for the theories and examples are presented with little comment and the writer is "satisfied to let the reader draw his own conclusions." With what Hancock gives, the reader would doubtless conclude that everything was readily explained by the theories presented—though by this method the theories have the advantage of being clearly and definitely formulated. The reader is rather disappointed when he finds that the hundred-page chapter headed "Ecology—Interpretation of Environment as Exemplified in the Orthoptera" consists mostly of short descriptions of the habits of grasshoppers, and he looks in vain for the "interpretation."

The general reader will probably be confused where such terms as lores, calamus, rachis, vanes, barbs, barbules (p. 46) and luna (p. 60) are introduced without explanation. There is frequent and somewhat monotonous allusion to a "plate photographic illustration" which is often several pages from the reference. The reader would have been saved much time by a page reference. At the top of page 384 reference is made to a plate that appeared in the *American Naturalist* in 1905 but does not appear in the book! Among other loose and careless statements, such as are likely to appear in any first edition, the following may be mentioned: Humming birds are said to occur "in the tropics" and they are found only in America (p. 43). On pages 73 and 75 "this species" is discussed when no species has been mentioned; on page 86 the pronoun "them" refers to "substance." The following sentence occurs on page 299: "The cherries were luciously ripe, and after eating a few, one is apt to feel a dislike for their pungent flavor." "Geophilous" is used to designate animals that feed on the surface of the ground (p. 356), and one wonders how an animal like the earthworm, that eats dirt, would be classified. These *definitions* are given (pp. 432 and 433): "Desert: Vast sandy tracts of land, appearing in western United States, where evaporation exceeds rainfall. . . . Man's Houses: Country and City Houses; (*a*) basement; (*b*) upper floor." *Rana catesbiana* appears on page 300 as *R. catisbiana* and on the plate facing this page as *R. catisbiani.* It is difficult to understand the writer's meaning when (p. 356), after stating that short-winged acridians are less numerous in treeless, arid districts than in humid, forested regions and that most flightless species of locusts are plant-feeding as distinguished from ground-feeding, he says: "My own conclusions . . . is simply this: that it is a question of food supply and nutrition derived therefrom. In the case of short-winged forms, they are due to under-development as the result of scant food."

A. S. Pearse

SPECIAL ARTICLES

ON POWERS OF TEN

For expressing numerically the widely varying magnitudes occurring in scientific work, two methods are in common use. Both are adequate and accurate, but results expressed by means of one are much more easily grasped and remembered than with the other. The more convenient method appears to be gaining in use. The present paper is written with the idea that this desirable change may be accelerated if the advantages of the method are stated, and thus presented to those who have hitherto not given the matter special attention.

The simplest way of writing a number is, of course, to write it out in Arabic notation. But this, in general, involves the presence of numerous ciphers, which the reader must count in order to learn what the number is. There is, therefore, a gain if the writer counts the ciphers for him and records the number obtained. Hence the familiar system, where a number is given as the product of (1) a series of significant digits, and (2) ten, with an exponent (*e. g.*, the velocity of light is 3×10^{10} cm. per sec.).

This system has still one great disadvantage: it calls in each case for the reading of two numbers, and thus greatly increases the strain on both the attention and the memory. And this difficulty is multiplied when the quantity expressed is less than unity, as it is about half the time. For then the exponent is negative, and the two numbers affect the resultant magnitude in opposite ways.

For instance, suppose a galvanometer which requires 3×10^{-8} amperes to give unit deflections: how will its sensitiveness compare with that of one for which both indicating numbers are numerically larger, say, 8.0×10^{-9} amperes? The larger significant figure, 8.0, indicates a larger current, and therefore less sensitiveness, but the exponent, 9, though also larger, indicates greater sensitiveness. Really, the second is about four times as sensitive as the first, but this fact is far from evident on a first reading; yet this is a very simple case. If a reader should see an account of one of these instruments on a Friday, and of the other on, say, the next Wednesday, it would require unusually careful reading indeed to leave him with any definite idea of the relative sensitiveness.

The difficulty of this system can also be well stated as follows: When a number of magnitudes, say diameters of small rods, is stated, sometimes in centimeters and sometimes in millimeters, it is evident that a good deal of unnecessary difficulty results, which can be avoided by sticking to one unit or the other. Now, between a millimeter and a centimeter there is the same difference as between any two consecutive powers of ten. An unrestricted system of notation by powers of ten, therefore, amounts practically to an unnecessary multiplication of the number of working units.

The remedy is obvious—to diminish the number of units. This is realized in the other system, which proceeds by steps of 1,000, instead of 10. A further gain is sometimes secured by using prefixes instead of exponents to indicate the working units, since the combination of a word and a number is preferable to two numbers, each of which interferes with the apprehension of the other, and even more with its recollection. This system is perhaps seen at its best in the field of electricity, where, besides the units, ampere, ohm, volt, etc., the milliampere, millivolt, microampere, microvolt, kilowatt, megohm, etc., are in common use, and have almost completely displaced the reckoning by powers of ten. The advantages of the system have been made available in stating galvanometer sensitiveness by the scheme proposed by Ayrton. The sensitiveness is simply put equal to the deflection produced by a unit current, usually the microampere. According to this scheme, the sensitiveness of one of the galvanometers mentioned above is 125, of the other, 33. Here the difficulty of remembering or comparing the two quantities would seem to be reduced to the minimum. And this illustration gives a fair idea of the value of the general method. Under it, but one thing claims attention: a single number, which need never exceed 3 digits unless the accuracy attained calls for a larger number of significant figures. Such a number is relatively easy to comprehend and to remember. The unit needs almost no attention, since all magnitudes between which a comparison is likely to be desirable will be expressed either in the same unit, or else in units so far apart that no confusion will occur.

This choice of units is, of course, the essential part of the method, and it, of course, can be realized under the form of the notation by powers of ten by those to whom that form seems desirable. All that is necessary is that those powers of ten shall be chosen which are also powers of 1,000, so that the use of 10^2, 10^4, 10^5, 10^7, 10^{-2}, etc., is to be discontinued. But the use of the prefixes to denote the units seems decidedly preferable. The electrician who should be advised to abandon his microvolts and milliamperes, and go back to "volts $\times 10^{-6}$," etc., would scarcely be profoundly impressed with the value of the advice.

A few special points seem worth noticing in this connection.

A single prefix to denote 10^{-9} seems desirable. Until it appears, 10^{-9} amperes (for instance) should of course be called a millimicroampere. "Micro-micro," of course, means a millionth of a millionth, or 10^{-12}, and is illogical when used for 10^{-9}, besides being less euphonious than the other. But it may be too late to stop the illogical use of $\mu\mu$ for the millimicron ($m\mu$) in the domain of optics.

There will undoubtedly be a tendency, as reckoning by powers of 1,000 comes more into use, for work in each particular line to be always expressed in the same derived unit. Here the advantage of a common unit more than compensates for the fact that in some particular cases the unit is not quite the most convenient. For instance, workers with thermoelements have generally found it advantageous to work in microvolts, and to keep to this unit even when the number of microvolts is over 10,000, that is, more than 10 millivolts.

In case of doubt between two units, it is probably better to use the smaller. For this diminishes the use of fractions, and also gives records more likely to be concordant with future work, since the increase of accuracy as time goes on increases the advantage of the lower unit.

In no class of quantities is more to be gained by reckoning by powers of 1,000 than with coefficients of expansion, and temperature and pressure coefficients generally. If these quantities were always tabulated in thousandths or millionths, instead of with a variable number of zeros, according to the fancy or convenience of the tabulator, a very much larger number of them would actually lie in the memory of the average working experimenter than are now to be found there. Yet these quantities, and some others, being pure numbers, have no special name, and therefore nothing to which the prefixes, milli-, micro-, etc., can be attached. They may legitimately be designated as "parts per mille," "parts per million," etc., but these expressions are rather awkward, particularly when the whole expression is "parts per mille per degree," or something like that. It would be convenient to use the fractional prefixes alone as nouns in such cases, milli meaning one part per thousand, and micro, one part per million. There is certainly considerable reason to wish that some leader, or committee, having sufficient authority, would authorize the use in this way of these terms (or something better). They have these advantages: They are brief; they would harmonize with the terms used for other physical quantities; they would tend to extend the use of powers of 1,000. For instance, at present, most observers, working to an accuracy of (say) 10 parts per million, would prefer to state it as one part per 100,000, while with the word "micro" in use the almost universal expression would be 10 micros. And the use of powers of 1,000 is quite as desirable in stating errors, etc., as in most other cases.

The use of fractional or multiple prefixes also sounds a little strange in those cases where, in order to adhere strictly to the C.G.S. system, the centimeter is used as the unit of all linear measurements. The real difficulty here, however, does not lie in the prefixes, but in the fact that two different fundamental units, the meter and centimeter, are in use, and that most physicists are probably more used to measuring small lengths in millimeters and microns. This difficulty would not be increased by the use of the term millicentimeter and microcentimeter, which are of course the logical terms to use if the centimeter is to become the practical unit of all lengths. It also seems logical to use the centimeter only where such other C.G.S. units as the absolute electrostatic and electromagnetic units would be used, and to use the millimeter and micron in cases corresponding to those where the ampere, ohm and volt would be considered appropriate.

In any case, it may be well to repeat, the main and essential advantage of the newer system that is coming into use is in the restriction of notation to powers of ten which are also powers of 1,000. And this restriction can profitably be adopted whatever may be thought or done regarding the other points mentioned in this paper.

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