SPECIAL ARTICLES

THE METHOD OF PROBITS

THE result of an investigtion of the action of a toxic agent upon the mortality of an organism is usually expressed as an asymmetrical S-shaped curve, in which the percentage mortality of each set of individuals is related to the dosage to which it has been exposed (Fig. 1). The effectiveness of a poison used

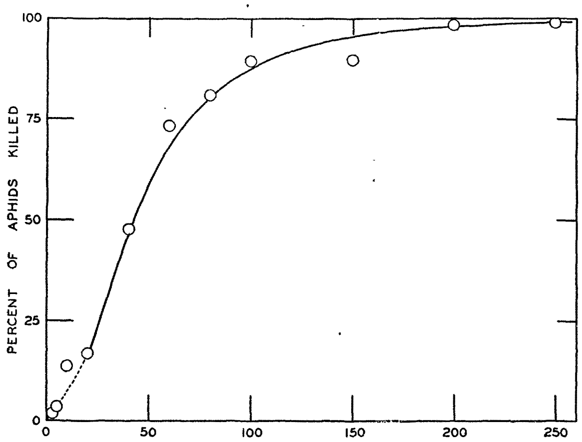

FIG. 1. Net mortality of *Aphis rumicis* L. sprayed in laboratory with different solutions of nicotine; summary of results over 3-year period. Tattersfield and Gimingham.[4] Heavy curve is same as that in Fig. 2 transposed back to original units.

to combat an insect pest is of primary interest to the economic entomologist in the range of dosages approaching 100 per cent. kill. But in this region, the usual type of curve flattens to an asymptote, so that comparisons are commonly based upon dosages which kill only from 25 to 75 per cent. of the organisms. Furthermore, the curve is ordinarily fitted free hand, and in instances where the data are more or less irregular, there is a tendency to adjust the usually asymmetrical S-curve to successive small segments of the data rather than to the observations as a whole. This practise introduces an indeterminate distortion due to the experimental errors and to unconscious bias on the part of the experimenter. It is believed that these and other difficulties can be minimized if percentage kill and dosage are transformed to units which may be plotted as straight lines on ordinary cross-section paper and hence permit fitting by the customary technique of least squares or of the straight-line regression equation.

A survey of the literature revealed that an inherent variability among individuals of a population in their susceptibility is considered to be responsible for the S-shaped character of the curve.[1] With any dosage to which some individuals succumb while others survive, the poison kills not only those which would survive any smaller amount, but also those more susceptible individuals which could be killed with a smaller amount. Because of this inherently cumulative character, the type of curve just discussed has been termed by Shackell[2] the "dose-effect ogive." So many different types of variation in a great variety of organisms have followed the symmetrical normal curve of error that the variation in resistance to poison might be expected to follow suit. Instead of assuming that the observed asymmetry in this case is due to a skewed distribution of errors, an explanation of the asymmetry has been sought in the mode of toxic action. When dosage is plotted directly on an arithmetical scale, the cumulative S-curve could be symmetrical only if equal additions in dosage at all concentrations resulted in equal increments in lethal action. It has been observed in many physiological processes that equal increments in effect are produced only when the stimulus is increased by a constant proportion of the given dosage, rather than by a constant amount. It seems probable that this same rule might hold for toxicological processes, in which case dosage would have to be plotted in logarithmic terms to show a uniform increase in kill or a symmetrical dose-effect ogive.

Of the different methods which might transform a dosage-mortality curve to a straight line, if the above analysis is a valid one, two offer advantages. By the first method, cross-section paper might be so ruled that a relationship involving the two functions, the cumulative curve (as ordinate) and logarithms (as abscissa), would plot as a straight line. Paper with rulings for a symmetrical cumulative curve and logarithms has been devised by Whipple and Hazen,[3] and can be purchased on the market. Because of greater ease in determining the straight line of best fit by the simple regression equation, the present author has found it more convenient to use a second method, to transform the data instead of the paper to the appropriate units. The transformation of dosage presents no difficulties, since tables of logarithms are universally available. For the percentage kill, no equally simple and direct system of transformation was at hand. The nearest approximation was offered by the tables of the probability integral, Nos. I and II in Part I of Pearson's Tables for Statisticians and Biometricians. The principal table (No. I) had the disadvantage of an origin at .50 (or 50 per cent.) and thus involved the use of plus and minus quantities. This difficulty has been avoided by a special table derived from those of Pearson by letting the observed 0.01 per cent. kill equal 0.00 on an arbitrary scale, 50.0 per cent. kill equal 5.00, and 99.99 per cent. kill equal 10.00, and then calculating

[1] S. C. Brooks, *Jour. Gen. Physiol.*, 1: 61, 1918.

[2] L. F. Shackell, *Jour. Pharm. and Exper. Therap.*, 25: 275, 1925.

[3] G. C. Whipple, *Jour. Franklin Inst.*, 182: 205, 1916.

TABLE I

Per cent. kill	Probits	Per cent. kill	Probits	Per cent. kill	Probits	Per cent. kill	Probits
1.0	1.87	50.0	5.00	80.0	6.13	95.0	7.21
5.0	2.79	52.0	5.07	81.0	6.18	96.0	7.35
10.0	3.28	54.0	5.14	82.0	6.23	97.0	7.53
15.0	3.61	56.0	5.20	83.0	6.28	98.0	7.76
20.0	3.87	58.0	5.27	84.0	6.34	98.5	7.92
25.0	4.09	60.0	5.34	85.0	6.39	99.0	8.13
30.0	4.30	62.0	5.41	86.0	6.45	99.1	8.18
34.0	4.44	64.0	5.48	87.0	6.51	99.2	8.24
36.0	4.52	66.0	5.56	88.0	6.58	99.3	8.30
38.0	4.59	68.0	5.63	89.0	6.65	99.4	8.38
40.0	4.66	70.0	5.70	90.0	6.72	99.5	8.46
42.0	4.73	72.0	5.78	91.0	6.80	99.6	8.57
44.0	4.80	74.0	5.86	92.0	6.89	99.7	8.69
46.0	4.86	76.0	5.95	93.0	6.98	99.8	8.87
48.0	4.93	78.0	6.04	94.0	7.09	99.9	9.16

the intermediate values in a symmetrical manner. These arbitrary probability units have been termed "probits" and are given above in an abbreviated table.

The method just described for the analysis of toxicological curves has been applied successfully by the author to a large series of data from the literature, as well as to unpublished records secured by himself or his associates. An example of this transformation is that of the curve in Fig. 1 into that shown in Fig. 2. Aside from an increased accuracy in calculating dosage-mortality curves and in interpolating dosages from such curves over a more extended range of mortalities than has been practicable with the usual asymmetrical S-curve, this type of presentation has led to the following advantages: (1) a test of the proposed theory of toxic action that (a) the variation in susceptibility among individuals is normal, and that (b) the effectiveness of the dose increases as its logarithm; (2) a closer scrutiny of experimental technique to determine if the organisms exposed to each dosage were truly equivalent and if the amounts administered experimentally were uniformly proportional to the effective dosage over the entire range covered by the experiment; (3) the disclosure of change in the mode of lethal action with certain poisons over different sections of the dosage range, indicated by an abrupt change in slope as illustrated in Fig. 2; and (4) a simple method of expressing, in the slope of a straight line, the relative uniformity or diversity between individuals in their susceptibility to a poison.

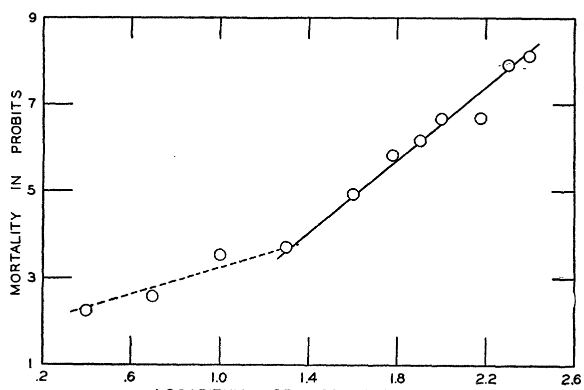

FIG. 2. Data in Fig. 1 converted to rectilinear form by use of logarithms and probits as explained.

The experimental records from the entomological literature to which this theory has been applied successfully include such diverse cases as the action of nicotine sprays upon aphids,[4] of several fumigants upon adult Tribolium,[5] of hot water upon Japanese beetle pupae,[6] of x-rays upon Drosophila eggs,[7] and of acid lead arsenate upon fourth instar silkworm larvae.[8] A more detailed table of probits and a more extended consideration of insect toxicological tests will be presented later.

C. I. BLISS

OXIDATION-REDUCTION REACTIONS BETWEEN NATURAL HYDROCARBONS AND OIL-FILLED WATERS

As far as known to the writers, it was G. S. Rogers who first pointed to certain constant relations between the occurrence of sulphide and sulphate waters on the one hand and of the composition of the associated petroleums on the other.[1] Rogers suggested that this relation might be interpreted as indicating that sulphate waters were reduced to sulphide waters by petroleums with paraffin as a base, the latter at the same time becoming oxidized and polymerized so as to yield naphthene or asphalt bases. Subsequently Bastin and his associates demonstrated that certain bacteria may serve as agents in such or similar changes and it may well be suggested, on the basis of Bastin's experimental evidence, that at moderate temperatures bacterial action is not only a sufficient but a necessary cause.[2]

In 1928 and 1930 Colacurcio and Bengtson,[3] at the

[4] F. Tattersfield and C. T. Gimingham, *Annals Appl. Biol.*, 14: 217, 1927.

[5] A. L. Strand, *Ind. and Eng. Chem.*, Analyt. Ed., 2: 4, 1930.

[6] W. E. Fleming and F. E. Baker, *U. S. Dept. Agr. Techn. Bull.*, 274, 1932.

[7] C. Packard, *Jour. Cancer Res.*, 10: 319, 1926.

[8] F. L. Campbell, *Jour. Econ. Entom.*, 23: 357, 1930.

[1] G. S. Rogers, "The Sunset-Midway Oil Field, California.—Part II, Geochemical Relations of the Oil, Gas, and Water," U. S. Geol. Surv. Prof. Paper 117, pp. 26–31, 1919.

[2] E. S. Bastin and others, "The Problem of the Natural Reduction of Sulphates," Am. Assn. Petrol. Geol., Bull., vol. 10, pp. 1281–1826, *et sequor*, 1926.

[3] M. J. Colacurcio, "Interactions of Hydrocarbons and Sulphate Waters," Univ. of Cincinnati, Unpublished Master's Thesis, 1928. R. A. Bengtson, "Interactions of Hydrocarbons and Sulphate Waters," Univ. of Cincinnati, Unpublished Master's Thesis, 1930.