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that the thyroid hormones owe their ability to moderate the process of oxidative metabolism to their high affinity for free electrons is supported by the following circumstantial evidence: the biological activities of trichloro-, tribromo- and tri-iodo-thyronine<sup>13</sup> are respectively: 1, 37 and 420. The electron affinities of chloro, bromo- and iodo-benzene are respectively: 1, 6, 370. Although the structures of the thyronines are very different from those of the halogen-substituted benzenes, the comparison is justified by the fact that the electron affinity conferred by halogen substitution is frequently independent of the nature of the molecule substituted; provided, of course, no other electrophores are also present. The resemblance between the biological activity of the thyroid hormones and that of dinitrophenol is further evidence in support of this interpretation.

Another reaction in biochemistry thought for some time to involve electron transfer is that between carcinogenic hydrocarbons and protein. A stumbling block to the understanding of the nature of this reaction has been the persistently held assumption that the hydrocarbon is the donor and the protein the acceptor of electrons; this has been difficult to reconcile with theory or observation. It was suggested tentatively<sup>14,15</sup> that these difficulties could be resolved if the hydrocarbon were in fact the acceptor of electrons. The unpopularity of the notion of a hydrocarbon so behaving in that way seems to have prevented the general acceptance of the suggestion. However, as shown in Table 1, complex hydrocarbons are very ready to function as electron acceptors. Because of their slight volatility, it has not yet been possible to test the carcinogenic hydrocarbons themselves, although it is of interest that stilbene and azobenzene both are able to capture electrons and give rise to simple derivatives with carcinogenic activity.

In general, where a similar toxic action is shared by compounds differing only in substitution with halogen- or nitro-groups, and where a disturbance of electron transport is thought to occur, then the toxicity of the compounds could be due to their ability to trap electrons. One important difference between normal intermediates which can trap elec-

trons and the toxic substances could be in the type of reaction which takes place. Trapping of electrons is potentially most harmful when it is irreversible; in these circumstances, the potential energy of the captured electron may be completely removed from the system. Furthermore, if dissociative capture occurs, and it is likely to occur with halogen- and nitro-compounds, then a highly reactive and potentially harmful free-radical may be formed. In addition to those classes of toxic agent already mentioned, other substances which may function in a similar way include halogenated insecticides, inhibitors of plant growth, certain fungistatic iodo- and nitro-compounds<sup>16</sup> and certain antibiotics such as chloramphenicol. Some of the limitations of the evidence provided from measurements of electron affinity arise from the need to conduct the observations on volatile derivatives in the gas phase. There is no reason in principle why similar measurements to those described should not be made in the liquid or even solid phases. The solution of the practical problems in this direction will greatly extend the range of measurement of this potentially important molecular property, and perhaps provide the evidence necessary for the confirmation or denial of the hypotheses outlined in this article.

I am indebted to my colleagues T. Nash and N. L. Gregory for the stimulus of their suggestions.

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## AGGREGATION, VARIANCE AND THE MEAN

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IN populations where the individuals are distributed at random, that is, are independent of each other, the variance ( $s^2$ ) at each population density is equal to the mean ( $m$ ). Individuals in natural populations are not, however, independent of each other; mutual attraction leads to aggregation which makes variance more than the mean ( $s^2 > m$ ), and mutual repulsion leads to regularity which makes variance less than the mean. Hence, in Nature, true randomness is only one of a continuous series of possible distributions (both in a spatial and a statistical sense) from regular to highly aggregated, and is consequently rare.

This property of natural populations, to show some degree of aggregation, is commonly thought to be highly specific; for example, soil zoologists know

that leather-jackets are 'more highly aggregated' than wireworms, yet the meaning of this is intangible, because no consistent measure of aggregation is at present available. In addition, many kinds of statistical analysis require that the variance should be made independent of the mean and there is no rational transformation available covering all grades of aggregation. Aggregation has been measured most widely using  $k$  in the expression:

$$s^2 = m + km^2 \quad (1)$$

derived from the negative binomial distribution. Unfortunately  $k$  is not always independent of  $m$  (ref. 5), and it is plainly desirable that an index of population structure should be the same at different

population densities, unless some actual change in behaviour is involved.

In all the sets of samples I have examined, variance appears to be related to the mean by a simple power law; variance is proportional to a fractional power of the mean:

$$s^2 = amb \quad (2)$$

where  $a$  and  $b$  are characteristic of the population in question. This is most clearly demonstrated by a  $\log \times \log$  plot of  $s^2$  on  $m$  as in Fig. 1, which includes some classic population surveys. Table 1 gives  $a$  and  $b$  for these and other populations, namely, virus lesions, macro-zooplankton, worms and symphylids in soil, insects in soil, on plants and in the air, mites on leaves, ticks on sheep and fish in the sea.

Table 1

Name	Site and sample	Range of		$N$	$a$	$b$	Transformation	Observer (refs. in brackets)
		$m$	$s^2$					
1 Shellfish on seashore, <i>Tellina tenuis</i> da Costa, Eulamellibranchiata: Mollusca	Sand, 63 units, various sizes	0.72-45.7	0.49-8.0	5	0.50	0.70	$x^{0.65}$	Holme (13)
2 European chafer larvæ, <i>Amphimallon majalis</i> Raz. (= <i>Melolontha melolontha</i> L.), Coleoptera: Insecta	Pasture soil, 25 units, each 1 ft. sq.	0.20-9.72	0.26-14.93	75	1.15	1.07	$x^{0.16}$	Burrage and Gyrisco (6)
3 Flying insects, various orders: Insecta	Open air, 16-104 units aerial density	1.9-238	1.7-606	24	1.0	1.17	$x^{0.41}$	L. R. Taylor (unpublished)
4 Wireworms, <i>Agriotes</i> spp. mainly <i>obscurus</i> , Coleoptera: Insecta	Grassland soil, 20 units, 4 in. cores	0.20-4.65	0.40-17.80	2,272	2.75	1.19	$x^{0.40}$	Yates and Finney (23)
5 Wireworms, <i>Agriotes</i> as above	Arable land soil, 20 units, 4 in. cores	0.20-4.65	0.39-22.50	525	2.85	1.26	$x^{0.37}$	Yates and Finney (23)
6 Wireworms, <i>Limonius</i> spp., Coleoptera: Insecta	Arable land soil, 175 units, each 1 ft. sq.	0.39-10.89	0.58-60.42	24	2.0	1.33	$x^{0.33}$	Jones (5, 14)
7 Gall midge larvæ, <i>Jaapiella medicaginis</i> (Rub.), Diptera: Insecta	Lucerne field soil, 10 units, 4 in. cores	0.22-5.6	0.19-13.82	1	1.3	1.33	$x^{0.33}$	Heath (12)
8 Spruce budworm larvæ, <i>Choristoneura fumifera</i> (Clem.), Lepidoptera: Insecta	Fir foliage, 25 units, larvæ/twig	0.48-15.04	0.348-51.30	1	1	1.40	$x^{0.30}$	Waters (4, 22)
9 Virus lesions, tobacco necrosis virus	Bean leaves, 4 units, lesions/half leaf	15.38-237.56	65.13-3,265.4	120	1	1.40	$x^{0.30}$	Kleczkowski (5, 15)
10 Colorado beetle adults, <i>Leptinotarsa decemlineata</i> Say., Coleoptera: Insecta	Potato foliage, 2,304 counts: insects/2 ft. row	1.0-12.1	1.4-37.7	16 16 5	1	1.48	$x^{0.26}$	Beall (2, 3, 5, 19)
11 Japanese beetle larvæ, <i>Popillia japonica</i> New., Coleoptera: Insecta	Soil, 10,000 units each 1 ft. sq.*	2.76-1,914	5.90-210,000	36	1.3	1.52	$x^{0.24}$	Fleming and Baker (10)
12 Macro-zooplankton	Water, net collection, slide count, 10 areas	95-1,750	1,444-194,480	4	1.0	1.57	$x^{0.21}$	Littleford, Newcombe and Shepherd (16)
13 Macro-zooplankton	As above, 50 areas	93-1,822	169-18,769	4	0.14	1.57	$x^{0.21}$	Littleford, Newcombe and Shepherd (16)
14 Ticks, <i>Ixodes ricinus</i> L., Acarina: Arachnida	Sheep, 20-86 units, ticks/sheep	0.84-85.6	2.5-2,292	10	1.0	1.66	$x^{0.17}$	Milne (18)
15 Enchytraeid worms, mainly <i>Fridericia vietosa</i> (Lev.), Enchytraeidae: Annelida	Pasture, 60-150 units, 3.6 cm. cores	40.8-381.5	441-29,584	4	1.0	1.66	$x^{0.17}$	Nielsen (20)
16 Corn borer larvæ, <i>Pyrausta nubilalis</i> (Hüb.), Lepidoptera: Insecta	Maize stalks, 2 stage†	6.7-970	88.5-180,220	1,054	3.0	1.66	$x^{0.17}$	Meyers and Patch (17)
17 Thrips, <i>Thrips imaginis</i> (Bagnall), Thysanoptera: Insecta	Rose flowers, 20 units, thrips/rose	20.6-137.5	223-7,900	16	1.0	1.80	$x^{0.10}$	Davidson and Andrewartha (8)
18 Leather-jackets, <i>Tipula</i> spp., Diptera: Insecta	Soil, 2 units, Nos./sq. ft.	3.10-63.50	3.5-409.0	36	0.2	1.85	$x^{0.07}$	Bartlett (1, 5)
19 Earthworms, all stages, <i>Allolobophora chlorotica</i> (Sav.), Oligochaeta: Annelida	Grassland, 4 units, 18 in. sq.	2.8-71.3	2.9-1,410	54	0.2	2.00	$\log x$	Gerard (11)
20 Red spider mite, eggs and adults, <i>Metatetranychus ulmi</i> (Koch), Acarina: Arachnida	Apple leaves, 20 units, mites/leaf	8.5-216	90-55,100	162	0.4	2.19	$1/x^{0.10}$	Daum and Dewey (7)
21 Haddock, <i>Melanogrammus aeglefinus</i> , Gadidae: Pisces	Sea, 4-47 units, Nos./trawl	4.09-288	39.1-1,239,500	15	1.0	2.35	$1/x^{0.18}$	C. C. Taylor (5, 21)
22 Earthworms, all stages, <i>Allolobophora caliginosa</i> (Sav.), Oligochaeta: Annelida	Grassland, 4 units, 18 in. sq.	4.3-44.8	4.0-500	42	0.05	2.54	$1/x^{0.27}$	Gerard (11)
23 Symphyla, <i>Symphyla</i> spp., Symphyla: Myriapoda	Various soils, 60-120 units, 2½ in. cores	4.5-31.8	0.49-690	5	0.06	2.75	$1/x^{0.58}$	Edwards (9)
24 Symphyla, <i>Scutigera</i> spp., Symphyla: Myriapoda	Various soils, 60-140 units, 2½ in. cores	1.3-31.4	0.64-1,250	6	0.035	3.08	$1/x^{0.54}$	Edwards (9)

\* Units combined to cover areas varying in size from 1 sq. ft. to 100 sq. ft. † Larvæ/stalk  $\times$  infested stalks/100: this introduces some bias in the variances.

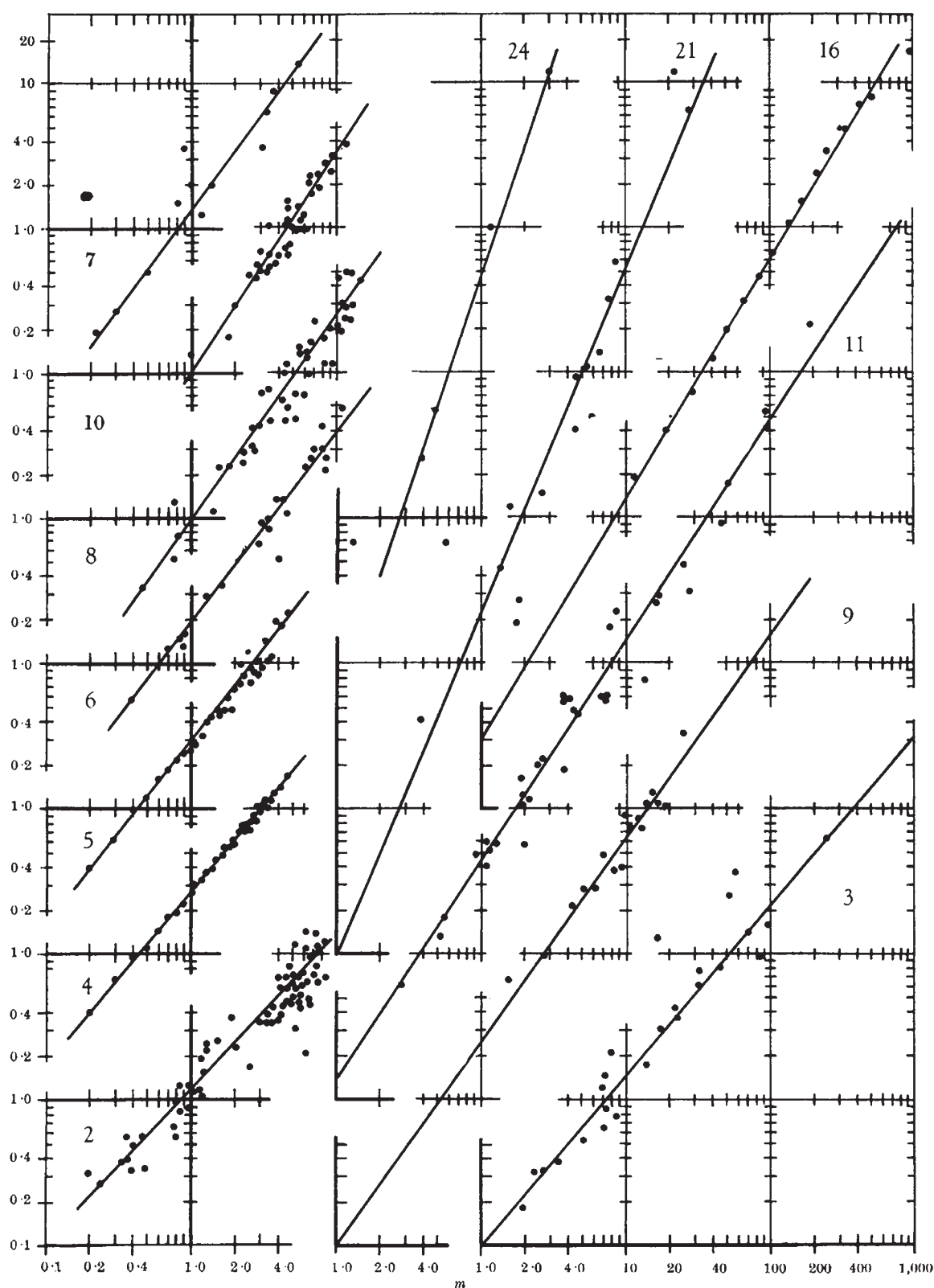


Fig. 1. Variance  $\times$  mean on log  $\times$  log scale for material numbered as in Table 1. The axes (heavy lines) are staggered to accommodate as much material as possible



$a$  is evidently largely, possibly wholly, a sampling or computing factor, depending upon the size of sampling unit and on which estimate of variance is used; this was not clearly stated in some of the analyses.  $b$  appears to be a true population statistic, an 'index of aggregation' describing an intrinsic property of the organisms concerned and with a continuous graduation from near-regular ( $b \rightarrow 0$ ), through random ( $b = 1$ ) to highly aggregated ( $b \rightarrow \infty$ ).

To use the analysis of variance technique raw data must first be transformed to make  $s^2$  independent of  $m$ . Using expression (2), the general transformation:

$$f(x) = Q \int m^{-b/2} dm \quad (3)$$

where  $Q$  is a constant, is obtained. Integration gives a square root transformation when  $b = 1$  and, logically, a logarithmic transformation when  $b = 2$ , as are commonly used; for highly aggregated populations ( $b > 2$ ) it gives a negative fractional power, for example, a reciprocal, as is appropriate to the powerful transformation required.

The power law appears to hold good down to low densities ( $m < 1$ ) in the material examined here. This implies that populations aggregated at high density tend to become regular when density diminishes, and

vice versa; the law may break down eventually or, alternatively, perhaps the concept of aggregation ( $s^2 > m$ ) is inappropriate at these low densities. In any event samples consisting mainly of 0's and 1's are likely to need special statistical treatment.

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## SURFACE ORIENTATION AND FRICTION OF GRAPHITE, GRAPHITIC CARBON AND NON-GRAPHITIC CARBON

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THE effect, if any, of surface orientation on the friction of various carbons has not yet been clearly established. Indeed, previous reports on the orientation developed by rubbing are conflicting<sup>1-4</sup>. To clarify the position and hence to improve our understanding of the mechanism of the friction of wear of these materials, an attempt has been made to provide fresh evidence, notably by a comparison of the behaviour of a carbon with a very low degree of graphitization<sup>5</sup> with graphite and graphitic carbon. These materials have been rubbed unidirectionally and the surface orientation studied by electron diffraction.

When graphite or highly graphitic carbon is rubbed unidirectionally against itself, mild steel or paper, the surface crystallites rapidly become orientated with their (001) basal planes at a small angle (5–10°) to the surface with the basal plane normals tilted against the direction of motion of the opposing surface, as shown by the electron diffraction pattern of Fig. 1. The deviation of this orientation from the parallel orientation previously reported<sup>1-3</sup> is small, but nevertheless significant, since, as the coefficient of friction is in the range 0.1–0.2 the present texture is consistent with a compression texture with its axis parallel to the resultant of the normal reaction and the friction forces. Similar textures have been recently reported by Porgoss and Wilman<sup>6</sup> to be developed by graphite when abraded with emery.

The following factors could contribute to the formation of this texture: (a) basal plane slip; (b) the plate-like shape of the crystallites; (c) preferential removal of crystallites in other orientations.

Concerning the first of these, an electron microscope study has confirmed that, as previously reported

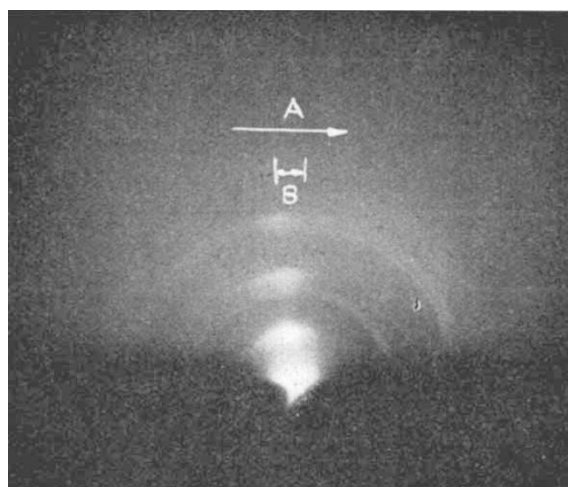


Fig. 1. Electron diffraction pattern of rubbed graphitic carbon. A, direction of motion of opposing surface; B, basal plane normals make angle of 5–10° to the surface normal