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symmetrical resonance curves (see l.c.⁅p. 642); those generated by paraboloid-shaped resonators or such as are more complicated, like some hearing apparatus, are surprisingly variable [1]).

A very curious shape of resonators is offered by the familiai shells, found on the beach after stormy weather, and in which the murmuring of the rolling waves is heard. Here numerous tones coalesce into a murmur. Testing them involves peculiar difficulties for the very reason, that narrow conduits are not appropriated to the examination of high tones. Nonetheless the difficulty can be overcome by exposing the measuring mirror directly to the point-shaped outlets, afforded by the fine openings in the wall of the shell.

Chemistry. — *"The viscosity of colloidal solutions."* By Dr. E. H. Buchner. (Communicated by Prof. A. F. Holieman.)

According to Einstein, the viscosity of a liquid, in which a great number of particles are floating, is connected with the relative total volume of the particles. If the viscosity of the pure liquid is represented by z, that of the suspension by z', and its volume by v, if further v' is the total volume of the suspended particles, then

$$\frac{z'-z}{z} = 2,5 \frac{v'}{v}$$

This formula has been applied to gamboge suspensions by Bancelin, who obtained fairly satisfactory results; the factor had to be taken, however, 2,9 instead of 2,5. Admitting the formula to be correct, we may, conversely, calculate the volume of the floating particles from measurements of the viscosity. If, then, we determine the number of the particles (e. g. ultramicroscopically), the volume of one separate particle may even be deduced.

The application of this formula to colloidal solutions will greatly deepen our insight in the nature of these systems. We might feel some doubt, whether the suppositions, made by Einstein, when deducing the formula, hold good in the case of colloidal solutions, the particles of which are so much smaller. But Einstein himself has applied it to sugar solutions, and has calculated from the result, in connection with determinations of the diffusion constant, Avogadro's number. The fact, that he found in this way $6,6.10^{23}$, shows, that his assumptions are not far from being correct. For the rest, I have found, that even several observations on the viscosity of ordinary

[1]) H. Zwaardemaker. These Proceedings, Vol. 16, p 496.

solutions may be represented by the same formula, as I hope to show in a more detailed paper. There is, therefore, no objection to the application of the formula to colloidal solutions, which, according to modern theory, stand between the ordinary solutions and the suspensions or emulsions, and differ from these only with regard to the size of the "dissolved" particles. For the present, it is not of much importance, that the value of the factor is not yet absolutely settled. In this communication, I only wish to show at least qualitatively, that the colloid particles are combined with a quantity of the solvent. For instance, the ultramicroscopically visible particles of a ferric hydroxide solution consist of a number of molecules ferric hydroxide and a number of molecules water, these are moving as an aggregate in the surrounding liquid. A great viscosity is to be ascribed to a great volume of the colloid particles, either they are very great themselves, or they take up much water. It must be pointed out, that, when comparing different solutions, one ought to express the concentration in volume percentage, because according to the point of view here adopted, the viscosity depends only on the volume of the dissolved particles.

The idea may also be applied to ordinary molecular solutions. The fact, that the viscosity of solutions of electrolytes is often relatively large, may be brought in connection with the property of the ions, to combine with or to envelop themselves by water, a faculty of which numerous investigators have furnished proof on the most different grounds. In accordance with this conception, the salt solutions, the ions of which show the smallest tendency to hydration, exhibit the smallest viscosity. But, for the present, I will not enter further into this question.

I have only to communicate measurements of two substances, molybdenum blue ($Mo_3 O_8$?) and iron hydroxide. I have determined at 30° and 40° the viscosity and specific gravity of some solutions of varying concentrations. The values for the two temperatures differing only slightly, the communication of the results at 30° will be sufficient. In the subjoined table z' represents the viscosity of the solution, that of water being taken $= 1$, v' the volume of the particles,

deduced from z' according to $z' - 1 = 2,5 \dfrac{v'}{v}$; v is put equal to 1 cc.

The concentration of the solutions c is expressed in g per c.c.; d' is the density thereof. As dissolved substance I regard the molybdenum ·blue, dried at 100°, respectively the ferric hydroxide : $Fe(OH)_3$. The concentration of the solutions of the former is known, for they are made by weighing; the content of the latter is determined iodo-

metrically, the hydroxide having been first converted into chloride.

Molybdenum blue				Ferric hydroxide			
c	d'	s'	v'	c	d'	s'	v'
0.0199	1.014	1.042	0.017	0.014	1.011	1.034	0.014
0337	1.022	1.066	026	037	1.026	1.082	033
0511	1.034	1.091	036	074	1.051	1.192	077
0969	1.064	1.168	067				
1943	1.137	1 390	156		—		

From this table we deduce at once, that the volume of the dispersed particles is considerably greater than would be expected, if these particles consisted of molybdenum blue, resp. iron hydroxide only. The specific gravity of the molybdenum blue used was found to be 3,1 at 12°, that of the iron hydroxide may be put equal to about 4. The volume of .0511 g molybdenum blue in the solid state is therefore .017 c.c., and here we calculate for the dissolved particles .036 c c., more than the double value. For the iron hydroxide the proportion· is still greater, and even rises to about 4. These results show conclusively that the colloid particles condense water molecules around themselves or combine with them, and that the hydroxide takes up more water than the molybdenum blue. Although it has often been maintained that such dispersed particles would be composed of colloid and water, it has, I think, never been so clearly demonstrated by experiment.

We may also proceed in a slightly different manner, and calculate the density of the particles. Let us imagine a volume v of the liquid, in which particles having the total volume v' and the density D are floating; the total weight of the particles being consequently $v'D$. Let further d' represent the density of the solution, and vd' its weight. Now, the volume of the "free" water, that is the water, which is not combined with colloid particles, will be $v—v'$; if its density be called d, then we have

$$v'D = vd' — (v - v')\, d.$$

$$D = \frac{v}{v'}\,(d' \quad d) + d.$$

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$$D = \frac{2,5}{z'-1}(d'-d) + d.$$

As the specific gravity of the solution must be determined for the viscosity measurements, it is easy to deduce the specific gravity of the particles. We find for molybdenum blue 1,83 to 1,93; for iron hydroxide 1,66 to 1,8. In this manner too, it becomes clear, that the particles suspended in the liquid cannot consist only of dissolved substance, the density of which is 3 or 4, but must also contain water. As has already been pointed out, the qualitative value of these conclusions is not attacked, if it should appear, that instead of $2,5\frac{v'}{v}$, for instance, $3\frac{v'^-}{v}$ must be written. Neither would this be the case, when we introduce into EINSTEIN's formula the second power of $\frac{v'}{v}$, as is necessary for the more concentrated solutions.

I hope to discuss later from the standpoint taken in this paper, the viscosity measurements previously published by other observers. A preliminary investigation already led to remarkable results, but a great part of what is known, cannot serve my purpose; I propose to fill up this lacuna by new determinations, and to discuss then at length the many questions, which arise in this field.

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Physics. — *"Some Remarks on the Capillarity Theory of the Crystalline Form".* By Prof. P. EHRENFEST. (Communicated by Prof. H. A. LORENTZ).

(Communicated in the meeting of May 29, 1915).

§ 1. As is known, W. GIBBS[1]) and P. CURIE[2]) have set forth the following view, and given further thermodynamic grounds for it. A crystal in a solution is in thermodynamic equilibrium only when it has that shape in which its surface energy has a smaller value than for any other shape with the same content. That this equilibrium

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[1]) W GIBBS: Thermodyn. Studien p. 320.

[2]) P CURIE: Bull. de la Soc. Min de France **8** (1885) p. 145 of Oeuvies p. 153. Cf. for the relations between the theories of GIBBS and CURIE:

J. J. P. VALETON. Kristalvorm en oplosbaarheid. Proefschr. Amsterdam 1915. Ber. d. Sächs. Ges. d. Wiss. **67**, (1915).