PHYSICAL PHENOMENA PERTAINING TO SOLUTION AND CRYSTALLIZATION.*

BY H. J. NOVACK, M.D.

INTRODUCTION.

Molecules, Atoms, Electrons, Ethereal Corpuscles.

Research in physics and chemistry has, within recent years, wrought many changes in the fundamental theories of the constitution of matter.

Sir J. J. Thomson finds in the atom particles only one seventeen-hundredth of the mass of the atom of hydrogen—the lightest element known.

Sir William Ramsay seems to have demonstrated the transmutation of metals by producing lithium from copper.

Prof. J. N. Collie and Mr. H. Patterson, at the February, 1913, meeting of the Chemical Society in London, gave results of a series of experiments with electric charges, which indicated that synthesis of the atom had been accomplished.

The electric theory of matter with its ions and electrons does not influence the existence of the old atom, which has its position in science as a definite unit in the subdivision of matter, and is still the smallest unit of matter that enters into the ordinary chemical combination.

Admitting the electron as a subdivision of the atom, modern physicists have gone still further and tend to consider the electron as a deformation or modification of the universal Ether.

The Ether particle or corpuscle, theoretically, now holds the position of being the ultimate subdivision of matter, though its nature is still imperfectly understood.

In defining the undulatory theory of light, the Ether is assumed as a perfectly elastic medium of inconceivable tenuity, filling all space and the interspaces of all material objects. It is susceptible of being thrown into the vibrations constituting light by impulses incessantly emanating from all luminous objects.

This elastic tenuous medium must be conceived as filling all space and the interspaces of all material objects, which embraces not only the pores, intermolecular and interatomic spaces, but, according to modern theory, the interspaces between the electrons forming the atom.

The question now arises, since light is the result of "impulses incessantly emanating from all luminous objects," what is the subdivision of matter in a luminous object that is capable of impinging upon the Ether in order that a vibratory effect will result? It must be the electron, since the molecule and atom are too gross or too bulky, and admit the passage of the Ether waves through their interspaces.

In burning metallic magnesium, the forcible union of the atoms of oxygen with those of magnesium liberates a large number of electrons, which, impinging upon the Ether, causes its vibration, resulting in the phenomenon of light. The number of electrons liberated and the force with which they strike the Ether determine the volume and intensity of the light; while color is determined by the wave-length, which is directly proportional to the mass of the electron. The smaller the electron the shorter the wave resulting.

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A white smoke is visible when metallic magnesium is burned. This smoke is magnesium oxide, not in a molecular state, for as such it is invisible; but, in a coarser form, the result of the grouping together and contraction into a " particle " or " corpuscle " of a large number of molecules. These particles or corpuscles can be seen and approximately counted, when a little of the magnesium oxide smoke is collected upon a glass slide and viewed under the microscope. One grain of magnesium ribbon, after burning, is resolved into five hundred billion individual particles or corpuscles. Every particle is composed of a number of molecules, for example, ten thousand, each of which liberates a number of electrons, say a thousand. The number of electrons given off during the combustion of one grain of metallic magnesium would be equivalent approximately to five billion billion. This great number of electrons is liberated in one second or a fraction of a second, as in a flash. It is highly probable that light is the direct result of an enormous number of electrons being shot off from its source with such force and manner as to attain both the velocity and vibratory character of light.

NOTE.—A possible experiment to determine this would be the burning of a quantity of metallic magnesium, in a specially closed glass apparatus containing a sufficient amount of oxygen for its combustion, so arranged that nothing will enter or escape, except light. If a sufficient amount of magnesium were burned, then, according to the electron-emission theory, a loss of weight must result. Such loss of weight, no matter how trivial, would prove conclusively the nature of light.

SOLUTION.

The most peculiar factor of solution is that substances many times heavier than the solvent are held in suspension in defiance of the law of gravitation.

Mendelèeff believed that a solution is a homogeneous liquid system of unstable dissociating compounds of the solvent with the substance dissolved. In a homogeneous liquid like water, the molecules occur in a certain state of, although still mobile, stable equilibrium. When a substance *A* dissolves in water, its molecules form, with several molecules of water, systems A_nH_2O, which are so unstable that when surrounded by molecules of water they decompose and reform, so that *A* passes from one mass of molecules of water to another, and the molecules of water which were at this moment in harmonious motion with *A* in the form of the system A_nH_2O, in the next instant may have already succeeded in getting free. The addition of water or of molecules of *A* may either only alter the number of free molecules, which in their turn enter into systems A_nH_2O, or they may introduce conditions for the possibility of building up new systems A_mH_2O, where m is greater or less than n. If in the solution the relation of the molecules be the same as in the system A_mH_2O then the addition of fresh molecules of water or of *A* would be followed by the formation of new molecules A_nH_2O. The relative quantity, stability and composition of these systems or definite compounds will vary in one or another solution."

For the conception of the various phenomena and principles involved in solution, one must form a mental picture of the solid, liquid and gaseous states of matter.

In the solid, cohesion is greatest. The molecules are stationary, while the atoms and electrons possess definite motion similar to that of the liquid or gaseous state.

In the liquid, cohesion is moderate, and motion to a certain degree exists between the molecules. The atoms and electrons are as free in motion as in the

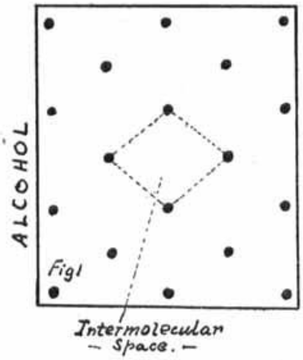

Fig 1

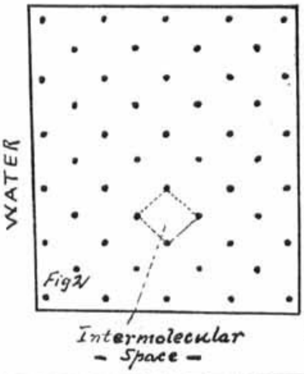

Fig 2

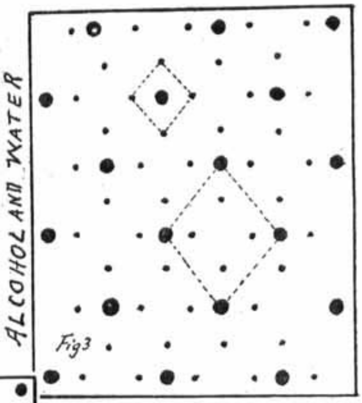

Fig 3

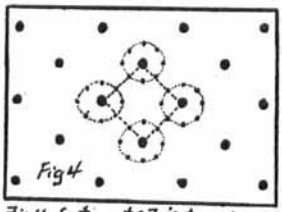

Fig 4

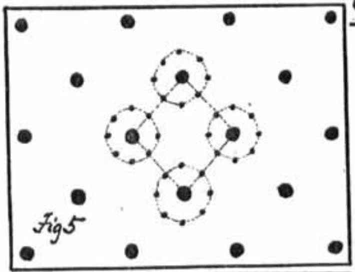

Fig 5

Fig 4.- Saturated interspace before increasing temperature.— Fig. 5.- Saturated interspace after raising temperature.

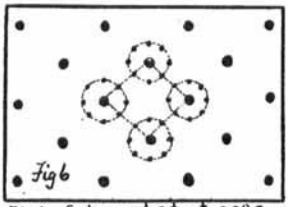

Fig 6

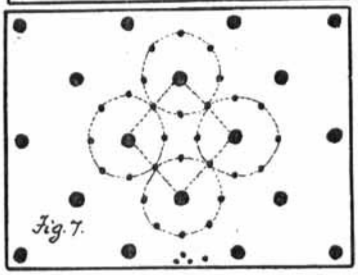

Fig. 7.

Fig. 6.- Saturated at 33°C.
Fig. 7.- Same solution heated above 33°C.

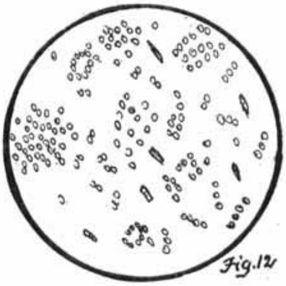

Fig. 12

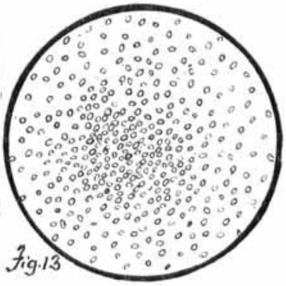

Fig. 13

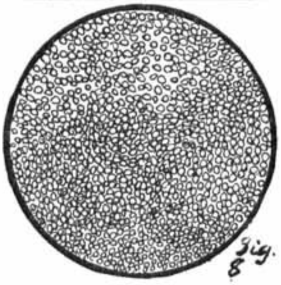

Fig. 8

Fig. 10

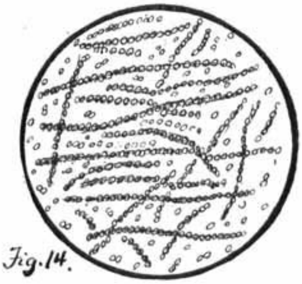

Fig. 14.

Fig. 9

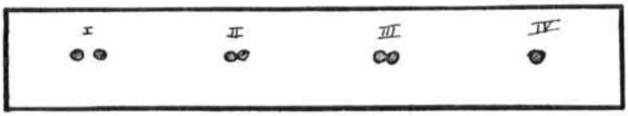

Fig. 11

gaseous or solid state. Density of liquids is dependent not only upon the volume and density of their molecules, but upon the size of their intermolecular spaces.

In the gaseous state, cohesion being absent, the molecules have free motion. The interspaces or distances between the molecules are as variable as the temperature and pressure.

The nature (size and shape) of the intermolecular spaces of a solvent and soluble substance is of utmost importance in determining the properties of the resulting solution, such as its increase or decrease in volume, point of saturation and degree of solubility. When alcohol is dissolved in water, though a solution of decreased density is obtained, the total volume is lessened. (Figs. 1, 2 and 3.)

In dissolving, a solid substance acquires a mobility of parts; that is, the molecules in a solid are at rest, while in a liquid they acquire motion. A gas, on the other hand, loses its elasticity and the motion of its molecules is decreased, due to the friction or resistance offered to its motion by the molecules of the solvent.

A substance distributed in water evidently breaks up, that is, becomes more like a gas, and acquires a greater mobility of parts. This mobility is apparent in the experiment by Gay-Lussac, with reference to diffusion of solutions, which he conducted in the cellars under the Paris Astronomical Observatory. The experiment lasted several months. Notwithstanding the uniformity of the temperature, the substance in solution, in time, ascended into the water and distributed itself uniformly through it, thus proving that there exists between the water and the substance dissolved in it a particular kind of attraction or striving for mutual interpenetration, in opposition to the force of gravity. Further, this effort or rate of diffusion is different for salt or sugar, or various other substances. It follows, therefore, that a peculiar force acts in solution and that solution is determined by a particular kind of motion which is proper to the substance dissolved and the solvent.

What is the peculiar force acting in solution which causes the ascension of a solid substance of an increased specific gravity, to the top of a solvent of less specific gravity, like salt in water? What is the particular kind of motion?

From many phenomena observed in the microscopic study of solutions and precipitations, it is reasonable to conclude that the molecules of a solution are in a state of constant rapid revolution, attaining sufficient speed to overcome the force of gravitation. For example, a solution may be likened to a number of aeroplanes in the air—the aeroplanes representing the salt molecules and the air the water or solvent. Without motion the aeroplanes could neither rise nor stay in the air. Without motion the molecules could neither rise, as in diffusion, nor stay in solution.

When an excess of a substance is added to a solution saturated by that substance, it will remain in its original state and not diffuse through the water. All the intermolecular spaces in the water of a saturated salt solution are occupied by the salt molecules in a state of motion. By raising the temperature the solubility of a salt increases, first, by imparting additional motion to the molecules so that they are able to stay in solution in groups instead of individual molecules; that is, while at the ordinary temperature single molecules remain in solution by virtue of the rapid motion they attain as a result of their small mass, an increase in temperature imparts such additional motion to the molecules that they are able to exist in solution in groups of two or more, depending upon the increase in temperature. Second, raising the temperature increases the solubility of a salt, inasmuch as the intermolecular spaces of the solvent already holding the salt to saturation also increase, admitting additional salt molecules. The solubility of sodium chloride varies comparatively little with the increase in temperature, which causes simultaneous increase in the intermolecular spaces of the water, as well as distances between the molecular groups of salt and molecules forming such groups (Figs. 4 and 5). The result is that at saturation the spaces of the solvent are filled, no matter what the temperature may be above the ordinary.

Glauber's salt or sodium sulphate diminishes in solubility after 33° C. This is explained by the fact that up to 33° C. the additional salt molecules are taken up by the molecular groups within the interspaces of the solvent; but after 33° C. the heat causes greater increase in the distances between the salt molecules than in the interspaces holding them, so that some of the molecules or groups of molecules are precipitated or dropped out (Figs. 6 and 7).

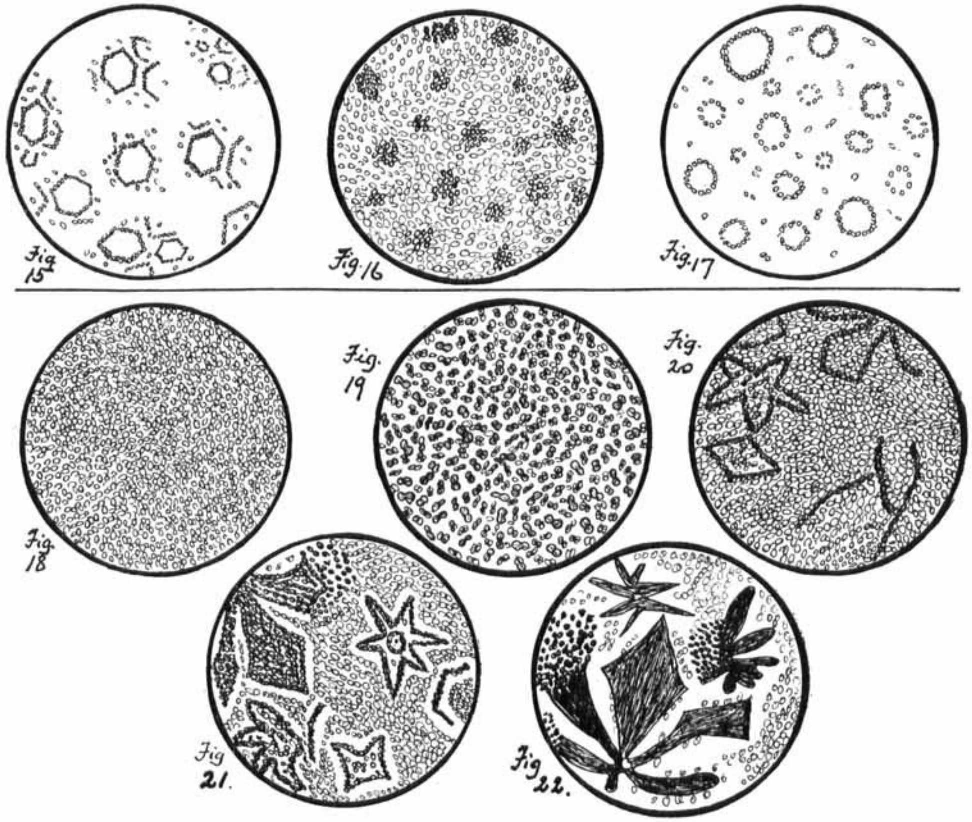

Fig 15

Fig. 16

Fig. 17

Fig. 18

Fig. 19

Fig. 20

Fig 21.

Fig 22.

When one salt is in solution and another added, the precipitation of the first may result if its molecules possess weaker motion than those of the salt added. Precipitation will also take place when the motion of the molecules of the two substances in solution is in opposite directions, the one with weaker motion falling to the bottom. For example, a powerful aeroplane in the air, meeting a smaller one, will unbalance and cause its precipitation to the ground.

When a solution of sodium chloride and silver nitrate are mixed, a chemical reaction takes place resulting in the formation of sodium nitrate, which remains in solution, and silver chloride, which is precipitated. The silver chloride is formed by the union of the silver of the silver nitrate and the chlorine of the sodium chloride, *and exists, for at least a fraction of a second, in a molecular state.* In such a state it would be capable of remaining in solution by its motion, were it not for the attraction or cohesion among the silver chloride molecules being greater than the separative power of the water molecules. It is interesting to note, with the aid of the microscope, the formation of the silver chloride "particles" out of the apparently clear solution. Evidently, a number of silver chloride molecules clump together as a nucleus towards which other silver chloride molecules are attracted, forming a very minute, rapidly-rotating visible speck. This small speck continues to increase in size by attracting around its surface additional molecules, and continues its motion until the particle becomes too heavy to remain suspended in the water, with the result that it falls motionless to the bottom of the glass slide holding the solution. The smaller the speck or particle the greater is its motion. These movements are an attenuated molecular motion similar to that existing in the molecules of any salt in solution. The properties of the actual molecules of a salt in solution are to a certain degree displayed by these particles or groupings of molecules. These phenomena will help to appreciate the cause of the Brownian movement or the motion of colloidal gold particles.

Ammonia dissolved in water evolves heat. This is due to its molecules being toned down from ultra-rapid motion in the gaseous state to that of solution. Heat is evolved as a result of contraction of its molecules, and then again, when already in solution, the rapid motion of the gaseous molecules also generates heat. This is why in the solution of gases in water a heat effect is observed.

This phenomenon is different in the solution of solid substances, because their passage from a solid to a liquid state is accompanied by an absorption of heat. Heat is required and used up in tearing the molecules of the solid asunder and to set them in motion. This causes the cooling effect when a solid is dissolved in water. Then again, when already in solution, the motion of the molecules may attain such great speed that heat will be generated. The definite chemical union of the solvent and substance dissolved evolves heat. Consequently, their sum may either be a cooling effect, as when the motion of the molecules is not sufficient to cause heat evolution while heat is used up in tearing the molecules apart and setting them in motion; or a heating effect is observed when the motion of the molecule is excessive or heat is generated by actual chemical combination.

One hundred and twenty-four grammes of sodium thiosulphate (employed in photography), $Na_2S_2O_3$, $5H_2O$, *melting* at 48° C., absorb 9700 units of heat; but, in dissolving in a large quantity of water at the ordinary temperature, 5700 units of heat are absorbed. In the melting of the salt, it takes 4000 units to heat it to a point where it will melt, *forming a saturated solution.* In a large quantity of water, the 124 grammes of salt take up less heat while dissolving, as it does not form a saturated solution. Then again, the separative action of the water upon the 124 grammes of salt is equivalent to 4000 heat-units, and, therefore, require only 5700 heat units to set the molecules of salt in motion or solution.

In most cases, solid substances in dissolving in water evolve heat, since their molecules, when once set in motion in the water, attain such great speed that heat is generated in excess of what is continually being taken up by the molecules entering the solution state. Thus, calcium chloride ($CaCl_2$), magnesium sulphate (anhydrous) ($MgSO_4$) and many other salts evolve heat in dissolving. For example, 60 grammes of magnesium sulphate evolve 10,000 units of heat in dissolving. Therefore, in the solution of solid bodies, either a cooling or a heating effect is produced.

Mendeleèeff believed "that the solution of a solid in water—although it is as with gases, a physical passage into a liquid state—is determined by its chemical affinity for water. This is clearly shown by the fact that in solution there occurs a diminution in volume, a change in the boiling point of the water, in the freezing point, and in many similar properties. If solution were physical and not a chemical phenomenon, it would naturally be accompanied by an increase and not by a diminution of volume. Contraction is the usual phenomenon accompanying solution, just as happens in the combination of substances when evidently new substances are produced."

The probability is that in solution we have a means of appreciating the nature of chemical affinity, since some solutions are close to the physical border, others median, and still others purely chemical. If diminution in volume, change in the boiling and freezing points are indicative of purely chemical phenomena, then, solution is chemical in nature. If, however, we admit that diminution in volume is the result of differences in the position of the molecules of the substance and solvent; that the boiling point is increased correspondingly with the concentration, because the solid or salt dissolved in the water takes up the extra heat to keep the molecules in extra rapid motion or rotation; that the freezing point is lowered, because it requires the extra reduction in temperature to stop the motion of the molecules of the substance dissolved in the water, then, solution is physical in nature; unless we admit these physical phenomena over the chemical borderline. For example, in winter, sea water will remain fluid, while river waters are frozen, because the salt molecules are in a state of motion in between the water molecules, which, at the ordinary freezing temperature, cannot rearrange themselves into the form of ice until the motion of the salt molecules ceases, requiring a lower temperature than 0° C.

"One hundred parts of water at 20° C. dissolve 34 parts of potassium nitrate; but, on the addition of sodium nitrate, the solubility of the potassium nitrate increases to 48 parts in 10 of water (Carnelly and Thomson)." The increase in solubility is due to the desiccation of one salt by the other, that is, the molecules of one get in between the molecules of the other substance, thereby aiding the water in lessening the cohesion of the less soluble salt. Then again, the molecules of a *slightly soluble* salt do not possess sufficient rapidity of motion to permit them to exist in solution in large groups; but, by the addition of a more soluble substance whose molecules must naturally possess greater motion, it is possible for them to act as a nucleus or center around which the molecules of the less soluble substance gather and are in this way held in solution in larger amounts.

Common salt is insoluble in oil, since there is no interpenetration of the salt by the molecules of oil or the oil by the molecules of salt. Therefore, it is the penetration between the molecules of a substance by a solvent, as well as the motion of the molecules of that substance in the solvent, that determines its ultimate solubility.

Solution is dependent upon a definite physical relation between the size and shape of the molecules and intermolecular spaces of the soluble substance and solvent. For example, water loosens very few molecules from iodine crystals, being unable to penetrate the interspaces of the iodine. Upon addition of potassium iodide, the iodine molecules are separated by the interpenetration of the potassium iodide molecules in solution. This is similar in a way to the physics of a colloidal gold solution, the result of an electric current tearing away gold particles. Water alone cannot do this unless aided by electricity, and is partly similar to the potassium iodide acting in solution upon crystals of iodine. Were the electric current capable of separating the gold into molecules, instead of groups of molecules in the form of particles, there would be formed an actual solution of gold in water and not a colloidal one, which it does form.

As regards their chemical composition, the colloids as a class are very complex—that is, they have a large molecular weight and a large molecular volume—in consequence of which they do not penetrate through membranes, and are easily subject to variations in their physical and chemical properties, owing to their complex structure and polymerism. They have but little chemical energy.

CRYSTALLIZATION.

By cooling a saturated solution or by slow evaporization, crystals of the substances dissolved are in many cases formed. The most remarkable circumstance is, that many solids, in separating out of an aqueous solution, retain a portion of water, forming crystallized solid substances which contain water. As a result of the linking together of the molecules of a crystalline substance, a number of molecules of water are enclosed and called "water of crystallization." Alum, copper sulphate, Glauber's salt, and magnesium sulphate contains such water; but, neither sal ammoniac, table salt, nitre, potassium chlorate, silver nitrate, nor sugar contains any water of crystallization. One and the same substance may separate out from a solution with or without water of crystallization, according to the temperature at which crystals are formed. Thus, common salt in crystallizing from its solution in water at the ordinary or higher temperature contains no water; but, if its separation from the solution takes place at a low temperature, namely, below –5° C., then the crystals contain 38 parts of water in 100. This is because at the ordinary temperature the salt molecules possess too much motion, while at a low temperature the motion of the salt molecules is toned down to a point similar to the motion of the water molecules, both being brought closer together so that crystals contain water of crystallization. Crystals of the same substance which separate out at different temperatures may contain different amounts of water of crystallization.

A supersaturated solution is similar to a saturated or even ordinary solution, except that the molecules of the salt forming the supersaturated solution are closer together or in larger groups. The slightest disturbance, such as the admittance of air or the dropping into the solution of a similar crystal, causes immediate crystallization. Thus, if a vessel holding the supersaturated solution of Glauber's salt be opened and a crystal of Glauber's salt be thrown in, crystallization suddenly takes place. The molecules nearest the crystal rush to attach themselves to its surface, and thus the molecules throughout the entire solution are thrown out of their regular orbits and fall on one another. A considerable rise in temperature is noticed during this rapid separation of crystals, due to the sudden cessation of the motion of the salt molecules and their contraction into crystals. Naturally, when two or more rapidly-rotating molecules suddenly come together so as to stop their motion, heat results.

In the majority of instances, where solid bodies are allowed to separate slowly from their solutions, they are found to assume regular geometrical forms. This tendency is much stronger in some substances than in others and it varies widely in the same substance under different physical conditions.

The regular external form of the crystal is its most striking feature, and the only one that, for a long time, was regarded as essential. But we now know that this form is only an outward expression of a regular internal structure.

The powers that are active in the formation of crystals and their mode of formation have been favorite subjects of speculation by past writers on crystallography. The microscope has, within recent years, aided in the study of this interesting subject, revealing some highly interesting and important phenomena.

Whenever molecules of a solid abound in a free state, their first manifestation of cohesion usually is in the form of minute microscopic particles, varying in volume and density with the substance forming them. These particles may be termed " primary crystalline molecules or particles," since many crystals can be traced directly to the arrangement and contraction of these particles into forms. The first microscopically visible trace of precipitation is in the form of these particles—which is the result of cohesion between the molecules thrown out of solution. Smoke of any kind is the result of cohesion of the molecules into primary crystalline particles. This particle is so universal that it may be called the " chemical cell."

The following observations will help elucidate the subject under consideration:

Magnesium Oxide.—A fraction of a grain of metallic magnesium is ignited and the smoke or oxide collected on a glass slide.

When viewed under the microscope, a large number of primary crystalline particles are visible. These particles are formed directly from the nascent molecules of the magnesium oxide as the metal burns, by attraction around one or more molecules as a nucleus or center in rapid motion of additional molecules, finally forming the smoke particle. After some time, the particles are gradually drawn closer together, and result in a sort of linear crystallization (Figs. 8 and 9).

Definite crystals never form. When a small drop of water is added to the slide and particles loosened from the surface by means of a needle, very active motion will be noticed. There are approximately five hundred to a thousand billion individual particles formed by the combustion of one grain of magnesium metal. Every particle measures approximately one twenty-thousandth of an inch in diameter.

Cupric Chloride.—A drop of a solution of this substance (4 grains to the ounce) is placed on a slide and viewed under the microscope.

A number of primary crystalline particles possessing active motion are noticed. After they fall to the bottom of the slide, the particles are seen to arrange themselves into forms by " looking for a place." A particle can often be seen to go between two other separate particles and make one out of all by " fusion."

A drop of a solution (¼ grain to the ounce) is placed on a slide and gently evaporated over a Bunsen flame. When the slide is examined, the appearance is like Fig. 10, the particles having a tendency to arrange or crystallize along lines radiating from a single point.

Arsenic Trioxide.—One five-thousandth of a grain on a needle point is heated in a Bunsen flame and the sublimate caught on a glass slide. A drop of water is placed over the sublimate and particles are disturbed by rubbing a needle over them.

The detached particles acquire definite and pronounced motion. Groups of particles also move, due to the impacts by invisible or undeveloped particles, as well as the transference of motion through the water by sympathy. There are approximately two trillion particles to every grain of this substance.

Cuprous Oxide (Red).—Being insoluble, one-fourth of a grain is mixed with one ounce of water.

Particles display very good motion. They seem to attack each other, separate, and return after a moment to repeat attack. Often, after persistent watching of two particular particles in process of attraction and repulsion, they may be seen to gradually unite into one. Manganese peroxide shows similar phenomena (Fig. 11).

Motion continues for a long time and the activity of the actual molecules imparts motion to any minute foreign body or fully developed particle. No crystals are formed in the water. The most is the union of two or formation of clumps.

Stannous Chloride.—One-fiftieth or one-twentieth of a grain to the ounce of water.

This substance absorbs oxygen from the air and changes to stannic oxide, precipitating as such. So-called life or motion is, therefore, very pronounced from the very faint speck of freshly formed stearic oxide, until it forms a fully developed particle of stannic oxide. It is strongly crystalline—one one-hundredth of a grain to one ounce of water shows crystallization and motion of particles.

Mercuric Iodide.—When mixed with water, motionless clumps are noticed, the substance being insoluble. When a little mercuric iodide on a pin-point is heated in a Bunsen flame and the vapor or sublimate collected on a slide, a good field of primary particles is procured.

The actual molecules actually form the gross molecules as soon as they strike the glass. When a drop of water is added, partial crystallization takes place. By drawing a needle over the field some particles are dislodged from their attachment and display motion for some time (Fig. 12).

Cadmium Chloride.—One-eighth of a grain to the ounce of water renders a good field of individual particles displaying fair motion (Fig. 13). When a little is heated, it volatilizes into the brown oxide, which can be caught on a glass slide. A small drop of water is placed on the sublimate and what may be termed partial crystallization takes place among the primary particles (Fig. 14).

Boric Acid.—A small crystal is heated and the sublimate collected on a cool slide.

The sublimate does not appear evenly over the entire slide when viewed microscopically. Instead, a number of particles, partially-formed crystals and crystals all forming a group are noticed away from another similar group (Fig. 15).

It seems that, crystallization being very strong in the sublimate, crystals form the instant the particles strike the glass surface. The contraction gives the appearance of groups. Hexagons are the prevailing forms in this substance. The particles are often visible in the partially-formed hexagon and are of a light-greenish color.

Calomel.—A small speck of calomel is vaporized and the sublimate collected on a slide. Individual crystalline particles are visible and interspersed are seen darker and larger bodies (Fig. 16), evidently an attempt at partial crystallization upon condensation on the slide. When a small drop of water is added to sublimate and particles loosened by a needle, they display motion.

Gold Chloride.—One-quarter grain to ounce of water.

This substance is one of the best for studying the life or motion of the individual particle. From a faint speck particles are seen to develop, and when heavy enough, sink to the bottom or surface of slide. Two particles may unite while in process of development or motion, or two may unite after falling near each other. The brass of the lens helps precipitate the solution, since no cover slips are used in making observations. Mercury bichloride and silver nitrate give similar phenomena.

Sulphur.—A small particle of sulphur is ignited and the smoke collected on a cool slide. Upon this slide are sulphuric acid—formed by the sulphur dioxide (gas) and sulphur trioxide (gas) with the moisture of the air—and a white deposit of pure resublimed sulphur. This sulphur deposit is in the form of crystalline particles. The slight moisture due to the little sulphuric acid formed permits the particles to float freely, and they are, therefore, very active. Particles are seen to run here and there and suddenly fuse with each other. The rings or serpent forms appear as if they had a capsule. This is due to the contraction around the outside causing better fusion of the particles.

A drop of water is placed on a slide in a hanging position so as to catch the fumes of the burning sulphur. When viewed under the microscope, a swarming bunch of particles are noticed. Sometimes they float on top of the water arranged in circles, like Fig. 17.

Copper Acetate.—A quarter of a grain is dissolved in an ounce of water. A small drop is placed on a glass slide and very gradually evaporated, at the same time the slide is studied microscopically.

The following five stages can be differentiated:

First, the development of the " primary crystalline particles " or " gross molecules " from the actual molecules of the solution (Fig. 18).

Second, the formation of pairs from the union of two primary particles (Fig. 19).

Third, a faint appearance or tendency towards arrangement in lines and shapes (Fig. 20).

Fourth, closer attraction and definite arrangement, the separate particles still being visible; " semi-fusion " (Fig. 21).

Fifth, complete " fusion," after which all lines of demarcation and traces of the individual particles are obliterated, thus forming a complete crystal (Fig. 22).

As soon as attraction between the particles and arrangement are manifested, a clear area containing fewer or no particles becomes noticeable in the vicinity of the crystal in formation or formed crystal.

CONCLUSION.

The various substances under experimentation, of which the preceding are but a few examples, were all reduced to a common, initial or fundamental form—" primary crystalline particles " or " gross molecules "—from which the development or formation of crystals can visibly be traced.

Most characteristic is the fact that these particles display very decided activity, so that it would be difficult to distinguish them from various living organisms of a low order. They possess the power of attraction and repulsion for each other. A particle already attached to several others may suddenly be seen to tear itself away from its fixed position and dart across a distance, to become attached to another particle or group of particles.

In short, the first visible trace of crystallization is the formation, out of the actual molecules in solution, of a very minute particle, which displays the phenomenon of definite motion, has the power of attraction and repulsion, and continues to increase in size by accumulation while in motion of additional actual molecules, until its mass has become so heavy as to fall to the bottom of the solution, where it combines or attaches itself to other similar particles, forming crystals.

As the atomic arrangement determines the molecule, and the molecular arrangement the " primary crystalline particles," so the arrangement of the " primary crystalline particles " determines the shape or form of the crystalline substance.