Mukherjee, R. (1946). Studies of protein metabolism in relation to cattle nutrition. Thesis, University of Dacca.
Murlin, J. R., Edwards, L. E., Hawley, E. E. & Clark, L. C. (1946). *J. Nutrit.* **31**, 533.
Palmer, W. W., Means, J. H. & Gamble, J. L. (1914). *J. biol. Chem.* **19**, 239.
Rojas, J., Schweigert, B. S. & Rupel, I. W. (1948). *J. Dairy Sci.* **31**, 81.
Saxon, G. J. (1914). *J. biol. Chem.* **1**, 131.
Schneider, B. H. (1934). *Biochem. J.* **28**, 360.
Schneider, B. H. (1935). *J. biol. Chem.* **109**, 249.
Schneider, B. H. (1947). *Feeds of the World, their Digestibility and Composition.* University of West Virginia Agricultural Experiment Station.
Schoenheimer, R. & Rittenberg, D. (1940). *Physiol. Rev.* **20**, 218.
Smuts, D. B. (1935). *J. Nutrit.* **9**, 403.
Steenbock, H., Nelson, V. E. & Hart, E. B. (1915). *Res. Bull. Wis. agric. Exp. Sta.* no. 36.
Swanson, E. W. & Herman, H. A. (1943). *Res. Bull. Mo. agric. Exp. Sta.* no. 372.
Terroine, E. F. & Sorg-Matter, H. (1927). *Arch. int. Physiol.* **29**, 121.
Thomas, K. (1909). *Arch. Anat. Physiol., Lpz., Physiol. Abt.* p. 219.
Treichler, R. (1939). The relationship between basal metabolism and endogenous nitrogen metabolism. Thesis, University of Illinois.
Van Slyke, D. D. & Cullen, G. E. (1910). *J. biol. Chem.* **24**, 117.
Wiese, A. C., Johnson, B. C., Mitchell, H. H. & Nevens, W. B. (1947). *J. Dairy Sci.* **30**, 87.
Young, E. G. & Conway, C. F. (1942). *J. biol. Chem.* **142**, 839.

The Nutrition of the Young Ayrshire Calf

2. A Spirometer for the Determination of the Respiratory Exchange of the Calf

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(*Received* 17 *July* 1950)

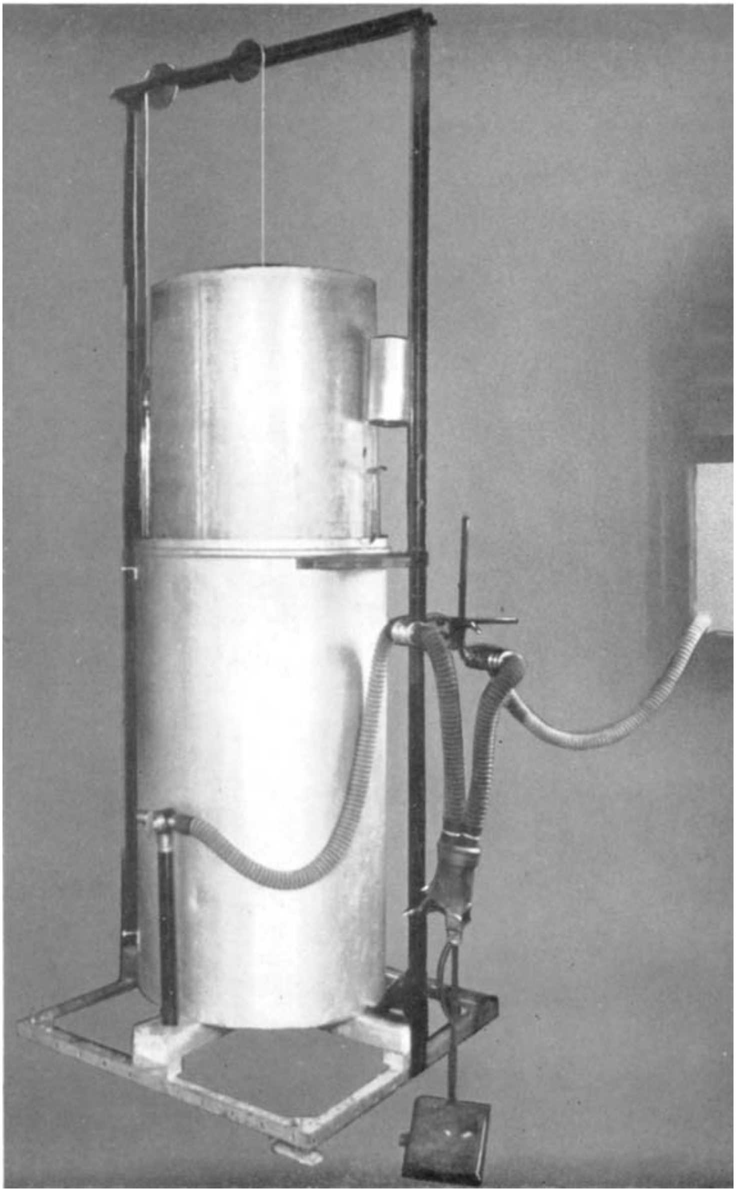
Determination of the energy exchange of farm animals by methods involving the principle of indirect calorimetry presents a number of technical difficulties. These are mostly due to the higher rate of lung ventilation in farm animals than in man. In cattle and sheep the minute volume of the respiration increases with increasing environmental temperature since in these species loss of water vapour from the respiratory passages is an extremely important channel of heat emission. With young cattle of the same weight as man, low environmental temperatures are associated with minute volumes of approximately 8–10 l., values quite comparable to those recorded for man, but at environmental temperatures approaching the animal's body temperature, values of over 25 l. may be obtained. Methods of indirect calorimetry involving the use of the Douglas bag or of the Tissot spirometer have never been popular in studies of energy metabolism in farm animals (Orr & Magee, 1923) since the large volumes of expired air soon fill the apparatus, and most of the work in this field has been conducted with large respiration chambers through which a measured stream of air is passed. Such instruments are expensive and cumbersome in use. Brody (1945), however, has devised a closed circuit method for determining the oxygen consumption, and hence the energy exchange, of animals varying in size from lambs to large steers. This method has many advantages in adaptability and ease of use. It has also decided disadvantages. Firstly, no estimate of the respiratory quotient is obtained; secondly, the carbon-dioxide absorbent causes some considerable resistance to the animal's respiration; thirdly, methane and hydrogen accumulate in the bell giving an underestimation of the true oxygen consumption, and lastly, the periods of time during which the determination is made tend to be rather too short for maximal accuracy. The absence of an estimate of the carbon-dioxide production and hence of the R.Q. is an obvious disadvantage though the error involved is in fact small. Analysis of the residual gas in the bell gives a valid estimate of the methane and hydrogen error. It was thought, however, that direct analysis of expired air, collected and measured over long periods of time, would be a more reliable method to use in studies on calf nutrition, and for this reason a very large spirometer has been built making possible accurate determinations both of oxygen consumption and of carbon-dioxide production over periods of 30–45 min.

EXPERIMENTAL

Construction of spirometer

Fig. 1 shows an elevation of the spirometer from which the general dimensions can be obtained, and Pl. 1 shows the instrument with mask and rubber-tubing connexions attached. The base consists of an angle-iron and wood frame which can be levelled by means of levelling screws (*H*) at each corner. The frame (*N*) carrying the pulleys (*G*) is also constructed of angle iron, and, for added rigidity, is stayed to the top of the outer wall of the galvanized iron tank. The main assembly consists of a special water tank and a light bell. The former is made of two tanks, the inner one being closed at the top and completely sealed. This allows a water space of 2 in. between the walls of the inner and outer tank in which the bell is free to rise or fall. These main tanks are constructed of 20 s.w.g. iron and were galvanized after assembly to prevent rust. Two 1 in. bore pipes pass through the top of the inner tank and can be connected through low resistance taps (*A*, *B*) of 1 in. bore to one-way valves and a face mask. These pipes are fitted with drainage cocks (*L*) at their lowest level since water vapour from the air expired by the animals tends to condense in them. The bell (*C*) is constructed of 18 s.w.g. aluminium sheeting and is lightly wired at the base to ensure rigidity. The bell is suspended by a thin cord which passes over two pulleys (*G*) mounted on ball races and is attached to the top of a brass tube (*M*) screwed into the centre of the top of the bell. This tube acts as a guard for a thermometer and is, of course, air-tight.

The correct counterpoising of the spirometer bell presented some difficulties since in such a large instrument it was not practicable to adopt the usual principle of concentric pulleys to compensate for the apparent decrease in weight of the bell when immersed. Nor was it possible to use a heavy chain instead of a light cord to compensate for this decrease in weight. A modification of the rigid automatic siphon tube of Tissot's (1904) original instrument was therefore devised. This consisted of a flexible levelling device and has proved extremely successful. The counterpoise weight (*F*)



General view of the spirometer

was made from a copper tube and a glass tube, the internal cross-sectional area of which was calculated to be equivalent to the cross-sectional area of the aluminium metal of the

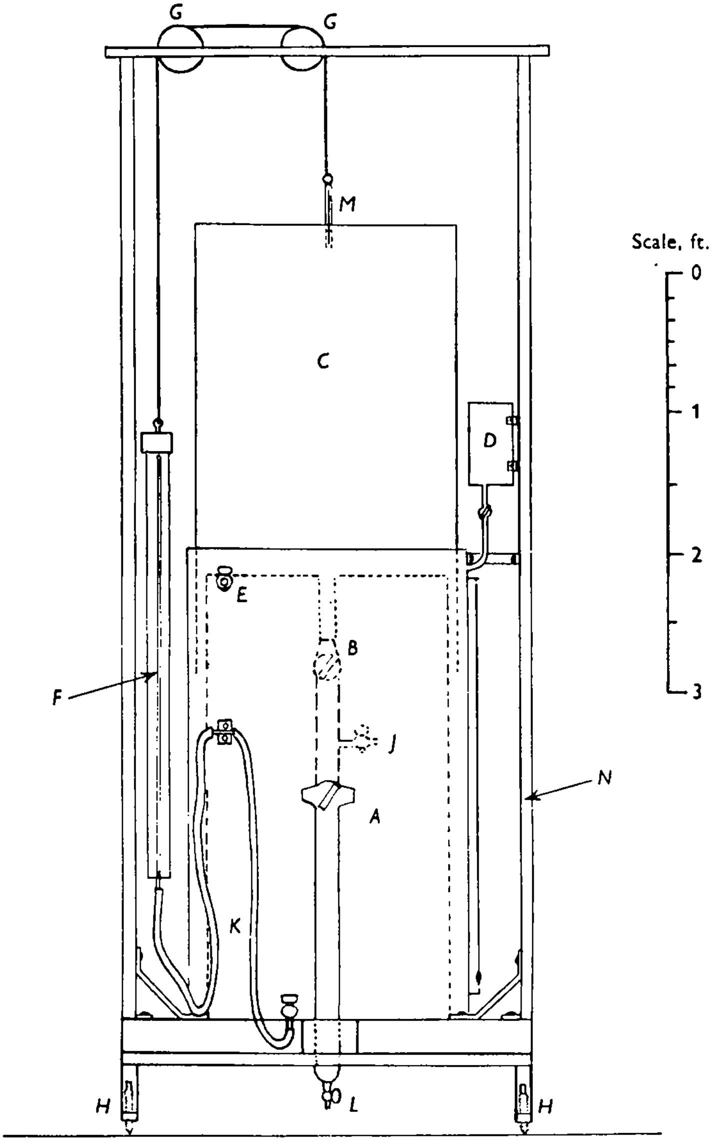


Fig. 1. Elevation of spirometer showing counterpoise device. *A*, ingoing-air two way stopcock and pipe; *B*, rinsing stopcock and pipe; *C*, aluminium bell; *D*, levelling device for water level in main tanks; *E*, overflow tap used in conjunction with *D* to maintain water level; *F*, counterpoise-siphon weight; *G*, ball-bearing pulleys; *H*, levelling screws; *J*, sampling stopcock; *K*, rubber-tubing siphon; *L*, drain cocks for inlet and rinsing tubes; *M*, thermometer and thermometer housing; *N*, framework.

bell multiplied by its specific gravity. When the bell rises 1 cm., sufficient water is automatically siphoned by a rubber tube (*K*) attached to the tank into the counterpoise weight to compensate for the apparent increase in the weight of the bell. The level of water is maintained constant in the tank by means of a constant overflow device (*D*) which is started at the commencement of a determination. The water level in the glass limb of the counterpoise weight is used to measure the gas volume, displacement of the counterpoise being exactly equivalent to displacement of the bell. The success of this method is shown by the absence of resistance to the respiration of the animal, however much expired air has been accumulated in the bell. There is a small inertia attached to the instrument but this is a negligible factor compared with the resistance of the one-way rubber flutter valves which are employed. A maximum of 220 l. of expired air may be collected in the bell.

Procedure

The calf is confined in a pen in the lying position and a face mask made of sheet rubber is attached and sealed on with petroleum jelly. By turning the two-way cock the expired air is diverted to the spirometer, which is allowed to fill for a period of 5 min. Tap *A* (Fig. 1) is then turned to divert the expired air to the room, a weight is placed on the bell and the expired air expelled by turning tap *B*. This procedure, which rinses gas from previous determinations out of the bell and connecting pipes, is carried out three times. The water level in the counterpoise weight is then noted, tap *A* turned and expired air collected for a period of 30 min. when it is again diverted to the room. The difference in water level in the counterpoise is then read and the temperature of the gas and the barometric pressure are recorded. A sample of the air in the bell is taken and analysed for carbon dioxide and oxygen. The amount of carbon dioxide in such samples ranges from 2 to 5 % with corresponding decrements of oxygen. Calculations of the inspired air volume, the oxygen consumption and carbon-dioxide production are made according to the methods employed in human physiology. Heat production is calculated from the oxygen consumption and R.Q. using Zuntz & Schumburg's (1901) tables.

Under these conditions, where a 15 min. period is used to rinse the apparatus, the calf soon becomes adjusted to the abnormal conditions. Slight struggling often occurs during the first 5–10 min. but by that time the calf has generally made itself comfortable. One disadvantage is that in the normal resting position the calf turns its head towards its flank and lies in a curled up position. A mask attached to its face thus tends to occlude the tubes leading to the one-way valves, and so only limited head movement is allowed by placing a pillow under and on either side of the neck. A period of training does not appear necessary, since, especially during the first few days of life, calves are not highly excitable animals.

Accuracy of the procedure

The errors associated with the determination, including instrumental and analytical errors as well as any real variation in the oxygen consumption of the animal in duplicate runs, have proved small. Analysis of variance of results of duplicate determinations resulted in a standard deviation of ± 1·5 Cal./kg. body-weight/24 hr. or ± 2·9 % of the determined heat production.

SUMMARY

Apparatus and technique for the determination of the oxygen consumption and of the carbon-dioxide production of the calf during periods of 30 min. are described. The apparatus is based on that of Tissot (1904), the chief modifications being the considerable increase in its size and the inclusion of a flexible counterpoise for the bell.

REFERENCES

Brody, S. (1945). *Bioenergetics and Growth.* New York: Reinhold Publishing Corporation.
Orr, J. B. & Magee, H. E. (1923). *J. agric. Sci.* **13**, 447.
Tissot, J. (1904). *J. Physiol. Path. gén.* **6**, 688.
Zuntz, N. & Schumburg, H. (1901). *Studien zu einer Physiologie des Marsches*, p. 361. Berlin.

The Nutrition of the Young Ayrshire Calf

3. The Metabolism of the Calf during Starvation and Subsequent Realimentation

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When a calf is affected by acute infantile diarrhoea, 'scouring', there is a marked fall in the amount of nutrients it absorbs from its digestive tract. This is sufficient to cause such negative nitrogen and energy balances that in many severe cases the calf is very close to a state of complete inanition. In farm practice a common and effective method of controlling this type of diarrhoea is to substitute boiled water for the normal milk allowance until the faeces become normal in appearance and then to commence realimentation very slowly. Such a method of control has the effect of substituting complete inanition for the partial inanition that results from diarrhoea. It is of some interest therefore, to study the metabolism of the calf during periods of starvation, and this paper is concerned with experiments designed to study nitrogen, sulphur, energy and mineral metabolism during short periods of starvation.

Much has been published on the effect of starvation on mature animals, especially man, but comparatively little study has been made of the effect of starvation on the metabolism of the really young animal. In the mature bovine, energy metabolism has been studied by Braman (1924), Benedict & Ritzman (1927) and Ritzman & Benedict (1938), and extensive studies of the N metabolism of the fasting steer or cow have been made by Carpenter (1927), Hutchinson & Morris (1936*a*, *b*) and Morris & Ray (1939). The energy metabolism of smaller mature ruminants, more especially sheep, has been studied in detail by Benedict & Ritzman (1931), Brody (1932), Ritzman, Washburn & Benedict (1936), Blaxter (1948) and Marston (1948). Little information, however, is