The Concept of Action as a Measure of Living Phenomena

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THE HISTORY OF SCIENCE is the history of measurement. The enormous strides made in the last three centuries in astronomy, physics, and chemistry can be directly traced to the ability to measure and compare forms of inert matter with precision and consistency. The balance, the scale, the clock, and their countless derivatives were the major source of facts upon which the inert sciences were nurtured.

Today increasing emphasis is being placed upon the study of living phenomena. But here an imposing barrier to progress exists: The measuring techniques which are the foundation of the inert sciences are not convenient for the measurement of living phenomena. The mass and dimensions of a rock, for instance, may remain remarkably constant from day to day, and year to year, whereas the mass and dimensions of a living thing, because of the growth and death process, food consumption, and other factors, are inherently variable with time. Furthermore, these properties cannot be as precisely defined for living things as for inert things. For example: What are the characteristic dimensions of an amoeba? In interspecies comparisons of mass, how are hair, bones, horns, hoofs, nails, etc. to be considered? Is the height of an animal the distance from top of shoulder—or head—above ground, or the distance from end of tail to tip of nose—or horn? Thus, uncertainty and variability in the mass and dimensions of living things vitiate the accuracy of their measurement, no matter how precisely obtained, and serve to preclude the application of the mass-length-time system to living phenomena. If this barrier were removed, i.e., if a universal measuring rod were made available for the biological sciences that could form the basis of a system of measurement similar to the mass-length-time system in the physical sciences, then immeasurable benefits could be expected.

There are two universal properties of living things upon which such a measuring rod could be based. First, every living thing absorbs and expends energy throughout its life span. Second, every living thing has a finite life span. These properties are common to all living substances from the single cell[1] to the largest animal. The desideratum is therefore a measurement which quantitatively unites these two properties, contains no other components, and is capable of being precisely determined.

Since the units of these properties are respectively energy and time, the physical concept of action suggests itself, for action is the product of energy and time. This choice is not adventitious, because action is one of the most important properties of inert matter. The macroscopic properties of inert things—gravitation, electromagnetic propagation, and mechanics—have been summed up in a single law, the Principle of Least Action; with the exception of entropy, action is the only invariant property that has survived the relativity theory; the curvature of space-time is determined by the action existing at each point in the universe; and finally, the most important quantity in atomic physics is a quantum of action—Planck's constant, *h*. Nature's emphasis on action strongly suggests it as a universal quantitative measure of life.

Calculation of Living Action

Action is defined as the time integral of energy. Expressed mathematically it is

$$A = \int^{T} U \, dt, \tag{1}$$

where U represents energy, T time interval, and A action. It has been shown by Rubner (*34*) and by Atwater and Benedict (*3*) that the Law of Conservation of Energy holds for living things to within 1 percent. Since the life span of a living thing can be measured very precisely, to within a fraction of 1 percent, its total action can be accurately determined by equation 1.

The energy expenditure of living things occurs at a finite rate, and it is this rate that is experimentally measured. Since

$$dU/dt = P, \tag{2}$$

where P is power, equation 1 may be more conveniently expressed by

$$A = \int\int^{T} P \, dt^2. \tag{3}$$

Many forms of living power, such as input, output, loss, growth, and muscular power may be substituted for P, and each determines a corresponding form of living action. It is beyond the scope of this article to investigate all the power and action characteristics;

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[1] The life span of a cell may be defined as the interval from birth to mitosis, for no active cell exists indefinitely without undergoing some form of division.

the purpose here is merely to introduce an experimental basis for the application of action to the study of living matter. Calculations based on basal metabolism will serve to illustrate the technique and permit a preliminary investigation into the nature of the variation of living action. Basal metabolism is especially suited for this purpose since it is easily and accurately measured, fairly constant, and one of the most important physiological properties of life (*5*), and considerable data are already available.

The generally accepted definition of basal metabolism is used in this report—namely, the basal (standard minimum) energy consumed by the living thing per unit of time per unit of body surface area. Basal power is therefore the basal (standard minimum) energy consumed per unit of time. If basal power is represented by P_b and basal metabolism by M, then

$$P_b = MS, \qquad (4)$$

where S is body surface area. This definition of basal power is generally synonymous with the term total basal metabolism in the literature.

For small animals it is feasible to make direct metabolism measurements from birth to death to determine the individual's power characteristic. For large animals, and especially man, this method is impractical. An alternative is to determine the average characteristics of the species by means of a cross-section survey. The basal action of an individual can then be determined if the deviations of its life span and basal power from the average are known.

A study of basal metabolism well suited for the calculation of basal action is that made on Americans by Boothby, Berkson, and Dunn (*9*). Only basal metabolism values, M, were reported, however, so that it is necessary to know the surface area characteristic of the average individual to obtain the desired basal power characteristic, P_b. This is tantamount to obtaining the weights and heights of the average male and female American, since the surface area used by Boothby *et al.* was calculated from the DuBois and DuBois formula:

$$S = .007184\ W^{0.425}\ H^{0.725}, \qquad (5)$$

where W is the nude body weight in kilograms, H is the unshod standing height in centimeters, and S is in square meters.

Values of average weight, height, and basal metabolism for all ages are listed in Table 1, along with the calculated surface area, basal power, basal energy, and basal action. The results are shown graphically in Figs. 1–3.

The gap from 0 to 6 years in the report by Boothby *et al.* is supplemented by results from Benedict and Talbot (*6*). The latter report, one of the most complete for the infant period, is consistently low (*6, 32*),

TABLE 1

BASAL ACTION OF THE AVERAGE WHITE AMERICAN

Exact age, yrs	Weight, nude kg		Height, unshod cm		Surface area m²		Bas. met.* Cal/m²/hr		Basal power Cal/day		Basal energy g-cal × 10^9		Basal action g-cal-Yr × 10^9	
	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female
1.5					0.514	0.483	59.1	57.0	729	661			0.15	0.16
3.0	15.1	14.8	96.5	95.7	0.625	0.617					0.72	0.68		
4.5					0.731	0.724	54.9	51.7	964	899			2.34	2.22
6.0	21.6	21.4	117.7	116.7	0.840	0.832					1.78	1.66		
7.5					0.951	0.941	52.4	48.5	1194	1095			7.71	7.24
9.0	30.1	30.0	134.3	133.8	1.067	1.061					3.09	2.87		
10.5					1.182	1.190	48.0	45.7	1362	1305			16.99	15.87
12.0	40.0	42.2	149.8	151.1	1.301	1.341					4.59	4.29		
13.5					1.450	1.480	46.5	42.5	1618	1509			30.79	28.78
15.0	54.5	53.3	167.1	161.9	1.607	1.555					6.36	5.93		
16.5					1.733	1.588	45.5	38.6	1891	1471			49.91	46.57
18.0	64.6	56.1	175.2	162.9	1.790	1.599					8.41	7.54		
19.5					1.804	1.605	42.2	36.6	1829	1410			75.13	69.18
21.0	66.8	57.1	"	"	1.814	1.611					10.42	9.08		
22.5	67.4	57.6	"	"	1.821	1.617	40.9	36.1	1790	1400			106.37	96.43
27.5	69.3	59.1	"	"	1.844	1.634					14.63	12.41		
32.5	71.3	60.6	"	"	1.864	1.650	39.3	35.8	1760	1418			252.79	220.70
37.5	72.8	62.1	"	"	1.881	1.668					20.95	17.59		
42.5	73.9	63.6	"	"	1.893	1.685	38.0	35.5	1728	1437			461.68	396.59
47.5	74.8	64.9	"	"	1.902	1.700					27.25	22.81		
52.5	75.1	65.7	"	"	1.905	1.709	36.7	34.0	1678	1394			734.16	624.66
57.5	75.0	65.7	"	"	1.904	1.709					33.38	27.90		
62.5	74.9	65.1	"	"	1.903	1.701	35.5	32.7	1621	1337			1067.91	903.58
67.5	74.8	64.3	"	"	1.903	1.694					39.31	32.77		
72.5					1.902	1.686	34.1	32.1	1564	1299			1460.85	1231.24

* After Benedict and Talbot (*6*) (0–5.5 yr) and Boothby, *et al.* (*9*) (6.5–74.5 yr).

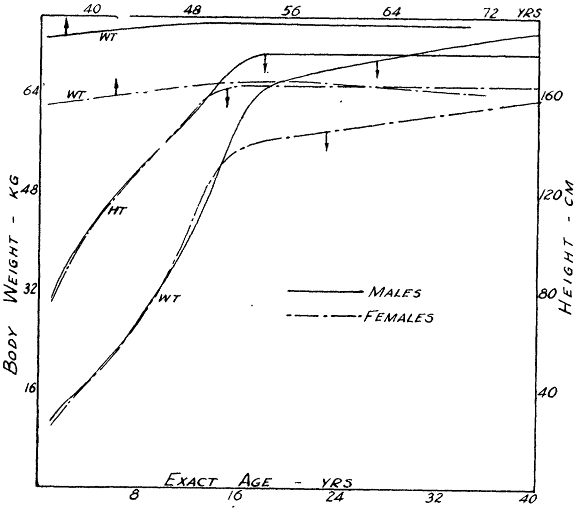

FIG. 1. Weight and height of average white American.

so that a correction factor has been applied. This factor for males and females is given in Table 2.

Eleven sources of average weights and heights (*1, 2, 4, 7, 10, 16, 18, 22, 31, 36, 38*), carefully chosen from the literature, provide the basis for the weight and height characteristics. These studies, which were selected for anthropometric accuracy, period in which the research was carried out, and type and number of subjects, fall naturally into two age groups: preadult and adult.

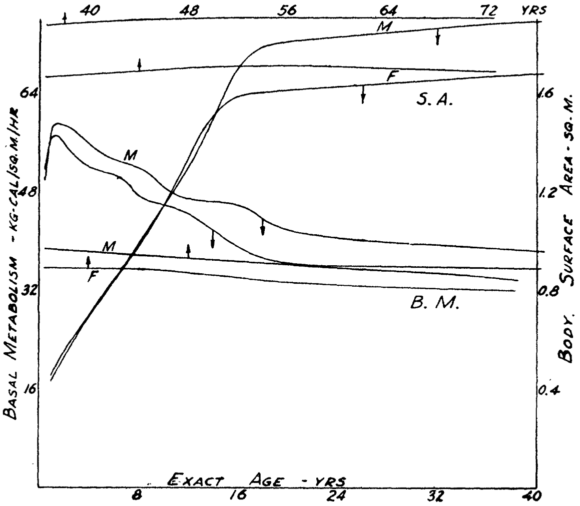

FIG. 2. Surface area and basal metabolism of average white American.

The preadult group is composed of five sets of averages from diverse sections of the United States (*1, 10, 16, 18, 22, 31*). The agreement among the sources is good. For the adult period, statistics available for this study are those of the *Medico-actuarial mortality investigation*. Although collected prior to 1910, these insurance statistics give a reliable variation of adult weight and height with age which, it is assumed, is essentially similar for all generations. The adult and preadult weight curves fit smoothly because the insurance statistics were obtained with subjects clothed, thus counterbalancing the increased weight of the modern generation. The curves of Weisse (*36*) and the 1924 U. S. Army Officers examination (*7*) verify the shape of the adult weight-age curves. Adult height is assumed constant after maturation. This is confirmed by existing studies when allowance is made for their cross-sectional nature.

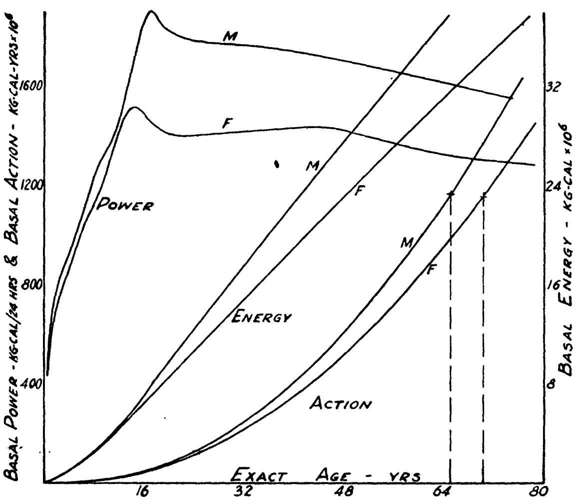

FIG. 3. Basal power, basal energy, and basal action of average white American.

TABLE 2

CORRECTION FACTOR FOR DETERMINING BASAL METABOLISM OF CHILDREN

Exact age yr	Basal metabolism Cal/m²/hr		Ratio other investigators : Benedict and Talbot
	Benedict and Talbot	Other investigators :	
		Females	
3.25	44.7*	53.7*	1.201
3.75	39.8*	53.8*	1.351
4.25	42.8*	51.7*	1.209
6.50	41.0‡	50.5†	1.231
7.50	40.5‡	48.5†	1.198
Average			1.238
		Males	
3.36	47.8‡	55.7*	1.166
3.79	47.3‡	54.7*	1.158
4.14	46.7‡	57.4*	1.229
6.50	44.4‡	53.0†	1.193
7.50	43.7‡	52.4†	1.199
Average			1.189

* After Robb (*32*).
† After Boothby *et al.* (*9*).
‡ Interpolated from curves of Benedict and Talbot (*6*).

The surface area characteristics are given by equation 5 and the basal power characteristics by equation 4. The basal power peaks at 17 and 14 years for the male and female respectively are due to a combination of high basal metabolism and rapid increase in size (surface area) in adolescence. The secondary peak in average female basal power at age 44 is undoubtedly connected with the menopause.

Integration of the power curves yields the energy curves; integration of energy yields the action curves. The integrations were accomplished by arithmetic summation of small age increments, the increment being one year to age 26, and two years past age 26.

The latest available life expectancy figures show male life expectancy for 1946 to be 65.1 years and female 70.3 years (*37*). Interpolating from the corresponding action data gives 1164.7×10^9 gram-calorie-years for the basal action of the average American male and 1154.1×10^9 gram-calorie-years for the average American female. The mean is 1159×10^9 gram-calorie-years, or 1.53×10^{27} erg-seconds.

INVARIANCE OF BASAL ACTION

Although this investigation demonstrates the calculability of living action, it gives no direct information on variation within the species. This variation is important, for the less it is, the more useful action will be as a quantitative tool. Pending direct experimentation, an insight into the nature of this variation may be obtained from a comparison of male and female basal actions.

If the life span of each individual is so related to its basal power that action is constant, i.e., so that equation 3 produces the same value for all members of the species, then variation in action would be zero and independent of the variations in P_b and T. On the other hand, if there is no correlation between P_b and T, then, since action is effectively power multiplied by life span, the variation in action, measured in terms of its standard deviation, σ_a, would be of the order of $\sqrt{\sigma_P{}^2 + \sigma_T{}^2}$. In this case σ_a is not zero and is greater than the standard deviation in P_b or T. The correlation between P_b and T may therefore serve as a measure of the invariance in action.

For zero variation in action, T and P_b must be inversely related in a manner determined by equation 3. Thus, an inverse relation between life span and power consumption is a sign of relative invariance in action, and the more this inverse relation approaches the one which produces constant action, the more invariant action becomes.

The greater male power consumption, approximately 15 percent, and the lower longevity, 7.68 percent, compared to females shows an inverse dependence of T upon P_b, at least for sex. The sex difference in action, on the other hand, is only 0.91 percent, or 8.4 and 16 times less than the sex difference in life span and basal power respectively. However, before considering the significance of this it is first necessary to make sure that the near equality of male and female basal actions is not a chance phenomenon but a real and significant result of the calculation.

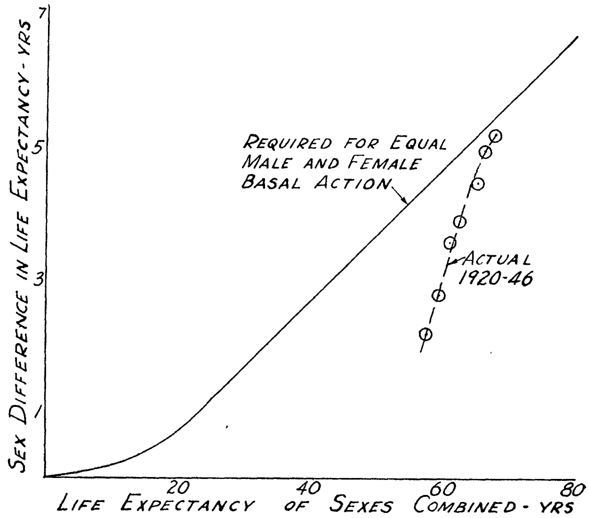

FIG. 4. Sex difference in life expectancy vs. life expectancy for average white American.

First, the reliability of the sex difference is greater than that of the actual values of basal action. Parallel studies of male and female metabolism, weight, and height were used throughout, so that inaccuracies due to the combination of different sources of data tend to cancel out in the sex difference. Thus the accuracy of the sex difference is not materially affected by errors introduced by the piecemeal method of calculation.

Second, the choice of life expectancy data is not critical. Both life span and size of the average American have increased in the last few decades. The increase in size is small and may be neglected here, but the increase in life span is appreciable. Its effect on the action sex difference is shown in Fig. 4. The solid line is obtained by assuming a value of action and determining from the curves of Fig. 3 the corresponding male and female life spans. The sex difference in life span is then plotted against the average of the two. The broken line gives the actual sex difference in life expectancy vs. average of male and female life expectancy for 1920 to 1946 (*14, 37*). This shows that as average man approaches the potential life span of the species, i.e., that given by the life curve of old persons, the condition for equal male and female actions is also being approached. That there is a natural limit to the potential span of life is clearly indicated by life expectancy figures, for there has been no significant change in the life expectancy of old persons in the last half-century although average life expectancy has increased about twenty years (*24*). Furthermore, this natural limit has almost been attained by the 1946 group. The use of the 1946 life expectancy values is thus justifiable.

Third, the first or third integral of power may also have a significantly low sex difference as well as the second integral. Emphasis on action would then be unwarranted, despite the philosophical arguments in its favor. Actually, the values for the first integral of power (basal energy) for the 1946 group are 37.80 and 34.49×10^9 gram-calories for the male and female respectively, giving a sex difference of 9.16 percent. Similarly, calculation of the third integral of power (integral of action) yields a sex difference of 8.71 percent. These values, which are 10 and 9.6 times the action sex difference respectively are not small enough to be considered.

It is unlikely, then, that the near equality of average male and female action can be attributed to fortuitous circumstances. This poses the intriguing possibility that the inverse relation between average male and female power and life span is such that action is invariant within narrow limits. Although direct quantitative data of the kind required to generalize this hypothesis appear to be lacking at present, it is nevertheless possible to confirm the existence of a general inverse relation between power and life span which supports invariance of action for other species and conditions. For purposes of analysis, variation in power consumption is considered with respect to five factors: sex, race, climate, magnitude of power consumption, and shape of power characteristic. The effect of these upon life span is summarized as follows:

I. *Sex.*

A. In a series of experiments on *Daphnia magna,* MacArthur and Baillie found that the metabolic rate as measured by heart beat is higher and life span lower for the male, while the product of the two is approximately the same for both sexes (*19*).

B. Landauer and Landauer (*17*) studied the higher mortality rate of male chicks and reported that "There is ample evidence for the conclusion that the higher metabolic rate of males [of all species] is not compensated by a different organization of the organism, but is actually brought about by a more rapid or more continuous functioning of the organs and cells of the male body. . . . It appears that there are no observations which are inconsistent with [this] assumption."

C. Basal power of male rats is greater than that of females (*11*) whose life span is greater (*21*).

D. Male life span has been reported shorter for *Drosophila melanogaster* (*26*) and others (*20*), and male basal power greater for swine, cattle and sheep (*11*), and others (*20*).

II. *Race.*

A. The wild strain of *Drosophila* normally has a life span three times as long as the vestigial strain. Pearl controlled the environment of 3,632 flies of both types by administering no food after birth (*30*), and found that under the equivalent conditions, the vestigial strain, which is smaller than the wild type, lived slightly longer.

B. In man racial and national differences in metabolism exist, but life span data are not equivalent except when two or more races, nations, or peoples exist side by side under the same conditions. The Jews, for instance, are one of the smallest peoples (*13*) and hence have a low basal power, but are also noted for their longevity (*33*).

III. *Climate.*

A. MacArthur and Baillie found that temperature had a profound effect on the length of life of *Daphnia magna* (*19*). The mean life span of both sexes was increased over four times for both sexes by a 20° C decrease in environmental temperature.

B. In cold-blooded animals increase of environmental temperature increases both metabolic rate and rate of senescence (*12*).

IV. *Magnitude of Power Consumption.* The components of basal power, surface area (size), and basal metabolism may each independently affect life span.

A. Effect of size.

1. Life insurance companies have carefully studied the relation of size to life span for many decades. One reports (*39*): "Studies show that body girth and length of life vary inversely with each other. . . . Overweight is distinctly detrimental to health and tends to shorten life."

2. The majority of centenarians are small in size and are frugal eaters (*33*).

B. Effect of metabolism. Physical and psychic factors may affect basal metabolism.

1. Physical exertion.

a) Slonaker found that voluntary exercise in albino rats decreased the life span 18.8 percent compared to a control group that was given no facilities for exercise (*35*).

b) In an exhaustive study, Pearl discovered that continued hard labor reduces the life span after the age of 40, but not before (*27*). Since his subjects were insured persons who had been in their respective occupations most of their lives, those in hard-working occupations always had an above-normal power consumption, and hence used up their supply of action at an early age. It is interesting to note that, since deaths of healthy but hard-working persons begin to occur at the age of 40 and not before, as Pearl found, then the maximum sustained physical exertion that normal man can tolerate over a long period of time increases power consumption to such an extent that the normal value of action, and consequent death, are attained soon after the age of 40. Any greater exertion would presumably incapacitate the worker early in his career and prevent further labor at this extreme rate.

2. Psychological factors affect basal metabolism through the reaction of the endocrine system.

a) Pearl, in a study of more than 2,000 individuals who lived to the age of 90 or more (*25*), was able to find only one significant trait among them, outside of their longevity, wherein the group differed from the rest of mankind as a whole: their calm mental make-up. They all were possessed of a placid temperament, were relaxed, and were rarely worried.

b) Brody points out that mental factors causing insecurity and tension shorten the duration of life in many ways (*12*).

c) Married persons live considerably longer than unmarried persons (*8*). The security and regularity of wedded life probably reduce the tension and insecurity that more often accompany the single state, as psychoanalysts and sexologists assert, with a consequent increase in life span of the average married person.

d) Urban dwellers have a much lower life expectancy than rural people, although the gap is gradually decreasing (*15*). An explanation of this difference may lie in the greater excitement and uncertainty of city life, a major sociophysiological difference between rural and urban life. The fact that newspapers, rapid transport, movies, and the radio are gradually bringing the tension and competitiveness of modern life to rural regions probably accounts for the lessening of the gap.

C. For single cells, it is a well-known cytological fact that, in general, increase in food consumption of cells produces a decrease in life span (interval between successive mitoses), and vice versa.

V. *Shape of the Power Characteristic.* Since action is the double integral of power, variations in the power characteristic in early life, owing to retarded or accelerated growth, for instance, must have a large effect on the life span if action is constant.

A. McCay and Crowell retarded the growth of rats, using a normal balanced diet but a limited calorific intake until maximum growth was attained (*21*). As a result, the life span of the group increased considerably with respect to a control group. Males benefited more than females, probably because male power consumption decreased more from its norm.

B. In the same article, McCay and Crowell report the results of experiments on brook trout whose rate of growth was restricted by limitation of their protein intake to a very low level. As a result, the life span of the trout increased to twice its normal value.

C. Northrop (*23*) has shown that the life span of fruit flies depends upon the rate of growth (length of time in the egg-larval-pupal period).

D. In experiments on cantaloupe seedlings, Pearl and his associates found the duration of life to be inversely proportional to the rate of energy expenditure during the growth of the seedlings (*28*).

E. Besides variations in rate of growth, there may be alterations in the shape of the power characteristic caused by prolonged illness. Generally, illness causes a reduction in activity, food intake, and weight, thus bringing basal power to a lower level. Pearl, in his study of the long-lived, found an abnormally large number who had been ill for a long period (*29*). Morbidity and mortality are totally different phenomena, and are often inversely related.

The primary requirement of any measuring rod is that it must be accurately obtainable. There are at least three major methods of determining the power properties of living things: by controlling or measuring the calorific intake, by obtaining the heat output, and by analyzing the respiration. All three methods are well known, and with careful application are amenable to very accurate evaluation, comparable to that obtained in the physical sciences. When power is combined with life span to form action, the resultant is still accurate, since life span can be measured precisely.

Either indirect (cross-sectional) methods, where a large number of subjects are studied in a short period, or direct (longitudinal) methods, where the same individual is followed throughout his life span, may be used. The choice depends largely upon the life span of the species being studied. Plants, insects, and small animals may be readily followed from birth to death, under conditions which simulate the natural environment of the species, by confining one or a specified number to a calorimeter or airtight chamber, or by administering a measured diet. With longer-lived species this becomes impracticable and the indirect cross-sectional technique must be resorted to. Cells, which should make very convenient subjects because of their short life span, may be readily studied directly under the microscope, or by the cross-sectional technique *in vitro*. A whole series of indirect experiments which quantitatively measure the relation between power and longevity is also possible, such as those based on the starvation and seedling experiments of Pearl, exercise tests of Slonaker, and rate of growth tests after Northrop, and McCay and Crowell. In sum, experimental possibilities for measuring living action are diverse, and cover the entire range of living phenomena.

The applicability of action to all forms of living matter suggests its use as the basis of a precise taxonomic scale, for the species may be arranged in ascending order according to their action values. At first this may seem ambiguous, since the elephant, which has a greater power consumption than man but a comparable life span, would be higher on the scale. The complexity of the nervous system, however, appears to be the most important factor in evolution, so that nerve action (or cerebral action) based upon the power consumed by the nervous system (or cerebrum) may be the most desirable action property for expressing the phylogeny of the species. It should be feasible to study evolution as a function of the characteristic nerve or cerebral action of each species.

The flexibility of living action is an important feature from an experimental point of view. Biologists and physiologists often have to deal with certain portions, rather than the whole, of the living thing. Since each cell may be represented by a finite action, any group of cells may also be represented by a finite action. This enables the experimenter to determine the action associated with any portion of the body, such as heart, eye, reticulo-endothelial system, or glands, which may also be extended to determining the intensity of a disease, calculating the action associated with tumors, cancers, and other abnormal conditions, and even to measuring the magnitude of epidemics occurring in the species as a whole.

The different forms of action also have special significance. Basal action is based upon the minimum power consumption required just to maintain life and therefore is probably related to the basic processes of species organization; output action, based upon power output, represents the "action" of the individual on the universe, and therefore has physiological significance when viewed with respect to muscular work, and social significance when regarded in terms of the work performed; total action measures the amount of energy-time absorbed from the outside world and is consequently indicative of the "action" of the universe on the individual; nerve and cerebral actions, as mentioned, are associated with evolution; loss action, obtained from internal power losses of the body, are probably connected with senescence and death; growth action, based upon power expended for growth, should yield information pertinent to the study of pediatrics, child development, and husbandry; and so on.

Because of the predominant role of the nervous system in living things, nerve action has interesting possibilities as a measure of mental and nervous phenomena. It is significant that the reaction of a neuron to a stimulus is of the nature of a constant of action, generally measured as an action potential. Unlike most other types of body cells, nerve cells that die are irreplaceable. If the inherent action of neurons is fixed, then the life span of each nerve cell is dependent upon the number of times it is stimulated. The death of critical nerve cells may thus precipitate senescence and ultimately lead to death. Which cells are the critical ones, and how their action may be extended, are subjects warranting investigation.

Nerve or cerebral action may also be used as a psychological tool. Associations and motor patterns are created by a finite system of nerve cells, as corroborated by the existence of the learning curve. The energy-time relation for the creation of these patterns and associations may therefore be represented by a finite quantity of action, so that mental phenomena, such as the formation of a neurosis or psychosis, memorization, habits, and learning, may be assigned a definite magnitude. This magnitude can be measured, since it is dependent upon the quantity of external action producing the stimuli. The cerebral action associated with the learning of a maze by a rat, for instance, is dependent in part upon the energy and time the rat spends in the maze.

It is evident that the mere calculability of action permits many applications, regardless of variation within the species. It is also evident, however, that if living action proves to be relatively invariant its usefulness will be greatly enhanced. All characteristics of life have some variation, and it is very unlikely that there is no variation whatever in living action. The evidence is admittedly inconclusive, but the near equality of average male and female basal actions and the existence of a general inverse relation between power and life span point to a relative invariance at least for basal and total actions. These findings indicate that the combination of power and life span to produce action is not factitious, and may have a natural origin.

Constancy of basal or total action affords a means for predicting life span. This technique is not entirely novel; insurance companies have been using it indirectly for some time in correlating size and longevity. It is also a common observation that the rate of living is inversely proportional to life span, as Rubner, Pearl, Brody, and other scientific investigators have realized for some time. But the possibility that action is the determinant may lead to more refined predictions. In this context, constancy of action would mean that a gain in longevity at the expense of power consumption is not real gain, but only a relative one, and that efforts to extend the existence of a living thing should be directed toward increasing its total action.

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TECHNICAL PAPERS

Plant Growth-regulating Properties of Some Nicotinium Compounds

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Six related nicotinium compounds have been found to possess growth-regulating properties when tested on bean plants. These include: parachlorobenzylnicotinium chloride, 2,4-dichlorobenzylnicotinium chloride, 3,4-dichlorobenzylnicotinium chloride, orthochlorobenzylnicotinium thiocyanate, benzylnicotinium bromide, and orthochlorobenzylnicotinium bromide. Applied to bean plants, these compounds brought about a reduction in stem elongation without typical gall formation or other form changes commonly observed in the use of other plant growth-regulating chemicals. The compounds were systemic in effect when applied to stems. The effects were expressed by illuminated plants as well as by others grown in darkness.

2,4-Dichlorobenzylnicotinium chloride (2,4-DNCl) was the most effective, ½ mg per plant greatly inhibiting elongation of plants grown in darkness and to a lesser degree the elongation of illuminated ones.

To test the effect of 2,4-DNCl on plants subjected to darkness, potted snap bean seedlings of the Black Valentine variety, germinated in a greenhouse, were selected for uniformity at a stage of development when only the hypocotyls were exposed above the surface of the soil. Half of the plants were treated by applying approximately