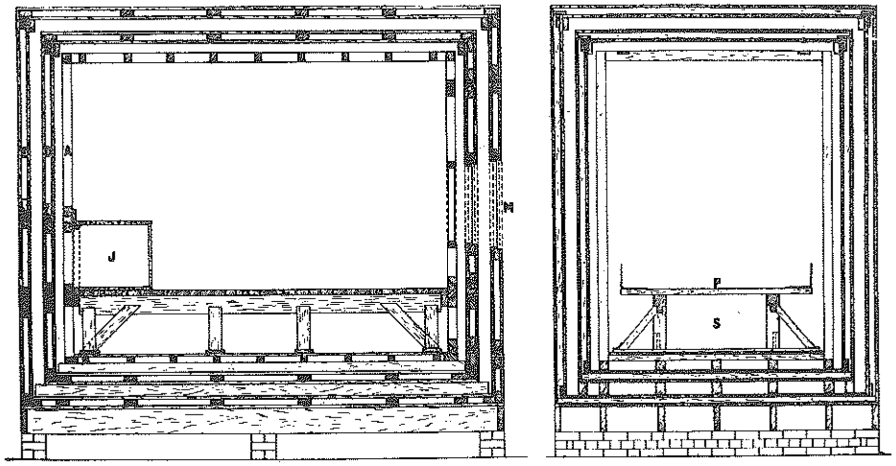

FIG. 6. VERTICAL CROSS-SECTION OF THE RESPIRATION CALORIMETER

Two vertical cross sections of the 3 boxes comprising the calorimeter, M, (in each box) a plate glass window; P, the stall platform with angle irons at the side edges; S, the space for the excreta air-lock beneath the platform.

the frames of the doors themselves; and the construction of the doors matches and continues that of the respective walls. The air-tight closure of these doors is provided for by a flat, pure-gum gasket cemented upon the door frame, and by a rubber tube gasket cemented into a groove on the inner face of the door. Compression door fastenings force the rubber tubing gasket on the door against the flat rubber gasket on the door frame.

The Stall.—The stall floor, on which the animal stands, is built of plank, and is supported on trestles 21 inches above the bottom of the inner chamber. This floor, and all other woodwork inside the chamber, is covered with copper, or with zinc, to prevent the absorption or the giving off of moisture. The animal is provided with no bedding, but stands or lies on a soft rubber mat. The stall and stanchion are built of iron pipe, and the stall is so constructed as to be 12 inches wider at the floor than at the top, thus allowing the animal sufficient room while in the lying position.

The two windows enable the operator to see the animal's head, the water bowl and the front part of the stall floor, and also to see into the rear of the chamber. The windows consist of pieces of plate glass sealed, air-tight, into openings in the walls. In addition to the openings in the chamber walls, there are openings for the ingoing and the outcoming air-flues, for the lever which operates the lid of the feed-box air-lock, for electric wires, and for the water pipes of the heat-absorption system.

The Feed Box.—The animal is fed by placing the feed into an unattached feed-box outside the calorimeter, next placing the feed-box into the feed-box air-lock, and then raising the lid of the air-lock by means of a lever, outside the calorimeter. This lever connects, through the wall, to a shaft made fast to the hinged edge of the lid of the air-lock. By lowering the lid the air-lock can be entirely shut off from the chamber.

At the right of the animal's head, and on a level with the top of the feed box, is the drinking bowl (Fig. 7).

The Floating Platform.—A visible record of the movements of the animal, which is of service by calling attention to abnormal conditions, is made on a kymograph. Superimposed upon the forward part of the stall platform is a loose floor, the rear edge of which is hinged to the stationary platform, while the forward edge is slightly elevated, and is supported by compression coil springs, one at each corner. These two forward corners are also supported from the ceiling joists of the calorimeter chamber by expansion coil springs, with turnbuckles for the adjustment of tension. At the right front corner this floating platform is attached to a pneumograph, which connects, by means of a small copper tube, to the tambour of a kymograph outside the chamber. Since the animal stands with its fore feet on this floating platform, any considerable movement of the body is recorded.

Standing and Lying Alarms.—The method of experimentation requires that an account be kept of the time spent by the animal in the standing and in the lying position, in order that the heat production, as

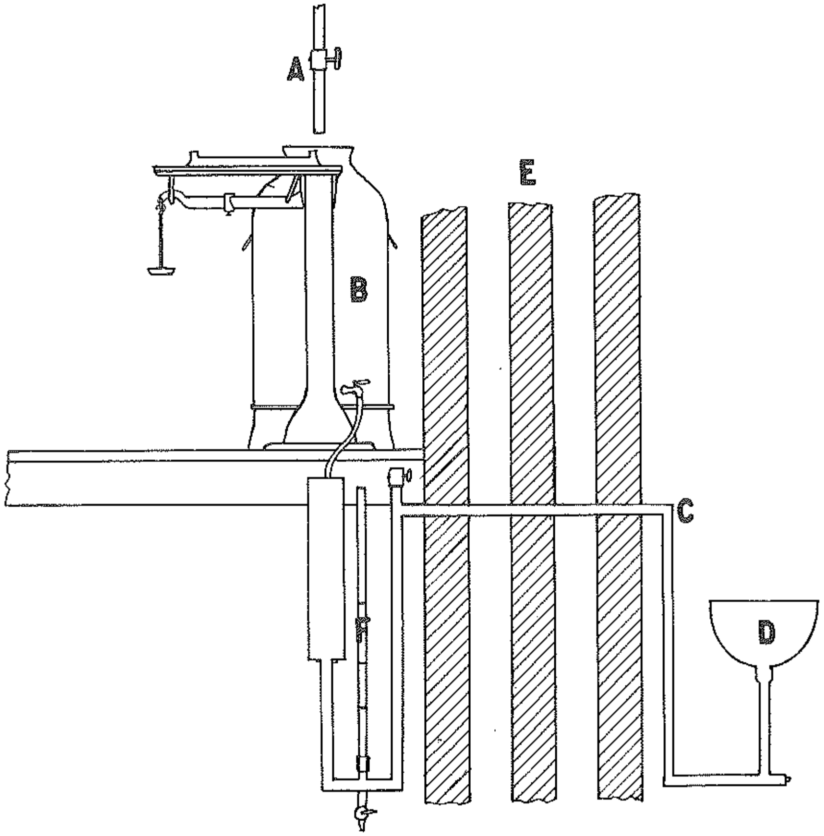

FIG. 7. DIAGRAM OF ARRANGEMENT FOR WATERING THE ANIMAL IN THE RESPIRATION CALORIMETER

The bowl, D, is connected at the bottom with a syphon, C, passing through the wall to the outside, where it receives water from a metal water tank, B, resting on weighing scales. Connected with the syphon is a glass tube, F, used as a level gauge. The syphon tube carries a valve at its top for the removal of air, and a valve at the bottom, for the withdrawal of water.

observed, may be computed to the basis of a standard day, as to time spent in these positions. To this end, the following apparatus has been devised. A cord is attached to the top of the surcingle of the harness. This cord runs to pulleys in the ceiling and to a weight which, as the animal changes position, slides up and down in an iron pipe, fastened vertically just outside the stall frame. At the bottom of this pipe is a make-and-break contact connected with a double-throw switch near the observer's table. The length of the cord over the pulleys is so adjusted that when the animal stands the weight in the iron pipe will make contact and ring a bell. The observer throws a switch, stopping the alarm, until the animal lies down, when the ascent of the weight rings the bell for the lying position.

The Excreta Air-lock.—Beneath the stall floor is the excreta compartment—a copper chamber 67 inches long, 34 inches wide and 18 inches high, supported above the chamber bottom. Access to this compartment is by doors through the three walls of the calorimeter, directly below the main entrance doors. This opening is shown in Figs. 8 and 9.

There are two openings from the excreta compartment up through the stall floor; one, 1¼ inch in diameter, and 27 inches back from the feed box, is for a rubber hose which conducts the urine from the funnel of the animal's harness into a tin-coated can in the compartment. The other, opening through the stall floor, 36 inches back of the hole for the urine hose, is 17¾ by 6½ inches. A hopper, with rubber apron similar to that used in the digestion stall, fits this opening and directs the feces into a galvanized iron box below.

This opening in the stall floor is closed by two pieces of sheet rubber, held in place by a light, removable, wooden frame, and stretched taut with edges meeting, thus providing a slit which opens readily to permit the passage of feces into the box below, and then closes again. Thus

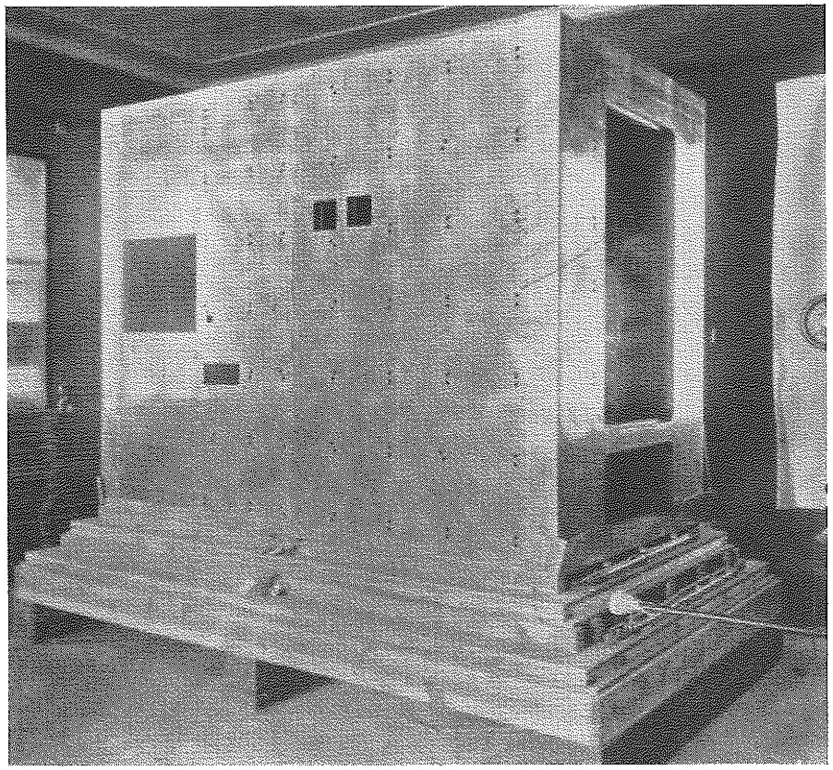

FIG. 8. FRAMEWORK OF THE CALORIMETER COVERED WITH THE ZINC WALL

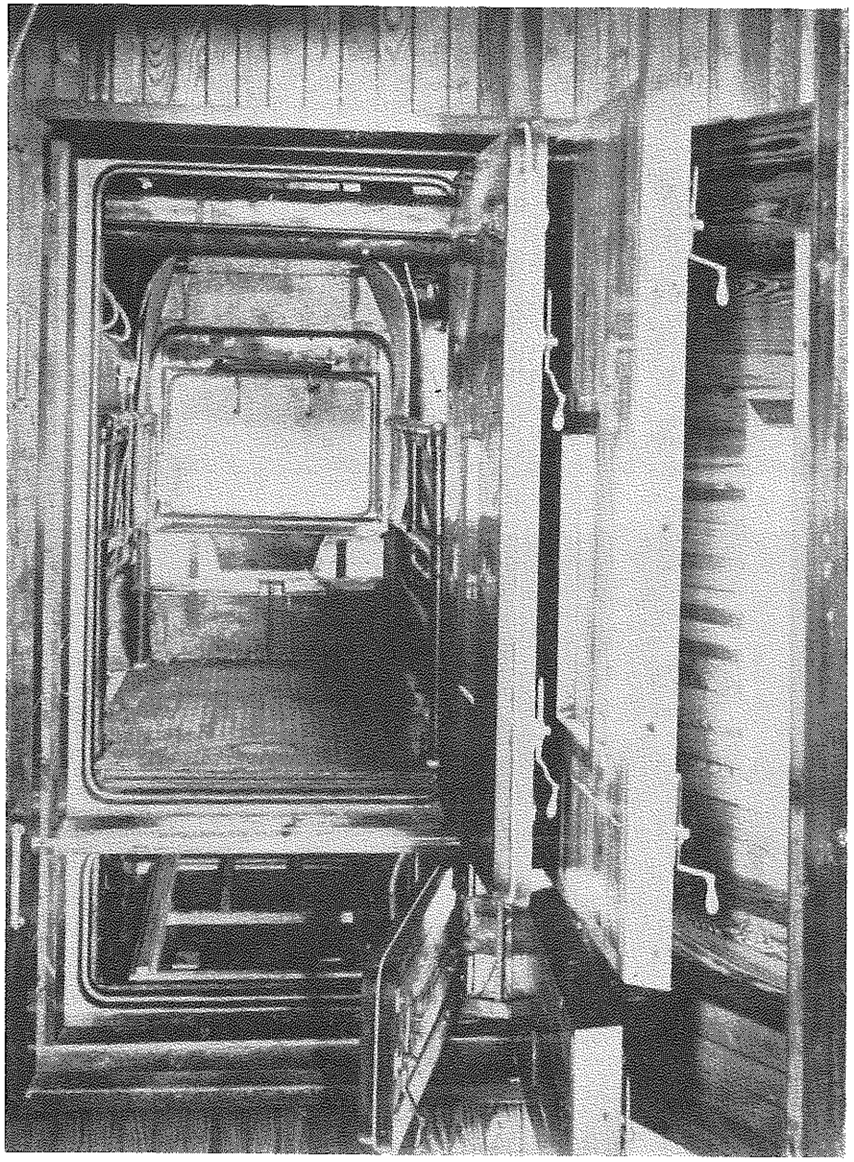

FIG. 9. VIEW OF THE INTERIOR OF THE RESPIRATION CALORIMETER, THROUGH THE REAR DOORS

the compartment is practically cut off from the chamber above. The compartment door is opened once in every 24 hours in order to change the excreta boxes.

Apparatus for Special Nitrogen Study.—When a special study is to be made of urine, requiring the separate accounting for successive voidings, the urine box in the excreta compartment is placed on one end of a light-weight wooden platform, arranged to tilt as does the beam of a balance. The urine box is slightly over-counterpoised; when urine flows into the box, the box descends and makes an electric contact which rings a bell at the observer's table, thus notifying the observer that a urine sample is to be removed. The observer notes the time and throws the switch. An attendant removes the can of urine and adjusts a fresh can on the tilting platform ready for the next voiding. The momentary opening of the compartment causes no disturbance of conditions in the chamber proper.

Emergency Light.—An electric light, operated by a switch conveniently accessible to the observer, is located inside the chamber. Two mirrors, one on each side of the animal, near the stall floor, are so arranged that the operator can view the floor at the animal's hind feet by momentarily throwing in the light switch. The amount of heat generated by this light, in the short time required for such inspection, is negligible.

The Ventilation of the Respiration Chamber

The oxygen required by the animal is supplied by a current of fresh outside air through a 6-inch metal flue, projecting through the roof of the building. This air is drawn into and through the calorimeter chamber by a special pump which maintains a steady flow of air (Fig. 10).

The maintenance of satisfactory conditions of experimentation requires that the air enter the chamber nearly dry. The greater part of the natural moisture, therefore, is frozen out of the incoming air by drawing it over ammonia expansion coils in a special chamber, this apparatus being located in the attic of the building. The air from the drying-box flows through a 6-inch metal flue to and through the chamber of the calorimeter in the room below.

Inasmuch as the design of the calorimeter contemplates the measuring of the heat given off by the animal after its absorption by a stream of cold water, which circulates inside the chamber, no heat must be removed in the air-stream. Obviously, this requires that the temperature of the incoming and the outgoing air be maintained identical, by the adjustment of the temperature of the incoming to agree with that of the outgoing air.

For the accomplishment of this purpose the incoming air flue is equipped with both heating and cooling facilities. Inside the calorimeter both the incoming and the outcoming air pass through separate divisions of an apparatus which indicates the difference in temperature between these air streams, and, therefore, the necessity of heating or cooling the incoming air.

The incoming air is liberated in the lower, left-hand corner of the chamber; is stirred in the chamber by a small fan, the motor of which is outside the calorimeter; is drawn from the calorimeter in a duct the opening of which is at the upper right-hand corner of the chamber, opposite the point at which the incoming air is liberated; after passing through the temperature-difference indicator it goes outside to the meter pump, which measures and records its volume, and discharges it into a flue leading to the outer air.

The Ventilating Pump.—The pump (Fig. 10) which maintains the flow of air through the apparatus was especially designed for this calorimeter, and has been described and illustrated in detail elsewhere.[1] The air is pumped by two cylindrical bells of drawn steel, 18 inches high and 18 inches in diameter, which move alternately up and down in wells of mercury held in a steel casting, the valves being mechanically actuated. The mercury acts as a seal for the air in the bells; and the two wells are so connected that the mercury flows back and forth, at each stroke, and remains at a constant level. The number of strokes and the volume per stroke can be regulated; the pump is calibrated for volume delivered, which, as the pump is ordinarily used, is approximately 50 liters per stroke. A cyclometer attachment records the number of strokes.

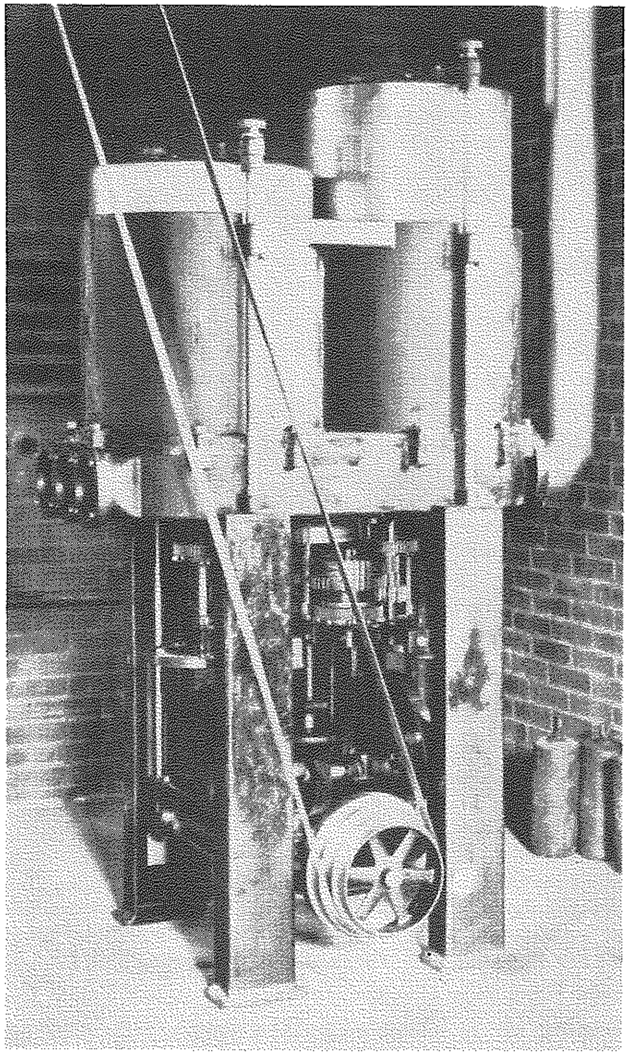

FIG. 10. THE METER PUMP

The variation in air pressure in the chamber, on account of the action of the ventilating pump, is equivalent to about a quarter-inch of water.

The Sampling of the Air

Three continuous air samples are regularly taken in connection with a calorimetric experiment, one of the ingoing and two of the outcoming air. A fourth sample, of the outcoming air, is taken, by means of the spirometer, when the heat is to be computed from the respiratory quotient. The three samples regularly taken are drawn through brass pipes connected with the air-flues at appropriate points. The sample of the ingoing air is drawn through a set of five glass-stoppered U-tubes, containing absorbents which retain the gases to be measured.

The first and second tubes contain medium-fine pumice stone saturated with concentrated sulphuric acid. These tubes remove all the water from the air current. The third tube, containing soda lime (15 per cent water), absorbs all the carbon dioxide. The fourth and fifth tubes contain acid-saturated pumice stone, as do the first and second; it is their function to absorb the water set free from the soda lime as a result of the absorption of carbon dioxide. The increase in weight of the first and second tubes, in the train, gives the weight of water in the sample. The total increase in weight of the soda lime tube and the two following acid tubes gives the weight of the carbon dioxide in the sample.

From this absorption train the ingoing air sample goes to a tube furnace in which it is drawn over platinized kaolin, which is kept at red heat, to oxidize the combustible gases present. The air sample goes next to an absorption train which collects the carbon dioxide and moisture produced by the combustible gases burned; then to a meter, in which it is measured, and finally to the outside air. The quantity of combustible gas in the ingoing air is normally negligible.

Two samples of the outcoming air are taken for the determination of carbon dioxide and moisture, one of them being subsequently used for the determination of combustible gases (mainly methane) produced by fermentation of carbohydrates in the ruminant digestive tract. In the measurement of the methane the air is first freed from carbon dioxide and moisture, and is then drawn through a tube furnace. This sample then goes to an absorption train, next to a meter, and finally to the outer air. All absorption sets are provided with by-passes, by means of which

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[1] *American Machinist* 25 (1902), p. 1297.

the tubing back to the air-flues can be swept out, for the removal of possible accumulations of moisture, before a measurement begins.

The movement of the air samples, from the air-flues through the absorption trains, the furnaces and the meters, is accomplished by the use of three air pumps (Fig. 11). These blowers are operated by pulleys from a single shaft, driven by a one-H. P. motor. The maximum suction required to draw the samples of air through the U-tubes, as indicated by mercury manometers in the circuits, is less than 25 mm. The manometers show at all times whether the sampling circuits are open and operating properly.

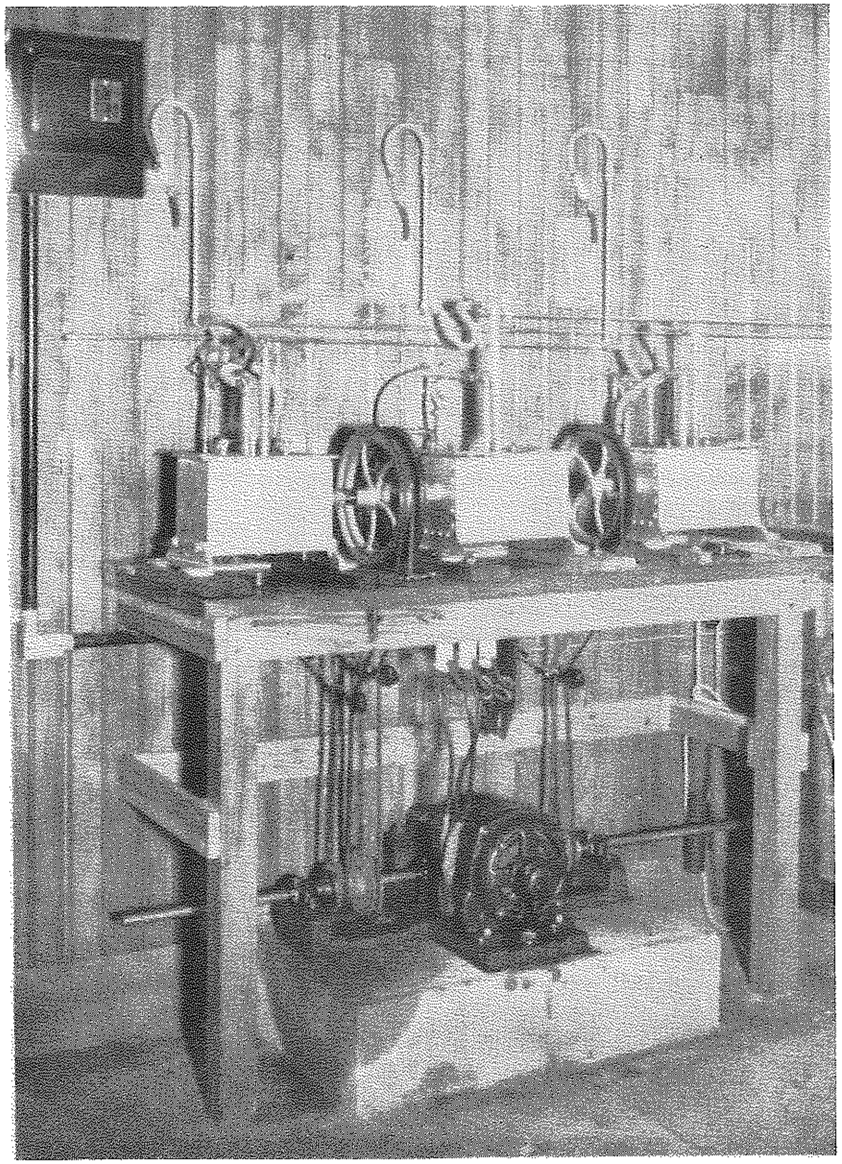

FIG. 11. PUMPS USED TO TAKE SAMPLES OF AIR FOR ANALYSIS

These pumps, after drawing the air samples through the absorption train, push the air into the meters, for measurement at barometric pressure. Between each pump and its meter is a bottle serving as an oil trap, and a second bottle containing water, to moisten the air current and thus prevent the dry sample from removing water from the meter. The air meters with the outgoing air absorption trains, are shown in Fig. 12. These are constant-water-level meters, made entirely of an aluminum alloy. The air exit tube at the back of the instrument has connected to it a vertical glass tube, 12 inches long, which serves to hold a thermometer.

Since the samples are much larger than the 10 liters measured by one revolution of the meter, provision is made for recording the number of times the pointer passes the zero mark. Through an opening in the top of each meter-case, but insulated from it, a thin, tongue-shaped piece of sheet copper is held in such position that a wire prong carried by the pointer makes momentary contact with it. When the contact is made

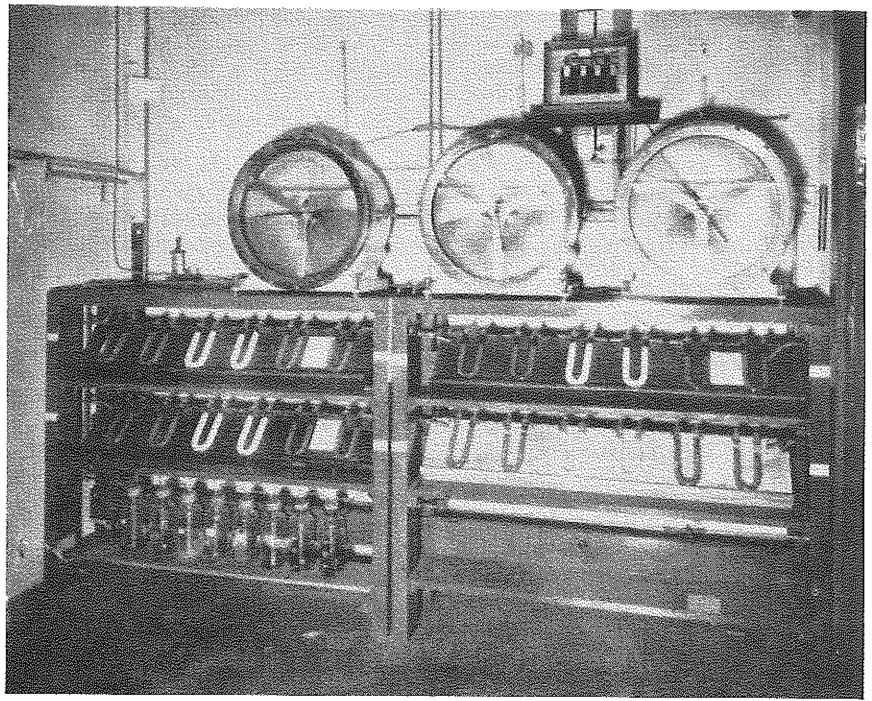

FIG. 12. AIR METERS AND OUTGOING AIR ABSORPTION TRAIN

a magnet, actuated by a six-volt direct current, moves a cyclometer forward and thus records the revolution.

The temperature of the air from the meter, the barometer reading and the cyclometer reading are recorded at the start and at the end of sampling, and every 30 minutes in between. The volume of any sample, therefore, can be computed to standard temperature and pressure.

These meters are located in the pump-house, in order that the measurements of the entire air-stream and of the samples may be subjected to the same temperature influences.

The Tube Furnaces

Each furnace for the determination of combustible gases in the air consists of a transite box 7 feet 1½ inches long, 8 inches high and 7 inches wide, inclosing a copper combustion tube, surrounded by a brass supporting tube, quartz insulation, the heating element, asbestos wrapping, and finally sand.

Each furnace is divided, crosswise, into three equal divisions by transite partitions, each with a center hole through which pass the copper, the brass, and the quartz tubes. The copper and brass tubes are continuous throughout the length of the furnace. The quartz insulating tubing is in three pieces, one to each division of the furnace. Each of these quartz tubes is wound with a ¼ inch nichrome ribbon, having a resistance of .173 ohms per foot. Asbestos cord, ⅛ of an inch in diameter, is wound between the spirals, and a ¾ inch asbestos tape is wound over the spirals of the ribbon. The nichrome ribbon at each end of each quartz tube passes outside to connect to a binding post.

The tubes are wrapped with asbestos paper, and the box filled with sand. Three peep-holes, one at the middle point of each division of the furnace, permit observation of the color of the tube, to judge its temperature. These openings are normally closed by transite plugs.

Three binding posts, one from each coil on a quartz tube, are connected with resistance coils. The other three connect with the lead from the 110-volt circuit. A 5-foot coil of nichrome ribbon, to furnish outside resistance, is put in each circuit immediately above the furnace. Coils of nichrome ribbon, one foot long, with two switches, are used as rheostats when the current fluctuates. About 30 amperes of current for the two furnaces maintain a temperature of about 700 degrees Centigrade.[2]

The brass supporting tube projects outside the furnace box about eight inches at each end; and the inside combustion tube of copper is filled, throughout eight feet of its length, with platinized kaolin, which catalyzes the combustion of the gases.

The ends of the copper tube are connected by reducers to copper tubes one-fourth of an inch in diameter. At the entrance end the connection is made directly with the brass tubing of the air-sample circuit. The ¼-inch copper pipe at the exit end is connected by heavy rubber tubing to a ¼-inch iron pipe for the return circuit. The exit end of the copper pipe is supported, to prevent bending, when heated, on account of the weight of the portion outside the furnace.

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[2] Fries, J. A., Journ. Amer. Chem. Soc. 32, p. 949, (1910).

The Spirometer

The fourth air sample, which represents the outcoming stream, and which is taken for oxygen determination, when the heat is to be computed from the respiratory quotient, is drawn by a special spirometer (Fig. 13) actuated from the same shaft that drives the large, ventilating meter pump. This sample is a 12-hour continuous aliquot.

The spirometer consists of two bells, each of 2 liter capacity, working over mercury, as in the large meter pump. A current of air from the exit flue at the meter pump is drawn through the base of the spirometer by a rotary blower, such as moves the other air samples in their course. As a bell is raised, a sample is drawn through a minute opening from this air stream. A bell is filled in 12 hours. After a bell is filled it automatically comes to rest, with its intake valve closed, and the second bell begins to fill.

While the second bell is filling a sample is drawn of the air in the first bell, through a valve provided for the purpose. The samples are drawn over mercury into glass gas-sampling tubes, and are analyzed for oxygen and carbon dioxide. In the illustration (Fig. 13) the front plate of the base of the machine has been removed to expose a part of the mechanism.

The Residual Air Sample

A sample of the air of the respiration chamber, called a residual sample, is taken at the beginning and the end of each period (12 or 24 hours) which is to be considered separately. This procedure is required by the facts that the volume of the chamber is large (approximately 12,000 liters) and that the gaseous products of metabolism are not produced at uniform rates.

To accomplish this purpose, a 25-liter sample is drawn from the outcoming air-flue during a period of 15 minutes. A 25-liter metal aspirator, employing water as a motive agency, draws the sample through a set of the usual absorption tubes, thus providing for weighing the water and carbon dioxide contained. The total quantities of water and of carbon dioxide respired are corrected by the amount of the difference in content of water and of carbon dioxide in the chamber between the beginning and ending of a period.

Indirect and Direct Calorimetry

Thus, given the quantities of feeds consumed, the quantities of urine, feces, methane, and carbon dioxide produced, the chemical composition and energy values of these products, and the water balance, it is possible to compute the balance between the income and the outgo of nutrients. This balance reveals the gain or loss of body substance, the heat production and the nutritive value of the ration. This general procedure of indirect calorimetry, known as the carbon-and-nitrogen balance method, may be utilized during experimental periods in which

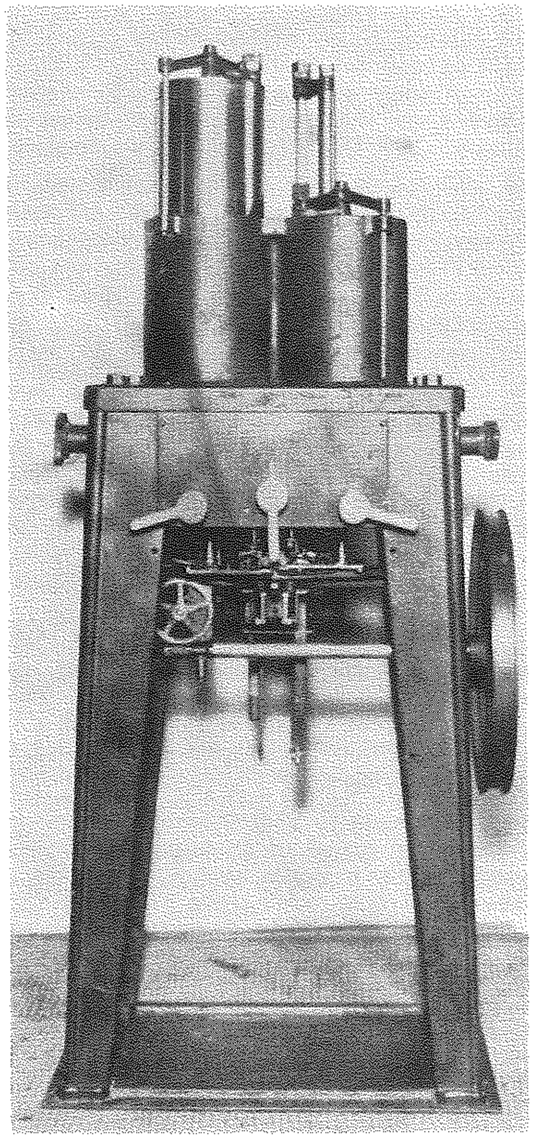

FIG. 13. SPIROMETER FOR TAKING ALIQUOT AIR SAMPLE FOR OXYGEN ESTIMATION

the animal receives feed. In addition, the respiratory quotient procedure, in which the heat produced is computed from the gaseous metabolism, is available during either feeding or fasting.

The special function of the respiration calorimeter, however, is the actual measurement of the heat produced. In the use of this equipment it has been customary at all times to measure the heat directly; the sensible heat in a continuous stream of cold water which passes through the calorimeter, and the latent heat of vaporization of water in the moisture which is in part condensed on the heat absorbers and in part carried out of the calorimeter in the air current.

At least two measurements of heat production are commonly made, therefore, by different methods, one to check against the other.

The Heat Absorber System

The temperature of the chamber is kept constant, within 1/100 or 2/100 of a degree, by removing the heat from the chamber as fast as the animal gives it up. The heat is removed by cold water flowing through a system of pipes, suspended 6 to 10 inches beneath the chamber ceiling. This heat absorption system consists of 4 separate copper pipes, ⅜ of an inch outside diameter, arranged in the form of a rectangle. The pipes carry copper discs, 2 inches in diameter and ½ inch apart, the purpose of which is to extend the surface. This absorber system hangs on a weighing scale.

The water for the absorber flows through a mixing receptacle situated between the copper and the zinc walls of the chamber. The mixing receptacle contains a special thermometer extending to the outside of the calorimeter. The water from this box flows through a brass pipe to the absorber system, with which it is connected by flexible rubber tubing, to permit weighing. After passing through the four pipes, the streams of water combine, and flow through a flexible rubber tubing and a brass pipe into a mixing box for outgoing water. This is located beside the box for incoming water, between the copper and zinc walls of the chamber.

A special thermometer extends from this mixing box, as from the other, through the calorimeter walls. The thermometers for ingoing and outcoming water are located side by side. The thermometers are made in a right-angle, the horizontal arm being 25 inches long, and the vertical arm, which bears the engraved scale, being 18 inches long. The thermometer in the ingoing water current is engraved for temperatures from 0° to 15°, and that in the outgoing water, from 4° to 19°C. These thermometers are graduated to 1/50 degree, and can be read to 1/100 degree. The vertical arms carrying the engraved scales are at the left of the observer's table (Fig. 14).

The outcoming water flows to measuring tanks where its volume is determined. These tanks are shown, beside the steps to the observer's platform, in Fig. 14. Each tank has a capacity of 100 liters. The

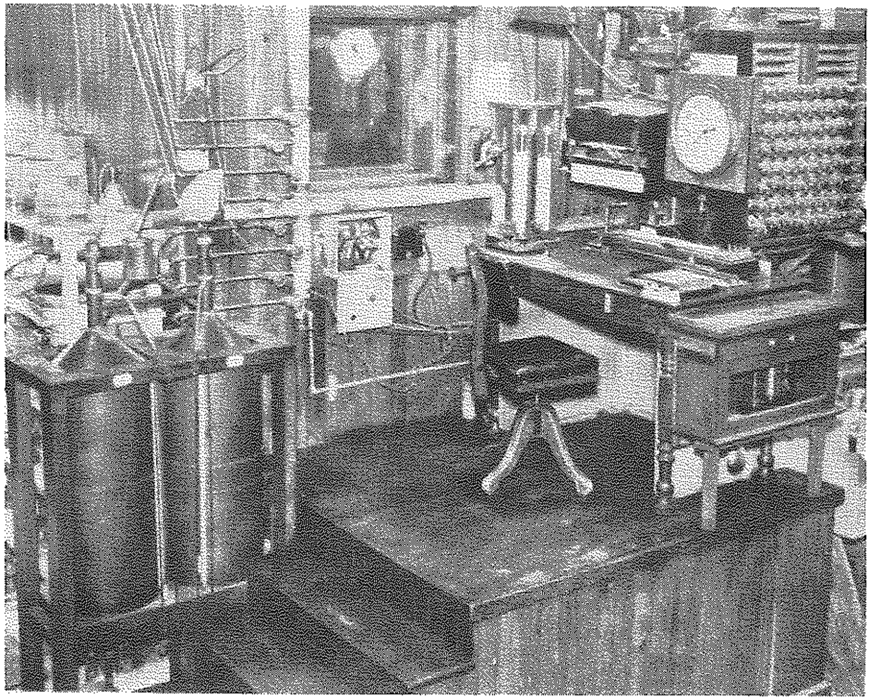

FIG. 14. OBSERVER'S TABLE AND ADJACENT CONTROL EQUIPMENT

filling and emptying are adequately controlled with the aid of a system of electrically actuated signals.

Beneath the absorber system, but suspended independently of its structure, is a U-shaped copper trough, 5 inches deep and 5 inches wide at the top, which is used to regulate the exposure of the absorber system to the air of the chamber. This trough, or shield, is suspended by light-weight phosphor-bronze cables, connected to a shaft. This shaft, in turn, is connected by a chain over sprockets to a second shaft which projects through the walls to the outside of the calorimeter, above the observer's table.

The movement of this shaft is controlled by a handle and a ratchet. By the use of this handle the observer can change the height of the copper trough, lower it away from the absorber pipes when more heat must be removed, or raise it when less heat must be taken out of the chamber. This shield is covered, externally, with lacquered cardboard, to increase its effectiveness. In addition to its regulating function, the shield catches condensed moisture dripping from the absorber system—water being conducted by a rubber tube to a bottle in the excreta compartment. When in its lowest position the shield hangs, with the absorber system, from the weighing scale.

The weighing scale is hung from the ceiling of the chamber, and resembles the common platform scale in construction. Changes in weight of the absorber and shield, on account of adherent condensed moisture, are read on a dial, through the window of the calorimeter.

Water for the Absorber System

Water is supplied to the heat-absorber system from a storage tank in the attic. From this storage tank the water is run into a small constant-level feed tank from which it flows, through a filter, into the absorber system. By this means water is supplied at a constant head, and free from solid contamination and bubbles.

The flow of the water through these tanks is controlled by a float valve. If the water from the attic for the heat absorber is not cold enough, a regulable portion of the flow is passed through a coil submerged in a brine tank, kept at about 5°C. by an ammonia expansion coil.

If the water for the heat absorber is too cold, it is not allowed to pass through the brine tank, but must be heated. This is accomplished by a heater, on the supply pipe, made of nichrome ribbon wound about the pipe. The pipe is insulated from the winding electrically, and the successive layers of winding are insulated from one another. The whole device is heavily covered with asbestos. The current to this heater is controlled by a switch and rheostat on the outside wall of the chamber, near the observer's table.

Resistance Thermometers for Determining the Temperature of the Air in the Chamber and of the Copper Wall of the Chamber

During an experiment it is necessary to know the temperature of the air in the chamber, in order that it may be kept as nearly constant as possible. Copper resistance thermometers are used, these thermometers being connected with a bridge and galvanometer. The bridge is at the back of the observer's table, and the galvanometer scale is immediately above. Twelve of these thermometers are held one-half inch from the copper wall, and 12 more in flat copper boxes soldered to the copper wall. These thermometers are made of copper wire wound on hard rubber spools. The air thermometers are in 6½ by 2 inch cylindrical, copper gauze containers, and the wall thermometers are in copper pockets 8 inches long, 3 inches wide and 1 inch deep. These resistance thermometers are distributed throughout the chamber in pairs, (1 for the air and 1 for the wall), 3 pairs at different levels on each side wall, 2 pairs on the ceiling, 2 on the front wall and 2 on the back wall, at different levels.

One set of these copper thermometers indicates, on the bridge, the average temperature of the air in the chamber, and the other set the average temperature of the wall. Readings are taken every four minutes, by keying-in the proper circuit, and operating the slide on the bridge so as to bring the image, as it is reflected from the galvanometer mirror, to zero. The bridge readings do not indicate the temperature directly, but the bridge scale is calibrated occasionally, when everything is in equilibrium, by comparison with a mercury thermometer inside the chamber, which is read to 1/20 of a degree through the window at the observer's table.

Temperature Regulation of the Ingoing Air

The detection of any necessity for raising or lowering the temperature of the ingoing air, to equalize its temperature with that of the outcoming air, is accomplished by means of a device contained in a metal drum, through which pass the ingoing and the outcoming air flues. This drum, which is located inside the chamber, is 72 inches long and 14 inches in diameter, and is double walled, with a narrow air-space between the walls. The inside cylinder is divided crosswise, in the middle, by a tight, double-walled, wooden partition, inclosing a dead-air space, internally. This divides the drum into two cylindrical air-spaces, end to end, through one of which passes the incoming and through the other the outcoming air, both containing thermocouple elements (Fig. 15).

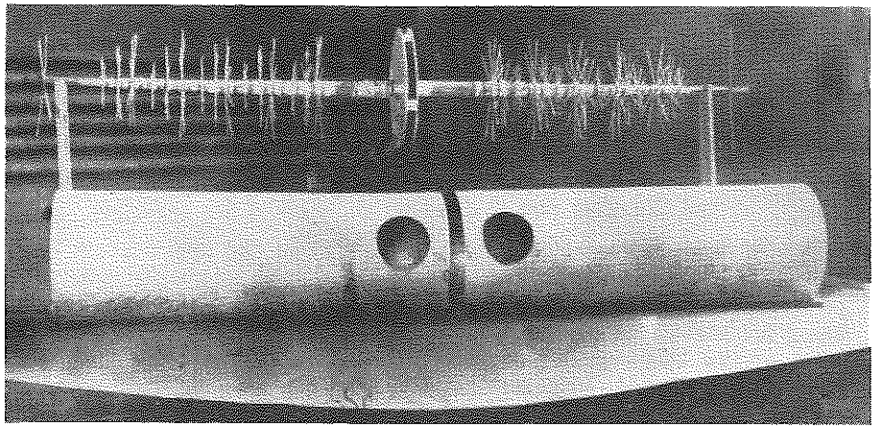

FIG. 15. CONSTRUCTION OF APPARATUS FOR COMPARING TEMPERATURE OF INGOING AND OUTCOMING AIR

These thermocouples connect with a switch to the galvanometer. If the temperature of both cylinders is alike the galvanometer reads zero on the scale. If the air in one cylinder differs in temperature from the air in the other, the galvanometer indicates this fact, by swinging to the right or to the left, according to whether the ingoing air is cooler or warmer than the outcoming air. If the ingoing air is not at the same temperature as the outcoming air it must be cooled or warmed, as is indicated by the galvanometer when put in circuit with the thermocouples in the air-current.

The vertical portion of the ingoing air flue, near the chamber, is enlarged to a diameter of 15 inches along 48 inches of its length. This enlargement contains a cooling device through which cold water may be passed. The internal construction of this device (Figs. 16 and 17) has for its purpose the presentation of an extensive cooling surface to the stream of air.

If the operator finds, from his galvanometer reading, that the ingoing air is warmer than the outcoming air, a valve is opened which permits cold water to flow through this apparatus; but if the ingoing air is cooler than the outcoming it is heated by resistance wires and light bulbs in the ingoing air flue.

Maintenance of the Chamber in Adiabatic Balance

The correct measurement of the heat produced by the animal requires that the chamber be prevented from gaining heat from or losing heat to the outside room, by passage through the walls. This is accomplished by maintaining the temperature of the air in the 3-inch air-spaces between the triple walls of the calorimeter the same as that in the inner chamber.

This regulation is accomplished by means of water pipes for cooling, and resistance coils for warming these air spaces. The necessity for cooling or for heating is indicated by many thermocouples in the walls of the metal chamber and in the walls of the wooden chamber next out-

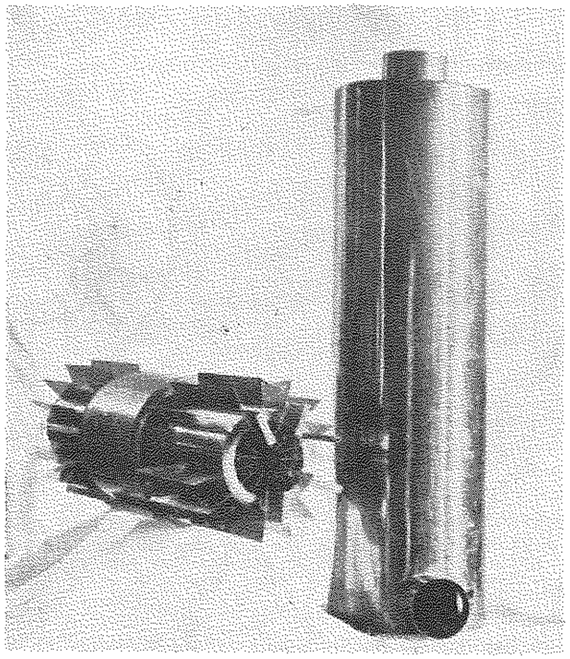

FIG. 16. CONSTRUCTION OF APPARATUS FOR COOLING THE INGOING AIR

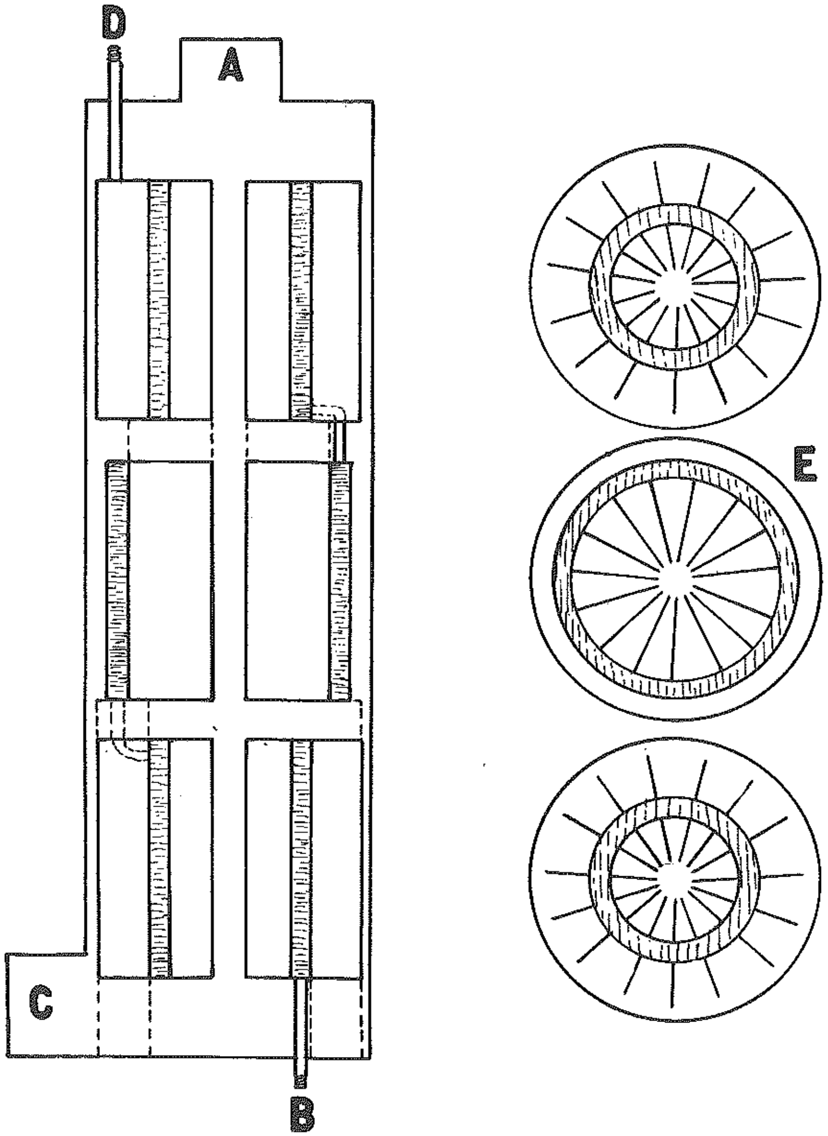

FIG. 17. CONSTRUCTION OF APPARATUS FOR COOLING INGOING AIR
A, the entrance of the ingoing air; B, the entrance for the cold water; C, the exit of the air going to the chamber; D, the overflow pipe for the water from the cooler; E, a cross-section of the 3 water drums, or cans, with the fins to give extra surface.

side; these show the difference in temperature between the two sides of each wall.

The thermocouple is fundamentally a pair of conductors so joined as

to produce a thermoelectric current when the junctions are at different temperatures, the intensity of the current varying with the difference between these temperatures. The thermocouple employed in the construction of this calorimeter (Fig. 18) is made of 4 pairs of wires, 1 wire of each pair being iron, F, and the other German silver, N. Each of the 8 wires is laid in a lengthwise groove in a hardwood cylinder 3¼ inches long and ⅝ inch in diameter; and the 8 wires are connected at their ends, in pairs, one iron and one German silver, by silver solder. The German silver wire of the first junction and that of the last junction are left free for connection to the copper wire leads.

Thermocouples are so placed in the double metal wall of the chamber as to extend from the copper wall to the zinc wall, across the dead-air space, thus providing for the detection of a difference in temperature between the copper and the zinc walls.

In placing each thermocouple unit in the wall of the metal chamber, a copper thimble ⅝ inch by ⅝ inch, B, was soldered against the outside of the copper wall, C, and opposite this thimble a zinc tube, E, was soldered into the zinc wall. The element was put through the tube in the zinc wall and then into the thimble in the copper wall. A mica wrapping prevents contact of the thermocouple wires with either copper or zinc. A cork stopper, D, for holding in position the two German silver projecting wires, in the open end of the zinc tube, holds the elements in place and keeps the leads apart.

These projecting leads of a series of thermocouples are connected by insulated copper wire to the reflecting galvanometer. The four junctions between the wires of a thermocouple near the copper wall assume the temperature of the adjacent copper, and the junctions near the zinc

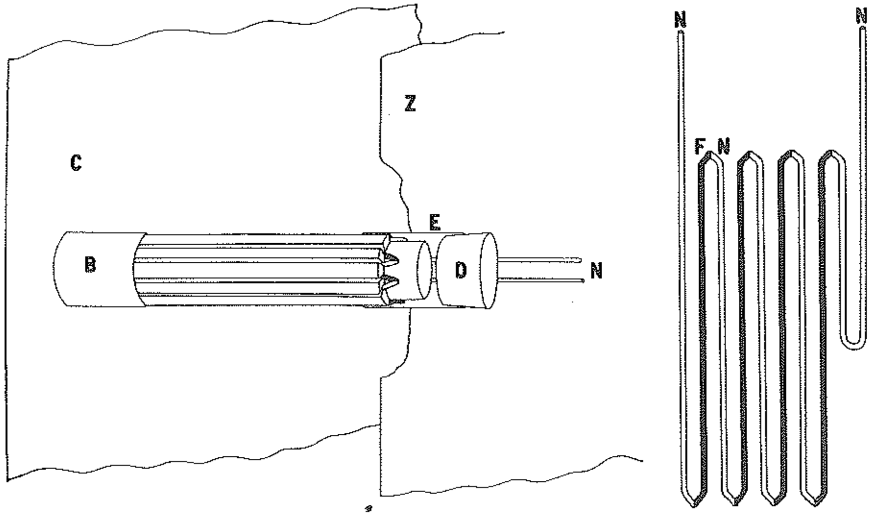

FIG. 18. DIAGRAM OF A THERMOCOUPLE IN THE AIR SPACE BETWEEN THE ZINC AND THE COPPER WALLS

wall assume its temperature. If there is a temperature difference between the copper wall and the zinc wall near these junctions a current of electricity is set up and is indicated on the galvanometer.

Copper and zinc are good conductors of heat. A change of temperature in any locality of either the copper or the zinc wall quickly spreads to adjacent localities, and tends to bring the whole wall to the same temperature. Since these thermocouple units are scattered over the six sides of the metal chamber, any slight difference in temperature between the copper wall as a whole, and the zinc wall as a whole, is indicated by the galvanometer. These units are installed in pairs, one of each pair being held in reserve for use in case of accident to the other. In the six walls of the metal chamber are 252 thermocouples distributed at approximately equal intervals over an area of about 380 square feet.

In addition, a similar system of 76 thermocouples in the wooden wall next outside the metal chamber indicates any difference in temperature between the two air-spaces. Since wood is a poor conductor of heat a metal plate 1¾ inches square, is fastened to the wall, at the point of attachment of each thermocouple, to take up the temperature of the air in the air-space and transfer it to the thermocouple.

The thermocouples in the walls of the metal chamber are wired in such manner that switches at the observer's table can put in circuit all units at once, or different groups of such units, one group at a time. There are 5 such groups, 1 each for the top and the bottom, and 3 for the sides, in horizontal bands, for the upper, the middle and the lower third. The thermocouples in the walls of the wooden box are connected in a similar way to the same galvanometer. In this case there are only 4 independent circuits, 1 each for top and bottom, and 2 for the sides. All the circuits on this wall can be united, to indicate the condition of all the thermocouples in one reading.

By putting in circuit all of the thermocouple units, in either the metal chamber or in the wooden box surrounding it, the observer can determine whether the average temperature of the inside of the wall (or adjacent air-space) differs from that on the outside of the wall (or adjacent air-space). If there is a difference it must be corrected. To locate such temperature differences, the circuits to the different sections are used.

For heating purposes, each dead-air space is provided with resistance circuits for the top alone, the upper half of the sides, the lower half of the sides, and the bottom. Each circuit is provided with a separate sliding rheostat switch, for the regulation of the quantity of heat in the desired location. These switches are at the right on the observer's table. The resistance devices connected with the rheostat at the observer's table consist principally of special wire wound on asbestos cylinders, but in part of light bulbs. In addition to serving as resistance these light bulbs indicate, by their incandescence, the continuity of the circuits. The bank of light bulbs, with resistance coils above, is shown in Fig. 14.

The cooling of the air-spaces is accomplished by means of water, which is carried in a small brass pipe to the several sections, corresponding in location to the circuits of the heating wires. Each top, each upper half, each lower half, and each bottom of the two inner walls, therefore, can be cooled independently. The eight valves controlling the cooling water are on the outer chamber wall, to the left of the operator (Fig. 14).

The heating wires in the air spaces are supported by insulators, and the brass water pipes by wooden blocks placed on the outer surfaces of the metal chamber and of the wooden wall next outside it. The arrangement and relative position of the wires and pipes is shown in Fig. 19.

The Building of the Calorimeter

In the building of the calorimeter the bottom of the outer wooden box was laid on timbers resting on three brick piers 15 inches high. Upon this outer box was put the heating wires and the cooling pipes.

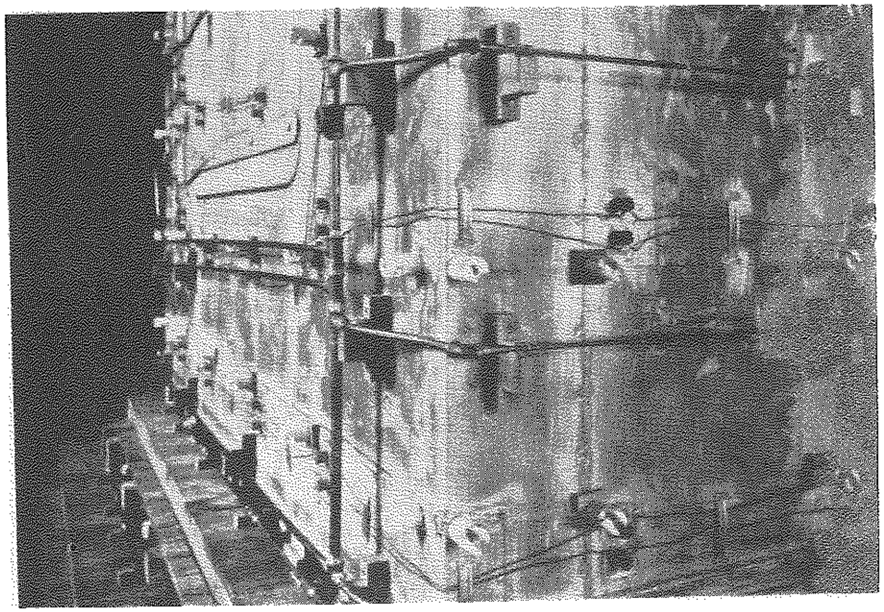

FIG. 19. HEATING WIRES AND COOLING PIPES IN THE AIR SPACE BETWEEN THE ZINC AND THE WOODEN WALLS

The bottom of the inner wooden box, with its thermocouples and connecting wires in position, and with the heating wires and cooling pipes for the inner air space on top, was then placed above the bottom of the outer box, and supported four inches above it. Fig. 20 shows the bottom of the inner wooden box in position. Leaning against the wall, to the right, is the bottom of the metal box, its zinc bottom side showing, with thermocouples in position.

After this metal bottom was in position the timber work of the metal

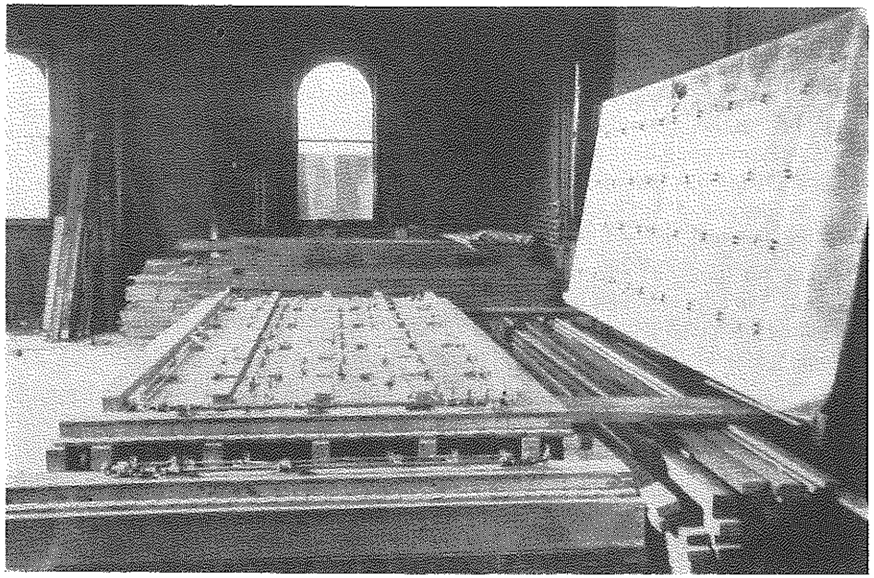

FIG. 20. BOTTOM OF THE WOODEN WALLS, IN POSITION, AND BOTTOM OF THE METAL WALL AT THE RIGHT

box was erected (Fig. 21). Then the inside of this framework was covered with sheet copper, and the outside with sheet zinc.

Fig. 8 shows the metal in position, and the small openings, in pairs, ready for the thermocouples, on one side. The entrance opening is shown at the right end, with the excreta air-lock opening below. On the side is seen the large square opening for the windows; two small square openings, side by side, for the ingoing and outcoming air flues; and a small oblong opening for the absorber water pipe and the absorber water thermometers.

Figs. 22 and 23 show the metal chamber with the thermocouples wired and in position, together with the heating wires and cooling pipes. The doors, also, carry thermocouples. Originally, as shown, the wires to the thermocouples passed directly from the body of the chamber to the doors. Later, sliding contacts, made of thin strips of brass, were placed in the circuits to connect across the crack at the hinge side of the doors.

The wiring and piping on the metal box having been fully tested, the inner wooden box was erected, thus creating the inner dead-air space. Fig. 24 shows the inner wooden box with its thermocouples, heating wires, and cooling pipes in position. Near the middle of the side are seen the coils of wire and leads from the thermocouples and copper thermometers to the outside.

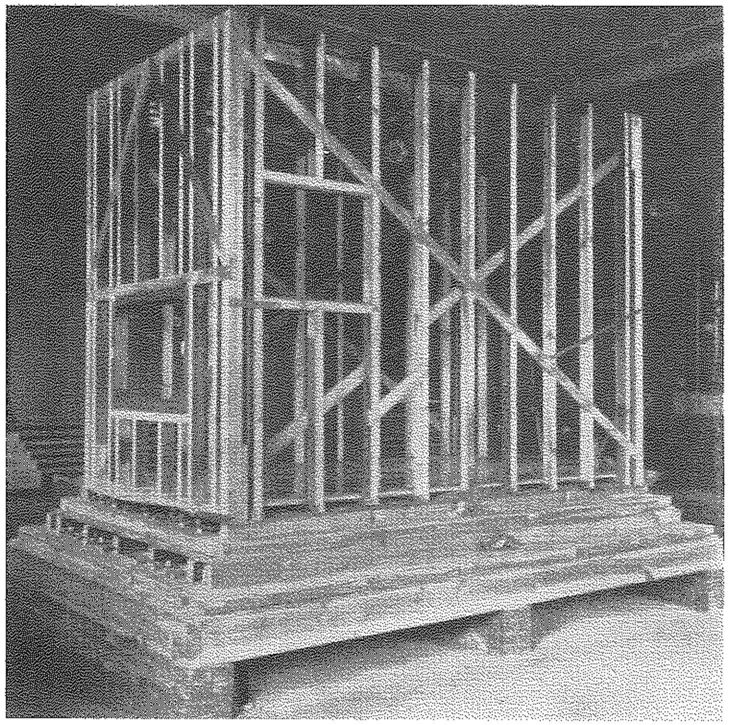

FIG. 21. FRAMEWORK OF THE RESPIRATION CALORIMETER

Control of the Calorimeter

The operation of the respiration calorimeter is under the control of an operator stationed at the observer's table, which is near the window in the chamber, at the head of the animal. Fig. 14 shows the table and the adjacent apparatus. These are also shown in the picture of the apparatus as a whole, in Fig. 25.

At the left of the table are the thermometers in the ingoing and outcoming absorber water. Further to the left, at the corner of the chamber, are the two 100-liter copper tanks for the measurement of the water coming from the absorber system. Each tank has a glass gauge marked for the reading of quantities less than 100 liters.

To the left of the window are eight water valves for the control of the cooling water for the different sections of the dead-air spaces.

At the left front of the observer's table is the multiple-point switch for connecting with the galvanometer the various sets of thermocouples in the walls and in the air current, in order to determine which sections

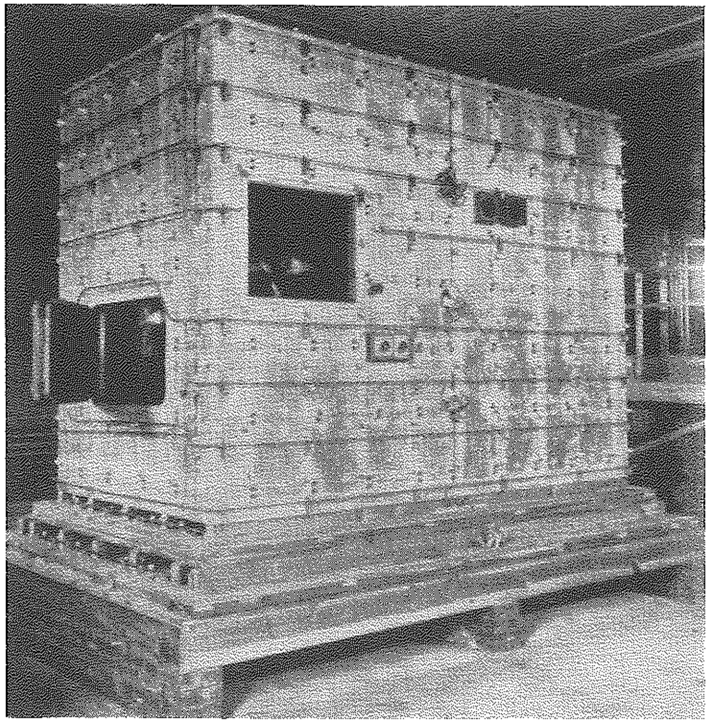

FIG. 22. METAL CHAMBER, WITH THERMOCOUPLES, HEATING WIRES, AND COOLING PIPES IN POSITION

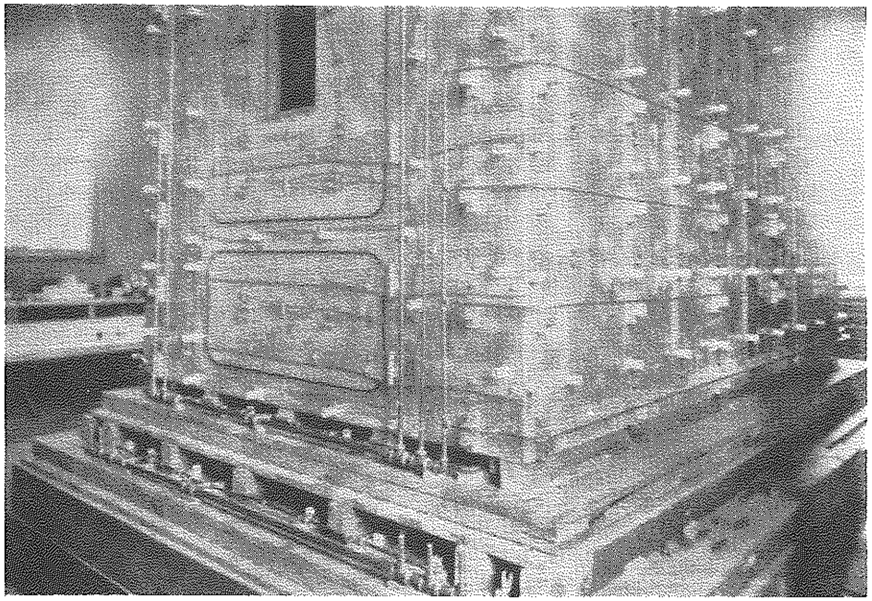

FIG. 23. METAL CHAMBER, WITH THERMOCOUPLES, HEATING WIRES, AND COOLING PIPES IN POSITION

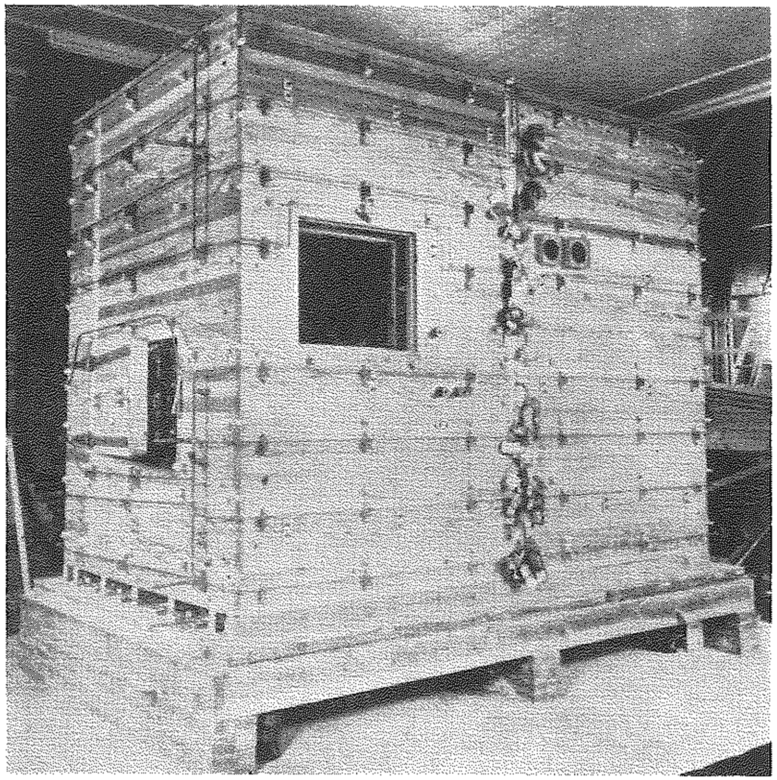

FIG. 24. INNER WOODEN WALL WITH THERMOCOUPLES, HEATING WIRES, AND COOLING PIPES IN POSITION

of the dead-air spaces need heating or cooling, and whether the ingoing air needs heating or cooling. To the right, on the table, are the switches controlling the current to the heating wires in the dead-air spaces, and to the heating circuits in the ingoing air current. At the back of the table is a slide-wire bridge, used in connection with the galvanometer, the scale of which is above the bridge, on a level with the eyes of the operator.

The galvanometer is mounted on a wooden block, resting in sand, in a metal cylinder 18 inches in diameter which rests on the cement floor, thus reducing to a minimum the jarring of the galvanometer. The lamp for the galvanometer mirror is a 15-watt bulb, 110 volt, adjustable in a metal cylinder. The mirror reflects a bright image upon the ground-glass millimeter scale six and one-half feet back, and above the observer's table.

This galvanometer can be put into circuit with the resistance thermometers in the chamber, and with slide-wire bridge, by means of switches

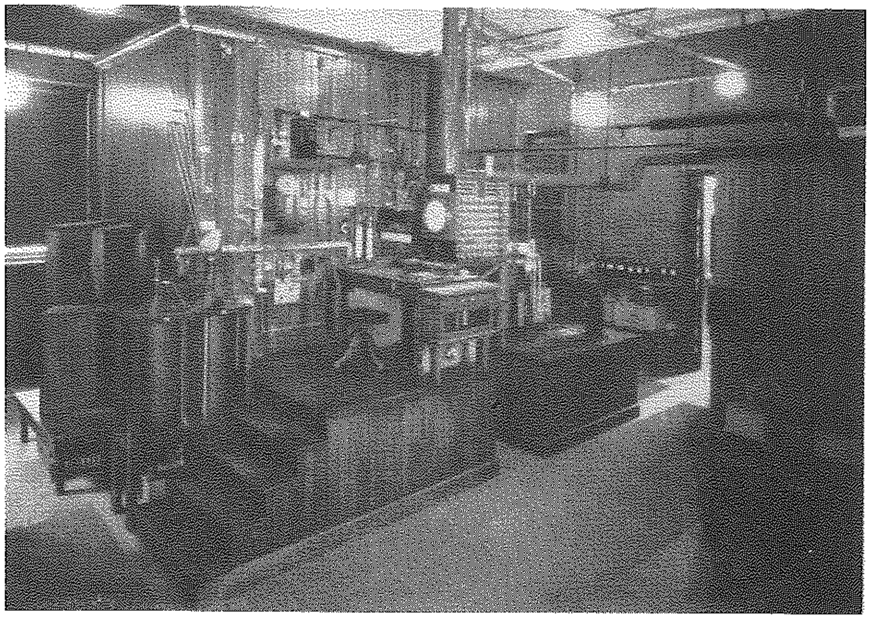

FIG. 25. GENERAL VIEW OF THE RESPIRATION CALORIMETER AND ACCESSORY EQUIPMENT

on the observer's table. Also it can be put in circuit with any one of the several thermocouple circuits in the dead-air spaces, or with the thermocouples between the ingoing and the outcoming air currents. Thus it is used to determine the temperature of the air inside the chamber, and of the copper wall itself, and to determine which sections of the air-spaces require heating or cooling.

Hanging from the absorber shield in the chamber, in view through the window of the observer, is a thermometer graduated in tenths of a degree. This thermometer, which gives the temperature of the air in the chamber, is read every 30 minutes.

At the observer's table the operator records six readings every four minutes, on printed forms. These readings, in order of taking, are as follows:

Outcoming water thermometer.
Ingoing water thermometer.
Temperature of air in chamber (by resistance thermometer).
Condition of first air-space, relative to wall on inside of chamber.
Condition of second air-space, relative to first air-space.
Condition of ingoing air, relative to outcoming air.

Other readings are made, but not recorded, at times in between the

sets of 4-minute readings, to trace the course of the temperature regulation.

The experimental work is timed by a master-clock, provided with a self-winding regulator movement, actuated by a 6-volt direct current. This master-clock operates a secondary clock conveniently placed for observation at the control table, and also a program machine, which gives signals denoting time for the instrumental readings. Thus, every four minutes a light flashes directly in front of the operator at the control table, indicating the time to begin taking a series of readings. Every half-hour a bell rings to indicate to the floor operator the time to begin a series of observations and duties in relation to various instruments other than those at the observer's table, especially with the barometer, the ventilating pump, the air-sample meters, the cooling-water meters, the tube furnace, and the brine tank.

In order to test the accuracy of the respiration calorimeter a known quantity of alcohol is burned, in a special lamp, inside the chamber, and the heat and gaseous products of combustion are measured. The experimental error of these alcohol tests has been found, by comparison with the theoretical values, to be, as a rule, less than 1.0 per cent.

Status of the Respiration Calorimeter as an Instrument of Nutritional Research

The respiration calorimeter for the larger farm animals, at The Pennsylvania State College, has proved to be a highly accurate and dependable instrument for the measurement of heat production. Through its use, principles have been established which are of great value as contributing to a correct background of understanding in nutritional research. For example, the demonstration that food energy is utilized at different rates of efficiency (1) for maintaining the animal, (2) for milk production, and (3) for body increase, and the establishment of these different rates, has been accomplished with the aid of this calorimeter.

The respiration calorimeter also has supplied evidence on the explanation of the relationship between the quantity of food eaten and the heat-loss, which is not a simple, direct proportion, but is expressed by a reversed curve. This is exceedingly important, especially as it shows (1) that nutritive values per unit of rations differ with the quantity of food eaten, (2) that the most practicable measure of the net energy requirement for maintenance is the directly determined heat production of fast, and (3) that the logical base value for determining the energy expense of utilization of food for body increase is the heat production at the point of energy equilibrium.

Furthermore, the respiration calorimeter has contributed extensively to the understanding that any deficiency of any essential nutrient must eventually affect the utilization of the energy of a ration and, consequently, to the establishment of the Law of Maximum Normal Nutritive Value. This signifies, in relation to studies of nutritive principles, that the rations compared must be complete, perfect and sufficient in all characteristics except the single one upon which evidence is sought.

It has not been found practicable, by means of the respiration calorimeter, or by any other means, to determine fundamentally significant energy values of individual foodstuffs, in general, for the reason that such values are much affected by the combinations in which foodstuffs are used; but the method of respiration calorimetry has proved highly serviceable in the determination of the most significant energy values of rations, as such.

The greater part of the equipment which has been built during recent years for the study of the energy metabolism of the larger farm animals has been of the nature of respiration chambers, providing for only the indirect measurement of heat production. Such facilities have the advantages of less expensive construction, and greater ease and economy of operation; but the disadvantage of not providing for as complete confirmation of the results as may be obtained by the use of the respiration calorimeter.

Animal feeding researches of comparatively crude character frequently involve as large expenditures as those involved in direct calorimetry. This method is not inordinately expensive for the establishment of principles of nutrition. The function of the respiration calorimeter, and of the respiration chamber as well, is primarily fundamental research, and not the solution of the every-day problems of practical animal production.

While there are in existence several respiration chambers, for indirect calorimetric research with cattle, the respiration calorimeter of The Pennsylvania State College is unique. It is the only apparatus in the world, of the size required for work with cattle, which measures energy directly.

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