the experimental time, which is limited to the natural hatching season of the year; (2) simplicity in the routine work, due to many automatic devices; (3) uniformity in the seasonal quality of hatching eggs in each group of experiments; and (4) results of several experiments suitable for comparison, particularly in the study of the effect of various environmental factors on the developing embryo.

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SPECIAL ARTICLES

ON THE LAWS OF KINETIC SYSTEMS

THE general law of growth which populations tend to follow is well known. It is expressed graphically by Verhulst's "logistic curve," rediscovered by Pearl and Reed,[1] and may be stated as follows:

> While periodic renewal maintains its limited resources in matter and energy at one level, a population so multiplies that the proportional increase anticipated in absence of checks fails in the same measure as the attained fraction of the limiting population grows.

This is the master law of populations composed of a single sort of organism, populations in the ordinary sense, *simple* populations. Consider the damping effect of population upon its own growth-rate a measure of pressure, and the law may be stated more briefly. It is set down next in its concise form, with four additional laws derivable from it by inspection.

General law of simple populations: While periodic renewal maintains its limited resources at a constant level, the pressure in a population varies as the attained fraction of its limit.

Secondary laws: (1) When in a population the average individual energy is constant, pressure varies inversely as the volume occupied.

(2) In a mixed population each component exerts the same pressure as if it alone occupied the whole volume, and the total equals the sum of the several partial pressures.

(3) If the average energy of their units be the same, equal volumes of two populations under the same pressure contain the same number of individuals.

(4) At constant pressure the volume occupied by a population, and at constant volume the pressure in a population, varies as the average individual energy.

Here it must be stated that in applying the secondary laws of populations, or in testing their applicability to empirical data, one must always measure volume in appropriate units. In working with flies, for example, a pint bottle doubly charged with banana-agar may not be considered an experimental "universe" of twice the volume of a half-pint singly charged. The true two-unit universe is one composed of two half-pint bottles with a single charge each.

In the pint bottle doubly charged, the whole method of yeast culture, for use of the adult *Drosophila* population it largely supports, is changed by altering the relation between surface and volume of the substratum on which the yeast is grown. The result is just such as a revolutionary change in agricultural methods would entail in the growth of a human population. Or, again, the transfer of a fly population from two communicating half-pint bottles normally charged to a pint bottle doubly charged, if all the details of Pearl's culture method were followed throughout, should induce just such a change in the curve of population growth as occurred when Germany and Japan turned from agriculture to industry in the nineteenth century.[2] A change opposite in sign should probably follow the transfer of a similar population to four gill-bottles connected with one another and provided with half the standard charge each.

The situation may be seen more clearly if approached from another direction. Space, from the standpoint of the kinetic theory of gases, does not differ qualitatively from point to point. But from that of populations it has structure virtually imposed upon it; if not by the mode of distribution of sources of matter and energy, then by the distribution of opportunity for the disposition of population wastes. Thus to add unit to unit of volume, when dealing with simple populations, it is necessary to add to one structured system another quite like it; or, in effect, to measure volume in terms of the unit universe, be it what it may, rather than in standard cubic centimeters or inches.

Another point requires passing mention: The pressure in a population varies with the attained fraction of its limit; and the limit is fixed by the ratio between available maximum in some critical factor and individual need. But need and expenditure, intake and outgo, are merely the debit and credit sides of the organism's ledger account with energy. Hence the legitimate substitution of the term "individual energy" for "individual need" in the secondary laws of simple populations to which we now return.

These laws relate to one another four terms—pressure, volume, number and average individual energy. But these are the terms which appear in the gas laws, and the relations said to exist between them are precisely the same in the two cases. We must therefore

[1] *Proc. Nat. Acad. Sci.*, vi, pp. 275–288, 1920.

[2] Raymond Pearl, "Biology of Population Growth," pp. 19–21, 1925.

count the secondary laws of simple populations homologues, not distant analogues,[3] of the gas laws: and, by the same reasoning as we pass from empirical laws to a kinetic theory of gases, we must pass from their own empirical laws to a kinetic theory of simple populations.

It has been suggested earlier[4] that in great natural groups of organisms genera grow according to one law which varies from group to group only as growth according to the logistic curve varies from population to population. This law of generic growth, law of differentiation, or law of evolution, is the master law of second-order populations. It may be expressed by a graph of which the ordinates in order are proportional to the sums, from the second onward, of the homologous terms of an infinite series of infinite descending geometric progressions of equal sum, whose common ratios lie between 0 and 1.0, with normal frequency distribution about the mean.

In this statement the veneer of mathematical phrases overlies sound biological and typically Darwinian construction. Aside from the idea that survival values fluctuate according to the law of chance, nothing is implied beyond the fact that variation, inheritance and natural selection are factors in evolution. But where species beget species by a process of generation in which like tends to produce like, a tendency for types to increase in geometrical progression will appear. And where there is struggle for place, a limit to the number of types which may be produced is indicated.

The joint effect of the two factors, tendency to geometric increase and the damping effect of pressure, imposed on the terms it is by the fixed limit, is to make growth in populations of organisms follow the logistic curve. But where the law of the logistic holds, lesser laws—homologues of the gas laws—hold also; and where these hold we deal with a kinetic system. Species-populations, or second-order populations, are therefore kinetic systems.

If at this point the soundness of the conclusion seems to depend wholly upon the correctness of the premises, the reader should consider these facts: Analysis of the data of taxonomy and distribution shows that species of large genera occupy upon the average large areas, while those of small genera similarly occupy small. This is clear evidence that descendant species inherit ancestral ability, more correctly the bases of ancestral ability. Jaccard's law, that the number of species per genus in a region varies with the ruggedness of the topography, shows as clearly that the number of species which may be produced in any natural group is limited. Finally, the data of paleontology, fragmentary as they are, as far as they go are consistent with the idea that increase in species-populations follows the logistic curve.

Besides the three mentioned still another type of kinetic system is the "excited" or glowing gas. The relative intensities of the lines in its spectrum change with changes in its temperature. The change proceeds regularly. The total number of its atoms active in absorbing (or emitting) a subordinate series of lines increases, passes through a maximum and decreases again, as the temperature is raised..[5] The effects of pressure are as general and regular. With increase all lines shift toward the red, the shift in each series being more marked on the part of lines appearing at high temperature.[6] Intensities, too, according to Miss Payne, should be affected by pressure generally and regularly.[7]

In short, then, a normal and an "excited" gas, a simple and a second-order population seem four distinct types of kinetic system. Because of the activity of their units, be they what they may, and their random action one upon another, certain of the laws of the four are alike in principle. This group of laws, common to kinetic systems as here understood, are the gas laws and their homologues.

But, besides the peculiarities they share, the units of these several systems have their distinctive attributes. One is neither variable nor capable of reproduction; another is capable of variation but incapable of reproduction. Still another is (by definition) capable of reproduction but no variation, and the last both reproduces and varies genetically.

It is to these differences we must ascribe the fact that the master laws of the several systems are different. That of the first is the ideal gas law, $pv = kT$. From it, as from the master law in each system, the lesser laws of the system are deducible in detail.

The master law of the second system is the law of distribution of energy in the line spectrum of an "excited" gas, for this clearly reflects the statistical distribution by state of its variable units, when that depends at once upon energy level maintained in the system and the pressure to which it is subjected. The curves setting forth its variations for a particular gas in different states of excitation will differ only as the curves of distribution of energy in the thermal spectrum differ with temperature, or those for the continuous x-ray spectrum differ with excitation potential, or as the logistic curve differs from popula-

[3] A. J. Lotka, "Elements of Physical Biology," pp. 305–306, 1925.

[4] W. H. Longley, SCIENCE, lxxiii, 1904, pp. 700–702, June 26, 1931, and *Anat. Rec.*, 51, pp. 89 and 113, November, 1931.

[5] C. H. Payne, "Stellar Atmospheres," pp. 23 and 101, 1925.

[6] H. D. Babcock, *Astrophys. Jour.*, lxvii, 230–261, 1928.

[7] C. H. Payne, *loc. cit.*, p. 144.

tion to population of one sort grown under different conditions.

The master law of the simple population has been discussed in full above. That of the second-order population, in addition to the gas laws' horologues. but the law of the logistic curve holds also in this population, in addition to the gas laws' homologues.

In conclusion we summarize the findings in this and preceding brief notes in SCIENCE a possible reader may perhaps, for obvious reasons, best take up in reversed chronological order.

The grouping of organisms in genera and species is justified by the order of nature. Taxonomy is a science, not an art. There is a definite mode of growth of knowledge of species in their genera and their ranges, from which it appears that evolution is a fact and its process Darwinian in principle. The differentiation of genera and species in a great natural group of organisms occurs according to a law affiliated with the gas laws and others, and is as capable as any of mathematical expression. These all are the laws of physical systems readily characterized, and associated naturally under the terms of an amplified kinetic theory.

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RATE OF SEA CLIFF RECESSION ON THE PROPERTY OF THE SCRIPPS INSTITUTION OF OCEANOGRAPHY AT LA JOLLA, CALIFORNIA

ABOUT two years ago measurements were made of the amount of recession of three cliffs on the property of the Scripps Institution between the years 1918 and 1930, that is, within twelve years. The results of the study were included in the report of the committee on features and changes of the shoreline of the Pacific Coast, Division of Geology and Geography, National Research Council, May 3, 1930, and they were distributed in mimeographed form, but there appears to be doubt as to whether the appearance of the results in the report mentioned constitutes publication. Since much interest has been manifested in the study it seems desirable to remove any doubt regarding publication. A summary of the results is as follows:

The first cliff is 21 feet high and it had receded 20 feet since 1918. The second cliff is 33 feet high and it had receded 15 feet since 1918, and was undercut at the time the measurement was made to a depth of 8 feet. The third cliff is 54 feet high and since 1918 it had receded between 10 and 12 feet. The heights of these cliffs were plotted as abscisses on coordinate paper and the amount of the recession as ordinates. The equation for rates of recession in terms of height was determined by Dr. G. F. McEwen, of the Scripps Institution. It is

$$y = 138\,x^{-.635}$$

Dr. McEwen has prepared a table of cliff heights in feet and rates of recession in feet per year according to this formula. It is as follows:

Height = x	Recession rates = y	Observations	
		Height	Recession in 12 yrs.
5	4.100		
10	2.650		
15	2.080		
20	1.720	21	20
25	1.490		
30	1.330	33	15
40	1.100		
50	.960	54	11
75	.740		
100	.620		
150	.470		
200	.400		
250	.340		
300	.300		
400	.250		
500	.220		

The material, composing the cliffs studied, is a non-indurated clay loam, but the lowest bed in the highest cliff is fairly tough, argillaceous, sandy material with considerable calcium carbonate cement. It appears that the rate of erosion of the loam is not faster than that of the basal bed of the cliff.

It scarcely needs to be said that, although measurements such as are given above are of interest, before entirely satisfactory conclusions can be reached there should be a much larger body of data.

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BOOKS RECEIVED

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