# DETERMINATION OF SPECIFIC GRAVITY OF LIVE HOGS BY A MODIFICATION OF THE AIR DISPLACEMENT AND HELIUM DILUTION PROCEDURES

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ABSTRACT

DETERMINATION OF SPECIFIC GRAVITY OF LIVE HOGS BY A MODIFICATION OF THE AIR DISPLACEMENT AND HELIUM DILUTION PROCEDURES

by Veldon Max Hix

The existing apparatus for measuring body volume by air displacement and helium dilution was modified by adding two additional chambers similar to those previously used. The addition of these chambers resulted in two identical systems; one a measuring system and the other a reference system. The subject to be measured was placed in the measuring system, while an inert reference of approximately the same volume as the subject was placed in the reference system. By means of this arrangement, the relatively small difference in volume between the subject and the reference was measured instead of the total volume of the subject.

The air displacement procedure utilized two standard chambers for reducing the pressure in the corresponding large chambers. In making a determination, a partial vacuum was drawn on the standard chambers. They were then connected to the large chambers, one of which contained the subject, and the other the reference. The difference in the final pressure between the two large chambers was measured using a U-tube manometer. The difference in pressure, when corrected for the temperature in the chambers, was used to calculate the difference in volume between the subject and the reference.

In the helium dilution method, a measured quantity of helium was injected into the subject and reference chambers. The difference in helium concentration between the two chambers was then measured by means

of a thermal conductivity cell attached to a recording potentiometer. Since the helium concentration in each chamber was proportional to the volume of the object in the corresponding chamber, the difference in helium concentration was proportional to the difference in volume of the subject and the reference. The apparatus was first calibrated with inert volumes in each chamber and then the live animal determinations were made.

The specific gravity of 24 live, anesthesized hogs was determined by the air displacement and helium dilution procedures. The specific gravity values obtained by air displacement varied from 0.9242 to 1.1253 with a mean of 0.9829. The values obtained by helium dilution ranged from 0.9856 to 1.0258 with a mean of 1.0005. A highly significant correlation coefficient of 0.638 was obtained between the specific gravity values determined by air displacement and those obtained by helium dilution. Specific gravity values determined by air displacement were significantly correlated ($r = 0.649$) with theoretical density values computed from the chemical analysis data. Neither the specific gravity values determined by air displacement nor those determined by helium dilution were significantly correlated with percentages of moisture, ether extract or protein as determined by chemical analysis. However, specific gravity values determined by both methods were significantly correlated with percent ash. Correlation analysis showed that although neither method of measuring body volume was reliable, the air displacement technique was more indicative of composition than the helium dilution procedure.

The major source of error with both the air displacement and helium dilution procedures was due to differences in relative humidity between

the subject and reference chambers and to changes in relative humidity within the subject chamber. This error was especially important because it occurred twice in the calculation of body volume with both methods -- once in the determination of empty chamber volumes and again in the measurement of the volume of the subject. Additional errors may have occurred as a result of the inability to accurately read pressure and temperature. Other errors may have occurred with the helium dilution procedure as a result of the accumulation of carbon dioxide and depletion of oxygen within the subject chamber.

The average chemical composition of the hogs used in this study was 52.00 percent moisture, 30.56 percent ether extract, 15.21 percent protein and 2.57 percent ash. The dressed carcasses contained an average of 68.46 percent of the total moisture in the whole animal, 90.06 percent of the ether extract, 76.50 percent of the protein and 77.87 percent of the ash. Results of the chemical determinations indicated that average values could be used for the analysis of the blood and hair without introducing a significant amount of error.

Of the cuts from the carcass (shoulder, loin, side and ham), the composition of the shoulder and ham was most closely related to the chemical composition of the whole animal. Regression equations were computed for predicting the composition of the whole animal from the composition of the shoulder and ham. A comparison of the correlation coefficients and the standard errors of regression for both the shoulder and the ham indicated the shoulder to be slightly more indicative of composition.

The magnitude of the standard error of the estimate, however, indicates that a substantial amount of error would be involved in predicting the composition of the whole animal from either the shoulder or the ham.

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By

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# INTRODUCTION

## Importance of Body Composition Studies

Since Robertson (1757) reported bribing ten "middling sized" men to submerge themselves in a tank of water in an attempt to measure their volume, researchers have been attempting to devise new ways in which to assess the body composition of living subjects. Although Robertson (1757) reported poor results and complained that the men seemed more interested in the bribe than in the experiment, this study initiated continuous effort to devise means for measuring body composition.

From the standpoint of human subjects, knowledge of body composition could be useful in several ways. Information on changes in composition could be used to assess the adequacy of different nutritional regimes, both in the treatment of deficiencies and in nutritional experiments. Body composition data would be useful from a clinical standpoint in the evaluation of pathological conditions, and to determine the effects of various treatments on such conditions. In summary, information on body composition would be useful for assessing the effect and importance of any conditions which might affect the fat, protein, water, and mineral components of the body.

In animals, body composition data would also be useful in assessing the results of nutritional studies on the adequacy of diets. Information on body composition could also be utilized in the selection of breeding stock for increased muscling, and in evaluation of market animals.

## Experimental Objectives

The primary objective of this study was to modify the existing apparatus for determining body volume by air displacement and helium dilution. It was hoped that modification of the apparatus would improve the accuracy so that these methods could be used to predict the body composition of live hogs. The second objective was to determine by chemical analysis, the relationship between body composition and specific gravity, and the interrelationships between chemical components of various compartments of the hog carcass.

## REVIEW OF LITERATURE

### The Relationship of Specific Gravity or Density to Body Composition

#### History of specific gravity

For some 200 years, scientists have been attempting to predict the body composition of animals and humans from specific gravity or density measurements. These attempts have been based primarily on the Archimedian principle which states that a solid object immersed in water will be buoyed up by a force equal to the weight of water displaced. Using water as a standard, specific gravity can be defined as the ratio of the weight of a given volume of a substance to the weight of the same volume of water. Some workers have also used the density of the body, which was defined simply as mass or weight per unit volume. Behnke (1961) stated that specific gravity was equal to the weight of an object in air divided by its weight in air minus its weight in water. Density could then be obtained by multiplying the specific gravity of the object by the density of the water displaced. However, as different methods were utilized, the two terms were used interchangeably and now are both generally referred to as weight per unit volume.

The specific gravity method of determining body composition is based upon the fact that the different body constituents vary in their density. Table 1 shows the densities of different tissues from several species, including human beings, which have been reported by various workers. In general, it may be stated that the densities of the three main components of the mammalian body, adipose tissue, lean tissue, and mineral

are 0.9, 1.1, 3.0, respectively. Since variation in density exists, it is theoretically possible to determine the relative amount of each body component from the measurement of whole body density. This principle has been used by a large number of workers (Rathbun et al., 1945; Morales et al., 1945; Kraybill et al., 1953; Pitts, 1956; Behnke et al., 1942; Brozek, 1946; Siri, 1953) in attempting to accurately predict the relative amounts of the fat, lean, and bone compartments of the animal or human body.

Table 1. Tissue density of various species.

| Investigator | Species | Tissue | Density |
|---|---|---|---|
| Keys et al. (1953) | Human | Fat | 0.9007 |
| | Human | Cell matter | 1.057 |
| | Human | Extracellular fluid | 1.002 |
| | Human | Bone mineral | 3.000 |
| Fidanza et al. (1953) | Pig | Fat | 0.9006 |
| | Rat | Fat | 0.9038 |
| | Guinea pig | Fat | 0.9042 |
| | Steer | Fat | 0.9000 |
| | Sheep | Fat | 0.9003 |
| | Human | Fat | 0.9000 |
| Kraybill et al. (1952, 1953) | Cattle | Fat | 0.92 |
| | Cattle | Muscle | 1.06 |
| | Cattle | Bone | 1.50 |
| | Swine | Fat | 0.914 |
| | Swine | Lean | 1.100 |
| Kirton & Barton (1958) | Sheep | Fat | 0.9223 |
| | Sheep | Fat-free carcass | 1.112 |

Animal Studies

Early studies on the composition of the animal body were made by Murray (1922) and Moulton (1923). These workers studied the relationship between fat and water in the body and also the effect of age upon the various constituents. Murray (1922) stated that the average composition of the whole body at any age could be determined, if the live weight and percent fat were known. Moulton (1923) concluded that water content decreased while protein and mineral content increased until the animal reached maturity, and thereafter, they all remained fairly constant.

Following the reports of Murray (1922) and Moulton (1923), Rathbun and Pace (1945) and Pace and Rathbun (1945) determined the specific gravity of the eviscerated bodies of 50 male and 50 female guinea pigs by underwater weighing. They then compared the values obtained with actual fat content. They obtained correlations of 0.989 between the percent fat of the whole animal and the percent fat of the carcass, 0.962 between whole animal specific gravity and carcass specific gravity, and -.972 between percent body fat and carcass specific gravity. Results indicated that the fat content of the whole body is equivalent to that of the eviscerated carcass.

Morales et al. (1945) reported that knowledge of the density of the various tissues of the body and the ratios of muscle, skin, and nervous tissue to bone could be utilized to determine gross body composition. Using this assumption, they derived the following formula for calculating the ratio of body fat to body weight ($\frac{M_f}{W}$):

$$\frac{M_f}{W} = \frac{\frac{1 + K}{G} - \frac{Dm + KD_b}{D_b\ Dm}}{\frac{1 + K}{D_f} - \frac{Dm + KD_b}{D_b\ Dm}} \qquad (1)$$

where:

K = total constant fractions for muscle, skin and nervous tissue

G = average body density

Dm = density of muscle

$D_b$ = density of bone

$D_f$ = density of fat

This formula was then used in deriving the following equations for calculating percent fat from specific gravity for the eviscerated carcass and whole body, respectively:

$$\% \text{ fat} = 100 \left(\frac{5.362}{\text{Sp.Gr.}} - 4.880\right) \qquad (2)$$

$$\% \text{ fat} = 100 \left(\frac{5.501}{\text{Sp.Gr.}} - 5.031\right) \qquad (3)$$

Pace *et al.* (1945) also studied the body water of guinea pigs and derived the following formulas for calculating body water from specific gravity, and body fat from body water:

$$\% \text{ water} = 100 \left(4.424 - \frac{4.061}{\text{Sp.Gr.}}\right) \qquad (4)$$

$$\% \text{ fat} = 100 - \frac{\% \text{ water}}{.732} \qquad (5)$$

This work was corroborated by Pitts (1956) with guinea pigs and Da Costa and Clayton (1950) with the albino rat. These workers obtained

high correlations between specific gravity and percent fat and between specific gravity and percent body water. They concluded that specific gravity measurements on eviscerated animals were a good indication of gross carcass composition.

More recently, specific gravity determinations have been applied to larger animals. Brown et al. (1951) measured the specific gravity of 66 hog carcasses and found an average value of 1.027. The individual specific gravity values were correlated with average backfat thickness, percent ether extract, percent moisture, percent protein and percent ash with correlation coefficients of -.49, -.75, 0.68, 0.65 and 0.72, respectively. Specific gravity indicated carcass composition as accurately as the measurement of percentage of lean cuts or percentage of fat cuts.

Whiteman et al. (1953) in a related study obtained high correlations between carcass specific gravity and specific gravity of the ham, the fat and skin, the lean, and the bone, as well as between carcass specific gravity and the percentages of lean, bone, fat and skin.

Kraybill et al. (1952) measured the specific gravity of 30 cattle carcasses and reported the average to be 1.045, with a range of 1.017 to 1.070. The fat content of these animals ranged from 13.6 to 39.5 percent of body weight with a mean of 25.1 percent. Highly significant correlations were obtained between carcass specific gravity and percent fat, percent water, and whole animal specific gravity.

Kraybill et al. (1953) also made a similar study with swine and obtained comparable results. They developed equations patterned after

those of Rathbun and Pace (1945), relating fat and water content to specific gravity as shown below:

$$\% \text{ body water} = 100 \left(4.400 - \frac{4.021}{\text{Sp.Gr.}}\right) \quad (6)$$

$$\% \text{ body fat} = 100 \left(\frac{5.405}{\text{Sp.Gr.}} - 4.917\right) \quad (7)$$

Gnaedinger et al. (1962) chemically analyzed the bodies of 24 hogs and used the following equation of Kraybill (1953) to compute theoretical density values:

$$G = \frac{M}{\frac{F}{D_f} + \frac{M - F}{D_l}} \quad (8)$$

where:

G = whole body density

M = weight of whole body

F = weight of body fat

$D_f$ = density of pork fat = 0.914

$D_l$ = density of lean body mass = 1.1

The calculated values ranged from 1.015 to 1.042 with a mean of 1.0312. These values were not significantly correlated with live animal specific gravity values as estimated by air displacement and helium dilution procedures.

Lynch and Wellington (1963) determined the density of 20 live, anesthesized hogs by a modified underwater weighing procedure, and compared the values obtained with various carcass components determined by

chemical analysis. Highly significant correlations were obtained between live animal density and percent lean body mass, percent lean carcass mass, percent whole body fat, percent carcass fat, average backfat thickness, and percent whole body water, with values of 0.694, 0.707, -.707, -.735, -.788, and 0.635, respectively. This study, along with those of Gnaedinger (1962) and Kraybill (1953) has given valuable information on the relationship of specific gravity to body composition in swine.

Various other workers (Pearson et al., 1956; Price et al., 1957; Orme et al., 1958; Kirton et al., 1958; and Kline et al., 1955) have carried out similar studies relating the specific gravity of the whole carcass or of certain cuts to the percentages of fat, lean, and bone or to the percentages of various cuts. In general, results of these studies indicate that specific gravity measurements provide a good estimate of the relative amounts of fat and lean. Since this is true, it is logical to assume that specific gravity of the live animal also should be a good indication of carcass composition.

Studies With Human Subjects

In 1933, Boyd presented a comprehensive review of the previous work on specific gravity measurements with human subjects and statistically analyzed the results. The major conclusion gained from the analysis was that obesity decreased specific gravity.

In the early 1940's U. S. Naval researchers (Welham and Behnke, 1942; Behnke et al., 1942) did a great deal of work with human subjects

in attempting to relate specific gravity values with body build. Welham and Behnke (1942), after determining the specific gravity of a large number of adult men by underwater weighing, stated that low values for specific gravity indicated obesity, whereas high values indicated leanness. They further proposed a specific gravity value of 1.060 as the borderline between leanness and obesity. Behnke et al. (1942) further stated that the human body can be divided into two parts; a fat-free portion of more or less constant composition and a fatty portion of variable quantity. They also suggested that the fatty portion is the major factor affecting the specific gravity of the whole body.

Messinger and Steele (1949) determined the specific gravity of 9 individuals by underwater weighing and observed an inverse relationship between body water and body fat. They concluded that the proportion of water in the body is highly variable, unless it is expressed in terms of fat-free tissue.

Brozek (1946) determined the specific gravity of 34 young men by underwater weighing and derived the following equation for computing percent fat from specific gravity:

$$\% \text{ fat} = 100 \left(\frac{5.548}{\text{Sp.Gr.}} - 5.044\right) \qquad (9)$$

Osserman et al. (1950) determined the specific gravity by underwater weighing and total body water by antipyrine dilution of 81 navy men. They then used the equation of Brozek (equation 9) to calculate the body fat and derived the following equation for determining body water:

$$\% \text{ water} = 100\ (4.317 - \frac{3.960}{\text{Sp.Gr.}}) \qquad (10)$$

These workers stated that the proportion of water in the lean body mass is constant for normal men (71.8%) with a standard error of ±0.33 percent.

Siri (1953) used the helium dilution procedure to determine the body volume of a large number of human subjects. He also determined the total body water on these subjects and derived the following formula relating body volume and body water to total fat:

$$\text{fat} = 2.66 \times \text{volume} - 0.78\ \text{water} - 1.9\ \text{weight} \qquad (11)$$

More recently, Brozek et al. (1963), on the basis of previous work using human subjects proposed the establishment of a "reference body" with a density of 1.064 and a fat content of 15.3 percent. On this basis, the human body could be divided into two parts; the "reference body" and the remainder, which they termed "obesity tissue".

However, as Wedgewood (1963) pointed out, it should be recognized that the composition of the lean body is changing throughout life. He stated that with the technological developments of the past few years, we should be able to directly measure the changing patterns of body composition through growth, maturation and aging without making assumptions for constancy.

It would appear from the statements of these authors that more research will be necessary in the area of body composition, especially from the standpoint of methodology, before the exact relationships between

the various constituents of the body are known. This is true for animals, particularly meat animals, as well as for human beings.

Determination of Specific Gravity by Air Displacement

The air displacement method for determining body volume and calculating specific gravity has been studied for some time. Spivak (1915), in reviewing this subject, indicates that Jaeger (1883) first used this technique, while attempting to find a relationship between body density and health. He used an apparatus called a Kopp volumeter, which was constructed in such a way that its volume could be changed by a known amount. The volume of an unknown object or subject was determined by placing it in the volumeter at a known initial volume (V) and at atmospheric pressure (P). The volume was then decreased by a known amount ($\triangle V$), causing a measured pressure change ($\triangle P$). The body volume of the subject ($V_o$) was calculated from the following equation:

$$V_o = \frac{(V - \triangle V)\ VP}{(P + \triangle P)} \qquad (12)$$

This procedure was reported to be quite accurate for inert objects, but less so with live subjects due to errors occurring as a result of changes in temperature and pressure, which were caused by the breathing of the subject.

Pfaundler (1916) constructed a felt-insulated, brass chamber, which he used to measure the volume of child cadavers. The body was placed inside the chamber immediately after death, and the measurement was not made until temperature equilibrium was reached. Body volume was deter-

mined after a positive pressure change was introduced, and again after introduction of a negative pressure. The average of these two values was taken as body volume. The major disadvantage of this procedure was that it required over 1 1/2 hours to make a determination. For this reason, it was impractical for live subjects. Values obtained by this method were not comparable with similar values obtained by water displacement, where the average of 16 determinations was 0.988 for water displacement as compared to 1.143 for air displacement.

Pfleiderer (1929), constructed an apparatus to measure body volume by the use of pressures greater than atmospheric. This apparatus consisted of two chambers, one containing the subject and the other a standard to which water could be added, thus forcing air into the subject chamber. The body volume of the subject was computed from the difference in pressure in the subject chamber before and after introduction of the compressed air. Using this procedure, Pfleiderer (1929) claimed to be able to compute body volume with a mean error of 1 to 2 percent. He stated that the major sources of error were due to inaccuracies in reading the manometer and fluctuations in pressure due to gaseous exchange.

Kohlrausch (1929) used a modified version of Pfleiderer's method to measure the body volume of dogs. He injected air into the chamber at atmospheric pressure instead of using compressed air. Body volumes of 4 dogs were obtained by this method and compared with their corresponding fat contents as determined by chemical analysis. However, no correlations were reported. The actual precision of measurement was

not given, but the method was reported to be highly accurate for determining the volume of inert objects.

Bohnenkamp and Schmäh (1931) measured the body volume of human subjects by a procedure similar to that of Kohlrausch (1929), except they used pure oxygen instead of air. The oxygen was injected into the chamber, and body volume was calculated from pressure differences determined with and without the subject in the chamber. According to these investigators, the volume of gas in the lungs and intestines was not included in the volume measurement. Temperature corrections were made, but the chamber was kept saturated so that corrections for relative humidity were not necessary. Average specific gravity values were 1.096 for men and 1.070 for women, however, extreme values of 0.98 and 1.13 were obtained.

Noyons and Jongbloed (1935) stated that the basic principle of the method utilized by Bohnenkamp and Schmäh (1931) was correct, but criticized it as being very difficult to carry out. They stated that one must know the exact temperature, water vapor content, and oxygen consumption in order to use this method. They also stated that the procedure was impractical to carry out due to excessive calculations. With these facts in mind, Noyons and Jongbloed (1935) proposed a method of calculating body volume from the difference in weight at two different pressures. They used this procedure with cats, which were weighed first at atmospheric pressure and again under negative pressure. The difference in weight was corrected for losses due to insensible perspiration, and was then equal to the increase in weight due to the increased pressure

of air. This increase in weight gave an indication of body volume and density.

Jongbloed and Noyons (1938) later used a similar procedure with human subjects. They reported from this study that positive pressures were more comfortable than negative pressures. Results of twenty determinations on the same subject over a period of two weeks showed an average specific gravity value of 1.080 ± 0.007. The complete procedure was reported to require about 30 minutes.

The greatest difficulties in measuring volume in all the reports mentioned seem to be due to gradual changes in temperature, water vapor content, and composition of the chamber gases. With this in mind, Wedgewood and Newman (1953) and Wedgewood et al. (1953) proposed a means for imposing a sine wave of changing volume on the gradual changes due to heat, water vapor, and gaseous exchange. The project, however, was abandoned before full details of the apparatus and operation were reported.

In 1958, Liuzzo constructed an apparatus for measuring the body volume of guinea pigs. This apparatus consisted of two desiccator jars of known volume, which could be interconnected or separately connected to the atmosphere. One jar was used as a standard and was hooked to a vacuum pump so that it could be partially evacuated. In making determinations, the animal was placed in one jar and a measured negative pressure was drawn on the standard jar. The jars were then interconnected and after equilibrium was established, the pressure was read on a U-tube mercury manometer. The difference in the pressure readings before and

after interconnection of the jars was proportional to the free air space in the chamber. Body volume was calculated from the following equation:

$$V_o = V_2 - \left(\frac{P_1 - P_2}{P_2}\right) V_1 \frac{273}{273 + \Delta T} \qquad (13)$$

where:

$P_1$ = initial pressure of standard chamber

$P_2$ = pressure of system with jars interconnected

$V_1$ = volume of standard chamber

$V_2$ = volume of animal chamber

$\Delta T$ = change in temperature of standard chamber

The specific gravity values for guinea pigs calculated from body volumes determined by this method were significantly correlated with percentages of various body components (fat, water, protein and ash) as measured by chemical analysis.

The results of the previous study prompted further investigations. Gnaedinger et al. (1960, 1962, 1963) and Hix et al. (1963, 1964) conducted experiments in attempting to apply these principles to larger animals, namely swine and human beings. The apparatus consisted of a large chamber of 465 liters capacity, which was used to confine the subject, and a standard chamber having a volume of 180 liters. In this procedure, a partial vacuum of approximately 345 mm Hg was drawn on the standard chamber. This chamber was then interconnected with the subject chamber. Body volume was calculated by means of the following equation:

$$V_0 = V_2 - V_1 \frac{\frac{P_s'}{T_a'} - \frac{P_s^\circ}{T_s^\circ}}{\frac{BP}{T_a^\circ} - \frac{P_a'}{T_a'}} \qquad (14)$$

where:

$V_1$ = volume of standard chamber

$V_2$ = volume of empty subject chamber

$T_a^\circ$ = temperature of animal chamber before equalization

$T_a'$ = temperature of animal chamber after equalization

$T_s^\circ$ = temperature of standard chamber before equalization

$T_s'$ = temperature of standard chamber after equalization

$P_s^\circ$ = pressure of standard chamber before equalization

$P_s' = P_a'$ = pressure of system after equalization

BP - barometric pressure (740 mm)

Gnaedinger (1960) used the above procedure to measure the body volume of human subjects. Specific gravity values calculated from these volumes ranged from 1.045 to 1.167. Although these values were not significantly correlated with similar values obtained by underwater weighing, they appeared to be generally related to the fatness of the subject. The major difficulty encountered was reported to be due to temperature changes within the chamber.

Gnaedinger (1962) used the same air displacement procedure in an attempt to measure the specific gravity of hogs. Specific gravity values obtained ranged from 0.975 to 1.222 with a mean of 1.075. These values were not significantly correlated with gross chemical composition (fat,

water, protein and ash). The major problem associated with the procedure was reported to be the varied activity of the animals in the chamber, which caused severe fluctuations in temperature and relative humidity.

Hix et al. (1964) used the same air displacement procedure to measure the body volume of 48 human subjects. The average specific gravity value for 24 men was 1.1309, with a range of 1.2192 to 1.0611. Specific gravity values for 24 women ranged from 1.2452 to 1.0412 with an average of 1.1233. These values were highly correlated with corresponding values obtained by the helium dilution procedure ($r = 0.964$ for men and 0.912 for women). Specific gravity values obtained by the air displacement procedure were significantly correlated with the weight-height ratio in both men and women (-.54 and -.45). The major sources of error associated with this method were reported to be due to fluctuations in temperature and relative humidity and inaccuracies in reading the pressure on the manometer.

A similar study was reported by Kodama and Pace (1963). The method utilized an animal chamber (A) having a volume of 375 $cm^3$ when used with hamsters, and 600 $cm^3$ when used with rats. This chamber (A) was situated so that it could be opened into a partially evacuated chamber (B), which had a volume of 250 $cm^3$. The following equation was used for calculating body volume:

$$P = \frac{a\,x + b\,v}{x + v - h\pi r^2} \tag{15}$$

where:

P = equilibrium pressure in the system

a = initial pressure in chamber A

b = initial pressure in chamber B

v = volume of chamber B

x = volume of chamber A - volume of animal

$h \pi r^2$ = correction for shrinkage of the system due to the rise of mercury in the manometer

The principle difficulty with this method was reported to be in reading the equilibrium pressure from the manometer. The body heat of the animal caused an increased temperature within the chamber, which in turn increased the pressure. This resulted in a constant upward movement of the mercury in the manometer making it difficult to obtain consistent readings. A correlation coefficient of 0.837 was reported between specific gravity values calculated by this method and corresponding values calculated from underwater weighing of the eviscerated carcasses. Values were not reported on the relationship between whole animal specific gravity and percent body fat.

Falkner (1963) tested an apparatus designed to measure the body volume of babies by air displacement. This apparatus consisted of a subject chamber equipped with a piston, so that the volume could be changed by a known amount. The volume of the subject was then calculated from the resulting change in pressure. Preliminary studies using this apparatus with inert objects showed positive errors, varying from 5.45 cc/100 ml

to 9.5 cc/100 ml. This error was increased substantially when a heated object simulating the body temperature of a living baby was placed in the chamber. In this case, the error was 4.1 cc/ml. These workers are presently in the process of modifying the apparatus in an attempt to reduce the magnitude of error.

The latest contribution to the determination of body composition by air displacement is offered by Beeston (1965). This author has constructed an apparatus to measure the body volume of live, anesthetized sheep. This apparatus consisted mainly of a subject chamber constructed so that its volume could be changed by introducing a measured quantity of water. The water was kept separated from the animal by means of a rubber diaphragm. The body volume of the animal could then be determined from the pressure change upon addition of the water.

The specific gravity of 14 mature sheep was determined, and the values were compared with those obtained for percent body fat as measured by chemical analysis. A highly significant correlation of 0.97 was obtained. The correlation coefficient would seem to be somewhat high, since it is doubtful if body fat is actually responsible for this much variation in whole body specific gravity. However, these results are encouraging and show promise for this method.

Determination of Specific Gravity by Helium Dilution

The first report on the use of helium dilution for estimating volume was given by Walser and Stein (1953). They stated that the procedure is based on the fact that when a known volume of gas is injected into a

chamber, it will be diluted in proportion to the amount of air in the chamber, which in turn is dependent upon the amount of space occupied by the subject. Body volume can be calculated from the following relationship:

$$\text{Volume of subject} = \text{Volume of empty chamber} - \frac{\text{Volume of gas added}}{\text{Final concentration of gas}} \quad (16)$$

Walser and Stein (1953) reported that helium is useful as a diluent gas for several reasons: (1) it is inert, sparingly soluble and diffuses rapidly through air; (2) it mixes with air in the respiratory passages, thus excluding this compartment from the volume measurement; (3) it has a high thermal conductivity, and thus can be easily measured; and (4) it is not present to any appreciable extent in the atmosphere so that background interference does not occur.

Walser and Stein (1953) first used helium dilution to determine the body volume of 10 cats and compared the results with those obtained by underwater weighing of the eviscerated carcasses. Their procedure consisted of injecting a measured quantity of helium into a dessicator jar containing the subject. After allowing time for thorough mixing, a sample of air was removed and analyzed for helium on a Cambridge Analyzer.

They did not make corrections for changes in temperature and relative humidity within the chamber; however it was reported that sufficient time was allowed for thermal equilibrium to be reached. Results obtained agreed quite well with those from underwater weighing, with a mean difference in specific gravity of 0.013 between the two methods. These authors

also reported that only 4 minutes were required for 98 percent equilibration of helium with alveolar air.

The major advancement in the helium dilution procedure was made by Siri (1955). He constructed an apparatus, which he subsequently used to measure the body volume of human subjects. This apparatus consisted of a subject chamber of 413 liters in capacity, a helium metering system, and a thermal conductivity cell to measure helium concentration. The significance of the procedure lies in the fact that the apparatus was calibrated with known reference volumes, and that corrections were made for temperature of the helium and of the subject chamber.

He was able to measure the volume of inert objects with a standard deviation of ± 0.028 liters. He stated that the probable error for a single body volume measurement would be ± 0.13 liters.

Gnaedinger et al. (1963) and Hix et al. (1964) used a modification of the Siri apparatus to measure the body volume of swine and human subjects, respectively. This apparatus consisted of a subject chamber of 460 liters in capacity, a helium metering system, and a helium analyzer made up of a thermal conductivity cell with an attached power supply and recording potentiometer. Temperatures of the helium and subject chambers were measured by means of thermistors.

The design of this method required that the apparatus be calibrated between the expected extremes in volume. This was done by making several runs using standard reference volumes and noting the deflection obtained on the recorder. A plot of deflection versus helium concentration was made, and a regression equation calculated for use with live subjects.

Helium concentration was computed from the following equations:

$$C = \frac{V}{(V_c - V_i)\ \gamma + V} \tag{17}$$

where:

$V$ = volume of helium chamber

$V_c$ = volume of empty subject chamber

$V_i$ = volume of reference used

$$\gamma = \frac{T_h}{T_c} \frac{(P - p)}{P} \tag{18}$$

where:

$T_h$ = temperature of helium at time of injection

$T_c$ = temperature of subject chamber at time of mixing

$P$ = barometric pressure

$p$ = vapor pressure of water at $T_c$ and $P$

Body volume was then calculated from the following equation:

$$V_o = \frac{V_2\ R_2\ (R_1 - R_1) - V_1\ R_1\ (R_1 - R_2)}{R_o\ (R_2 - R_1)} \tag{19}$$

where:

$V_o$ = volume of subject

$V_1$ = volume of reference 1

$V_2$ = volume of reference 2

$R_o$ = observed deflection with subject in chamber

$R_1$ = computed deflection with $V_1$

$R_2$ = computed deflection with $V_2$

Gnaedinger et al. (1963) reported that specific gravity values obtained with the helium dilution procedure on hogs were related, but not significantly correlated with values obtained for various carcass components as determined by chemical analysis. They reported, however, that the helium dilution values were more indicative of composition than similar values obtained by the air displacement procedure.

The major problem associated with this method was reported to be due to the varied activity of the hogs within the chamber. This caused extreme variations in temperature, relative humidity, and composition of the gases within the chamber. The increased respiratory rate of the more active animals resulted in an abnormal buildup of carbon dioxide within the chamber, thus causing a lowering of thermal conductivity and resulted in low values for body volume.

Hix et al. (1964) computed the specific gravity of 24 men and 24 women to determine if increased accuracy could be obtained by having the subjects lie quietly in the chamber. Specific gravity values were significantly correlated with values obtained by air displacement for both men and women (0.964 and 0.912). These specific gravity values were also significantly correlated with the weight-height ratio of the subjects, with "r" values of -.57 for men and -.44 for women.

The major source of error in this study was reported to be due to a lack of precision in adjusting the current for the power supply to a constant value for each determination. Some error also occurred as a result of temperature changes within the subject chamber.

Fomon et al. (1963) also used a modification of the Siri (1955) apparatus to determine the body volume of infants. The apparatus consisted of a stainless steel chamber with a lucite hood, having a volume of 30.395 liters. Helium was introduced into the chamber by means of a gas buret. Two identical pumps circulated the sample and reference gases through a thermal conductivity cell. Soda lime and magnesium perchlorate traps served to remove carbon dioxide and water vapor from the air before it entered the thermal conductivity cell. A spirometer was used to measure the change in volume of the system as a result of alterations in temperature and the partial pressure of the gases. The apparatus was first calibrated with known references and the following equation was derived

$$K = \frac{(He)}{R - R_z} \tag{20}$$

where:

K = increase in concentration of helium in the chamber per unit of response of the recorder

R = observed response of the recorder

$R_z$ = recorder response at zero partial pressure of helium

(He) = partial pressure of helium at time of measurement

With a subject in the chamber, the helium concentration was equal to K x R. Body volume was calculated from the initial and final concentrations of helium and the volume of the chamber. The mean error of 12 determinations on known volumes was reported to be 0.42 percent.

Results of these studies show a good deal of promise for the helium dilution procedure. However, more research will be necessary to eliminate some of the problems involved if this method is to be of practical value.

## EXPERIMENTAL PROCEDURE

### Experimental Animals

Twenty four market weight hogs were obtained from the Michigan State University swine farm for use in this study. The live weight of these hogs varied from 180 to 238 lbs. No attempt was made to select these hogs as to breed or sex. The animals were taken off feed but allowed free access to water for 24 hours prior to the volume measurements. All animals were given an intramuscular injection of approximately 3 cc. of Sernalan (Phencyclidine hydrochloride, 100 mg/ml., Parke, Davis and Company) just prior to the measurements.

This injection served to immobilize the animals so that they would lie quietly in the chamber. It appeared to have no depressing effect on respiration. In almost all cases, the animals remained immobilized throughout the measurements and up to the time of slaughter, which required approximately 45 minutes.

### Determination of Body Volume by Helium Dilution

#### Apparatus

The helium dilution apparatus was adapted from the system described by Hix (1963) and modified as suggested by Giacoletto (1965). A schematic diagram of the apparatus is shown in Figure 1. Chambers 1 and 4 were round, steel tanks with air-tight baffles welded inside (Figure 2) to give inside dimensions of 16 by 30 inches and a volume of approximately

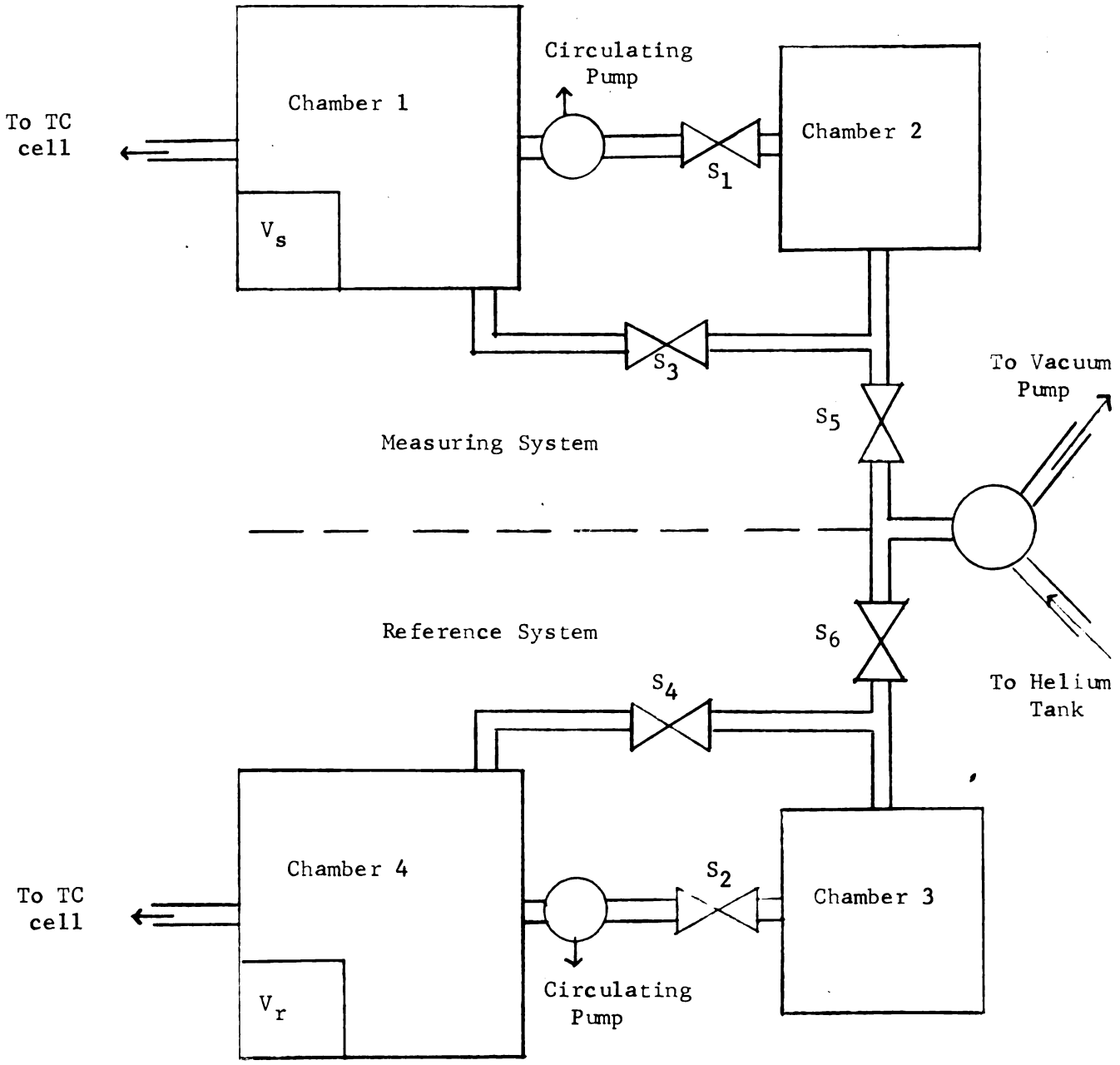



Figure 1. Schematic diagram of helium dilution system

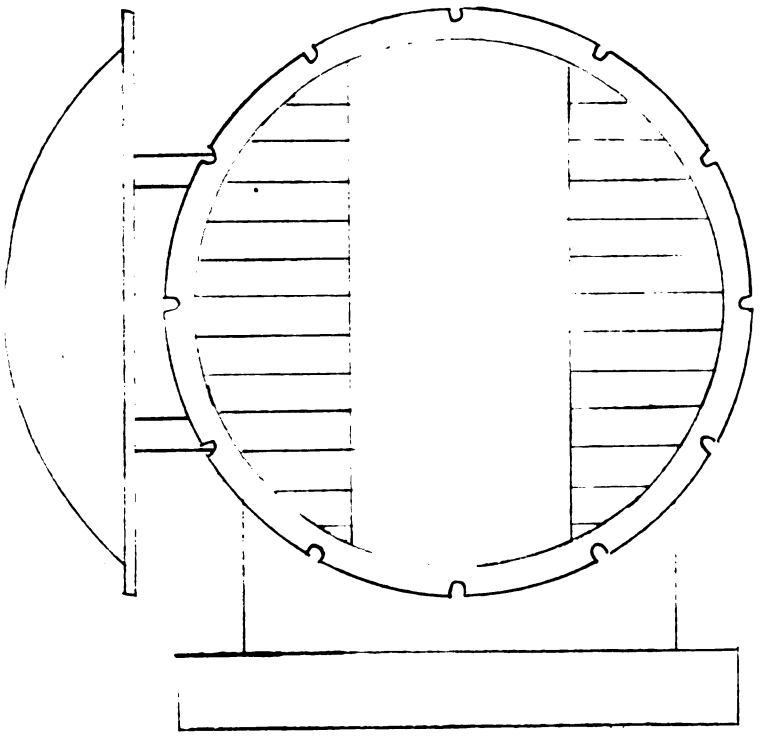


Figure 2. End view of open animal chamber showing location of baffles

470 liters. These chambers were constructed so that they could be sealed by bolting a hinged, steel door against a rubber-covered flange. Each chamber contained a squirrel cage fan for circulating the air, a thermistor for measuring temperature, and an electric hygrometer element for measuring relative humidity.

Chambers 2 and 3 consisted of identical Pyrex glass jars, each having a capacity of approximately 13 liters. These chambers were also fitted with thermistors for measuring the temperature. The set up of these chambers was arranged so that (a) they could be completely evacuated; (b) they could be filled with helium at atmospheric pressure; (c) the helium could be injected simultaneously into chambers 1 and 4; and (d) the helium-air mixture could be circulated between chambers 1 and 2 and between chambers 3 and 4. A Cenco, Hy-vac model, vacuum pump was used to evacuate the helium chambers. A dry ice-acetone trap was used to remove the water vapor from the air before it entered the vacuum pump. The helium-air mixture was circulated between the chambers by means of identical Eberbach air pumps with a capacity of 1.5 cubic feet per minute.

The helium-air mixtures from chambers 1 and 4 were analyzed by means of a thermal conductivity cell with an attached power supply and recording potentiometer. The thermal conductivity (T/C) cell was a Gow-Mac, model 9737, 30-S containing 8 tungsten, type 9225, resistance filaments mounted in a brass, 2-pass T/C cell. The current to the cell was supplied by a Gow-Mac power supply, model 9999-C, 1:1. The potentiometer used for recording the signal was a Sargent model SR recorder, 2.5 mv.

Since the signal sometimes exceeded the range of the recorder, an attenuating resistance circuit (Figure 3) was wired into the system between the power supply and the T/C cell. This circuit consisted of two resistance decades wired in series to give a total resistance of 10 ohms in 0.1 ohm steps. The total signal attenuated was calculated by calibrating the resistance decades with reference to the deflection obtained on the recorder for each 0.1 ohm change in resistance. In this study, the instrument was calibrated so that a 0.1 ohm change in resistance was equal to 50 units of deflection on the recorder using a full scale of 100 units. In practice, a change in resistance of ± 0.1 ohm was sufficient to keep the recording on the scale of the chart.

The thermal conductivity cell was maintained in an oil bath (Figure 4) at a constant temperature of 52.75 ± 0.1°C by means of a thermistor-actuated Sargent thermonitor. Two heaters were used to maintain the temperature of the oil bath. One of these was a 250 watt, knife-type heater, and the other a cycling 60-watt light bulb. A Lightning stirrer was used to circulate the oil in the bath.

The air from chambers 1 and 4 was monitored through the thermal conductivity cell by means of two identical pumps (Dynapump, model 4K). The flow rate was maintained at a constant value of 700 ml. per minute by means of identical valves (Hoke, model 303-brass) and flow meters (Fischer and Porter, model 10A1017). Soda lime and magnesium perchlorate traps were used to remove $CO_2$ and water from the chamber air before it passed through the thermal conductivity cell.

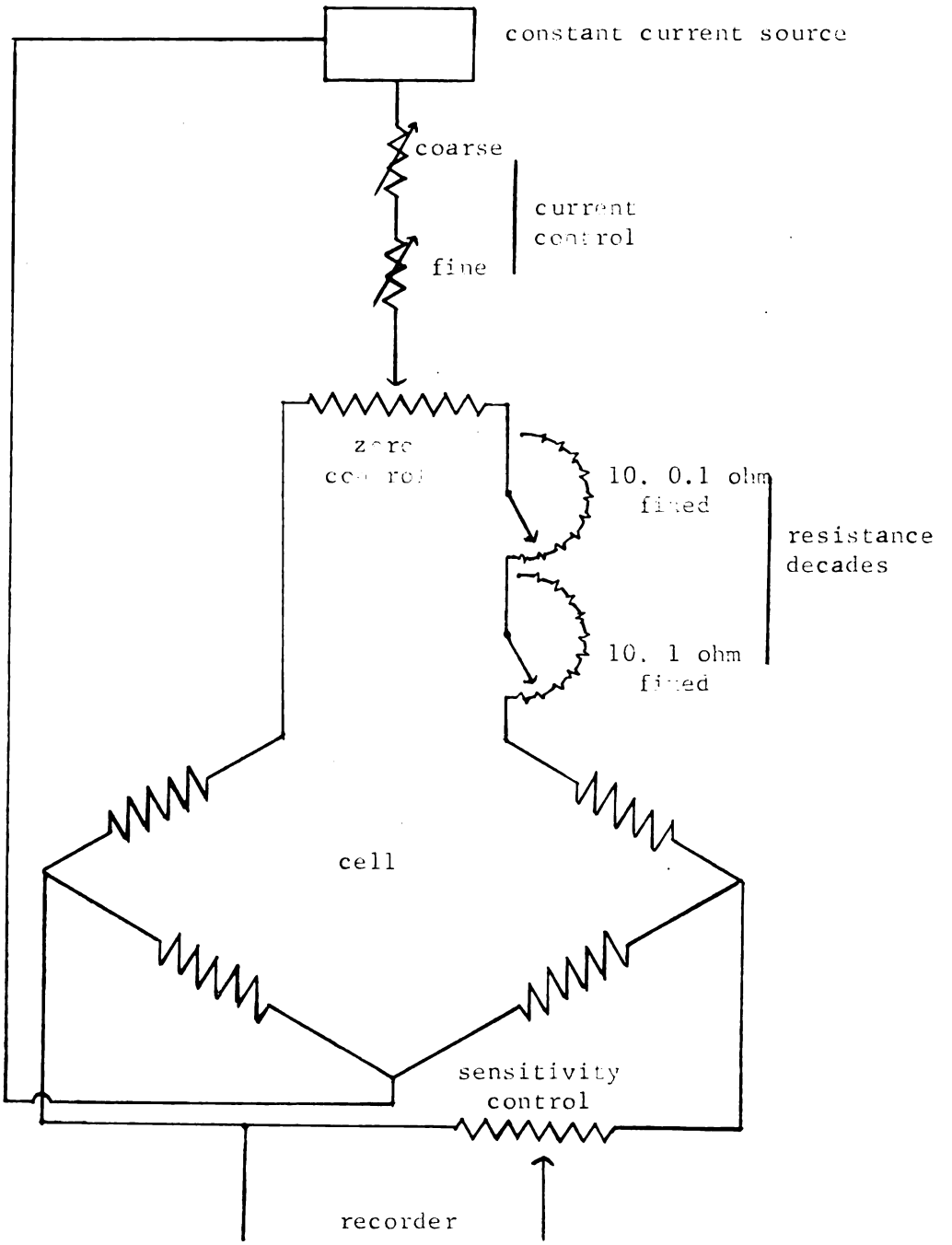
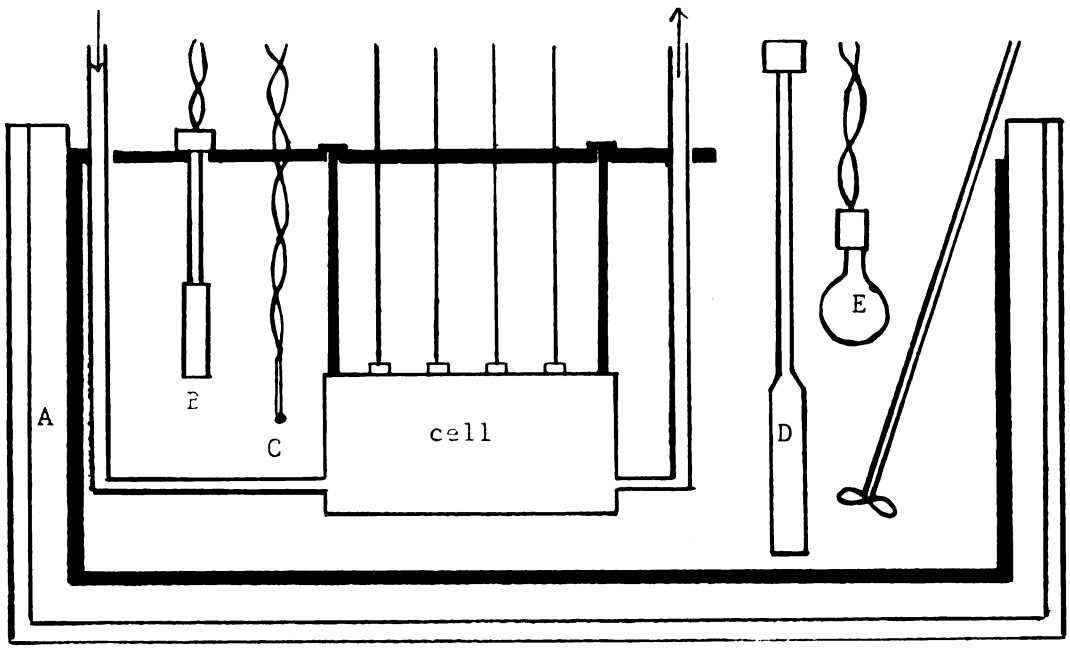



Figure 3. Schematic of helium analyzer showing location of resistance decades




A = styrofoam insulation block
B = thermistor thermoregulator
C = thermistor
D = heater, 250 watts
E = heater, 60 watt light bulb
F = stirrer

Figure 4. Schematic of oil bath and accessories

The helium dilution apparatus described above and shown in Figure 1 actually consisted of two systems; a reference system and a measuring system. The reference system consisted of chambers 4 and 3 and the measuring system chambers 1 and 2. With this arrangement, the difference in volume between the subject and the reference was shown by a difference in helium concentration in chambers 1 and 4 as indicated by a positive or negative deflection on the recorder. In order to use this apparatus to determine body volume, it had to be calibrated relating the deflection on the recorder to the difference in helium concentration.

The helium concentration in each chamber was calculated by the following equation:

$$C = \frac{v}{(V_c - V_i)\ \gamma + v} \tag{21}$$

where:

$v$ = volume of the helium chamber (13.13 liters)

$V_c$ = volume of empty subject or reference chamber (chamber 1 or 4)

$V_i$ = volume of reference used in calibration

$$\gamma = \frac{T_h\ (P - p)}{T_c\ \ (P)} \tag{22}$$

where:

$T_h$ = temperature of helium at time of injection

$T_c$ = temperature of subject or reference chamber just prior to mixing

$P$ = barometric pressure

$p$ = vapor pressure of water at $T_c$ and $P$

Since the hygrometer was not accurate (± 2-3 percent), the chambers were saturated by adding a small amount of water. Thus, the humidity correction was eliminated. Equation 21 then became:

$$\gamma = \frac{T_h}{T_c} \tag{23}$$

Since the difference in volume between the subject and the reference could be either positive or negative, it was necessary to calibrate the apparatus within two expected ranges of volume difference. These were arbitrarily chosen as 0.29 liters to 15.88 liters ($\triangle V_1$) and -0.29 liters to -10.02 liters ($\triangle V_2$). The calibration was made by placing reference volumes in both chambers, so as to give the proper difference in volume ($\triangle V$) and making several runs at each $\triangle V$. The difference in helium concentration for each $\triangle V$ was calculated from equations 21 and 23. These values were plotted against the deflection values obtained from the recorder. The plots are shown in figures 5 and 6. Using the plotted values, regression equations were calculated for use with live subjects as follows:

$$R_i = 270.94\ C_i + 47.65 \tag{24}$$

$$R_i = 270.08\ C_i + 28.88 \tag{25}$$

where:

$R_i$ = calculated deflection

$C_i$ = difference in helium concentration computed from equations 21 and 23

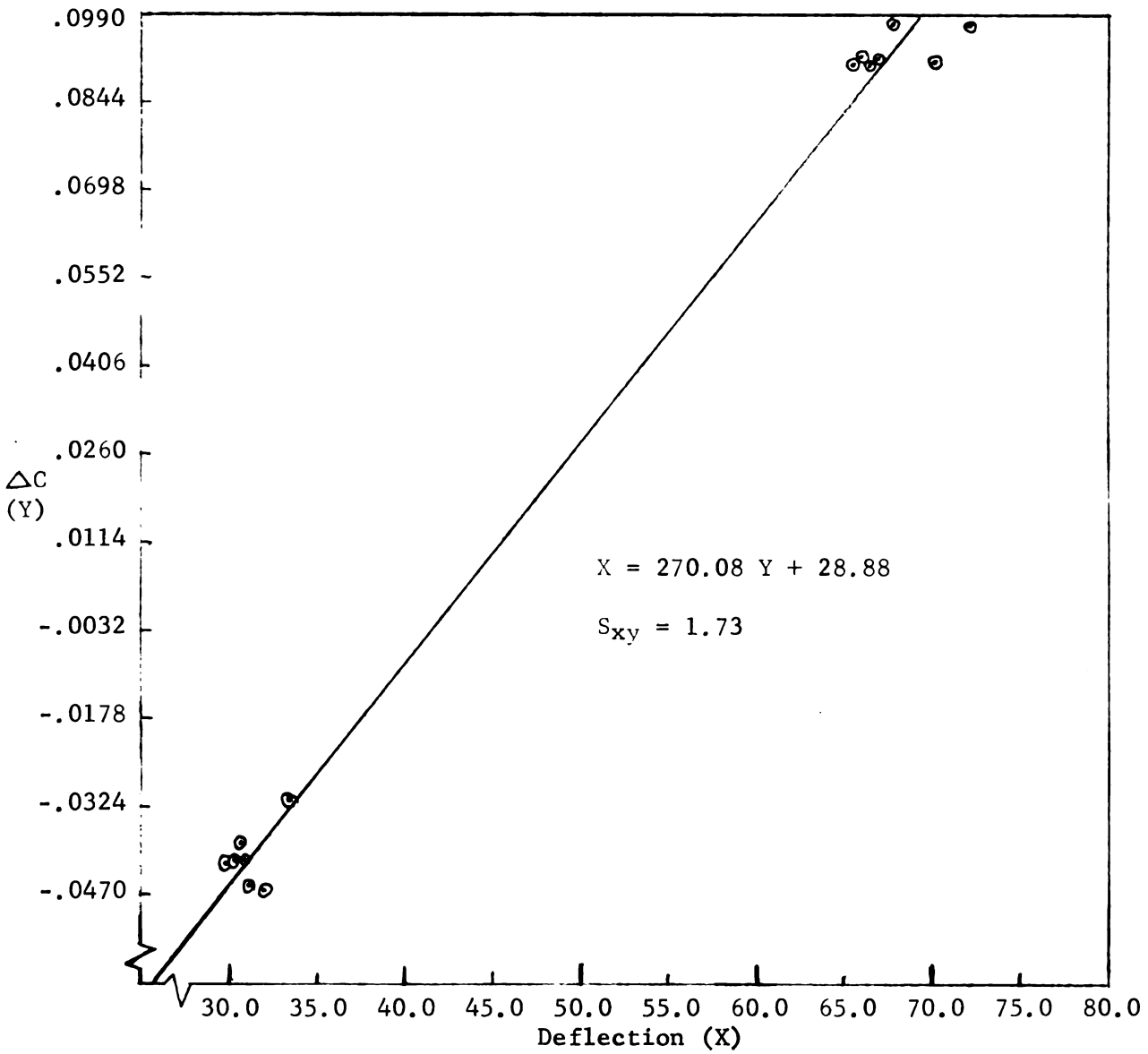



Figure 5. Graph of deflection values vs. difference in helium concentration for volume range $\Delta V_1$

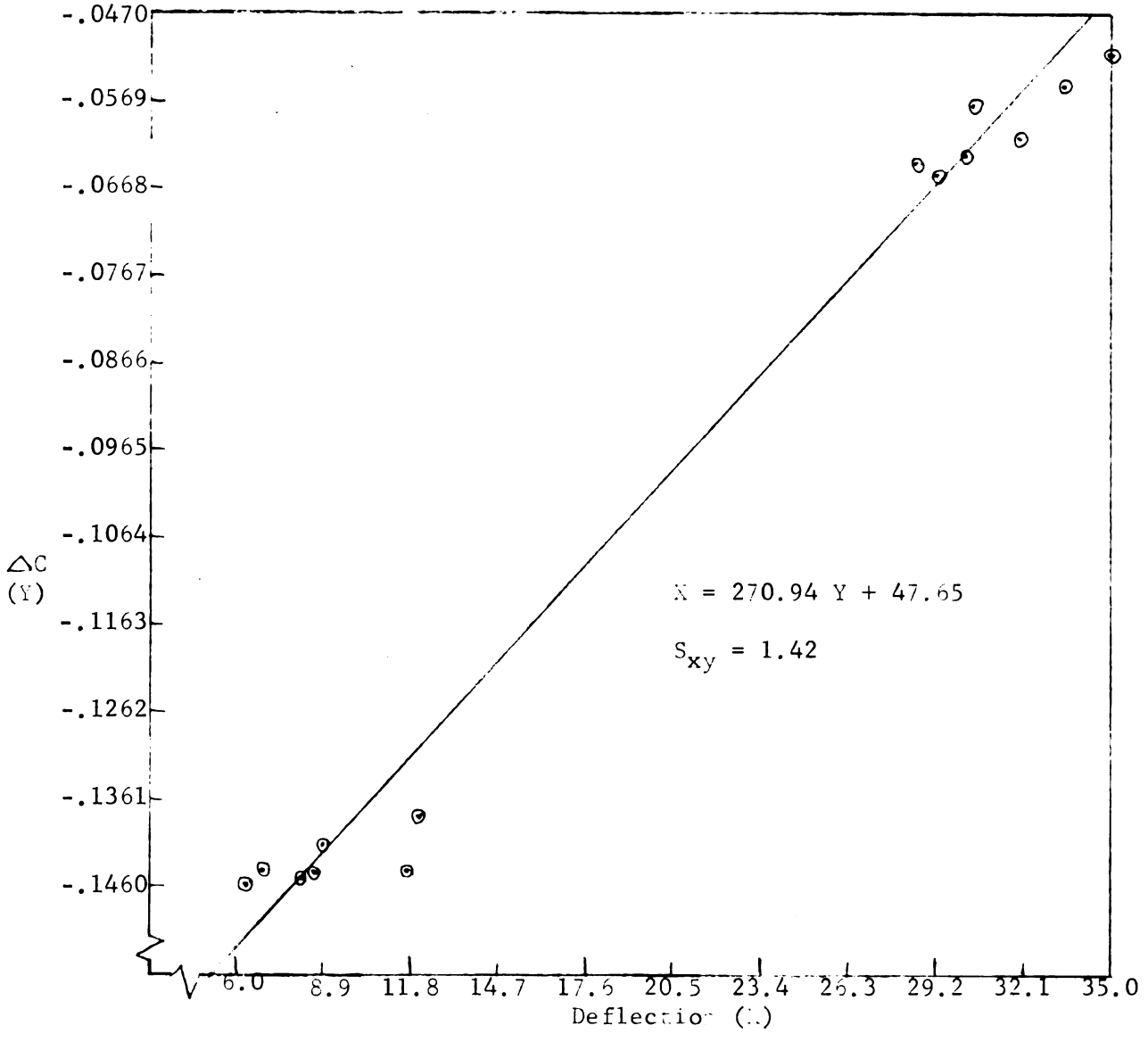



Figure 6. Graph of deflection values vs. difference in helium concentration for volume range $\Delta V_2$

The following equation was used for computing the difference ($\triangle V_o$) in volume between the subject ($V_s$) and the reference ($V_r$):

$$\triangle V_o = \frac{\triangle V_A \, R_1 \, (R_o - R_2) - \triangle V_B \, R_2 \, (R_o - R_1)}{R_o \, (R_1 - R_2)} \qquad (26)$$

where:

$\triangle V_o$ = difference in volume of subject and reference ($V_s - V_r$)

$\triangle V_A$ = 1st difference in volume of references used for calibration (15.88 or -.029 liters)

$\triangle V_B$ = 2nd difference in volume of references used for calibration (0.29 or -10.02 liters)

$R_o$ = observed deflection on the recorder with subject in chamber 1

$R_1$ = deflection computed from equation 24 or 25 at temperature conditions of $R_o$ with reference to $\triangle V_A$

$R_2$ = deflection computed from equation 24 or 25 at temperature conditions of $R_o$ with reference to $\triangle V_B$

In practice, the deflection obtained on the recorder with the live hog in chamber 1 fell within the second range of calibration (-0.29 to -10.02 liters), and these values were used throughout this study for computing body volumes. Some difficulty was experienced in reading the deflection value from the recorder. This was due to the fact that a curve of constant negative slope was obtained in response to the helium concentration in the two chambers. When this curve was extrapolated back to zero time, it gave a higher value than was indicated by the volume

difference. However, during the calibration runs it was noted that after a certain period of time (average 4.25 minutes) the curve leveled off and remained almost horizontal. This was the point at which the helium-air mixture in each chamber reached equilibrium, and thus, the point at which the helium concentration in each chamber was at a maximum. The deflection on the recorder at this point was closely related to the difference in volumes, and this equilibrium point was used in figuring the deflection with live subjects.

Procedure

The animals were placed in chamber 1 facing towards the rear in order to avoid any possible effects from their breathing upon the temperature sensing device, which was located near the front of the chamber. Water was splashed on the animal and on the sides of the chamber so that the air inside would be saturated. The door was then shut and sealed.

From the data of Gnaedinger (1962), a regression equation was computed relating body volume to live weight as shown below:

$$Y = 0.45X - 1.8 \qquad (27)$$

where:

Y = body volume

X = live weight

This equation was used to determine the approximate volume of the hogs used in this study. Pyrex glass bottles, which had previously been calibrated, were utilized in making up a reference volume equal to the

estimated volume of the animal using the value calculated from equation 27. The calibrated bottles were then placed in chamber 4. Water was added as with chamber 1 and the door was sealed.

Chambers 2 and 3 were filled with helium by evacuating them twice and refilling them back to atmospheric pressure with helium after each evacuation. The current to the thermal conductivity cell was set at 110 ma. The flow rate through both sides of the thermal conductivity cell was adjusted to approximately 700 ml. per minute. The recorder was zeroed at the midpoint (50 units) of the chart, with air from chambers 1 and 4 going through both sides of the thermal conductivity cell.

At this time, the temperatures in chambers 1, 2, 3 and 4 were recorded, and the circulating pumps were started simultaneously in order to inject helium into chambers 1 and 4. The difference in volume between the subject and the reference produced a deflection on the recorder. This deflection was used to calculate the volume of the subject as previously explained.

## Determination of Body Volume by the Air Displacement Method

### Apparatus

The apparatus for determining body volume by the air displacement method was adapted from the system described by Hix (1963) and modified after the method of Loh (1956). A schematic diagram of this apparatus is shown in Figure 7. This system utilizes the same large chambers (1 and 4) as described in the helium dilution procedure. The small chambers (2 and 3) were similar to the large chambers, except that they had a

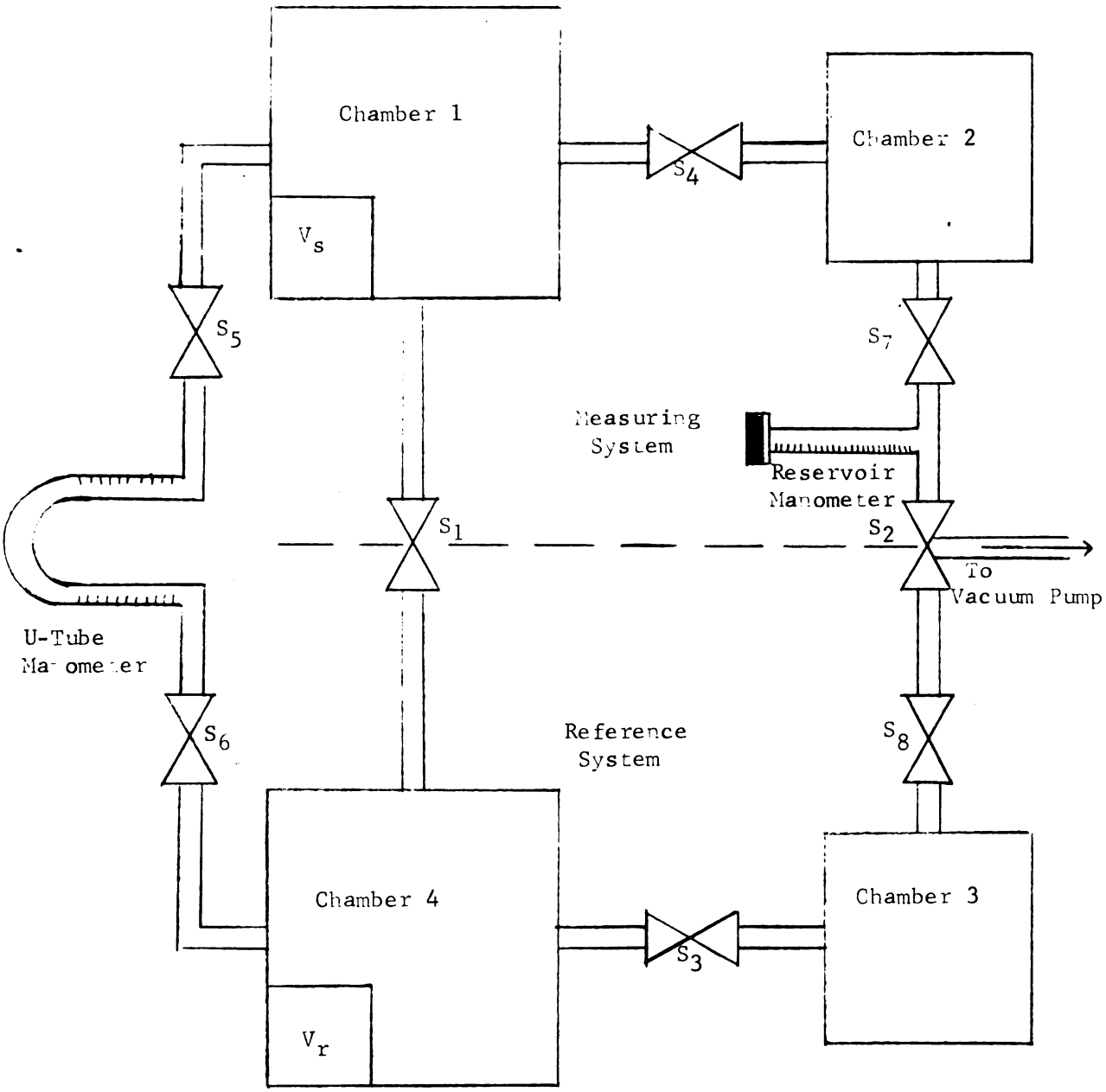



Figure 7. Schematic diagram of air displacement system

capacity of approximately 170 liters. The apparatus contained two systems; a measuring system comprising chambers 1 and 2, and a reference system made up of chambers 3 and 4. The arrangement of these four chambers was such that 2 and 3 could be commonly connected to a vacuum pump and manometer, or separately connected to the manometer. They were also arranged so that chamber 2 could be separately connected with chamber 1, and chamber 3 with chamber 4. Chambers 1 and 4 were arranged so that they could be interconnected through a U-tube manometer or separately connected to the atmosphere. A cistern-type, rising stem mercury manometer was used to measure the pressure in chambers 2 and 3. A U-tube manometer with colored silver nitrate solution as the fluid was used to record the difference in pressure between chambers 1 and 4. This pressure difference was related to the difference in volume between the subject and the reference.

Procedure

The subject and the reference were situated in the chambers and the chambers were saturated as described in the helium dilution procedure. In fact, the air displacement determinations were made immediately after the conclusion of the helium dilution determination without opening the chambers. In making an air displacement run, the following manipulations were made in order: (1) a partial vacuum of approximately 345 mm. of mercury was drawn on chambers 2 and 3 with valves $S_3$ and $S_4$ closed and valves $S_2$, $S_7$ and $S_8$ open; (2) two minutes were allowed for equilibrium to be established in the chambers; (3) the pressure in chambers 2 and 3

was recorded along with the temperature of all four chambers; (4) with valves $S_5$ and $S_6$ open and valves $S_1$, $S_2$ and $S_8$ closed, valves $S_3$ and $S_4$ were opened simultaneously in order to connect chamber 2 with chamber 1 and chamber 3 with chamber 4; (5) two minutes were again allowed for equilibrium to be established; (6) the differential pressure was recorded from the U-tube manometer along with the final pressure in chambers 1 and 2 and the temperature of all four chambers.

The difference in volume between the subject and the reference was calculated by means of the following equation:

$$V_s - V_r = (V_1 - V_4) - V_2 \frac{\frac{P_2'}{T_2'} - \frac{P_2^\circ}{T_2^\circ}}{\frac{BP}{T_1^\circ} - \frac{P_2'}{T_1'}} + V_3 \frac{\frac{P_3'}{T_3'} - \frac{P_3^\circ}{T_3^\circ}}{\frac{BP}{T_4^\circ} - \frac{P_3'}{T_4'}} \qquad (28)$$

where:

$V_1$ = volume of chamber 1 empty

$V_4$ = volume of chamber 4 empty

$V_2$ = volume of chamber 2 (167.75 liters)

$V_3$ = volume of chamber 3 (166.25 liters)

$P_2^\circ = P_3^\circ$ = initial pressure in chambers 2 and 3 (approximately 345 mm Hg)

BP = barometric pressure (740 mm Hg)

$P_2'$ = final pressure in chambers 1 and 2 (from reservoir manometer)

$P_3'$ = final pressure in chambers 3 and 4 ($P_2'$ - differential pressure from U-tube manometer)

$T_i'$ = final temperature in each chamber as indicated by number

$T_i°$ = initial temperature in each chamber as indicated by number

The empty chamber values for chamber 1 and chamber 4 were determined by the air displacement method described by Hix (1963). These values were calculated each day before making the determinations on the live subjects.

With the above procedure, two determinations were made on each subject and the average taken as body volume. Density was calculated by dividing weight by volume.

Sampling and Analysis of Carcasses

Immediately after the body volume determinations were completed, the animals were killed by exsanguination. The blood was collected quantitatively in a plastic bag and weighed. A sample of blood was also taken for chemical analysis. Clotting was prevented in these samples by adding a small amount of citric acid. They were frozen and stored at -20°F. until removed for analysis.

The animals were scalded and dehaired in the conventional manner. The hair, scurf and toenails were collected quantitatively and air dried. The dried hair was then ground twice through a meat grinder and sampled for chemical analysis. The values for composition of the hair were taken from the analysis of a composite sample from five pigs.

The head was removed, leaving the jowls on the carcass. The carcass was eviscerated over a container, which served to catch any body fluids, blood clots, etc., that were present in the body cavity. The entire viscera, including the kidneys and the head, were sealed in a plastic bag, which was weighed and then frozen at -20°F. The carcass was split in half, weighed, and placed in a cooler at approximately 38°F.

After 24 hours, the carcass was removed from the cooler and weighed. Carcass length and backfat thickness were measured. The carcass was divided into four parts as follows: (1) the shoulder, which was separated by cutting across the 3rd rib and perpendicular to the vertebrae; (2) the ham, which was separated by cutting across the 2nd and 3rd sacral joint and perpendicular to the shank; (3) the loin, which was separated by cutting along a line drawn from the ventral edge of the remnant of the blade bone found in the loin to the ventral edge of the psoas major muscle, at the posterior end of the loin; and (4) the side, which was the remaining portion. This separation is shown in Figure 8. The feet were left on the shoulder and ham. The side contained the spareribs, while the fatback, jowl and clear plate were left on their respective intact cuts. A tracing was made of the longissimus dorsi muscle at the 10th rib of the right loin, which was later used for measurement of loin eye area. Each part was then sealed in a plastic bag and frozen at -20°F. By using this procedure, each hog was divided into seven compartments for chemical analysis. This method of separation yielded no less than 99% recovery of the live weight of the individual animal.

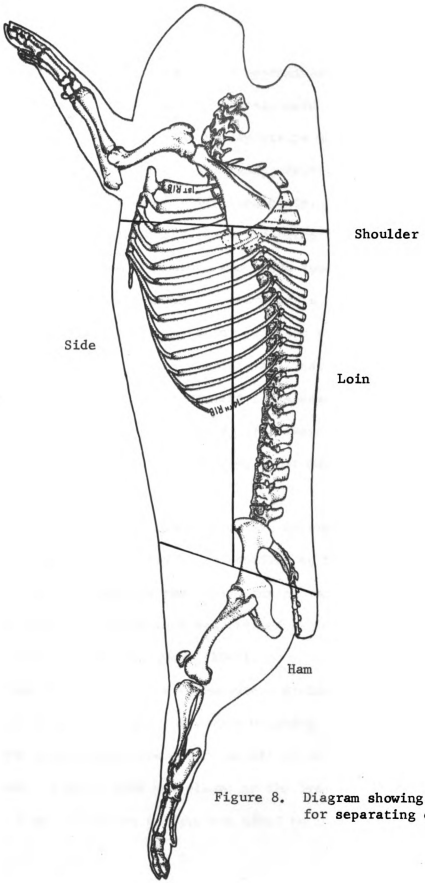



Figure 8. Diagram showing points for separating carcass

Each compartment was cut into strips approximately 1/8 inch in thickness on an electric meat saw. A special, hard steel saw blade was necessary for cutting the head. The frozen strips were then ground six times using a 1.5 hp, Enterprise, model 2632, electric meat grinder. Each part was ground once through a 1/2 inch plate, twice through a 1/4 inch plate, once through a 1/8 inch plate and twice through a 5/64 inch plate. With this procedure, the bones and teeth appeared to be quite well macerated and mixed with the meat. However, a number of small pieces remained behind the small plate following the last grinding. Since the amount was small, it was discarded. After the final grinding, a sample weighing approximately 70 gms. was removed for subsequent chemical analysis. These samples were stored at -20°F until used.

Each sample was analyzed for moisture, ether extract, protein and ash.

The amount of moisture in the samples was determined according to the procedure of Benne et al. (1956) as modified by Gnaedinger (1963). Ether extract was determined on the dried samples remaining after the moisture determination. Extraction was carried out on the Goldfisch apparatus as described by Gnaedinger (1963).

Protein was determined using a semi-micro Kjeldahl procedure adapted from an outline by Brent (1965). A sample weighing approximately 0.5 gm. was weighed out on nitrogen-free paper and placed in the micro Kjeldahl digestion flask. A glass bead was placed in the flask to prevent bumping. Approximately 1 gm. of sodium sulfate was added to increase the boiling

temperature of the mixture. Six ml. of concentrated sulfuric acid and 1 ml. of 10 percent copper sulfate solution were then added to the flask. The samples were heated on a micro Kjeldahl burner for 6-8 hrs. until a clear, pale green solution was obtained.

During digestion, the flasks were cooled and washed down twice with distilled water. At the end of the digestion period, the flasks were cooled and 20 ml. of distilled water were added. The flasks were then placed on the distillation apparatus and heated. The ammonia was distilled over into 10 ml. of 2% boric acid solution containing 2 drops of brom cresol green. The distillation was carried out for a total of 11 minutes in order to drive all of the ammonia over. The boric acid-ammonia solution was then titrated to a greenish-yellow end point with approximately 0.1 N standard sulfuric acid. The percent protein in the sample was calculated from the following equation:

$$\% \text{ Protein} = \frac{(a)\ (b)\ (14)\ (6.25)\ (100)}{C} \qquad (29)$$

where:

a = normality of standard acid

b = ml. of standard acid used

14 = molecular wt. of nitrogen

6.25 = factor for converting nitrogen to protein

C = sample wt. (mg.)

The ash content was determined on samples weighing approximately 3 gms. The sample was weighed into a porcelain crucible (Coors #3), which

had previously been ignited for 10 minutes at 525°C and cooled to room temperature in a dessicator. The samples were dried in a hot-air oven for at least 6 hours at 100°C. They were then placed in a muffle furnace and the power supply was adjusted, so that the temperature inside the furnace increased at a rate of approximately 45°C per hour.

The samples were left in the furnace until the temperature reached 525°C, at which time they were removed, cooled, and reweighed. This procedure required about 10-12 hours and appeared sufficient to produce a fine, white ash from the samples with a minimum of spattering.

## RESULTS AND DISCUSSION

### Relationship of Various Specific Gravity Values

The individual volume and specific gravity values are given in Appendix Table I. The air displacement volumes varied from 84.13 to 106.06 liters with a mean of 97.69 liters. The helium dilution volumes ranged from 81.61 to 105.33 liters with a mean of 95.78 liters. Specific gravity values calculated by air displacement showed a range of 0.9242 to 1.1253 with a mean of 0.9829. Specific gravity values calculated by helium dilution varied from 0.9686 to 1.0258 with a mean of 1.0005.

Theoretical density values were calculated as outlined by Kraybill (1953) using equation 8, which utilizes a value of 0.914 for the density of fat and 1.1 for the density of the lean body mass. These theoretical density values were computed in order to compare them with the specific gravity values obtained by air displacement and helium dilution. Theoretical density values ranged from 1.0160 to 1.0505 with a mean of 1.0323. In order to test the validity of the theoretical density equation (equation 8), the calculated values were correlated with the percentage of each chemical component (ether extract, moisture, protein and ash) of both the live animal and the carcass. The specific gravity values determined by air displacement and helium dilution were also compared with the values for each chemical component on both the live animal and the carcass. In addition, correlations were calculated between body volumes and specific gravity values as determined by each method. A summary of these correlation coefficients is shown in Table 2.

Table 2. Summary of correlation coefficients between volume, specific gravity and chemical analysis data.

| Variable | Air displacement volume | Helium dilution volume | Air displacement specific gravity | Helium dilution specific gravity | Theoretical density |
|---|---|---|---|---|---|
| Live Animal | | | | | |
| Helium dilution volume | 0.576** | --- | --- | --- | --- |
| Helium dilution specific gravity | --- | --- | 0.588** | --- | 0.130 |
| Air displacement specific gravity | --- | --- | --- | --- | 0.631** |
| % Moisture | -.311 | -.243 | 0.053 | -.182 | 0.649** |
| % Ether extract | 0.326 | 0.147 | -.172 | 0.107 | -.729** |
| % Protein | -.009 | -.192 | -.211 | -.209 | 0.224 |
| % Ash | -.415* | 0.393 | 0.901** | 0.549** | 0.597** |
| % Lean body mass | -.274 | -.210 | 0.052 | -.160 | 0.610** |
| Carcass | | | | | |
| % Moisture | -.431* | -.277 | 0.161 | -.011 | 0.681** |
| % Ether extract | 0.387 | 0.155 | -.242 | 0.050 | -.737** |
| % Protein | -.037 | -.194 | -.171 | -.151 | 0.292 |
| % Ash | -.289 | -.223 | 0.754** | 0.438* | 0.598** |

**Significance at 1% level
* Significance at 5% level

Highly significant correlation coefficients were obtained between volumes measured by air displacement and helium dilution, as well as between specific gravity values determined by helium dilution and air displacement. Only the specific gravity values determined by air displacement were significantly correlated with theoretical density values ($r = 0.631$). Except for percent ash, neither air displacement specific gravity nor helium dilution specific gravity values were significantly related to

the percentages of any of the chemical components for either the live animal or the carcass.

In all cases, the air displacement specific gravity values were more highly correlated with the percentages of the chemical components than were the helium dilution specific gravity values. Specific gravity values for both methods showed a slightly higher relationship with the chemical components of the carcass than with those for the live animal with the exception of percent ash. The data show that the air displacement specific gravity values were slightly more indicative of composition than those obtained by helium dilution.

Theoretical density values were highly significantly correlated with percentages of all chemical components except percent protein on both the live animal and the carcass. Although these correlations were statistically significant, they were not as high as would be expected, since the theoretical density values were computed from actual chemical analysis data (equation 8). This could have been due to either one or a combination of two factors. The values of 0.914 for density of fat and 1.1 for density of lean may not have been valid for the group of hogs used in this study. On the other hand, the individual variation in the density of fat and lean of these hogs may have resulted in the low correlation.

In order to determine the validity of equation 8 for the hogs used in this study, it would be necessary to have an accurate set of values for the whole body specific gravity. However, it would be possible to gain some indication of the validity of the values used by Kraybill *et al.* (1953) by relating the values obtained in the present study to those

obtained for a similar group of hogs. Thus, the data of Price (1957) were utilized, since he had determined the specific gravity of the hams from thirty-six market weight pigs by underwater weighing and subsequently analyzed each ham for ether extract. Using a multiple regression analysis, values of 0.9614 for the density of fat and 1.1171 for the density of lean were calculated. These values were then used with equation 8 to calculate a new set of values for theoretical density.

When the new theoretical density values were correlated with the percentage of various chemical components, the relationships were lower than before. It should be noted, however, that the data of Price (1957) were based only on the ham and therefore would be subject to some error when compared with data from the whole animal.

It is possible that the low relationship between theoretical density and percentage of chemical components could have been due to the variation in density of the individual hogs. However, if this were true, the validity of accurately predicting composition from density values could be questioned. It appears that more research will need to be done in determining the variation in density of the fat and lean compartments of the hog before this problem can be solved.

Errors in Measuring Specific Gravity by Air Displacement

Gnaedinger (1962) mentioned that the greatest difficulty encountered with the air displacement method was the lack of precision from day to day in measuring the volume of the empty chamber. This may also have been true

in the present study. In preliminary determinations with the chambers at ambient relative humidity, a significant difference was obtained between the average volumes determined each day, but not between the three volume determinations made on the same day (Table 3).

Table 3. Analysis of variance of empty chamber volumes under conditions of normal relative humidity.

| | Source of variation | Degrees of freedom | Mean square | F ratio |
|---|---|---|---|---|
| Chamber 1 | Total | 26 | -- | -- |
| | Between means | 2 | 0.33 | 1.18 |
| | Within means | 8 | 4.75 | 16.96** |
| | Errors | 16 | 0.28 | -- |
| Chamber 4 | Total | 23 | -- | -- |
| | Between means | 2 | 1.26 | 3.32 |
| | Within means | 7 | 4.76 | 12.53** |
| | Error | 14 | 0.38 | -- |

**Significance at 1% level

The calculated volumes for chamber 1 ranged from 450.88 to 455.63 liters with a mean of 453.76 liters and a standard deviation of ±1.29. The volume of chamber 4 varied from 447.20 to 452.70 liters with a mean of 451.28 liters and standard deviation of ±1.34.

When the chambers were saturated, the variation increased substantially. The empty volume of chamber 1 varied from 463.51 to 482.80 liters with a mean of 474.80 liters and a standard deviation of ±5.91. The empty volume of chamber 4 ranged from 462.18 to 472.27 liters with a mean of 465.89 liters and a standard deviation of ±2.86.

Analysis of variance (Table 4) showed a significant difference in the average, day to day volumes for both chambers, and also a significant

difference in the individual determinations made on the same day with chamber 4. The standard deviation and mean square values indicated a substantial increase in variation when the chambers were saturated. Equation 28 shows that a change of one liter in the volume of either empty chamber will result in a corresponding change of one liter in the volume of the subject. Thus, any variation in the volume of the empty chambers would be a significant source of error.

Table 4. Analysis of variance of empty chamber volumes under conditions of complete saturation.

| | Source of variation | Degrees of freedom | Mean square | F ratio |
|---|---|---|---|---|
| Chamber 1 | Total | 13 | -- | --- |
| | Between means | 1 | 3.50 | 1.16 |
| | Within means | 6 | 89.62 | 29.77** |
| | Error | 6 | 3.01 | --- |
| Chamber 4 | Total | 13 | -- | --- |
| | Between means | 1 | 2.54 | 7.26** |
| | Within means | 6 | 19.62 | 56.06** |
| | Error | 6 | 0.35 | --- |

**Significance at 1% level
* Significance at 5% level

This can be shown even more clearly by examining the differences between the empty volumes ($V_1 - V_4$) under the two conditions of saturation. The difference in volume between chambers 1 and 4 under normal conditions of relative humidity varied from 1.19 to 5.21 liters, with an average of 3.30 liters. When the chambers were saturated, the values varied from 0.95 to 16.31 liters, with a mean of 8.92 liters. It appears from these facts that differences in relative humidity between the subject and reference chamber caused substantial variation in the empty volumes calculated for these chambers.

An error in the empty chamber volume would naturally cause a corresponding error of the same magnitude in the volume of a subject. An error in volume of 3 liters would cause an error of approximately 0.03 units of specific gravity for a 200 lb. hog. An error in volume of 8 liters would cause an error of 0.08 in specific gravity. Obviously, relative humidity could cause errors in volume with live subjects besides those inherent in the empty chamber volume determinations.

With a live subject in chamber 1, an increase in temperature was noted. This would tend to decrease the level of saturation in the chamber. At the same time, chamber 4, which contained an inert reference volume, showed no increase in temperature. Therefore, the amount of saturation in chamber 4 would stay constant. However, the average temperature increase in chamber 1 was only 0.61°C, which would result in a decrease in relative humidity of no more than 0.15 percent. It is also possible that any water vapor added to the chamber from the body of the hog would tend to offset the decrease in relative humidity due to increasing temperature. Thus, changes in temperature in the subject chamber were probably not an important source of error. The major source of variation in relative humidity was probably caused by differences in the initial addition of water to the chambers.

In order to determine the amount of error inherent in the apparatus, Hix (1963) performed an estimation of errors on the equation for computing body volume (equation 14). Since the apparatus used in the present study is of the same design, a similar estimation of errors should be valid.

The following conditions were set up in order to estimate the maximum error inherent in the present apparatus: (1) the maximum error in reading pressure was ±0.1 mm Hg on the cistern-type manometer and ±0.2 mm Hg on the U-tube manometer; (2) the maximum error in reading temperature was ±0.1 °C; and (3) no corrections were made for relative humidity. Under these conditions, the maximum percentage error was computed to be 0.92 percent. In preliminary determinations with inert objects, a mean error of ±0.73 liters for 21 determinations was obtained. This amounted to an average error of 0.81 percent for a volume of 90 liters. An error of this magnitude could result in an approximate error of ±0.009 units of specific gravity for a 200 lb. hog.

It was thought that differences in temperature within the subject chamber could have contributed significantly to the total error. Since the temperature was measured with a single thermistor located at one end of the chamber, it is possible that temperature errors of up to ±0.5°C could have occurred. This would increase the percentage error due to temperature from 0.5 percent to 2.5 percent. However, since the air in the chamber was circulated by a fan and the ambient temperature was maintained within 10°F of body temperature, it is doubtful if errors of this magnitude actually occurred.

Another possible source of error would be the U-tube manometer used to measure the difference in pressure between chambers 1 and 4. In preliminary determinations, it was found that mercury was not useful as a manometer fluid because it could not be read accurately with the small

pressure differences involved. Water could not be used since it was too sensitive and fluctuated with the respiration of the subject. For these reasons, a silver nitrate solution having a density of 2.134 was used as the fluid. The values from the manometer were divided by 6.09 to give the pressure reading in mm. of mercury.

It is possible that some changes may have occurred in the density of the silver nitrate solution during the course of the study since silver nitrate is not completely stable in the presence of light. Furthermore, changes in density of the silver nitrate solution may also have occurred due to differences in ambient temperature. Whether such errors actually existed and their magnitude is not known.

In summary, the major source of error in the air displacement procedure appeared to be due to difficulties in calculating the day to day volumes of the empty chambers as a result of differences in relative humidity. A second important source of error could have been the result of differences in relative humidity between the chambers during the actual determinations.

If further studies are to be carried out using this method, it will be necessary to measure the relative humidity in the chambers with a high degree of accuracy (less than 1% error). If this accuracy could be achieved, humidity corrections could be made at ambient relative humidity. In this case, it would be necessary to determine the relative humidity of the subject chamber at the beginning and again at the conclusion of a determination. The final pressure in the subject chamber and the difference

in pressure between the subject and reference chambers could then be corrected for the increase in relative humidity of the subject chamber.

Another possibility for improving the accuracy of this method would be to enclose the chambers in a smaller space where the temperature could be more closely controlled. With this arrangement, the temperature in both the subject and the reference chambers as well as the surrounding atmosphere could be maintained at the body temperature of the subject. This would eliminate any changes in temperature, thus making temperature corrections unnecessary. A constant temperature system would also reduce fluctuations in pressure and relative humidity.

Errors in Measuring Specific Gravity by Helium Dilution

In preliminary studies, the volume of inert objects was determined with a mean error of 0.48 liters for 14 determinations. The major source of error with the helium dilution procedure appeared to be the variation in relative humidity between the reference and the subject chambers. Although an attempt was made to saturate both chambers, differences of up to 10 percent relative humidity may have occurred. Since the hygrometer in use was only accurate to ±2-3 percent, it was not possible to correct for these differences.

In preliminary runs with inert objects in the chambers, it was found that an increase in relative humidity of approximately 10 percent resulted in an increase of 5 units of deflection on the recorder. However, this relationship did not appear to be linear, as the increase in deflection

became higher as the relative humidity approached saturation. In terms of body volume, an increase in deflection of 5 units would mean an increase in volume of approximately 0.20 liters.

Another probable source of error with this method was the empty chamber volumes used in computing helium concentration. These volumes were calculated by the air displacement method, and therefore had all inherent errors of the air displacement procedure. In view of the extreme variation in the empty chamber values, it is possible that this was the major reason for a significant portion of the error with helium dilution.

Gnaedinger (1962) and Hix (1963) reported that one of the major problems with the helium dilution procedure was the inaccuracy in adjusting the current to the thermal conductivity cell. However, this did not appear to be a significant source of variation in this study. The arrangement of the power supply unit was such that the on-off switch and the fine control were on the same dial and the coarse control on another dial. Thus, for the first determination, the fine control was turned full on and the coarse control was adjusted to approximately 110 ma. and fastened securely. In subsequent determinations, the fine control was turned full on to give the same current supply each time.

In this study, a great deal of variation was found in the slopes of the lines obtained on the recorder in response to the difference in helium concentration between the subject and reference chambers. This variation could have been due to any one or a combination of several

factors, such as temperature, relative humidity, and ratio of oxygen to carbon dioxide.

A change in temperature within the subject chamber could have several effects. Since the subject chamber was open to the atmosphere through the small opening where helium was injected, an increase in temperature could cause some air to be forced out of the chamber. This would result in less dilution of the helium, and therefore a higher value for body volume. An increase in temperature would also cause an increase in the capacity of the air to hold water, thereby reducing the amount of saturation in the chamber. This would cause a decreased helium concentration, and thence a lower value for body volume. Since the average increase in temperature of the subject chamber in this study was only 0.61°C, it seems unlikely that temperature alone was a significant source of variation. However, in combination with changes in relative humidity and carbon dioxide accumulation, it could have been an important factor.

Increases in relative humidity within the subject chamber would have the effect of decreasing the dilution of helium, thereby giving a higher value for body volume. The accumulation of carbon dioxide and corresponding depletion of oxygen in the subject chamber would have the effect of lowering the thermal conductivity of the gas mixture, and therefore would give a lower value for body volume.

In this study, an attempt was made to remove the carbon dioxide from the air entering the thermal conductivity cell by means of a soda lime trap. However, the carbon dioxide accumulation with live hogs was too

great for efficient removal. Thus, part of the variation in the slope of the lines on the recorder was probably due to differences in the accumulation of carbon dioxide within the subject chamber.

In order to make the helium dilution procedure useful for determining the volume of live subjects, it will be necessary to determine the exact effect of each one of the variables mentioned above. This could be done by holding all the variables constant except one, and then changing that one and noting the effect on helium concentration. This procedure could be repeated for each of the variables and for different combinations of the variables, until the exact effect of each was known. These effects could be incorporated into the original helium dilution equation (equation 16), and the calculation of body volume would be greatly simplified. However, a study of this kind would require very precise instruments for measuring relative humidity, oxygen and carbon dioxide content, and temperature. Furthermore, it would be possible to eliminate the need for temperature corrections if the complete apparatus could be maintained in a closed system at the body temperature of the subject as was suggested for the air displacement method.

## Body Composition Relationships

The weights of the various body compartments as well as live weight, hot carcass weight and chilled carcass weight are shown in Appendix Table II.

Chemical analyses of the whole animal and of the carcass are shown in Appendix Table III. The moisture content of the whole animals ranged

from 47.07 to 56.78 percent, with a mean of 52.00 and a standard deviation of 2.40 percent. Gnaedinger (1962) reported a mean value of 48.49 percent for the moisture content of the empty bodies (the entire live animal minus the contents of the G.I. tract) for a similar group of hogs. Part of the difference in moisture content of the two groups may be attributed to the exclusion of the intestinal contents in the study by Gnaedinger (1962). He reported that the intestinal contents contributed an average of 2.82 percent of the total moisture with an average moisture content of 79.41 percent.

The moisture content of the dressed carcasses varied from 43.08 to 53.22 percent with a mean of 47.85 and a standard deviation of 2.81 percent. Gnaedinger (1962) reported an average value of 45.81 percent for the moisture content of the dressed carcasses. Thus, the carcasses used in the present study contained about 2 percent more moisture than those analyzed by Gnaedinger (1962).

The ether extract content of the whole animals ranged from 25.28 to 36.49 percent with a mean of 30.56 and a standard deviation of 3.04 percent. This was about 3 percent lower than the average value of 33.50 percent ether extract for the empty bodies as reported by Gnaedinger (1962). There was less difference in the ether extract content of the carcasses in the two groups of hogs than for the whole animals. The values for the ether extract content of the carcasses obtained in the present study varied from 28.16 to 41.33 percent with a mean of 35.28 percent and a standard deviation of 3.66. Gnaedinger (1962) reported an average ether extract content of 37.45 percent for the dressed carcasses.

The protein content of the whole animals in the present study varied from 13.57 to 17.11 percent with a mean of 15.21 and a standard deviation of 0.93 percent. This was about 1.5 percent higher than the average value of 13.78 percent protein as reported by Gnaedinger (1962). The protein content of the dressed carcasses ranged from 13.21 to 16.85 percent with a mean of 14.92, and a standard deviation of 0.95 percent. Gnaedinger (1962) reported a somewhat lower value of 13.19 percent for the average protein content of the dressed carcasses.

The ash content of the whole animals varied from 2.17 to 3.12 percent with a mean of 2.57 and a standard deviation of 0.26 percent. Gnaedinger (1962) reported comparable results with a mean ash content of 2.74 percent for the empty bodies and 2.75 percent for the carcasses. The ash content of the carcasses in the present study ranged from 2.21 to 2.96 percent with a mean of 2.56 and a standard deviation of 0.21 percent.

In summary, the data show that the hogs in the present study contained more moisture, more protein and less ether extract, and therefore as a whole, were not as fat as those analyzed by Gnaedinger (1962). This fact was shown even more clearly when the two groups were compared on an ether extract-free basis.

The data on an ether-extract free basis are shown in Appendix Table IV. The average values for the composition of the ether extract-free whole animal were 74.51, 21.80 and 3.69 for the percentage of moisture, protein and ash, respectively. The standard deviations were 0.72 for moisture, 0.86 for protein and 0.31 percent for ash. Gnaedinger (1962)

reported average values of 74.51 percent moisture, 21.41 percent protein and 4.23 percent ash for the composition of the ether extract-free empty bodies.

The mean values obtained for the ether extract-free carcasses were 73.91 percent for moisture, 23.05 for protein and 3.96 for ash. The standard deviations were 0.72 percent for moisture, 0.75 for protein and 0.39 for ash. The values reported by Gnaedinger (1962) for the ether extract-free carcasses were 74.17, 21.41 and 4.46 for the percentage of moisture, protein and ash, respectively. Thus, the ether extract-free carcasses from the present study were about 2 percent higher in protein and slightly lower in ash than those of Gnaedinger (1962).

The standard deviation values indicate that a substantial part of the variation in the moisture content of the hogs used in the present study was due to the variation in fat content. For instance, the standard deviation for percent moisture of the whole animal was 2.40 percent; however, on an ether extract-free basis the standard deviation was only 0.72 percent. This is further substantiated by the fact that a highly significant correlation coefficient of -.982 was obtained between the percent moisture and the percent ether extract of the whole animal.

The following regression equation was derived for predicting the percent ether extract of the whole animal from percent total body water:

$$Y = 95.04 - 1.24X \qquad (30)$$

$$S_{y.x} = \pm 2.91\%$$

$$r = -.982$$

where:

Y = calculated value for percent ether extract

X = percent total body water

$S_{y.x}$ = standard error of the estimate

r = correlation coefficient

This agrees with the data of Gnaedinger (1962) which gave a highly significant correlation coefficient of -.974 between percent total body water and percent ether extract.

Gnaedinger (1962) also derived the following equation for predicting the percent ether extract of the empty body from the percent water of the ether extract-free, empty body:

$$Y = 306.26 - 3.66X \qquad (31)$$

$S_{y.x} = \pm 2.92\%$

$r = -.579$

where:

Y = calculated value for percent ether extract of the empty body

X = percent water of the ether extract-free, empty body

He stated that the correlation coefficient indicated that the water content of the fat-free, empty body was not independent of the ether extract content of the body. He further stated that this relationship suggested that the animals were not chemically mature.

The following equation was derived from the experimental data in the present study for estimating the percent ether extract of the whole animal from the percent moisture of the ether extract-free, whole animal:

$$Y = 77.86 - 0.64X \qquad (32)$$

$$S_{y.x} = \pm 14.56\%$$

$$r = -.153$$

where:

Y = calculated value for percent ether extract of the whole animal

X = percent moisture of the ether extract-free, whole animal

This equation suggests that the animals used in the present study were more nearly chemically mature than were those utilized by Gnaedinger (1962). There is a very small relationship between the percent ether extract and the percent moisture of the ether extract-free, whole animal. This suggests that estimates of body fat could be made from the measurement of total body water for this group of hogs. Keys and Brozek (1953) and Harrington (1958) have stated that the validity of the technique of estimating total body fat from body water requires a non-significant relationship between total body fat and percent water of the fat-free body. Thus, it would appear that equation 31 could be used for predicting body fat from body water for the hogs used in the present study. However, the individual variation in these hogs, shown by the magnitude of the standard error (2.91 percent) would limit the usefulness of the prediction equation.

Appendix Tables V through VIII show the percentage of moisture, ether extract, protein and ash of the various whole animal compartments. The average composition of the shoulders showed 49.75 percent moisture with

a standard deviation of 2.62, 31.99 percent ether extract with a standard deviation of 3.35, 16.00 percent protein with a standard deviation of 1.02, and 3.16 percent ash with a standard deviation of 0.28.

The composition of the loins showed values of 42.58 ± 3.47, 41.02 ± 4.78, 14.43 ± 1.26 and 2.75 ± 0.38 for the means and standard deviations for percentage moisture, ether extract, protein and ash, respectively.

Analysis of the sides showed mean and standard deviation values of 39.00 ± 3.34, 48.22 ± 4.42, 12.74 ± 1.17 and 1.08 ± 0.12 for percentage moisture, ether extract, protein and ash, respectively.

The hams contained an average of 53.69 percent moisture with a standard deviation of 2.83, 26.86 percent ether extract with a standard deviation of 3.52, 17.20 percent protein with a standard deviation of 1.02 and 3.07 percent ash with a standard deviation of 0.26.

Chemical analysis of the four carcass compartments was much the same as that of the whole animal. Percentage of ether extract showed the greatest variation in all cases, followed by percent moisture, percent protein and percent ash. Of the four carcass compartments, the loin generally showed the most variation in chemical composition followed by the side, ham and shoulder.

Analysis of the head and viscera showed mean values of 65.48 percent moisture with a standard deviation of 2.25, 16.98 percent ether extract, with a standard deviation of 1.96, 13.75 percent protein with a standard deviation of 0.97 and 3.02 percent ash, with a standard deviation of 0.77. The standard deviations for the chemical components indicate that the

variation in composition of the head and viscera was of about the same magnitude as that of the whole animal and the dressed carcass.

Gnaedinger (1962) presented chemical analysis data from the viscera as divided into the following compartments: (1) the stomach, caul fat and intestines; (2) the kidneys, spleen, esophagus, trachea, liver, lungs and heart; (3) the intestinal contents; and (4) the head and tongue. From his experimental data, the following values were calculated for the head and viscera as a whole for comparison with values obtained in the present study: 61.23 percent moisture, 20.61 percent ether extract, 12.83 percent protein and 3.23 percent ash. These values show that the viscera from the hogs used in the present study were about 4 percent higher in moisture, 3.5 percent lower in ether extract, 1 percent higher in protein and slightly lower in ash content than those used by Gnaedinger (1962). The differences in composition between the viscera analyzed in the present study and those used by Gnaedinger (1962) were of approximately the same magnitude as the differences in chemical composition of the whole animals and the dressed carcasses.

Analysis of the blood showed mean values of 79.15 percent moisture, 0.01 percent ether extract, 20.15 percent protein and 0.96 percent ash. The standard deviations for these values were 0.88 percent for moisture, 1.52 for protein and 0.05 for ash. The percent of ether extract in the blood was quite small which made the analysis difficult. For this reason, the figure presented here was taken from an average of the ether extract analysis of the blood from the first five hogs. Thus, no standard deviations were calculated for the ether extract content of the blood in the present study.

Gnaedinger (1962) reported average values of 79.75 percent moisture, 0.10 percent ether extract, 18.95 percent protein and 1.22 percent ash for the blood of the 24 hogs. Thus, the blood of the animals in the present study contained slightly less moisture and fat, about 1 percent more protein and 0.25 percent less ash than the blood of those utilized by Gnaedinger (1962).

Analysis of the hair, including scurf and toenails, showed an average of 4.81 percent moisture, 2.29 percent ether extract, 92.27 percent protein and 1.47 percent ash. Since these values were obtained from a composite sample of the hair from five pigs, standard deviations could not be calculated. Gnaedinger (1962) reported average values of 8.25 percent moisture, 1.91 percent ether extract, 89.00 percent protein and 1.31 percent ash. The difference in the percent moisture of the hair from the two studies was undoubtedly due to differences in the degree of air drying of the hair before analysis. The hair from the hogs in the present study was slightly higher in percent ether extract, percent protein and percent ash than that of the hogs of Gnaedinger (1962). The higher values were probably all a consequence of the lower moisture content of the hair in the present study.

The contribution of each body compartment to the whole animal in terms of moisture, ether extract, protein and ash in shown in Appendix Tables IX through XII. A summary of the means and standard deviations of these values is shown in Table 5.

The standard deviations indicate the percentage error which would occur in the chemical analysis of the whole animal if any body compartment

Table 5. Contribution of each compartment to the whole animal as percentages of total moisture, ether extract, protein and ash.

| | Moisture | | Ether extract | | Protein | | Ash | |
|---|---|---|---|---|---|---|---|---|
| | Mean | S.D. | Mean | S.D. | Mean | S.D. | Mean | S.D. |
| Shoulder | 20.93 | 1.14 | 22.99 | 1.18 | 23.08 | 1.07 | 26.86 | 1.58 |
| Loin | 16.34 | 0.85 | 26.93 | 2.05 | 18.92 | 0.87 | 21.19 | 1.64 |
| Side | 10.63 | 0.53 | 22.61 | 1.45 | 11.91 | 0.74 | 5.95 | 0.49 |
| Ham | 20.56 | 0.59 | 17.53 | 1.15 | 22.59 | 0.93 | 23.87 | 1.97 |
| Head and viscera | 22.41 | 2.12 | 9.90 | 1.14 | 16.04 | 1.29 | 20.56 | 2.94 |
| Blood | 5.74 | 0.54 | --- | -- | 5.00 | 0.58 | 1.40 | 0.22 |
| Hair, scurf and toenails | 0.04 | <0.01 | 0.03 | <0.01 | 2.47 | 0.29 | 0.20 | 0.04 |

was excluded. Thus, Table 5 shows that the analysis of the blood and the hair, scurf and toenails could be excluded without introducing more than one percent error for any single chemical component. This error could be further reduced by using average values for the composition of these two compartments in making computations of composition. This would simplify the analysis, in that only the weights of these two compartments would need to be recorded. A further illustration of this fact can be shown by adding the means of the other five compartments (shoulder, loin, side, ham, and head and viscera). These five compartments contributed 90.87 percent of the total moisture, 99.96 percent of the total ether extract, 92.54 percent of the total protein and 98.43 percent of the total ash of the whole animals.

Table 6 shows a summary of correlation coefficients between the percentage of each chemical component of the whole animal and the corresponding chemical component of each of the cuts which make up the carcass (shoulder, loin, side and ham). These correlations were calculated in order to ascertain the usefulness of the composition of any single cut for predicting the composition of the whole animal.

Since the correlations are all highly significant, it would seem that chemical analysis data from any one of them would be useful in predicting total composition. On the whole, the correlation coefficients for the shoulder were the highest, although the relationships were approximately the same for the ham. Thus, the following equations were derived from the experimental data:

(1) percent total body water from percent moisture of the shoulder

$$Y = 0.84X + 10.26 \qquad (33)$$

$$S_{y.x} = \pm 4.65\%$$

$$r = 0.917$$

where:

Y = calculated value for percent total body water

X = percent moisture of the shoulder

(2) percent total ether extract from percent ether extract of the shoulder

$$Y = 0.85X + 3.30 \qquad (34)$$

$$S_{y.x} = \pm 5.32\%$$

$$r = 0.934$$

Table 6. Summary of correlation coefficients between chemical analysis data on the whole animal and the carcass compartments and between various physical measurements and chemical analysis data.

| Variable | "r" value |
|---|---|
| % Total water vs. % water of shoulder | 0.917** |
| % Total water vs. % water of loin | 0.831** |
| % Total water vs. % water of side | 0.912** |
| % Total water vs. % water of ham | 0.917** |
| % Total ether extract vs. % ether extract of shoulder | 0.934** |
| % Total ether extract vs. % ether extract of loin | 0.863** |
| % Total ether extract vs. % ether extract of side | 0.935** |
| % Total ether extract vs. % ether extract of ham | 0.942** |
| % Total protein vs. % protein of shoulder | 0.910** |
| % Total protein vs. % protein of loin | 0.854** |
| % Total protein vs. % protein of side | 0.892** |
| % Total protein vs. % protein of ham | 0.861** |
| Carcass length vs. % total water | -.100 |
| Carcass length vs. % total ether extract | -.072 |
| Carcass length vs. % total protein | -.192 |
| Average backfat thickness vs. % total ether extract | 0.608** |
| Loin eye area vs. % total protein | 0.619** |

**P < .01

where:

Y = calculated value for percent total ether extract

X = percent ether extract of the shoulder

(3) percent total protein from percent total protein of the shoulder

$$Y = 0.83X + 1.91 \qquad (35)$$

$$S_{y.x} = \pm 1.85\%$$

$$r = 0.910$$

where:

Y = percent total protein

X = percent protein of the shoulder

The standard error of the estimate ($S_{y.x}$) for each of these equations shows the error which would be expected to occur in the prediction of whole body composition from chemical analysis of the shoulder. The magnitude of these errors indicates that a prediction of this kind would be limited in its usefulness. The high standard deviations for the percentage composition, as mentioned earlier, indicate substantial variation in chemical composition among the individual hogs utilized in this study. This is undoubtedly the reason for the high standard errors in the above equations.

In order to ascertain whether the ham was more indicative of composition than the shoulder, regression equations similar to equations 33, 34 and 35 were calculated for percent moisture, ether extract and protein. Standard errors of the estimate for these equations were 4.63 for percent

moisture, 5.12 for ether extract and 2.32 for protein. Although the standard errors were similar for both percent moisture and ether extract in the ham, the greater error for percentage protein of the ham as compared with the shoulder indicates the latter cut may be slightly more indicative of composition.

It should be pointed out that the data presented here are from hogs of approximately the same weight, age and breed. The same relationships might not exist for hogs of a different age, weight or breed.

Appendix Table XIII shows the values obtained for carcass length, average backfat thickness, loin eye area and dressing percentage.

Table 6 shows the correlation coefficients for carcass length, average backfat thickness and loin eye area with chemical analysis data. Carcass length was not significantly correlated with percent total body water, percent total ether extract or percent total protein. Average backfat thickness was significantly correlated ($P < .01$) with percent ether extract of the whole animal. Loin eye area was significantly correlated ($P < .01$) with the percentage of protein of the whole animal. Although the latter two values are highly significant, they are too low to accurately predict composition. The correlation coefficient of 0.608 obtained between average backfat thickness and percent total fat indicates that only about 36 percent of the variation in total fat content was accounted for by differences in average backfat thickness. Since the relationship is approximately the same between loin eye area and percent total protein, loin eye area accounted for only about 36 percent of the variation in

percent total protein. In order for these relationships to be of value in predicting total composition, the correlation coefficients would need to be about 0.9 or greater. With a correlation coefficient of this magnitude, the independent variable would account for 81 percent or more of the variation in the dependent variable.

The high relationship between the composition of the carcass and the composition of the whole animal suggests that from a knowledge of one the other can be predicted. From a practical standpoint, the most useful procedure would be to predict the composition of the carcass from the composition of the whole animal, preferably using the live animal. However, this procedure requires an accurate method of assessing the composition of the whole animal. Specific gravity has been shown to be highly related to the composition of the animal by several workers (Rathbun et al., 1945; Kraybill et al., 1953; and Pitts, 1956). Thus, if specific gravity could be accurately determined on the live animal, the composition of the carcass could be estimated with a reasonable degree of accuracy.

## SUMMARY

The original apparatus for measuring body volume by air displacement and helium dilution techniques was modified by adding two additional chambers, which were identical with the existing chambers. These chambers formed a reference system, which was a mirror image of the measuring system utilized in the previous apparatus. An inert reference of approximately the same volume as the subject was placed in the large chamber of the reference system, while the subject was placed in the other large chamber. By means of such an arrangement, the relatively small difference in volume between the subject and the reference was measured instead of the total volume of the subject as was done in previous studies.

The modified air displacement and helium dilution procedures were used to determine the body volume of 24 market weight hogs. A highly significant ($P < .01$) correlation coefficient of 0.576 was obtained between the volumes determined by the air displacement and helium dilution methods. Specific gravity values calculated from volumes obtained by the air displacement method were also significantly correlated ($r = 0.588$) with specific gravity values determined by the helium dilution procedure.

Specific gravity values calculated by air displacement were significantly correlated ($r = 0.649$) with theoretical density values computed from chemical analysis data. Neither the air displacement nor the helium dilution procedure, however, gave specific gravity values which were significantly correlated with percentages of moisture, ether extract or protein as determined by chemical analysis. Percent ash was significantly

correlated ($P < .01$) with the specific gravity values obtained by both methods.

Differences in relative humidity between the subject and reference chambers and changes in relative humidity within the subject chamber appeared to be responsible for a substantial amount of the error with both the air displacement and helium dilution procedures. The error due to relative humidity was especially significant because it occurred twice in the calculation of specific gravity; once in the measurement of the empty chamber volumes and again in the determination of the body volume of the subject. Additional errors may have occurred with the air displacement procedure as a result of the inability to accurately read temperature and pressure. Other errors may have occurred with the helium dilution procedure resulting from the accumulation of carbon dioxide within the subject chamber.

For the purpose of chemical analysis, each hog was divided into seven compartments: shoulder, loin, side, ham, head and viscera, blood, and hair including the scurf and toenails. The contribution of each compartment to the whole animal in terms of percentage moisture, ether extract, protein and ash was determined. The data showed that the five largest compartments (shoulder, loin, side, ham, and head and viscera) contained 90.87 percent of the total moisture, 99.96 percent of the total ether extract, 92.54 percent of the total protein and 98.43 percent of the total ash from the whole animal. The data further suggest that average values could be used for the composition of the blood and hair

without introducing a significant amount of error into the analysis.

For the seven compartments of the whole body, the shoulder and ham appeared to be most closely related to the whole animal in terms of percentage composition. Equations were derived for predicting total composition from the composition of the shoulder and ham, however the magnitude of the standard errors of the estimate indicates that a prediction of this kind would be limited in its usefulness.

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# APPENDIX

Appendix Table I. Summary of body weight, volume and specific gravity values.

| Pig No. | Live weight (lbs.) | Live weight (Kg.) | Air displacement Specific gravity | Air displacement Volume (liters) | Helium dilution Specific gravity | Helium dilution Volume (liters) | Theoretical density |
|---|---|---|---|---|---|---|---|
| 1 | 220.0 | 99.88 | 1.1253 | 88.76 | 1.0142 | 98.48 | 1.0390 |
| 2 | 210.0 | 95.34 | 1.1105 | 85.85 | 1.0150 | 93.93 | 1.0505 |
| 3 | 238.0 | 108.05 | 1.1061 | 97.68 | 1.0258 | 105.33 | 1.0327 |
| 4 | 223.0 | 101.24 | 1.0588 | 95.62 | 1.0159 | 99.66 | 1.0415 |
| 5 | 203.5 | 92.39 | .9395 | 98.34 | 1.0203 | 90.55 | 1.0256 |
| 6 | 215.0 | 97.61 | .9652 | 101.13 | .9686 | 100.77 | 1.0405 |
| 7 | 217.5 | 98.75 | .9903 | 99.72 | .9958 | 99.17 | 1.0267 |
| 8 | 217.0 | 98.52 | 1.0018 | 98.34 | 1.0145 | 97.11 | 1.0376 |
| 9 | 196.0 | 88.98 | .9504 | 93.62 | .9877 | 90.09 | 1.0253 |
| 10 | 217.0 | 98.52 | .9929 | 99.22 | .9969 | 98.83 | 1.0380 |
| 11 | 211.0 | 95.79 | .9360 | 102.34 | .9867 | 97.08 | 1.0288 |
| 12 | 219.0 | 99.43 | .9505 | 104.61 | 1.0084 | 98.60 | 1.0283 |
| 13 | 218.0 | 98.97 | .9524 | 103.92 | 1.0033 | 98.64 | 1.0337 |
| 14 | 208.5 | 94.66 | .9457 | 100.10 | 1.0048 | 94.21 | 1.0287 |
| 15 | 213.0 | 96.70 | .9428 | 102.57 | .9960 | 97.06 | 1.0335 |
| 16 | 206.0 | 93.52 | .9517 | 98.27 | .9982 | 93.69 | 1.0345 |
| 17 | 211.0 | 95.79 | .9242 | 103.65 | .9899 | 96.77 | 1.0216 |
| 18 | 196.0 | 88.98 | .9300 | 95.68 | .9775 | 91.03 | 1.0337 |
| 19 | 200.0 | 90.80 | .9279 | 97.86 | .9955 | 91.21 | 1.0160 |
| 20 | 226.0 | 102.60 | .9674 | 106.06 | 1.0107 | 101.51 | 1.0266 |
| 21 | 209.5 | 95.11 | .9739 | 97.66 | .9987 | 95.23 | 1.0339 |
| 22 | 196.5 | 89.21 | .9675 | 92.21 | .9856 | 90.51 | 1.0371 |
| 23 | 215.5 | 97.84 | 1.0067 | 97.19 | 1.0011 | 97.73 | 1.0301 |
| 24 | 180.0 | 81.72 | .9714 | 84.13 | 1.0013 | 81.61 | 1.0302 |
| Mean | 211.1 | 95.85 | .9829 | 97.69 | 1.0005 | 95.78 | 1.0323 |

Appendix Table II. Weights of various compartments, live animal and hot dressed carcass (lbs.)

| Pig No. | Live wt. | Hot dressed carcass | Chilled carcass | Shoulder | Loin | Side | Ham | Viscera and head | Blood | Hair, scurf and toenails |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 217.0 | 168.80 | 165.13 | 47.80 | 40.35 | 34.28 | 42.70 | 37.50 | 7.67 | 0.78 |
| 2 | 207.5 | 164.55 | 160.53 | 49.40 | 38.82 | 29.03 | 43.28 | 34.00 | 6.00 | 0.84 |
| 3 | 236.0 | 186.80 | 182.85 | 50.83 | 47.85 | 36.28 | 47.89 | 38.25 | 7.71 | 1.00 |
| 4 | 224.5 | 177.55 | 173.12 | 50.99 | 44.86 | 32.23 | 45.04 | 36.25 | 7.67 | 0.86 |
| 5 | 201.5 | 155.80 | 152.30 | 43.99 | 37.78 | 29.23 | 40.82 | 36.00 | 7.74 | 0.69 |
| 6 | 214.5 | 167.30 | 163.80 | 45.99 | 43.61 | 31.54 | 41.95 | 37.50 | 7.84 | 0.89 |
| 7 | 216.5 | 165.80 | 162.30 | 46.36 | 42.16 | 31.01 | 42.17 | 41.10 | 8.08 | 0.73 |
| 8 | 216.0 | 165.30 | 161.80 | 46.73 | 42.83 | 30.63 | 41.38 | 40.50 | 8.53 | 0.68 |
| 9 | 196.0 | 150.30 | 146.80 | 40.10 | 38.47 | 27.84 | 40.22 | 37.25 | 6.95 | 0.70 |
| 10 | 217.5 | 164.80 | 161.80 | 46.22 | 41.53 | 29.22 | 43.48 | 41.25 | 9.49 | 0.93 |
| 11 | 212.0 | 161.00 | 157.00 | 43.59 | 42.18 | 30.29 | 40.41 | 42.25 | 7.75 | 0.72 |
| 12 | 219.5 | 166.80 | 162.80 | 43.76 | 45.48 | 30.99 | 42.23 | 43.00 | 8.63 | 0.77 |
| 13 | 218.5 | 166.30 | 162.80 | 46.31 | 41.67 | 29.52 | 44.81 | 41.50 | 8.82 | 0.89 |
| 14 | 208.5 | 157.30 | 154.30 | 43.34 | 40.37 | 29.29 | 40.77 | 41.25 | 8.37 | 0.79 |
| 15 | 213.0 | 165.80 | 161.80 | 45.97 | 42.11 | 30.40 | 43.11 | 38.80 | 7.19 | 0.95 |
| 16 | 206.0 | 162.30 | 158.80 | 45.46 | 41.71 | 29.75 | 41.56 | 33.50 | 8.76 | 0.96 |
| 17 | 211.0 | 170.30 | 166.80 | 48.59 | 44.28 | 31.20 | 42.29 | 32.00 | 7.94 | 0.95 |
| 18 | 196.5 | 155.05 | 151.30 | 44.29 | 40.20 | 27.57 | 38.84 | 32.75 | 7.08 | 0.79 |
| 19 | 201.0 | 160.55 | 156.80 | 46.11 | 39.62 | 30.03 | 40.27 | 33.25 | 7.20 | 0.78 |
| 20 | 227.5 | 182.80 | 179.30 | 51.19 | 48.65 | 34.05 | 44.33 | 36.25 | 7.71 | 0.78 |
| 21 | 210.0 | 162.30 | 158.80 | 44.90 | 43.05 | 27.98 | 42.18 | 36.75 | 9.10 | 1.00 |
| 22 | 197.0 | 150.30 | 146.80 | 44.40 | 40.80 | 25.10 | 36.06 | 36.00 | 8.59 | 0.98 |
| 23 | 216.5 | 170.30 | 166.30 | 48.67 | 44.18 | 29.46 | 43.65 | 35.25 | 8.26 | 1.03 |
| 24 | 181.0 | 139.80 | 136.30 | 39.58 | 36.51 | 23.21 | 36.27 | 33.50 | 6.92 | 0.99 |
| Mean | 211.2 | 164.18 | 160.53 | 45.98 | 42.09 | 30.01 | 42.01 | 37.34 | 7.89 | 0.85 |

Appendix Table III. Percentage composition of whole animal and hot dressed carcass.

| Pig No. | Whole animal | | | | Carcass | | | |
|---|---|---|---|---|---|---|---|---|
| | Moisture | Ether extract | Protein | Ash | Moisture | Ether extract | Protein | Ash |
| 1 | 51.24 | 31.30 | 13.84 | 3.12 | 47.46 | 35.92 | 13.53 | 2.85 |
| 2 | 55.08 | 25.58 | 15.85 | 3.01 | 52.88 | 28.16 | 15.87 | 2.91 |
| 3 | 50.44 | 31.81 | 14.76 | 3.04 | 46.70 | 36.17 | 14.47 | 2.96 |
| 4 | 50.93 | 30.99 | 14.34 | 3.05 | 47.86 | 35.12 | 14.02 | 2.70 |
| 5 | 50.90 | 33.01 | 14.20 | 2.43 | 46.39 | 38.15 | 14.24 | 2.43 |
| 6 | 51.57 | 31.13 | 14.20 | 2.48 | 46.99 | 36.30 | 13.83 | 2.49 |
| 7 | 50.26 | 32.75 | 14.83 | 2.63 | 45.15 | 38.50 | 14.89 | 2.63 |
| 8 | 52.55 | 30.07 | 14.66 | 2.61 | 48.20 | 35.14 | 14.69 | 2.56 |
| 9 | 49.67 | 34.70 | 13.57 | 2.30 | 44.90 | 40.47 | 13.21 | 2.24 |
| 10 | 53.30 | 28.34 | 15.81 | 2.77 | 48.40 | 33.37 | 15.46 | 2.91 |
| 11 | 52.78 | 30.85 | 14.85 | 2.17 | 47.69 | 36.45 | 14.61 | 2.21 |
| 12 | 51.55 | 31.85 | 14.70 | 2.40 | 45.95 | 37.87 | 14.33 | 2.50 |
| 13 | 52.27 | 29.80 | 15.65 | 2.63 | 47.47 | 35.23 | 15.37 | 2.71 |
| 14 | 50.23 | 32.87 | 14.94 | 2.19 | 44.90 | 38.69 | 14.57 | 2.24 |
| 15 | 55.03 | 26.71 | 16.75 | 2.50 | 51.24 | 30.90 | 16.57 | 2.64 |
| 16 | 55.36 | 26.08 | 17.11 | 2.49 | 51.78 | 29.98 | 16.85 | 2.58 |
| 17 | 48.21 | 34.99 | 14.83 | 2.51 | 43.81 | 40.18 | 14.16 | 2.50 |
| 18 | 55.39 | 26.66 | 16.50 | 2.43 | 52.12 | 30.28 | 16.21 | 2.46 |
| 19 | 47.07 | 36.49 | 14.86 | 2.40 | 43.08 | 41.33 | 14.24 | 2.37 |
| 20 | 49.97 | 32.78 | 15.25 | 2.47 | 46.48 | 36.65 | 14.98 | 2.35 |
| 21 | 53.56 | 28.48 | 16.05 | 2.52 | 49.65 | 32.62 | 15.63 | 2.53 |
| 22 | 56.78 | 25.28 | 16.39 | 2.45 | 53.22 | 29.06 | 16.15 | 2.50 |
| 23 | 50.64 | 31.53 | 15.57 | 2.63 | 46.41 | 36.79 | 15.00 | 2.72 |
| 24 | 53.24 | 29.33 | 15.71 | 2.54 | 49.69 | 33.43 | 15.10 | 2.50 |
| Mean | 52.00 | 30.56 | 15.21 | 2.57 | 47.85 | 35.28 | 14.92 | 2.56 |

Appendix Table IV. Percentage composition of ether extract-free whole animal and ether-extract-free carcass.

| Pig No. | Whole animal | | | | Carcass | | | |
|---|---|---|---|---|---|---|---|---|
| | Weight (lbs.) | Moisture | Protein | Ash | Weight (lbs.) | Moisture | Protein | Ash |
| 1 | 146.48 | 75.12 | 20.30 | 4.58 | 108.16 | 74.08 | 21.12 | 4.45 |
| 2 | 151.88 | 74.49 | 21.44 | 4.08 | 118.21 | 73.61 | 22.09 | 4.05 |
| 3 | 159.51 | 73.91 | 21.63 | 4.46 | 119.24 | 73.16 | 22.67 | 4.64 |
| 4 | 151.90 | 74.54 | 20.99 | 4.46 | 115.19 | 73.77 | 21.62 | 4.16 |
| 5 | 135.21 | 75.38 | 21.03 | 3.59 | 96.37 | 75.00 | 23.01 | 3.93 |
| 6 | 145.74 | 75.56 | 20.81 | 3.63 | 106.57 | 73.77 | 21.70 | 3.90 |
| 7 | 146.08 | 74.21 | 21.90 | 3.89 | 101.93 | 73.44 | 24.22 | 4.28 |
| 8 | 150.12 | 75.26 | 21.00 | 3.74 | 107.72 | 73.96 | 22.54 | 3.93 |
| 9 | 127.91 | 75.80 | 20.70 | 3.50 | 89.47 | 75.42 | 22.19 | 3.76 |
| 10 | 155.58 | 74.15 | 22.00 | 3.85 | 109.81 | 72.63 | 23.20 | 4.37 |
| 11 | 147.78 | 75.62 | 21.27 | 3.11 | 102.31 | 75.05 | 22.99 | 3.48 |
| 12 | 150.48 | 75.09 | 21.42 | 3.49 | 103.63 | 73.96 | 23.07 | 4.02 |
| 13 | 153.45 | 74.10 | 22.18 | 3.73 | 107.71 | 73.30 | 23.73 | 4.18 |
| 14 | 139.92 | 74.57 | 22.18 | 3.25 | 96.44 | 73.23 | 23.76 | 3.66 |
| 15 | 158.02 | 74.09 | 22.55 | 3.36 | 114.57 | 74.16 | 23.98 | 3.82 |
| 16 | 154.05 | 73.85 | 22.82 | 3.32 | 113.65 | 73.95 | 24.07 | 3.68 |
| 17 | 138.43 | 73.55 | 22.63 | 3.83 | 101.87 | 73.24 | 23.67 | 4.17 |
| 18 | 145.42 | 74.54 | 22.20 | 3.27 | 108.10 | 74.75 | 23.26 | 3.52 |
| 19 | 129.85 | 73.18 | 23.10 | 3.73 | 94.19 | 73.42 | 24.27 | 4.05 |
| 20 | 154.02 | 73.83 | 22.53 | 3.64 | 115.81 | 73.36 | 23.65 | 3.70 |
| 21 | 150.86 | 74.25 | 22.25 | 3.50 | 109.36 | 73.68 | 23.19 | 3.76 |
| 22 | 148.12 | 75.09 | 21.68 | 3.23 | 106.63 | 75.02 | 22.76 | 3.52 |
| 23 | 147.90 | 73.56 | 22.62 | 3.82 | 107.64 | 73.42 | 23.73 | 4.31 |
| 24 | 129.54 | 74.47 | 21.97 | 3.56 | 93.06 | 74.64 | 22.68 | 3.76 |
| Mean | 146.59 | 74.51 | 21.80 | 3.69 | 106.15 | 73.91 | 23.05 | 3.96 |

Appendix Table V. Percent moisture of various whole animal compartments.

| Pig No. | Shoulder | Loin | Side | Ham | Head and viscera | Blood | Hair, scurf and toenails |
|---|---|---|---|---|---|---|---|
| 1 | 48.31 | 48.18 | 35.51 | 50.93 | 63.24 | 80.30 | 4.81 |
| 2 | 54.89 | 47.55 | 44.84 | 56.36 | 62.70 | 79.29 | 4.81 |
| 3 | 49.96 | 41.76 | 36.53 | 51.52 | 64.00 | 79.53 | 4.81 |
| 4 | 49.78 | 41.96 | 39.19 | 52.65 | 61.20 | 78.56 | 4.81 |
| 5 | 48.93 | 40.81 | 35.96 | 52.22 | 65.10 | 79.82 | 4.81 |
| 6 | 50.39 | 39.47 | 38.14 | 54.14 | 67.26 | 79.62 | 4.81 |
| 7 | 47.03 | 39.78 | 34.27 | 52.56 | 65.85 | 79.80 | 4.81 |
| 8 | 49.85 | 41.83 | 38.59 | 55.93 | 65.30 | 80.03 | 4.81 |
| 9 | 46.84 | 40.59 | 34.94 | 49.38 | 64.17 | 79.65 | 4.81 |
| 10 | 50.59 | 44.18 | 40.95 | 53.03 | 67.88 | 79.76 | 4.81 |
| 11 | 49.05 | 41.16 | 40.27 | 54.04 | 68.17 | 79.20 | 4.81 |
| 12 | 48.56 | 38.28 | 37.57 | 52.89 | 68.43 | 79.93 | 4.81 |
| 13 | 48.71 | 42.99 | 39.48 | 52.06 | 66.82 | 79.15 | 4.81 |
| 14 | 47.37 | 39.48 | 35.49 | 50.91 | 65.37 | 80.06 | 4.81 |
| 15 | 52.38 | 45.94 | 42.09 | 57.38 | 67.96 | 78.96 | 4.81 |
| 16 | 53.98 | 45.87 | 44.14 | 57.13 | 68.46 | 77.11 | 4.81 |
| 17 | 45.47 | 37.66 | 35.14 | 50.56 | 65.67 | 77.36 | 4.81 |
| 18 | 52.68 | 48.82 | 41.73 | 58.18 | 66.84 | 79.86 | 4.81 |
| 19 | 44.98 | 36.92 | 34.73 | 48.70 | 60.81 | 77.84 | 4.81 |
| 20 | 49.08 | 41.22 | 37.85 | 52.79 | 62.60 | 78.06 | 4.81 |
| 21 | 52.02 | 43.85 | 40.38 | 55.82 | 65.75 | 79.49 | 4.81 |
| 22 | 53.49 | 48.52 | 46.38 | 59.06 | 67.76 | 79.03 | 4.81 |
| 23 | 47.04 | 40.51 | 38.57 | 52.41 | 66.00 | 78.06 | 4.81 |
| 24 | 51.08 | 43.66 | 39.93 | 56.61 | 64.15 | 79.04 | 4.81 |
| Mean | 49.75 | 42.58 | 39.00 | 53.69 | 65.48 | 79.15 | 4.81 |

Appendix Table VI. Percent ether extract of various whole animal compartments.

| Pig No. | Shoulder | Loin | Side | Ham | Head and viscera | Blood | Hair, scurf and toenails |
|---|---|---|---|---|---|---|---|
| 1 | 33.86 | 33.37 | 52.93 | 30.10 | 17.48 | 0.01 | 2.29 |
| 2 | 25.23 | 33.12 | 40.11 | 21.67 | 18.14 | 0.01 | 2.29 |
| 3 | 30.28 | 42.02 | 50.95 | 28.35 | 17.69 | 0.01 | 2.29 |
| 4 | 31.82 | 40.27 | 48.20 | 27.81 | 18.01 | 0.01 | 2.29 |
| 5 | 34.31 | 45.07 | 52.45 | 29.35 | 18.45 | 0.01 | 2.29 |
| 6 | 31.63 | 45.43 | 49.45 | 25.67 | 15.25 | 0.01 | 2.29 |
| 7 | 34.66 | 44.80 | 54.08 | 28.80 | 16.42 | 0.01 | 2.29 |
| 8 | 31.30 | 42.62 | 48.91 | 24.71 | 16.19 | 0.01 | 2.29 |
| 9 | 37.00 | 45.19 | 54.67 | 33.30 | 18.46 | 0.01 | 2.29 |
| 10 | 30.93 | 38.82 | 45.00 | 26.27 | 15.36 | 0.01 | 2.29 |
| 11 | 33.51 | 44.07 | 47.49 | 27.50 | 15.61 | 0.01 | 2.29 |
| 12 | 33.11 | 46.63 | 50.45 | 28.03 | 15.39 | 0.01 | 2.29 |
| 13 | 32.68 | 40.00 | 47.17 | 28.73 | 14.93 | 0.01 | 2.29 |
| 14 | 35.04 | 44.52 | 52.73 | 30.06 | 17.94 | 0.01 | 2.29 |
| 15 | 27.94 | 36.00 | 44.46 | 22.53 | 14.36 | 0.01 | 2.29 |
| 16 | 26.72 | 36.12 | 41.27 | 22.02 | 14.68 | 0.01 | 2.29 |
| 17 | 36.39 | 47.85 | 53.30 | 30.58 | 17.04 | 0.01 | 2.29 |
| 18 | 28.56 | 33.35 | 44.51 | 22.20 | 15.84 | 0.01 | 2.29 |
| 19 | 38.52 | 48.50 | 53.47 | 33.07 | 21.79 | 0.01 | 2.29 |
| 20 | 32.57 | 43.24 | 49.25 | 28.21 | 20.92 | 0.01 | 2.29 |
| 21 | 29.00 | 39.59 | 46.09 | 23.65 | 17.98 | 0.01 | 2.29 |
| 22 | 28.10 | 33.93 | 38.96 | 21.00 | 16.19 | 0.01 | 2.29 |
| 23 | 35.21 | 42.93 | 48.41 | 28.15 | 14.34 | 0.01 | 2.29 |
| 24 | 31.37 | 39.65 | 47.34 | 24.41 | 19.05 | 0.01 | 2.29 |
| Mean | 31.99 | 41.02 | 48.22 | 26.86 | 16.98 | 0.01 | 2.29 |

Appendix Table VII. Percent protein of various whole animal compartments.

| Pig No. | Shoulder | Loin | Side | Ham | Head and viscera | Blood | Hair, scurf and toenails |
|---|---|---|---|---|---|---|---|
| 1 | 14.07 | 14.43 | 10.65 | 15.54 | 12.74 | 18.08 | 92.27 |
| 2 | 16.68 | 15.74 | 13.13 | 18.38 | 13.38 | 18.68 | 92.27 |
| 3 | 15.12 | 13.61 | 13.75 | 16.37 | 13.36 | 18.62 | 92.27 |
| 4 | 14.66 | 13.78 | 12.36 | 16.11 | 13.00 | 19.39 | 92.27 |
| 5 | 15.82 | 13.12 | 11.56 | 16.86 | 11.87 | 17.29 | 92.27 |
| 6 | 15.57 | 11.60 | 10.99 | 17.73 | 12.81 | 20.21 | 92.27 |
| 7 | 16.51 | 14.30 | 12.12 | 17.20 | 12.54 | 18.30 | 92.27 |
| 8 | 15.83 | 13.80 | 12.44 | 17.30 | 12.62 | 17.60 | 92.27 |
| 9 | 14.12 | 13.21 | 10.92 | 15.12 | 12.28 | 19.98 | 92.27 |
| 10 | 15.66 | 15.69 | 13.11 | 18.15 | 14.63 | 19.49 | 92.27 |
| 11 | 16.01 | 13.72 | 12.98 | 16.88 | 13.22 | 21.59 | 92.27 |
| 12 | 16.06 | 13.22 | 12.53 | 16.56 | 13.69 | 19.98 | 92.27 |
| 13 | 16.57 | 15.22 | 13.23 | 17.06 | 13.88 | 21.42 | 92.27 |
| 14 | 15.72 | 14.18 | 11.63 | 17.12 | 13.77 | 20.29 | 92.27 |
| 15 | 18.02 | 16.19 | 14.19 | 18.70 | 15.06 | 20.21 | 92.27 |
| 16 | 18.01 | 16.14 | 15.08 | 19.11 | 14.84 | 22.26 | 92.27 |
| 17 | 15.62 | 12.96 | 11.85 | 16.75 | 14.25 | 22.32 | 92.27 |
| 18 | 17.50 | 16.09 | 14.12 | 18.09 | 15.35 | 19.53 | 92.27 |
| 19 | 15.46 | 13.57 | 12.06 | 16.72 | 14.57 | 21.80 | 92.27 |
| 20 | 16.73 | 13.85 | 12.61 | 17.59 | 13.64 | 21.45 | 92.27 |
| 21 | 16.52 | 15.66 | 13.05 | 17.90 | 14.81 | 20.24 | 92.27 |
| 22 | 16.67 | 16.39 | 14.85 | 17.90 | 14.28 | 21.01 | 92.27 |
| 23 | 15.41 | 15.00 | 12.87 | 17.46 | 14.50 | 22.44 | 92.27 |
| 24 | 16.54 | 14.53 | 13.54 | 16.88 | 14.83 | 21.30 | 92.27 |
| Mean | 16.00 | 14.43 | 12.74 | 17.20 | 13.75 | 20.15 | 92.27 |

Appendix Table VIII. Percent ash of various whole animal compartments.

| Pig No. | Shoulder | Loin | Side | Ham | Head and viscera | Blood | Hair, scurf and toenails |
|---|---|---|---|---|---|---|---|
| 1 | 3.39 | 3.60 | 1.13 | 3.15 | 4.85 | 0.94 | 1.47 |
| 2 | 3.15 | 3.35 | 1.36 | 3.55 | 3.95 | 0.91 | 1.47 |
| 3 | 3.81 | 3.00 | 1.23 | 3.55 | 3.93 | 0.91 | 1.47 |
| 4 | 3.23 | 3.29 | 1.15 | 2.87 | 5.24 | 1.07 | 1.47 |
| 5 | 3.20 | 2.26 | 1.03 | 3.02 | 2.73 | 0.97 | 1.47 |
| 6 | 3.16 | 2.41 | 1.05 | 3.18 | 2.77 | 1.05 | 1.47 |
| 7 | 3.50 | 2.58 | 1.01 | 3.18 | 2.99 | 1.03 | 1.47 |
| 8 | 3.28 | 2.51 | 1.09 | 3.11 | 3.21 | 0.95 | 1.47 |
| 9 | 2.60 | 2.42 | 0.89 | 2.83 | 2.78 | 1.05 | 1.47 |
| 10 | 3.40 | 3.15 | 1.23 | 3.59 | 2.64 | 0.95 | 1.47 |
| 11 | 2.79 | 2.24 | 1.00 | 2.71 | 2.25 | 0.95 | 1.47 |
| 12 | 3.56 | 2.40 | 1.00 | 2.86 | 2.33 | 0.86 | 1.47 |
| 13 | 3.25 | 2.96 | 0.96 | 3.30 | 2.73 | 0.89 | 1.47 |
| 14 | 2.72 | 2.34 | 0.87 | 2.84 | 2.25 | 0.95 | 1.47 |
| 15 | 3.28 | 2.93 | 1.07 | 3.03 | 2.20 | 0.98 | 1.47 |
| 16 | 2.96 | 2.79 | 1.24 | 3.14 | 2.53 | 0.97 | 1.47 |
| 17 | 3.02 | 2.47 | 1.01 | 3.23 | 3.02 | 0.88 | 1.47 |
| 18 | 3.06 | 2.79 | 1.10 | 2.65 | 2.63 | 0.94 | 1.47 |
| 19 | 2.77 | 2.45 | 1.01 | 3.13 | 2.87 | 0.92 | 1.47 |
| 20 | 2.97 | 2.48 | 0.99 | 2.75 | 3.42 | 0.96 | 1.47 |
| 21 | 3.24 | 2.49 | 0.99 | 3.10 | 2.94 | 0.92 | 1.47 |
| 22 | 2.99 | 2.77 | 1.21 | 2.75 | 2.63 | 0.94 | 1.47 |
| 23 | 3.21 | 3.22 | 1.07 | 3.07 | 2.59 | 0.96 | 1.47 |
| 24 | 3.01 | 2.68 | 1.07 | 2.99 | 3.08 | 1.00 | 1.47 |
| Mean | 3.16 | 2.75 | 1.08 | 3.07 | 3.02 | 0.96 | 1.47 |

Appendix Table IX. Percent of total body moisture contributed by each compartment.

| Pig No. | Total moisture (lbs.) | Shoulder | Loin | Side | Ham | Head and viscera | Blood | Hair, scurf and toenails |
|---|---|---|---|---|---|---|---|---|
| 1 | 110.04 | 20.98 | 17.67 | 11.06 | 19.77 | 21.56 | 5.60 | 0.04 |
| 2 | 113.13 | 23.97 | 16.32 | 11.51 | 21.56 | 18.85 | 4.21 | 0.04 |
| 3 | 117.90 | 21.54 | 16.95 | 11.24 | 20.92 | 20.76 | 5.20 | 0.04 |
| 4 | 113.23 | 22.41 | 16.62 | 11.15 | 20.94 | 19.60 | 5.33 | 0.04 |
| 5 | 101.92 | 21.11 | 15.13 | 10.31 | 20.92 | 23.00 | 6.06 | 0.03 |
| 6 | 110.12 | 21.04 | 15.63 | 10.92 | 20.62 | 22.90 | 5.67 | 0.04 |
| 7 | 108.41 | 20.11 | 15.47 | 9.81 | 20.44 | 24.96 | 5.95 | 0.04 |
| 8 | 112.98 | 20.61 | 15.86 | 10.46 | 20.48 | 23.41 | 6.06 | 0.03 |
| 9 | 96.95 | 19.37 | 16.10 | 10.04 | 20.48 | 24.65 | 5.71 | 0.03 |
| 10 | 115.37 | 20.27 | 15.91 | 10.38 | 19.99 | 24.27 | 6.56 | 0.04 |
| 11 | 111.75 | 19.13 | 15.53 | 10.92 | 19.54 | 25.77 | 5.49 | 0.03 |
| 12 | 113.00 | 18.81 | 15.41 | 10.30 | 19.77 | 26.04 | 6.11 | 0.04 |
| 13 | 113.70 | 19.84 | 15.75 | 10.25 | 20.52 | 24.39 | 6.14 | 0.04 |
| 14 | 104.34 | 19.68 | 15.28 | 9.97 | 19.90 | 25.85 | 6.42 | 0.04 |
| 15 | 117.07 | 20.57 | 16.53 | 10.93 | 21.13 | 22.52 | 4.85 | 0.04 |
| 16 | 113.77 | 21.57 | 16.81 | 11.51 | 20.87 | 20.15 | 5.93 | 0.04 |
| 17 | 101.81 | 21.70 | 16.38 | 10.77 | 21.00 | 20.64 | 6.03 | 0.05 |
| 18 | 108.39 | 21.52 | 18.11 | 10.61 | 20.85 | 20.20 | 5.21 | 0.04 |
| 19 | 95.02 | 21.82 | 15.39 | 10.97 | 20.64 | 21.27 | 5.89 | 0.04 |
| 20 | 113.71 | 22.09 | 17.63 | 11.34 | 20.58 | 19.95 | 5.29 | 0.04 |
| 21 | 112.02 | 20.85 | 16.85 | 10.09 | 21.01 | 21.57 | 6.45 | 0.05 |
| 22 | 111.22 | 21.35 | 17.80 | 10.47 | 19.15 | 21.93 | 6.11 | 0.05 |
| 23 | 108.80 | 21.04 | 16.45 | 10.44 | 21.03 | 21.39 | 5.93 | 0.05 |
| 24 | 96.47 | 20.95 | 16.52 | 9.61 | 21.28 | 22.27 | 5.67 | 0.05 |
| Mean | 109.21 | 20.93 | 16.34 | 10.63 | 20.56 | 22.41 | 5.74 | 0.04 |
| S.D. | --- | 1.14 | 0.85 | 0.53 | 0.59 | 2.12 | 0.54 | <.01 |

Appendix Table X. Percent of total body ether extract contributed by each compartment.

| Pig No. | Total ether extract (lbs) | Shoulder | Loin | Side | Ham | Head and viscera | Blood | Hair, scurf and toenails |
|---|---|---|---|---|---|---|---|---|
| 1 | 67.22 | 24.09 | 20.02 | 26.99 | 19.12 | 9.76 | - | 0.03 |
| 2 | 52.53 | 23.72 | 24.48 | 22.16 | 17.86 | 11.75 | - | 0.04 |
| 3 | 74.35 | 20.70 | 27.05 | 24.86 | 18.26 | 9.11 | - | 0.03 |
| 4 | 68.91 | 23.55 | 26.22 | 22.54 | 18.18 | 9.48 | - | 0.03 |
| 5 | 66.09 | 22.83 | 25.77 | 23.20 | 18.13 | 10.05 | - | 0.03 |
| 6 | 66.47 | 21.89 | 29.80 | 23.47 | 16.20 | 8.61 | - | 0.03 |
| 7 | 70.64 | 22.75 | 26.74 | 23.74 | 17.19 | 9.56 | - | 0.03 |
| 8 | 64.66 | 22.63 | 28.22 | 23.17 | 15.81 | 10.15 | - | 0.03 |
| 9 | 67.73 | 21.91 | 25.66 | 22.47 | 19.77 | 10.16 | - | 0.03 |
| 10 | 61.35 | 23.31 | 26.28 | 21.43 | 18.61 | 10.33 | - | 0.03 |
| 11 | 65.31 | 22.37 | 28.46 | 22.02 | 17.01 | 10.11 | - | 0.03 |
| 12 | 69.81 | 20.76 | 30.38 | 22.39 | 16.96 | 9.48 | - | 0.03 |
| 13 | 64.81 | 23.35 | 25.72 | 21.48 | 19.86 | 9.57 | - | 0.03 |
| 14 | 68.28 | 22.25 | 26.32 | 22.61 | 17.96 | 10.84 | - | 0.03 |
| 15 | 56.82 | 22.60 | 26.68 | 23.79 | 17.09 | 9.80 | - | 0.04 |
| 16 | 53.59 | 22.67 | 28.12 | 22.91 | 17.07 | 9.18 | - | 0.04 |
| 17 | 73.90 | 23.92 | 28.67 | 22.50 | 17.50 | 7.37 | - | 0.03 |
| 18 | 52.16 | 24.25 | 25.71 | 23.52 | 16.53 | 9.95 | - | 0.04 |
| 19 | 73.63 | 24.12 | 26.10 | 21.81 | 18.09 | 9.85 | - | 0.03 |
| 20 | 74.59 | 22.35 | 28.21 | 22.48 | 16.77 | 10.16 | - | 0.03 |
| 21 | 59.57 | 21.86 | 28.61 | 21.66 | 16.75 | 11.10 | - | 0.03 |
| 22 | 49.52 | 25.20 | 27.95 | 19.75 | 15.29 | 11.77 | - | 0.04 |
| 23 | 67.73 | 25.31 | 28.01 | 21.05 | 18.15 | 7.46 | - | 0.03 |
| 24 | 53.14 | 23.37 | 27.25 | 20.68 | 16.65 | 12.01 | - | 0.04 |
| Mean | 64.28 | 22.99 | 26.93 | 22.61 | 17.53 | 9.90 | - | 0.03 |
| S.D. | - | 1.18 | 2.05 | 1.45 | 1.15 | 1.14 | - | <.01 |

Appendix Table XI. Percent of total body protein contributed by each compartment.

| Pig No. | Total protein (lbs.) | Shoulder | Loin | Side | Ham | Head and viscera | Blood | Hair, scurf and toenails |
|---|---|---|---|---|---|---|---|---|
| 1 | 29.73 | 22.64 | 19.58 | 12.28 | 22.33 | 16.08 | 4.68 | 2.42 |
| 2 | 32.56 | 25.31 | 18.77 | 11.70 | 24.42 | 13.97 | 3.44 | 2.40 |
| 3 | 34.50 | 22.30 | 18.87 | 14.46 | 22.72 | 14.81 | 4.17 | 2.67 |
| 4 | 31.89 | 23.46 | 19.38 | 12.48 | 22.77 | 14.77 | 4.67 | 2.48 |
| 5 | 28.43 | 24.48 | 17.45 | 11.89 | 24.20 | 15.02 | 4.71 | 2.25 |
| 6 | 30.33 | 23.61 | 16.68 | 11.44 | 24.53 | 15.83 | 5.21 | 2.70 |
| 7 | 31.99 | 23.91 | 18.85 | 11.75 | 22.66 | 16.10 | 4.63 | 2.09 |
| 8 | 31.52 | 23.48 | 18.75 | 12.09 | 22.72 | 16.21 | 4.76 | 2.00 |
| 9 | 26.48 | 21.37 | 19.18 | 11.48 | 22.96 | 17.26 | 5.25 | 2.49 |
| 10 | 34.22 | 21.16 | 19.05 | 11.19 | 23.06 | 17.62 | 5.41 | 2.51 |
| 11 | 31.44 | 22.20 | 18.42 | 12.50 | 21.69 | 17.78 | 5.31 | 2.10 |
| 12 | 32.23 | 21.81 | 18.65 | 12.04 | 21.69 | 18.27 | 5.34 | 2.20 |
| 13 | 34.03 | 22.54 | 18.63 | 11.49 | 22.45 | 16.93 | 5.55 | 2.41 |
| 14 | 31.03 | 21.95 | 18.43 | 10.99 | 22.49 | 18.30 | 5.48 | 2.35 |
| 15 | 35.64 | 23.23 | 19.14 | 12.09 | 22.62 | 16.39 | 4.07 | 2.47 |
| 16 | 35.16 | 23.29 | 19.14 | 12.77 | 22.58 | 14.14 | 5.55 | 2.53 |
| 17 | 31.32 | 24.23 | 18.33 | 11.81 | 22.61 | 14.56 | 5.65 | 2.81 |
| 18 | 32.28 | 24.01 | 20.04 | 12.05 | 21.78 | 15.58 | 4.28 | 2.26 |
| 19 | 29.99 | 23.77 | 17.94 | 12.07 | 22.44 | 16.14 | 5.24 | 2.40 |
| 20 | 34.70 | 24.67 | 19.42 | 12.36 | 22.48 | 14.24 | 4.76 | 2.07 |
| 21 | 33.56 | 22.11 | 20.08 | 10.88 | 22.50 | 16.21 | 5.48 | 2.74 |
| 22 | 32.11 | 23.05 | 20.83 | 11.62 | 20.09 | 16.01 | 5.61 | 2.80 |
| 23 | 33.45 | 22.42 | 19.82 | 11.33 | 22.78 | 15.28 | 5.53 | 2.84 |
| 24 | 28.46 | 23.01 | 18.62 | 11.03 | 21.50 | 17.46 | 5.17 | 3.20 |
| Mean | 31.96 | 23.08 | 18.92 | 11.91 | 22.59 | 16.04 | 5.00 | 2.47 |
| S.D. | --- | 1.07 | 0.87 | 0.74 | 0.93 | 1.29 | 0.58 | 0.29 |

Appendix Table XII. Percent of total body ash contributed by each compartment.

| Pig No. | Total ash (lbs.) | Shoulder | Loin | Side | Ham | Head and viscera | Blood | Hair, scurf and toenails |
|---|---|---|---|---|---|---|---|---|
| 1 | 6.71 | 24.14 | 21.61 | 5.81 | 20.12 | 27.12 | 1.04 | 0.15 |
| 2 | 6.19 | 25.20 | 21.00 | 6.30 | 24.88 | 21.65 | 0.81 | 0.16 |
| 3 | 7.11 | 27.29 | 20.25 | 6.33 | 23.91 | 21.10 | 0.98 | 0.14 |
| 4 | 6.78 | 24.34 | 21.83 | 5.46 | 19.03 | 28.02 | 1.18 | 0.15 |
| 5 | 4.86 | 29.01 | 17.49 | 6.17 | 25.31 | 20.16 | 1.65 | 0.21 |
| 6 | 5.29 | 27.41 | 19.85 | 6.24 | 25.14 | 19.66 | 1.51 | 0.19 |
| 7 | 5.68 | 28.52 | 19.19 | 5.46 | 23.59 | 21.65 | 1.41 | 0.18 |
| 8 | 5.62 | 27.22 | 19.22 | 5.87 | 22.95 | 23.13 | 1.42 | 0.18 |
| 9 | 4.48 | 23.21 | 20.76 | 5.58 | 25.45 | 23.21 | 1.56 | 0.22 |
| 10 | 5.99 | 26.21 | 21.87 | 6.01 | 26.04 | 18.20 | 1.50 | 0.17 |
| 11 | 4.59 | 26.58 | 20.48 | 6.54 | 23.97 | 20.70 | 1.53 | 0.22 |
| 12 | 5.25 | 29.71 | 20.76 | 5.90 | 23.05 | 19.05 | 1.33 | 0.19 |
| 13 | 5.72 | 26.40 | 21.50 | 4.90 | 25.87 | 19.76 | 1.40 | 0.17 |
| 14 | 4.55 | 25.93 | 20.66 | 5.49 | 25.49 | 20.44 | 1.76 | 0.22 |
| 15 | 5.31 | 28.44 | 23.16 | 6.21 | 24.67 | 16.01 | 1.32 | 0.19 |
| 16 | 5.12 | 26.37 | 22.66 | 7.23 | 25.39 | 16.60 | 1.56 | 0.20 |
| 17 | 5.30 | 27.74 | 20.57 | 6.04 | 25.85 | 18.30 | 1.32 | 0.19 |
| 18 | 4.75 | 28.63 | 23.58 | 6.32 | 21.68 | 18.11 | 1.47 | 0.21 |
| 19 | 4.84 | 26.45 | 20.25 | 6.20 | 26.03 | 19.63 | 1.45 | 0.21 |
| 20 | 5.61 | 27.09 | 21.57 | 6.06 | 21.75 | 22.10 | 1.25 | 0.18 |
| 21 | 5.28 | 27.46 | 20.27 | 5.30 | 24.81 | 20.45 | 1.52 | 0.19 |
| 22 | 4.79 | 27.77 | 23.59 | 6.26 | 20.67 | 19.83 | 1.67 | 0.21 |
| 23 | 5.65 | 27.61 | 25.13 | 5.66 | 23.72 | 16.11 | 1.42 | 0.35 |
| 24 | 4.61 | 25.81 | 21.26 | 5.42 | 23.43 | 22.34 | 1.52 | 0.22 |
| Mean | 5.42 | 26.86 | 21.19 | 5.95 | 23.87 | 20.56 | 1.40 | 0.20 |
| S.D. | -- | 1.58 | 1.64 | 0.49 | 1.97 | 2.94 | 0.22 | 0.04 |

Appendix Table XIII. Carcass length, average backfat thickness, loin eye area and dressing percentage data.

| Pig No. | Carcass length (in.) | Average backfat thickness (in.) | Loin eye area (sq. in.) | Dressing percent |
|---|---|---|---|---|
| 1 | 32.6 | 1.36 | 4.47 | 78.60 |
| 2 | 30.9 | 1.20 | 4.89 | 80.12 |
| 3 | 32.8 | 1.60 | 5.04 | 79.91 |
| 4 | 32.5 | 1.47 | 4.44 | 79.86 |
| 5 | 29.7 | 1.32 | 4.09 | 77.81 |
| 6 | 30.9 | 1.42 | 4.14 | 78.35 |
| 7 | 30.6 | 1.30 | 5.30 | 76.86 |
| 8 | 30.7 | 1.03 | 4.45 | 76.88 |
| 9 | 28.0 | 1.64 | 4.11 | 77.00 |
| 10 | 30.8 | 1.31 | 5.29 | 76.13 |
| 11 | 29.7 | 1.46 | 4.50 | 76.04 |
| 12 | 30.5 | 1.56 | 4.40 | 76.09 |
| 13 | 31.2 | 1.39 | 5.25 | 76.46 |
| 14 | 30.3 | 1.42 | 4.01 | 75.73 |
| 15 | 31.5 | 1.25 | 5.39 | 77.94 |
| 16 | 30.8 | 1.15 | 4.99 | 78.97 |
| 17 | 30.7 | 1.55 | 4.51 | 80.64 |
| 18 | 30.4 | 1.22 | 5.52 | 79.24 |
| 19 | 31.2 | 1.31 | 3.67 | 79.57 |
| 20 | 31.9 | 1.39 | 4.99 | 80.34 |
| 21 | 31.0 | 1.29 | 4.85 | 77.60 |
| 22 | 30.4 | 1.22 | 5.31 | 76.73 |
| 23 | 31.6 | 1.52 | 4.95 | 79.27 |
| 24 | 29.3 | 1.17 | 4.64 | 77.15 |
| Mean | 30.9 | 1.36 | 4.72 | 78.07 |