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On the Motion of Growth. III. The Determination of ρ and the Energetics of Human Basal Metabolism.

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We have already pointed out¹ that none of the coefficients, λ , ρ or κ appearing in the original equation of energy (1) and in all subsequently derived relations can be separately determined from an analysis of data on growth alone. All that can be done is to calculate the ratio $\left(\frac{\rho}{\lambda}\right)$, and the product $(\lambda\kappa)$. But, if, as also noted, some independent relationship could be found, their computation would in general be a simple matter. Admittedly, the ultimate goal here must be a determination, if possible, not so much of the numerical values of λ , ρ and κ as of their fundamental physical and physiological attributes and counterparts; but from what has already been given,¹ even a knowledge merely of the values of any one of these coefficients would greatly aid in a fuller understanding of the basic mechanism at work. Many observations will, accordingly, need to be repeated with such an end in view.

Thus, in seeking for some independent relation by which any one of these coefficients could be numerically determined, we were attracted almost at once, in view of the purely dissipative character of the energy accounted for in the term $\rho \int \left(\frac{dq}{dt}\right)^2 dt$ to an examination of heat production during life, under conditions necessarily recognized as "basal". Further inquiry showed, moreover, that the term in ρ should not of itself account for the entire heat output, for the energy involved in synthesis as well as that concerned with nutrition and maintenance ought theoretically also to find an ultimate outlet in heat. The energy represented in the remaining terms of (1) could not, clearly, collaborate in this way, being, as it were, "bound" in doing work of another kind. Consequently, if U be taken as the rate of heat production per unit of weight, we have, for the human case, by selecting the terms just described,

$$\rho \left(\frac{dq}{dt}\right)^2 + \left[E_0 + E_2 \epsilon^{-\beta t} \sinh(\theta t - \zeta)\right] \frac{dq}{dt} + A' = U \quad (6)$$

if $E_0 = (E_1 + E_2)$. U thus accounts for a portion of the external

¹ Wetzel, N. C., *Proc. Soc. Exp. Biol. and Med.*, 1932, **30**, 227.

work of growth, namely that of dissipation, without which no finite natural process may be accomplished; that involved in the process of cellular synthesis, and finally that required for continued maintenance. Now, while it is impossible to enter here into a complete analysis of this equation, we ought, nevertheless, to point out that U is henceforth unrestricted as to the sign of $\left(\frac{dq}{dt}\right)$, the relative rate of change in mass (weight), and that accordingly, the first fraction on the left is *irreversible heat*, whereas that concerned with synthesis (second term) is necessarily *reversible heat*, depending, however, not only upon the sign of $\left(\frac{dq}{dt}\right)$ but also upon the relative numerical values of E_c and E_2 when $bt < \xi$.

Since all the factors except ρ , E_c and E_2 can be obtained either from the foregoing results in respect to growth, or, in the case of A' and U , from suitable experimental data, it is clear that the numerical value of ρ , primarily, as well as of E_c and E_2 may be computed to as close a degree of approximation as the data allow. Thus, choosing A' and U in the common units of calories per Kg. per day, we have computed by least squares the values given in the first column of Table I from the original data on basal metabolism reported by Benedict and his associates.² Due, however, to the

TABLE I.
The Numerical Value of ρ , E_c , and E_2 .

	When $A' = 25.3425$ Cal./Kg./Day	When $A' = 38665 \times 10^3$ Joules/Kg./Year
ρ	53.840886	82,145.04
E_c	54.521815	83,183.93
E_2	2,093.144316	3,193,510.28

fact that $\left(\frac{dq}{dt}\right)$ is more conveniently calculated in terms of Kg./Kg. of body weight per year, we have also set up in the second column the corresponding values in terms of Joules per Kg. per year.

As a crucial test of these procedures it is merely necessary to re-substitute the foregoing values for ρ , E_c and E_2 , as well as those for the other terms into (6), thereby obtaining the results throughout the entire period of growth given in the third column of Table II,

² Benedict, F. G., and Talbot, F. B., *Metabolism and Growth from Birth to Puberty*, Carnegie Institution Publication No. 302, Washington, 1921. Harris, J. A., and Benedict, F. G., *A Biometric Study of Basal Metabolism in Man*, Carnegie Institution Publication No. 279, Washington, 1919. Benedict, F. G., *Am. J. Physiol.*, 1928, **85**, 607.

TABLE II.
The Theoretical Values for Human Basal Metabolism from Birth through Adult
Life Computed as Described in the Text.

Age	(Uz)	(U)
<i>yrs.</i>	<i>Cal./Day</i>	<i>Cal./Kg./Day</i>
Birth	155.13	47.72
6 mos.	446.97	59.08
1 yr.	664.09	66.00
2 yrs.	680.89	53.63
3 "	607.41	42.80
4 "	633.93	40.94
6 "	760.63	40.35
8 "	897.39	37.77
10 "	1041.81	34.76
12 "	1193.49	32.33
14 "	1343.74	30.54
16 "	1481.77	29.22
18 "	1602.00	28.25
20 "	1702.73	27.53
22 "	1782.54	27.00
24 "	1847.57	26.56
32 "	1989.99	25.74

for "unit heat production"—or, when the latter are multiplied by the corresponding values of the weight, z , from (5)—for what may here be called "total" metabolism per day. The respective curves are shown in Figure 1, their trend representing as closely as can be determined the real course through the observational points. Note-worthy here in the case of "unit" metabolism (lower curve) is the comparatively low value at birth, the rise to a maximum just beyond one year of age and the shoulder-like descent during the period of pre-school and school life. This curve for U should especially be compared with that for $\left(\frac{dz}{dt}\right)$ the absolute rate of gain in Figure 1 of the preceding paper.¹ Taken together these two curves demonstrate a remarkable succession of events in the energetics of growth which cannot, however, be thoroughly discussed here.* Likewise of interest in the curve for total metabolism is the curious "double inflexion" between 1 and 3 years of age, yet here—during this critical phase—the trend is unmistakably in the immediate neighborhood of all observational points. This is not the place for a discussion of the possible physiological significance

* Riddle, Nussmann and Benedict³ have just recently commented upon a similar group of phenomena in respect to heat production per unit of surface. The events described above and displayed in Figure 1 for both unit as well as for total metabolism per day may now be traced directly to the dynamical relationship between growth and heat production as defined by equations (1-6).

³ Riddle, O., Nussmann, Theodora, and Benedict, F. G., *Am. J. Physiol.*, 1932, **101**, 251.

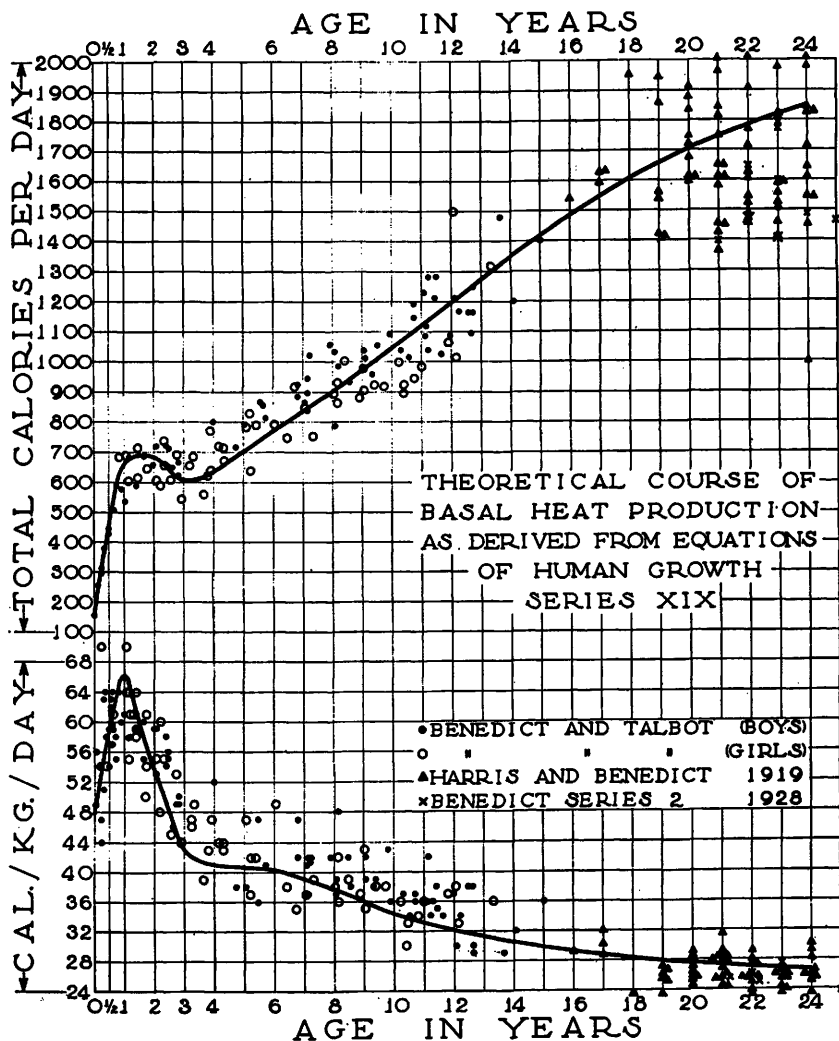


FIG. 1.

The smooth curves display the theoretical trend of heat production from birth to 24 years corresponding to growth (Series XIX).¹ The lower is the curve of equation (6) and represents U ; the upper, the curve of (Uz).

of these various features—but it must be stated here that much of the confidence we have placed in these results is to be traced to the fact that we had at our disposal such trustworthy data as those established by Benedict and his coworkers.