its much greater complexity and in the much greater indirect influence of external stimuli upon the rhythms and their patterns. But the fact remains that much that is most characteristic of the behaviour of both worms and birds depends on highly individual patterns of rhythmic activity apparently of internal origin.

The address is stimulating and leads one to many questions. What are these ‘clocks’ that control rhythmic behaviour? When we consider rhythmic contractility, on one hand, and reproductive cycles, on the other, it is clear that the clocks work on very varied principles. The one common feature is the rhythmic activity of the system whatever its grade of organization. Possibly it is a general character that they are systems in relaxation oscillation. Living organisms are dynamic, and it does not follow that they will naturally tend towards a constant steady state. Indeed, in many cases such steadiness is only achieved by the evolution of elaborate controls—like the proprioceptive machinery of limbs. Systems in relaxation oscillation may arise at many different levels of organization. Once they are there, they may inevitably be built into the behaviour of the organism through the operation of natural selection.

C. F. A. Pantin

USE OF LOGARITHMIC NOTATION IN SCIENCE AND ENGINEERING

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For the past ten or twelve years I have been using, and encouraging colleagues and students to adopt, a logarithmic system of notation, in place of the conventional arithmetical one, as the normal one in which to express physical magnitudes and relations. Suggestions that logarithmic scales and units be used more widely have been made by numerous writers, and such systems have obvious advantages. The experience gained in the use of a general system of this sort confirms that the advantages are substantial, perhaps more than is generally appreciated, and that they definitely outweigh its drawbacks and are sufficient to justify its more widespread use.

A large proportion of statements in physical science are in the form: the quantity X, as measured (calculated), is n times a specified unit. The number n is not normally integral or exact. It is not arrived at by counting but by computation from primary physical measurements (empirical quantities), and in this process of computation multiplication plays a dominant part. One can see that this is the case by inspecting a typical table in a compilation of physical data, such as fundamental constants, electrical resistivities of metals, wave-lengths of X-ray lines, or abundances of isotopes. One will find, normally, that the numbers are spread roughly uniformly over a limited logarithmic scale: for example, about 30 per cent of the entries will have the first significant figure 1, whereas only 5 per cent will begin with 9. (Even when the primary quantities are not logarithmic, the quantities derived after a few multiplicative steps soon tend to be so.)

The fact that most, although not all, of the quantities used in physical expressions and calculations are of this ‘logarithmic’ sort suggests that the normal notation to be used in expressing them, and numerical relations between them, should also be logarithmic, with some convenient unit of relative magnitude. A very convenient unit that has long been used in several branches of physics and engineering to denote a ratio of powers is the decibel (10^1/20, or approximately a factor 1-2), and many proposals have been made to adopt it (either with the same or a new name) for wider use. For the quite general use proposed in this article, a simple and distinct name and notation is called for. I have used the term ‘jot’ for the unit, and I have found the notation x = (unit ± x unit) jot, with the word ‘jot’ normally omitted, to be simple and unambiguous. It readily permits the simultaneous use of logarithmic and normal notation. Thus, for example, electron charge = (e.s.u. - 93-2), velocity of light = cm./sec. + 104-8), to an implied accuracy of ± 0-05 jot (or about 1 per cent). No confusion arises in addition, subtraction, etc.; for example, (c.g.s. + 82-1) + (c.g.s. + 88-2). A notation such as this which emphasizes the unit has considerable pedagogic value. Some other advantages of the logarithmic notation are as follows.

Simplicity of calculation. Just as so many of the physical quantities one deals with are ‘logarithmic’, so, naturally, the arithmetical manipulations in which they are involved are predominantly multiplicative (including roots, powers, reciprocals). These manipulations become, obviously, greatly simplified and far less liable to error if one starts, works and finishes with the quantities expressed in logarithmic notation. Of course, addition and subtraction become more complicated, but since these operations normally involve quantities of the same order of magnitude, whereas multiplication often involves many orders of magnitude, it is advantageous to have the notation suited to the more frequent and important operation.

Economy of notation. As previously indicated, ordinary arithmetical notation does not use all the digits equally when dealing with usual physical magnitudes. Less digits are required, on the average, to indicate a specified accuracy on the logarithmic scale. This, coupled with the simpler notation, makes quantities expressed logarithmically easier to write, remember, and particularly to manipulate mentally. Compare, for example, m = 1-87 x 10^-14 gm. with m = (gm. - 237-8), which has three less digits, and all the digits are on a similar footing.

Another feature of the logarithmic system is the possibility of ‘normalizing’ the scale of measurement so that a high accuracy can be expressed with few digits. For example, the specific gravity of a liquid might be expressed as (unity + 0-2), with an accuracy of 1 per cent, whereas normally this accuracy would require three digits.

Simplification of units. An expression such as a = 5-239 x 10^-4 centimetres (Bohr radius) is clearly both inconsistent and uneconomical in its notation. First, we have a mixture of logarithmic and linear notations: the digits themselves are
linear; whereas the decimal, exponent of 10, and the prefix centi- are all logarithmic, and all three doing the same job. With a consistent logarithmic notation such as the one proposed, multiplication even by large powers of ten does not result in clumsy expressions, so that the need for many units differing by powers of 10 is largely obviated.

For example, suppose we are making (mental) calculations to an accuracy of about 10 per cent, so that we work to the nearest jot, with mean individual error of 5 per cent. Then with four hundred three-digit numbers and ± signs we cover the range of magnitudes 10^{100} to 1, sufficient for most purposes. Moderately accurate calculations can be made in any system of units, and the task of memorizing physical data is made significantly easier. For example (to an accuracy of 1 jot), \( r_e \) (classical radius of electron) = (cm. - 126). Using \( c = (\text{cm./sec.+105}) \) and year = (sec. + 75), we get \( r_e = (\text{light-year-306}) \), which is scarcely more difficult to deal with than (metre = 146) or (angstrom = 46). With a notation that can express the size of the electron as conveniently in light years as in angstrom units, there is little need for a large multiplicity of units (and especially of length). The use of a single unit in all branches of physical science would not only simplify many calculations, but it would also bring out, most directly, the relative magnitudes of different physical quantities, related and otherwise.

Representation of errors. In logarithmic notation the sign and the number of digits before the decimal point indicates the magnitude; that after the precision. Without further specification, no digits after the point indicate an average accuracy of ± 5 per cent, one digit ± 0.5 per cent, etc. For normal error distributions, the accuracy can be given directly and absolutely by additional figures (for example, superscripts) giving the size of error in units of last digit written. (The ± sign is redundant, and more than one figure is seldom required.) For example, \( c = (\text{cm./sec.+104-772}) \) would indicate an accuracy of the quoted value of 0.02 jot or about ± 0.4 per cent.

The systematic use of logarithmic notation does involve transcription into this notation of quantities such as meter readings, some numerical constants, and data presented in conventional form. The most frequent of these is the last-mentioned, and this task would be avoided if the notation were generally used and accepted. The incorporation of non-dimensional constants presents no difficulties; for example, the expression \( 4\pi (\text{e.s.u.} - 82-5) \) is quite unambiguous and, moreover, displays the nature of the quantities involved very directly. Fortunately, \( \pi \) and powers of 2 can be expressed quite accurately in integral units (jots), and even '137' can be replaced by 21-37 to an accuracy of one or two parts in a thousand. Primary observations fall into two groups: some, such as micrometer or thermometer readings, involve counting and additive operations; others, such as most electrical instruments, do not, and there is much to be said for having the scales of these latter marked in both logarithmic and linear fashion.

To summarize: the use of logarithmic systems simplifies notation and calculation, eases the burden on memory and reduces the need for a multiplicity of units. Whenever I have had occasion to propound the merits of the system, I have generally found ready acceptance of the points made here, and this leads me to propose general use of some such system.

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SONIC SCATTERING LAYERS OF HETEROPODS

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DURING a nineteen-day oceanographic cruise in April 1955 in Bass Strait, southern Australia, the Fisheries Research Vessel Derwent Hunter, using a 14-kc/s. echo-sounder (Kelvin Hughes MS 24E), repeatedly detected some sonic scattering layers over a large and well-defined area of continental shelf. The layers were diffuse and quite unlike fish traces, and varied greatly in density; they were virtually confined to the top 20 m. of the sea and were generally found in the upper 10 m., by both day and night.

Fig. 1 shows the track of the ship, distinguishing the long echo-sounded portion; the stations at which plankton was collected; and the sections of the track along which the layers were found, which were all east of 145° 15' E. long. The longest section over an unbroken layer was about seventy miles.

Fig. 2 shows a portion of the echogram record of the densest of these layers, taken just before and during the occupation of one of the stations (No. 1 in Fig. 1), on a calm night.

Vertical bottom-to-surface hauls were made in duplicate with the "Discovery" N70 plankton net at each station on the continental shelf, and similar paired hauls from 500 m. to the surface were made at each station on the continental slope. Echo-sounding was done at twenty-seven stations, fourteen at which layers were detected and thirteen at which they were not, and was omitted at fourteen stations (mostly on the continental slope).

The plankton catches were checked to try to identify some organism which (a) was present at each station at which a scattering layer was found, and (b) was absent at each station at which no layer occurred. No organism completely satisfied these conditions, but three species met them closely: the cladoceran Evadne nordmanni Lovén, the lancelet Paramphioxus bassanus (Günther), and the heteropod mollusc Firoloides desmarestii Lesueur.

Evadne nordmanni was absent at one station where there was no scattering layer, and present at three stations, including one as far west as 143° 15' E. long. (No. 4 in Fig. 1), where there was no layer. This species is most unlikely to have caused the echo-sounder traces because it is very small (about 0.5 mm. long) and was not very abundant at any