The screened probe has been found to be of special value in studying the electron-energy distribution at the high-energy end. In argon the distribution has been found to fall well below the Maxwellian value at energies above 15 volts. These facts are of considerable importance in the study of the reaction-rates of processes occurring in the plasma, and the study is now being extended to include electro-negative gases. A fuller account of these experiments will shortly be published elsewhere.

¹ Langmuir and Tonks, *Phys. Rev.*, **34**, 876 (1929).

² Tonks, Mott-Smith and Langmuir, *Phys. Rev.*, **28**, 104 (1926).

³ Sena, L., *Trans. All-Union Electrotechn. Assoc.*, **42** (1935).

⁴ Sena, L., *J. Phys. U.S.S.R.*, **10**, 179 (1936).

SCATTERING OF WAVES BY SPHERICAL PARTICLES

EVER since Tyndall's beautiful series of experiments in 1868 demonstrating the relationship between the intensity and polarization of light scattered by suspended particles and the density of the particles, and Rayleigh's subsequent deduction, on the elastic solid concept of aether vibration, that for particles of size very much smaller than the wave-length of light the intensity of scattering is proportional to the inverse fourth power of the wave-length, much interest, both theoretical and experimental, has been taken in this phenomenon of scattering. In 1908, the first rigorous treatment, according to the methods of electromagnetic theory, of the complete diffraction of a plane wave by a spherical particle of any composition was given by Gustav Mie, and this has become the classic contribution to the subject upon which subsequent discussions have been based.

Several years ago the Computation Laboratory of the United States National Bureau of Standards applied the Mie theory to compute extensive tables of scattering functions for both real and complex values of the index of refraction of spherical particles, and these have recently been published*.

The various intensity functions, which are listed, give the angular distribution of intensity and the total light scattered as a function of $\alpha = 2\pi r/\lambda$, where r is the radius of the small spherical particle from which the light is scattered; λ is approximately equal to λ , the wave-length of the incident light. From the angular distribution and the total light scattered by a suspension of particles of uniform size, the particle-size and concentration can be deduced, and the method of deduction is described. The tables are divided into four sections, the first three of which relate to real indices of refraction m , and the fourth to certain complex indices. In Part 1 the angular distribution functions, proportional to the intensities of the two incoherent, plane-polarized components scattered by a transparent particle illuminated with natural light, for values of m between 1.33 and 2.00, and in Part 2 the total scattering coefficient, for $m = 1.50$, are tabled. From Part 3 the total scattering (and absorbing) coefficient can be obtained for absorbing materials of extinction coefficient varying between 0 and 0.1 and of m between 1.44 and 1.55.

* U.S. Department of Commerce: National Bureau of Standards. Applied Mathematical Series 4: Tables of Scattering Functions for Spherical Particles. Pp. 119. (Washington, D.C.: Government Printing Office, 1948.) 45 cents.

The sets of tables for real m were computed originally on the recommendation of Prof. V. K. La Mer, professor of chemistry at Columbia University, and arose out of a series of investigations relating to chemical warfare. In Part 4 the tables have been extended to certain values of complex arguments and have application in microwave radar, where the echoes received on radar sets from suspended or falling water-droplets in the atmosphere are a particular case of the scattering problem. The range of wave-length thus considered is 10 cm.-3 mm., and the dispersion measurements made by Dr. J. A. Saxton, of the National Physical Laboratory, are used.

An admirable foreword to the tables is contributed by Prof. J. A. Stratton, who briefly reviews the history of the problem of scattering, describes Mie's formal solution, the method by which the tables have been compiled, and their particular applications. Confidence is expressed that the tables will be of considerable benefit to physical and biological science. Mathematical definitions of the tabulated functions, as well as the physical significance of the tabulated quantities, together with a short bibliography, are given in the introduction. The tables themselves are clear and easy to read, though the size and spacing of the numbers in the tables vary almost from page to page. The paper cover is to be deplored.

S. WEINTROUB

REPEATABILITY OF TEST RESULTS

A RECENT meeting of the London Group of the Royal Statistical Society's Industrial Applications Section was devoted to a discussion of the difficulties arising from discrepancies in what are supposed to be replicate test results.

Especially in the field of chemical analysis, a great deal of empirical standardization has taken place, resulting in the publication of handbooks of standard methods of tests. These, by closely specifying the conditions of test and even in some cases the dimensions of the apparatus used, endeavour to reduce the variation experienced. It is well known, however, that in spite of these attempts at reducing variation, differences between the results of tests on the same sample made by different laboratories are experienced which are larger than those found between replicate results of the same observer or even by different observers in the same laboratory using the same apparatus.

Following the lead of the Institute of Petroleum in its Standard Methods Handbook, the names 'repeatability' and 'reproducibility' are given to measures of the two kinds of variability, between replicates of the same operator and between laboratories. Mr. A. H. Dodd, of Newton, Chambers and Co., criticized this choice of names on the grounds of confusion, since in ordinary use the two words mean much the same. If there is any difference, it is that reproducibility implies an attempt to make two results alike, thus introducing the suggestion of faking results. He thought that the coining of new words (and he gave as an example the word 'squariate' for squared deviation) preferable, in this instance at least, to the twisting of old ones to bear new meanings. The new words would be even more acceptable if they conveyed within themselves the ideas of these two separate sources of variation.

Mr. J. R. Fraser, Government Chemist's Laboratory, discussed an analysis by the late Dr. Tocher of 356 test results, obtained from ten different laboratories and involving thirty-five different operators, on portions of the same material. A previously held suspicion that results from different laboratories would be significantly different was confirmed. The report makes no attempt to distinguish the two kinds of variability, but directs the attention of analysts to the need to avoid local techniques. It is, in other words, a plea for the standardization which is now being brought about. Mr. Fraser made the point that, while it is necessary to recognize and to measure the two kinds of variation, a method of test cannot be regarded as good until the two are equal; that is, the replication of a test in another laboratory should be subject to the same variability as one by the same operator. He also stressed the fact that good replication cannot be taken to indicate the correctness of the result.

After reviewing former procedure, Mr. G. Claxton, of the National Benzol Co., pointed out how the work of the Standardization of Tar Products Tests Committee and similar bodies has considerably reduced the disagreement which formerly existed between laboratories. The discrepancies have been reduced, but not completely to the level of the repeatability that a single operator can achieve. It is necessary to have some measure of each of the sources of variability in order, first, that an operator may know that his technique and apparatus are reasonably good, since departure in either respect presumably leads to greater variability among his own replicates; and, second, in order that due weight may be given to discrepancies between the test results of different laboratories.

When, in drawing up specifications, an attempt is made to allow for discrepancies between laboratories, difficulties arise. Mr. Claxton illustrated this by reference to one particular test, that for the sulphur-content of motor benzol, usually specified to be not more than 0.4 per cent by weight. The usual procedure is that the maker, having collected a bulk for dispatch, draws a sample, of which one portion is sent to a central laboratory and the other tested in his own laboratory. These two portions will be almost identical in sulphur-content, even though owing to difficulties in sampling they do not truly represent the average of the batch. If the tests on the two portions agree that the specification is complied with, both buyer and seller are satisfied. If not, and after a second test they still do not agree, the buyer may call for a sample and test it himself. This sample, because it is separately drawn from the bulk, may differ from the previous one in its true sulphur-content. Thus, in addition to the so-called repeatability and reproducibility, a third source of variation may enter into the specification, namely, the variability of samples drawn from the same bulk.

By means of a diagram, Mr. Claxton explained how these sources of variation can operate to cause a batch to be accepted which is actually above specification in sulphur-content. He showed that the logical way of dealing with this is to achieve some measure of these variabilities and to set an arbitrary specification-limit lower than the actual tolerable maximum, thus ensuring that, even when the variability operates unfavourably, bulks above the tolerable maximum sulphur-content are rarely accepted. The Standardization of Tar Products Tests Committee is in process of making these measures

of repeatability and reproducibility; but its figures have to be based on only a few results and are thought to be unnecessarily high. He entered a plea that the thousands of tests which are made annually in the routine of business might be modified so that by statistical analysis the estimates of variability might be extracted. This method of collecting information would have the advantage that the operators would not be tempted to spoil the estimates by taking special care, as they might with specially arranged tests.

Mr. R. G. Newton, of the British Rubber Producers' Research Association, spoke of the difficulty in rubber testing of achieving standard conditions of test, a difficulty which leads to high values of repeatability as well as of reproducibility. He quoted the case of a test for which repeat tests by the same operator made in quick succession varied more than tests made on different occasions. In this particular case the variability was traced to the effect of warming up the machine in which the rubber was mixed. Mr. Newton drew the conclusion that where so many causes of great variability exist, it is important to identify each and to estimate the variation to be attributed to each. Repeatability and reproducibility are all-embracing terms and are not sufficient in the case of rubber testing.

A routine analysis during production was discussed by Mr. A. E. Worley and Mr. C. E. Rhodes, of Reckitt and Colman, Ltd. They have found it necessary to employ several operators and to devise a routine of analysis which is quicker than ordinary standard methods and yet does not invite any lowering of standards of care on the part of the operator. Their methods have some originality, especially in their application to the chemical field, in that they first determined tolerable limits for the result of a test on an acceptable batch of products, and then adjusted the 'accuracy' of the test, relaxing where possible, so that batches of the product would be wrongly accepted only very rarely. This relaxing of accuracy effectively divides the presented batches into only three kinds: those below the tolerable lower limit for the test result, those within the tolerable limits and those above the higher tolerable limit.

This procedure can be thought of as equivalent to the engineer's use of a go-and-not-go gauge. By studying and measuring the various sources of variability in the test procedure, they were able to eliminate most of the variability between operators and to adjust the total effect of the other sources of variability to produce the required degree of accuracy. Their adjustment took the form, for example, of an alteration in the amount or strength of titrating fluid delivered by an auto-pipette. The important point is that the relaxation was not achieved by allowing slipshod methods, but only by broadening the classifications used to express the results. The relaxation is, as it were, under control and was only achieved after a study of the magnitudes of the various sources of variation. The authors of the scheme estimate that by its use they have achieved a reduction in the time taken for one test from five minutes to half a minute.

In the discussion, members of the audience were agreed that statistical analysis provides a useful means of interpreting the various sources of variation experienced in test results of all kinds, and that the estimation of the magnitudes to be attributed to the various sources (or groups of sources) is of value in control and interpretation. E. D. VAN REST