as to hold it better. Care must be exercised in placing the Orbitoid in the cork so that when the specimen is cut the embryonic apparatus is not damaged. For cutting, a common fret saw frame (Fig. 1) was strung with a piece of No. 10 B & S gauge copper wire under slight tension. This with F.F.F. carborundum and plenty of water was used to cut off a portion of the test. The cut was made as close to the center as possible without damaging the embryonic apparatus. This cutting can be judged only from experience in handling specimens. The wire cuts the test quickly and easily and if due care is exercised in handling the saw, the sawed surface is relatively plane and smooth. The portion cut off is used for a vertical section.

The larger part containing the embryonic apparatus was then mounted in Canada Balsam, as is usually done in making equatorial sections. This part was then ground down on a fine hone; stopping every few strokes to make a Camera Lucida tracing. When the equatorial plane was reached a final tracing was made and measurements of the various parts taken. The Orbitoid was reorientated in additional Canada Balsam as for a vertical section and another series of tracings made, until the embryonic apparatus is again bisected. The cut-off part is then used to make a vertical section in the usual way. There is left a complete vertical section and a piece of the specimen with two polished surfaces; an equatorial and a vertical plane.

The series of Camera Lucida tracings were then drawn on separate sheets of celophane by means of India ink and studied. I have found this method of great use in the study of deformed Orbitoids, especially one that had a twin growing up from one surface. This method is rapid and sure, and it gives a convenient way to study the various chambers of the "larger foraminifera."

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SPECIAL ARTICLES

A POSSIBLE PHYSIOLOGICAL INTERPRETATION OF THE LAW OF THE DIMINISHING INCREMENT

Workers in animal nutrition have long felt the need for some satisfactory means of expressing mathematically the relation between growth and feed consumption. The interpretation of the results obtained in many feeding experiments is often complicated by differences in the amounts of feed consumed by the lots which are being compared. Obviously, it would be very desirable to have some means of calculating the true efficiency of any given feed for growth, regardless of the amounts of feed consumed by the experimental animals.

The applicability of the law of the diminishing increment to the problem of describing the relation between feed consumption and live-weight of growing animals was demonstrated by Spillman.[1] More recently Jull and Titus[2] have shown that the equation as given by Spillman is a fairly accurate means of expressing the live-weight of growing chickens as a function of feed consumption. Titus[3] showed that the growth of ducklings can be described by the equation equally well. Beyond pointing out the fact that each successive gain in live-weight for an equal increment of feed intake tends to bear a constant ratio to the gain immediately preceding, neither of the abovementioned investigators offered any explanation to account for the relationship.

The differential form of the equation of the curve of the diminishing increment is:

$$\frac{dW}{dF} = k(A - W) \qquad (1)$$

which merely states that the gain in live-weight per unit of feed intake is directly proportional to the difference between some constant and the live-weight already attained. The constant A has been interpreted to represent the mature weight of the animal, since when growth ceases,

$$\frac{dW}{dF} = 0, \text{ and } W = A.$$

No matter how accurately this equation may describe the relation between feed consumption and growth, it throws very little light upon the physiological processes involved unless some rational explanation is presented to show why the equation fits the facts.

It is common knowledge among workers in animal nutrition that the feed intake of a growing animal is utilized essentially in two different ways. One portion is used to supply the fuel required to carry on the metabolic activities of the animal and may be designated as the maintenance requirement.* The other portion is used for growth and part of it is retained and incorporated into the body tissues, pro-

1 W. J. Spillman and Emil Lang, "The Law of Diminishing Returns," World Book Co., Chicago, 1924.

2 Morley A. Jull and Harry W. Titus, "Growth of Chickens in Relation to Feed Consumption," *Jour. Agr. Res.*, 36 (6): 541–550 (1928).

3 Harry W. Titus, "Growth and the Relation between Live-weight and Feed Consumption in the Case of White Pekin Ducklings," *Poultry Sci.*, 7 (6): 254–262 (1928).

* This, of course, includes the energy requirements for all voluntary muscular activity.

ducing a gain in live-weight. It is self-evident that if no feed were required for maintenance and if the fraction of the feed incorporated into the body tissues was always of the same chemical composition, the live-weight of a growing animal would be a linear function of feed consumption. Expressed mathematically the relation would be:

$$\frac{dW}{dF} = C \qquad (2)$$

Since some feed is used for maintenance and the amount required for this purpose is known to increase as the animal becomes larger, $\frac{dW}{dF}$ can not be constant but must be some diminishing function of live-weight. It is necessary in this connection to express the amount of feed used for maintenance in terms of a loss of body tissues. If it is assumed that the loss in live-weight per unit of feed consumed is proportional to the live-weight of the animal, we may express the relation between feed consumption and growth as follows:

$$\frac{dW}{dF} = C - mW \qquad (3)$$

When this equation is rewritten in the form:

$$\frac{dW}{dF} = m\left(\frac{C}{m} - W\right) \qquad (4)$$

it becomes identical with equation (1) for $m = k$ and $\frac{C}{m} = A$.

The integral forms of equations (1) and (4) are, respectively:

$$W = A - Be^{-kF} \qquad (5)$$

$$W = \frac{C}{m} - Be^{-mF} \qquad (6)$$

in which e is the base of the natural system of logarithms and B is derived from the constant of integration. As pointed out by Spillman, B represents the total possible gain in live-weight of which the animal is capable between its initial live-weight and its weight at maturity.

In accordance with the assumptions made in deriving equation (6) certain conclusions may be drawn from the constants in equation (5). Obviously kA represents the gain in live-weight which the animal is capable of making for each unit of feed eaten if no feed were required for maintenance, for it is readily apparent from equations (5) and (6) that $kA = C$. In other words, kA represents the true efficiency of the feed for growth. It is interesting to note that $\frac{1}{k}$ represents the amount of feed which would have been required for the animal to reach its mature weight if no feed had been required for maintenance, for $kA \cdot \frac{1}{k} = A$ and A represents the live-weight of the animal at maturity.

This interpretation of the law of the diminishing increment may be employed for the purpose of estimating the maintenance requirement of a growing animal at any stage of growth. Let W_1 represent the live-weight of the animal when it has consumed F_1 units of feed. If no feed had been used for maintenance, the live-weight would have been $kA \cdot F_1 + W_0$, in which W_0 represents the animal's initial live-weight. The number of units of live-weight which have been lost because of the maintenance requirement while the animal was attaining the weight W_1 is, therefore, $kA \cdot F_1 + W_0 - W_1$. Since a gain in live-weight of one unit is equivalent to $\frac{1}{kA}$ units of feed, the maintenance requirement, expressed in units of feed, is $F_1 + \frac{W_0}{kA} - \frac{W_1}{kA}$. Similarly, the total amount of feed which has been used for maintenance by the time the animal reaches another live-weight, W_2, is $F_2 + \frac{W_0}{kA} - \frac{W_2}{kA}$. Therefore, the amount of feed used for maintenance during the time the animal is consuming the increment of feed, $F_2 - F_1$, is

$$F_2 - F_1 - \frac{W_2 - W_1}{kA}$$

Jull and Titus, in their work on "Growth of Chickens in Relation to Feed Consumption," give the results of fitting the equation of the curve of the diminishing increment to data obtained from four lots of cross-bred chickens, obtained by mating Barred Plymouth Rock females with Rhode Island Red males. Two of the lots consisted of pullets and two of cockerels, the sexes being separated at hatching time. Although all four lots were fed the same diet and received the same treatment, the duplicate lots did not eat the same amounts of feed. However, the values of kA calculated from the fitted equations agree very well for the duplicate pens as the accompanying table shows.

According to these values the cockerels were able to make better use of the feed for growth than the pullets.

Some idea of the reliability of these results can be obtained by comparing them with a value obtained for white Leghorn pullets recently reported by Titus.[4] In determining the gross maintenance requirement

[4] Harry W. Titus, "The Gross Maintenance Requirement of White Leghorns." *Poultry Sci.* 8(2): 80–84 (1928).

VALUES OF kA CALCULATED FROM EQUATIONS OBTAINED BY JULL AND TITUS

Lot	Sex	A	k	kA (Efficiency of feed for growth)
		Kilograms		
1	Females	3.0726	.0970791	.298
2	Females	3.6084	.0817604	.295
3	Males	4.9142	.0710867	.349
4	Males	4.1954	.0873561	.366

of a group of White Leghorn pullets, having an average live-weight of 1,632 grams, Titus found that a gram loss in live-weight was equivalent to about 3.45 grams of feed. Taking the reciprocal of this value, a gram of feed is found to be equivalent to .290 grams of body tissue. This value agrees very well with the corresponding values calculated for the cross-bred pullets by means of the equation of the diminishing increment.

The writers have calculated the maintenance requirements of chickens at various ages from the above-mentioned data, using the method described above. They appear to be of reasonable magnitude but, unfortunately, no experimentally determined values are available with which to check the results.

If the fundamental assumption that the fraction of the feed incorporated into the body tissues is always of the same chemical composition is valid, the maintenance requirements must be correct. By rewriting equation (3) in the form:

$$dW = C \cdot dF - mW \cdot dF \qquad (7)$$

it is readily apparent that the time relationships are as follows:

$$\frac{dW}{dT} = C \cdot \frac{dF}{dT} - mW \cdot \frac{dF}{dT} \qquad (8)$$

The maintenance requirement of an animal at any particular time is, according to this equation, proportional to the product of the live-weight of the animal and the amount of feed ingested, which agrees with the well-known fact that the heat production of an animal is increased as its plane of nutrition is raised. During the actively growing period the chemical composition of the animal probably does not change sufficiently to introduce any great error into the calculations.

In view of the number of possible factors which may affect the maintenance requirement of an animal and the relative lack of refinement of the conditions under which feeding experiments are ordinarily carried on, the expression of the maintenance requirement as given in equations (3) and (8) is probably as justifiable as any other proposed up to the present time. However, it should be regarded as being merely a tentative approximation to the true mathematical relationships involved. A better equation expressing the relation between feed consumption and growth can doubtless be evolved when more information regarding the metabolism of the growing animal is available. Until such information is available the law of the diminishing increment may be of much help in the interpretation of the results of a feeding experiment.

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THE RÔLE OF COPPER IN THE SETTING AND METAMORPHOSIS OF THE OYSTER

THE most important and critical period in the life history of the oyster is that during which the fully developed larva cements itself to some clean submerged surface such as old shells or stones and then undergoes a metamorphosis into a spat and adult oyster. The term setting is applied to this process of attachment, which is a biological reaction of a most positive character requiring a definite chemical stimulus for its initiation. A study of the setting reaction under natural conditions in Milford Harbor, Connecticut, showed that it occurred during the low water stage of the tide or, in other words, when river discharge had its greatest effect on the physical and chemical condition of the water over the oyster beds. The environment of the oyster is exceedingly complex from a physical and chemical standpoint, and at periods of low tide we find the extremes of many factors as the mixing of fresh and salt water is taking place. Experiments with the oyster larvae under controlled laboratory conditions showed that changes in temperature, salinity, hydrogen-ion concentration, oxygen content, CO_2 tension and water pressure would not induce in a single instance the setting reaction. However, if in reducing the salinity, river water was used instead of distilled water, the larvae gave a positive setting reaction, which indicated that there was some substance in the river water which served to stimulate and control their attachment and metamorphosis. Further experiments involving variations in the amount and proportion of the cations and anions of the neutral salts were found to be ineffective in producing setting of the larvae, as were also the compounds of iron, zinc, tin, lead, aluminum, manganese and silver. The only element of those tested that produced a positive setting reaction was copper in the form of a pure metal or as a carbonate, sul-