ed for transporting the raw material to the textile mill, the cars had been moved one at a time by three horses harnessed in tandem. The storerooms were so constructed that the horses would have no means of exit in driving in ahead of the car, for which reason it had to be sent in under its own momentum. Starting some distance back, speed was gotten up, and, at the psychological moment, the "tag-holder" unhooked the "tag" fastened to the traces in the front of the car. The method is obviously dangerous. Sometimes with a heavily-loaded car the horses were unable to give it the necessary momentum, and the services of a loading gang had to be requisitioned. This is all done away with now; one man is all that is needed. In light switching service, the batteries can be recharged at various times during the day, while the locomotive is waiting between hauls. For heavier service it can be recharged during the noon hour or after working hours in the evening. Each motor has a separate gear case, so that in an emergency the locomotive can be operated with one motor. This, to be sure, means a corresponding reduction in the hauling capacity; but on the other hand, the locomotive is still in commission.

THE SENSITIVENESS OF CHEMICAL REACTIONS.

By DR. L. BRANDT.

CHEMICAL science, existing as such only since the close of the eighteenth century, has to-day a deep influence upon almost every domain of human activity. On the one hand, its laws and teachings are turned to benefit in the chemical branch, to produce by synthesis a great number of products which have become indispensable to modern man; but on the other hand, they have become of constantly increasing importance to the world at large through the opposite analytical process. Chemical analysis furnishes in industry, commerce, and agriculture valuable information regarding the character of the most varying substances; in the hygienic field it has proven of great usefulness for the common weal in the testing of food products for purity; and in the service of justice it often renders possible the unraveling of intricate criminal cases. In the following lines I will try to present to the reader a general picture of the sensitiveness peculiar to chemical reactions, and at the same time of the accuracy which the analytical chemist may attain in his work.

Indispensable for the very exact analyses is a very delicate balance, which as a rule will still respond in the case of a weighting of 100 grammes to as small a quantity as 1/10 milligramme, that is, to the millionth part of the weighting. For physical and especially for particularly exact chemical investigations still finer scales are used, which are sensitive even to 1-100 or 1-200 milligramme.

For the mere detection of a body without ascertaining its weight, frequently considerably smaller quantities are required than can be determined on the most accurate scales.

Among the most sensitive material actions which we know are those which many substances exert upon our organs of sense, especially the sense of smell. A piece of musk will send its emanations into the remotest corners of a large room, betraying its presence to every one who may enter; yet it would be impossible for a chemist to detect the substance in the air of the room in any other way. The extremely unpleasant odor of mercaptan, an organic sulphur compound, is, according to reliable tests, perceptible to the sense of smell in the quantity of one four-hundred-and-sixty-millionth of a milligramme (1-460,000,000 milligramme) in one cubic centimeter of air; this is a sensitiveness not attained by the most delicate reactions of spectral analysis. In spite of these astonishing performances, it is well known that our sense of smell is not to be compared with that of many animals, the dog, for example. It is difficult to conceive that actually material particles, emanating from the fleeing game, come into action in the nose of the dog when he is following a track several hours old; or that they excite the wild animal's olfactory nerves when he scents the hunter from afar. Yet there are indubitable traces of such material particles, which produce these effects, and are obedient to the law of gravity, though we must give up even a rough estimate of their weight.

The sense of taste also shows a high degree of sensitiveness, though far below that of smell. About 4-5 milligramme of cane sugar, placed upon the tongue in a solid state, is perceptible to the taste; of saccharine, which is 550 times sweeter, about 1 1/2-1,000 of a milligramme would be sufficient. The extremely bitter taste of strychnine and of picric acid has not quite this intensity, since with strychnine 1-200 milligramme of the nitric salt is required, and with picric acid 1-500 milligramme of the substance.

The actual chemical methods also, which are employed for the detection of separate substances, do not all show the same sensitiveness. We will first consider those which are founded upon the insolubility or the difficult solubility of a compound. Very many substances which are soluble in water or other liquids can be converted by the addition of fixed reagents into insoluble compounds, which are then separated as precipitates. The more difficult of solution the resulting compound is, the weaker can be the solution used for precipitation, and consequently the greater is the sensitiveness of the reaction. Among the compounds most difficult of solution are sulphate of barium, one part of which requires more than 400,000 parts of water for solution, and chloride of silver, which requires about 1,000,000 parts of water, by weight. The latter substance results when a solution of common salt is brought together with a solution of silver; in strong

solutions there is formed a white precipitate, of the appearance of fresh cheese, in very dilute solutions only a milky cloudiness. By this reaction the salt can be detected when dissolved in 2,000,000 volumes of water, that is, 1/2 milligramme in a liter, or 1/2 gramme in a cubic meter. If 10 cubic centimeters are employed for the test, the quantity which will produce reaction is about 1-200 milligramme.

I wish to mention here a reaction distinguished by great sensitiveness, which from its nature can be compared to the formation of precipitates; namely, the formation of arsenic mirrors through decomposition of arsenic of hydrogen. Here is a matter of the separation of a solid substance, not from a liquid, but from a gas, a phenomenon which is exactly analogous to the formation of precipitates in liquids. To test a substance for arsenic, it is placed in a dissolved state in a gas-generating apparatus, in which hydrogen gas is produced, whereupon the arsenic present escapes, mixed with quantities of free hydrogen, as the extremely poisonous arsenide of hydrogen. On heating the current of gas in a suitable tube, the arsenide is decomposed, and the arsenic is separated as a dark, mirror-like film upon the heated portion of the tube. By this method 1-100 milligramme—according to some authorities 1-1,000 milligramme—of arsenious acid can be detected with certainty. It is even not easy to procure reagents which after this test are found entirely free from arsenic. The greatest care is therefore necessary, particularly in investigations for courts of justice, lest arsenic be discovered, originating not in the object under examination, but in the reagents.

Of late the method of Gutzeit is frequently preferred, in which the arsenide of hydrogen, produced as before, is made to act upon paper soaked in a solution of silver nitrate, and the presence of arsenic detected by the appearance of a brown color. This test is still more sensitive than the other, and it is asserted that 1-10,000, even 1-20,000, milligramme can be detected by it in its improved form.

The reactions which are made known by the appearance of colorings are in general more sensitive than those characterized by the formation of precipitates, since many substances possess an astonishing coloring power. It is a familiar fact even to the unscientific that a little crystal of permanganate of potassium will color a glass of water intensely red. If the solution is so much diluted that the color becomes pale, though still distinct, it will contain about 1-5 milligramme to a liter. Iron can be detected in about the same dilution of 1 to 5,000,000 through the formation of the deep-red rhodanide of iron; since only about 10 cubic centimeters are necessary for the reaction, the actual amount of iron which can be detected is about 1-500 milligramme.

We find even more intense coloring power in the organic dye-stuffs, as will be shown by some examples. One milligramme of phenolphthalein is sufficient in alkaline solution to give a reddish color to 30 liters of water; while one milligramme of fuchsine is perceptible in 50 liters of water, thus diluted in the proportion of 1 to 50,000,000. Among the numerous organic dyestuffs, fluoresceine, whose sodium salt has the commercial name of uranine, is also worthy of mention from the fact that its alkaline solutions possess the quality of fluorescence, that is, they show different colors in light falling through them than in light simply falling upon them. This quality, also observable in ordinary petroleum, is splendidly exhibited in uranine solutions, so that this dyestuff almost equals fuchsine in intensity. Since uranine is besides this very permanent, it has been used to trace the course of streams underground, and in numerous cases has been the means of discovering the subterranean connection of watercourses with each other or with their source.

An extraordinary sensitiveness is shown by some reactions used in detecting nitric or nitrous acid, and therefore important in the examination of drinking water. Nitric acid is detected by letting the water fall in drops into a sulphuric solution of diphenylamine, whereby a deep-blue ring forms around the water drops. According to Lunge, this reaction is perceptible when only 1-20 milligramme of nitrogen to the liter, thus 50 milligrammes to a cubic meter of water is present in the form of nitric acid. Since only 1/2 cubic centimeter of water is used in this test, the real acting quantity of nitrogen is only 1-40,000 milligramme—certainly an astonishing sensitiveness.

For the detection of sulphurous acid there are a number of reagents, the most sensitive of which is the one suggested by Griess, sulfanilic acid in combination with sulphate of alphanaphthylamine; this will detect with certainty 10 milligrammes of nitrous anhydride in a cubic meter of water. Thus 1-100 gramme of the substance diffused in 10 hectoliters or 2,000 pounds of water can be detected by this reagent—one part by weight to 100,000,000 parts of water.

Having observed the greatest dilutions in which substances can be discovered by the most delicate chemical reactions, it will perhaps be interesting to compare these with dilutions which the homeopaths have occasionally employed in their medicines. The tinctures which were the starting point were diluted according to the decimal or the centesimal scale, that is, to tenfold or hundredfold volumes. A part of the "first potency" thus obtained was again diluted ten to a hundredfold; and this process was often repeated as far as the thirtieth potency or beyond. With a saturated solution of salt, containing about 26 per cent of salt, there would result at the sixth potency of the decimal scale a solution so dilute that no salt could be detected in it by silver nitrate. The greatest dilu-

tion in which the extraordinarily delicate reaction of nitrous acid with Griess's reagent takes place (1 to 100,000,000), would be about equal to the eighth potency. The thirtieth potency corresponds to a dilution of about one part to a quintillion, a number expressed by 1 with thirty ciphers. In the centesimal scale the thirtieth potency contains one part to a decillion (1 with 60 ciphers). The days, however, when the homeopaths considered such exaggerations a proof of their skill, and vied with each other in greater and greater dilutions of their medicines, are now past; later homeopathy has learned moderation in this point.

Chemical science has not for all substances such delicate reactions as the above described. But in cases where a sufficiently sensitive reaction is lacking, very slight traces of dissolved substances can be discovered through concentration of the solution by evaporation. An example of this is the discovery of gold and silver in the water of the ocean. It has been proved that a cubic meter of salt water contains 6-100 gramme of gold and nearly as much silver, so that one gramme of gold is contained in 17 cubic meters of water. In spite of this small percentage of 0.000006, the gold dissolved in the sea water of the whole globe would reach the amount of 73 milliard (thousand million) tons; since the total amount of the waters of all the oceans is estimated at twelve hundred million cubic meters, this gold, if in one solid bar, would fill a space of four cubic kilometers, or four milliard cubic meters. To obtain this treasure would certainly be difficult, in view of the extreme dilution; yet in the last few years processes for this purpose have been repeatedly patented, without, however, any practical results having been heard of.

Almost all the above-mentioned reactions are surpassed in sensitiveness by a method which has, to be sure, only a limited use, but exhibits a positively phenomenal sensitiveness; namely, spectral analysis. A knowledge of its nature must be taken for granted here, and I shall only give a few examples of its action.

The detection of common salt is possible with the aid of the sodium line when only a three-millionth part of a milligramme is employed. In the spectro-scope there is always a pale sodium line, because the air always contains traces of salt, which is drawn up in evaporation from the flood of salt water covering the greater part of the earth's surface, and carried by the winds all over the continents. In order to bring out the sodium line in perfect distinctness, it is only necessary to raise a little dust near the spectral apparatus. The sodium reaction is, to be sure, equaled in delicacy by no other reaction of spectral analysis; of lithium carbonate 1-100,000 milligramme is the smallest discoverable quantity, of potassium salts 1-1,000 milligramme.

Spectral analysis is practicable for the examination of liquids if the latter, in vessels with even parallel walls, are placed between a source of light and the spectro-scope. It is frequently made use of in this way to distinguish between different dyestuffs, and can serve, for example, to detect artificial coloring matter in red wines. Blood in very minute quantities can be discovered spectroscopically; and carbonic-oxide poisoning can be detected with great certainty in dead bodies by a spectroscopic examination of the blood, since the coloring matter of the blood, containing carbonic oxide, behaves in a very characteristic manner. Blood is also used, therefore, for detection of minute quantities of carbonic-oxide gas in the air. A portion is shaken with water and a few drops of blood, and the liquid tested by the spectro-scope. In this way one part, by weight, of carbonic oxide to 1,000,000 parts of air can be detected.

After considering so many reactions of remarkable delicacy, at the command of analytical chemistry, it is the more surprising to hear of the late discovery of many widely-diffused substances, which have until the very latest times escaped observation. Argon is to be mentioned in the very first instance, a gas which constitutes almost one per cent of the atmospheric air, but whose existence has only been known for a few years. In this case the great similarity of this gas to nitrogen, and its extremely slow chemical action, explain the striking fact. Several other elements have been lately discovered in the air—crypton, xenon, and neon; which, however, are present in extremely slight traces, and therefore were not discovered until we learned how to liquefy air in considerable quantities, and to bring about through partial evaporation a concentration of the rare elements. The amount of crypton in the air, for example, is about 1-50,000 per cent.

I will point out in closing a few technical achievements which deserve notice on account of the great dilution of the substances to be obtained. A material must be very valuable to make its extraction profitable in such a case; we find our examples therefore among the precious metals. The metallurgist separates silver from lead when it amounts to only 1-10,000 of the latter. One part of gold can be profitably extracted from 2,000 parts of silver. According to the newer method of extracting gold from auriferous sand, this is worked for as little as 2.3 grammes of gold per ton, or 0.00023 per cent. These are noticeable achievements, which in part surpass the accuracy of many analytical operations. That they are exceptional, and to be carried out only under especially favorable conditions, is easily understood when we remember that in technical operations the expense of the process must be considered, a fact which as a rule soon sets a limit to the admissible dilution of the substance to be obtained.—Translated for the SCIENTIFIC AMERICAN SUPPLEMENT from Prometheus.