allowing for evaporation, 485 million cubic metres. In the cycle of seasonal flow, the reservoir will be filled during November, when the river is free from silt, and the impounding water will be used for irrigation from the middle of January to the middle of April. This reservoir will enable the whole of the natural supply of the upper Nile to be transmitted into Egyptian territory, only that portion of the water being retained in the Sudan for irrigation purposes which would otherwise pass off during flood into the Mediterranean. The present cultivable area lies at a distance of 57 kilometres from the dam and is served by a main canal, 114 kilometres in length. In the process of cultivation, crops will be grown in rotation. Of the 300,000 acres now irrigated, one-third will be assigned to cotton cultivation each year, and 100,000 acres to other crops, of which one-half will be maize, the staple food of the cultivator, and one-half lubia, a leguminous bean suitable for cattle fodder. The remaining 100,000 acres will lie fallow.

The full development of the scheme for the irrigation of the Gezira Plain involves the construction of another dam across the White Nile at Gebel Aulia, about

thirty miles south of Khartum. The object of this dam, the construction of which is not yet commenced, is to ensure the summer water supply of Egypt.

The whole project is a remarkable manifestation of the benefits to be derived from the regularisation of forces of Nature, which in their unrestrained condition cause barrenness and waste, but when skilfully controlled add immeasurably to the resources at the disposal of mankind and bring comfort and prosperity in their train.

The consulting engineers for the scheme during the last two years have been Messrs. Cooode, Fitzmaurice, Wilson, and Mitchell, who have courteously supplied the photographs reproduced herewith. The contractors were Messrs. S. Pearson and Son, Ltd., represented by Sir Frederick Hopkinson. The chief resident engineer for the Sudan Government was Mr. O. L. Prowde. The cost of the dam structure has been about 5,600,000*l.*, or, including the canalisation works, 8,500,000*l.*, but with preliminary expenses and other outlays the total cost of the project, so far, to the Sudan Government is in the neighbourhood of 13,000,000*l.*

Smokes as Aerial Colloids.

By Prof. R. WHYTLAW-GRAY.

CONSIDERING the rapid growth of colloid chemistry, it is remarkable that systems of finely divided matter suspended in gases have attracted so little attention from workers in pure science. This is all the more surprising because, on first consideration, such systems appear to be the simplest of all forms of disperse material, and it might be contended that just as the principles of the older chemistry originated from a study of gases, the investigation of aerial suspensions might throw a new light on the many complexities of the colloid state.

Apart from researches in physics which deal with the motions of individual particles mainly of microscopic dimensions, and centre around the question of unit electronic charge, much of the literature in this field is of an applied character, such as, for example, the cause and prevention of dust explosions in coal mines and factories, electrical precipitation, filtration, and settling, and the pathological effects of silicious and other dusts. Information on the stability of smokes, their electrical character and constitution, the size and nature of the aggregates formed on flocculation, is inadequate and meagre, so that the inquirer, unless he is prepared to make experiments himself, is perforce compelled to deduce the properties of these systems from first principles. This is the method followed by Dr. W. E. Gibbs in the very interesting survey of the subject delivered before the Chemical Engineering Group of the Society of Chemical Industry on October 9, and entitled "Aerosols in Industry."

From the literature available, Dr. Gibbs concludes that a close parallelism exists between these systems and the better known hydrosols. Thus smokes in general should owe their stability to the particles all carrying a charge of the same sign, and loss of charge should bring about flocculation or coagulation. The

existence of an iso-electric point is assumed, and this it is stated can be reached by adsorption either of gaseous ions or of smoke particles of opposite electric sign. Stability is believed to be enhanced by adsorption from the medium of a protective gas sheath which diminishes the chance of adhesion or coalescence of the smoke particles on collision. It must be confessed that this is an attractive working hypothesis which is supported by the work of Rudge on the charges carried by dusts and also by many observations which have been recorded in the literature.

It seems but a step to go from aerosols to aerogels, and from protection to peptisation, and to assume, as the present writer did some years ago, that the counterpart of all the main characteristics of suspensoid colloids can be discovered in these aerial systems. This, indeed, may prove ultimately to be the case, but in the present state of our knowledge, more is to be gained from a study of the differences than by the pursuit of an analogy which is based on scanty experimental evidence.

Before this view can be tested, it is essential to be able to determine the degree of dispersion in aerosols and to trace how this varies under different experimental conditions. In the case of dusts, many methods are available for estimating the total weight of suspended matter and the number of particles in a given volume, but with the more highly disperse systems consisting mainly of units near the limit of the microscope, to which alone the term aerosol is really applicable, recourse must be had to the ultra-microscope and to special methods of filtration. An attempt along these lines has been made by the present writer and his colleagues. During the last few years a number of fine oxide smokes, composed of non-volatile materials, have been examined in some detail, and it has been shown conclusively that these differ sharply from hydrosols in two fundamental points at least.

(1) These smokes even when dilute are continually undergoing spontaneous aggregation. In contradistinction to the stable metallic sols, they are unstable coagulating systems. No exception to this behaviour has been found, and a non-coagulating aerosol, if capable of existence, has yet to be discovered.

(2) The charged particles in these smokes are never all of the same sign. Usually the oppositely charged units are present in equal numbers so that the smoke as a whole is neutral. Uncharged particles are invariably present and in some cases far outnumber the charged.

The aerosol, then, is not a stable suspension of the primary particles condensed from supersaturated vapour, but is largely a collection of aggregates of a wide range of complexity the proportions of which depend on how far coagulation has proceeded, *i.e.* on the age of the smoke. A corresponding condition in hydrosols is only found during the process of quick coagulation after the addition of an electrolyte.

Whilst the agitation of the particles under molecular bombardment brings them occasionally in close proximity, it is difficult to decide whether electric forces may not play an important part in rendering the collisions effective and so causing aggregation. Analogy may, however, be misleading, and so far no marked difference has been noticed in the rates of coagulation of slightly and highly charged smokes.

A quantitative study of coagulation from the point of view of Smoluchowski's theory is much easier to realise experimentally with aerosols than with hydrosols, for whilst with a gold sol of suitable dilution the process is completed in a few minutes, a dilute smoke alters comparatively slowly and permits the changes to be followed for several hours. It has been found possible, too, with these systems to estimate the size distribution at different periods, for not only does the brightness of the aggregate as seen in the field of the ultra-microscope increase with size, but the rate of fall increases also, so that the desired result can be attained either by a statistical classification of the particles by their brightness or their rates of fall, provided that these can be correlated with the radii with sufficient accuracy.

Now whether the radii calculated by means of the Stokes-Cunningham equation from the observed rates of fall are even approximately correct depends on the structure of the complexes. If these are compact and formed by the true coalescence of the primary units, the calculated radii will not be much in error even if the particles are irregular in shape and not truly spherical. If, however, the complexes or aggregates consist of units not actually in contact but separated from each other by minute interspaces filled with air, the mean density of the aggregate will be much smaller than that of the primary particles from which it is formed, and unless this is taken into account the radii deduced will be found to be much too small.

It is clearly necessary to know, to a first approximation at least, the mean densities of these composite particles. Millikan's oil drop method for determining the value of the unit electronic charge requires a knowledge of the density of the suspended droplet; conversely, the density of a suspended smoke particle, provided that it is roughly spherical in form, can be

calculated from its rate of fall under gravity in conjunction with its rates of rise in a known electric field when carrying different charges. If the number of charges on the particles is known and the value of the unit charge is substituted in the equations, the mean density of a smoke complex can be deduced.

Considerations which cannot be discussed here make it probable that the rate of fall of these complexes is represented closely by the Stokes-Cunningham equation, provided the structure is not too loose and that the packing is close. Experiments along these lines have been made recently in my laboratory, and it appears that the composite particles in smokes of magnesium oxide, mercuric chloride, mercury and silver, possess densities varying from one-sixth to one-eleventh of that of the material in bulk, whilst coagulation in paraffin oil smoke gives particles of normal density, *i.e.* true coalescence takes place and homogeneous spheres are formed.

It seems probable, therefore, that any smoke formed by high temperature volatilisation must contain large numbers of these aggregates, and it is not surprising that the use of such particles by Ehrenhaft and others for finding the electronic charge should lead to erroneous values.

From the foregoing, it follows that the true radii of the majority of smoke particles are very much larger than has been supposed, and even in fine smokes usually exceed 3×10^{-5} cm., so that in many cases the supposed ultra-microscopic particles are really of microscopic dimensions. Recently, with a suitable optical system, it has been found possible to resolve these complexes when suspended in the air, and when this is done, the interesting fact emerges that the constituents, though closely joined together, are capable of independent Brownian motion. The smoke particle thus appears to be a system of primary units in dynamic equilibrium under the opposing forces of Brownian agitation and electrical or cohesive attraction.

It is probable that many of the properties of smokes can be explained by this structure of the complex aggregates, such as the low density of electrically precipitated smokes, and the fact that in some cases such material is peptised by weak acids or alkalis to form colloidal solutions as observed by Kohlschutter and Tuscher: the large amount of air carried down by zinc oxide fume and by carbon black pointed out by Gibbs; the immediate resolution of the large flocks of some smokes into their constituent particles on wetting; as well as the apparent stability consequent on their slow rate of diffusion and settling so marked in many fine industrial smokes.

Much work of a fundamental character is needed to elucidate the many aspects of these systems. Next to nothing is known definitely of the conditions under which ions are caught from the air and the particles acquire electric charges. The same may be said about the adsorption of gases by this type of finely divided material and also of its catalytic activity. Again, the investigation of systems composed of liquid droplets or of solid units of appreciable vapour pressure has scarcely been attempted. Indeed, the whole field of aerosols presents many interesting features and its further exploration is likely to yield results of much interest and importance.