

in which lattice theory enters into various branches of mathematics is briefly as follows. Many fundamental theorems in a mathematical discipline often deal directly with distinguished subsets of elements rather than with the elements themselves. Now these distinguished subsets in various mathematical domains are found to possess common properties. So there is value in studying a discipline in which an undefined element is abstracted from a distinguished subset of elements of a totally different discipline—and that is what lattice theory does. For example, invariant subgroups are such distinguished subsets of elements in group theory. It is problematical, however, whether pure lattice theory would in the future have as much influence on group theory as some other branches of mathematics have already had.

There are very few branches of mathematics that have not been applied to the solution of problems in the pure physical, biological and social sciences, and the day is dawning when the same could be said about the engineering sciences. I mean this statement to be as sweeping as possible; for there are indications in the scientific literature that show that advanced portions of function space theory and non-linear functional equation theory will, with all their topological paraphernalia, become very useful in practical engineering problems.

Physical and astronomical research from ancient times to the present era has exercised a potent influence on mathematical research. This influence has often been in the form of hunches and heuristic guides. An admirable illustration of this is furnished by the choice of appropriate boundary conditions for a partial differential equation, say, for those equations occurring in potential theory. All this has been common knowledge for many years. There is another side to this influence of physics on mathematics that is not so well known and is taking place right before our eyes. I am referring to some of the misconceptions of physicists that have led mathematicians to start interesting mathematical researches. An excellent example is furnished by the so-called ergodic hypothesis of the classical statistical mechanics. Physicists now seem to be unanimous in their opinion that there

is no known physical system that operates under the ergodic hypothesis. Even a hasty survey of the recent mathematical literature shows, however, that mathematicians were first led to the study of the so-called ergodic theorems on linear transformations by their own curiosity concerning the ergodic hypothesis. Another illustration is furnished by the numerous abortive attempts of physicists to manufacture unified field theories in general relativity. All these attempts at a unified field theory seemed to be physically vacuous or untenable, and yet some of the most beautiful work by mathematicians in the field of modern differential geometry was directly inspired by such misconceived attempts.

In conclusion, we would like to make a few more remarks concerning this present-day trend towards more abstract and general work in mathematics—a trend that results more and more in the omission of the real number system as a necessary part of many mathematical disciplines, and a trend that points the way to the Olympian heights of the stately mountain peaks that loom in the ever-widening horizon of the mathematical world. Until rather recently, many mathematical concepts such as limit point, open set, closed set, continuity, differentiability—just to mention a few—were thought to be intimately connected with the real number system. We now know that such is not the case and that these concepts have natural domains of existence that are much more general than real number domains. The methods of proof used in real number theory often have to be radically changed so as to conform to the more general patterns. All this is interesting, and frequently great difficulties arise in the proofs of theorems; but the more novel and often highly original aspects of a general theory are met in the situations which have no real number analogues or in those whose real number analogues are trivial—the latter cases are frequently accompanied by a large number of non-equivalent concepts that become equivalent whenever the domains are specialized to number domains. We have already mentioned the novel contributions of the general theories to the real variable domain and we need not dwell on it here, but merely mention it for the sake of completeness.

## PRECIOUS AND SEMI-PRECIOUS JEWELS—THEIR CHEMICAL AND BEAUTIFYING QUALITIES<sup>1</sup>

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IN the time before records primitive man searched for the beautiful and rare. When we come to early

<sup>1</sup> Lecture illustrated by specimens, delivered before Sigma Xi at Purdue University, Indiana University and Union College, and before the Rochester and Cornell sections of the American Chemical Society.

writings we read descriptions of gems, and we find examples of these in ancient burials. As man became more civilized, this search for jewels went on with increasing eagerness. Accompanying these early discoveries, and perhaps as a mark of their unusualness,

superstition grew up and clustered around these gems. If any think this has died out we need only to call to mind that there are still intelligent people who will not wear opals, considering them bad luck. In less civilized days men and women ascribed all kinds of miraculous attributes to gems, for instance, it being commonly accepted that if one carried a ruby with him, in case of a fall there would be no injury.

Here in Sigma Xi we are interested in research—the understanding of the present and the development of the new. In the field of our jewels, by the application of the usual principles of scientific analysis and classification, man has been successful in unraveling the determinative qualities of the principal gems. He has also succeeded over the past thirty years in outdoing nature by the making of certain gems, such as rubies, sapphires and spinels. The methods of approach have been the same as in other endeavors. First came careful analysis of the chemical and physical qualities which give to gems their striking properties, such as color, fire, hardness and the like. Then in the chemist's laboratory synthesis was undertaken to duplicate what was found in nature. Finally, the third step of development, or improvement, was undertaken, until now in the field of corundum and spinel gems we have the synthetic sapphires, synthetic rubies and synthetic spinels, which are the same as the natural in their essential properties, and which excel the natural in variety of color. These synthetics are not imitations, but duplicates of the natural gems. Recently we hear of synthetic emeralds. The story is only started, as our research has but touched the fringes of the possible in this field. Such analysis and synthesis has greatly increased our understanding of the entire domain of jewels, natural and synthetic, and the underlying causes of their beauty, and why they are prized and sought after.

Let us see what a jewel is and what are its outstanding characteristics of beauty! Let us list these attributes as found in our gems:

(a) *Beauty of color*: This may be natural and inherent (idiochromatic) as occurs in lapis lazuli, malachite, turquoise and hematite. This type of color is based on the very nature of the mineral, and is destroyed if the composition is changed. On the other hand, there are the great majority of jewels in which their beautiful color is due to an "impurity." Here the gem is colorless when pure (allochromatic), and among this type occur many of our finest gems, as sapphire, topaz, emerald, aquamarine, amethyst and agates.

(b) *Beauty of structure*: Irregularities within the jewel are responsible for some of the most prized effects, such as inclusions, bands and fibrous arrangement.

*Inclusions* occurring in a systematic manner are the foundation of the rare asterisms, as seen in the

star sapphire and the star ruby. When these inclusions are formed in a dendritic or tree-like manner in the agate, we call this moss agate.

*Banding* of color arrangement causes much of the attractiveness in agates, malachite and onyx, and is the basis of the carving into cameos and intaglios.

*Play of colors* is due to internal irregularities leading to light interference, and forms the soft radiance of the pearl, or the gorgeous and changing color sequences of the opal.

*Chatoyance* is owing to a fine fibrous structure, and is the velvety appearance seen in tiger's eye (crocidolite) and satin spar.

- (c) *Beauty of luster*: This is that phenomenon of light thrown off from the surface, largely caused by brilliance of reflection and high index of refraction, and resulting in the adamantine luster of the diamonds and the resinous luster of amber.
- (d) *Beauty due to fire*: The wide dispersion of light, exemplified in diamonds and zircons, causes those color flashes of clear fire that are judged by many to be one of the chief attributes of beauty of our jewels.
- (e) *Beauty due to transparency*: Being able to see into the "depths" of a stone enhances its other qualities and lends to its value. We can better appreciate the beauty of transparency by considering how we avoid the opposite or a muddy stone.
- (f) *Durability or hardness*: Jewels to be prized must be sufficiently hard to be durable. The extreme hardness of the diamond maintains its high worth through the years.
- (g) *Rarity*: This psychological value is very real. There are still, and always will be, people who will gladly pay for rarity. The ruby commands a ready market at a hundred times the valuation of its counterpart in the synthetic field.

The *precious* stones—the emerald, ruby, sapphire, diamond and pearl, with perhaps the opal, are those that possess these various characteristics of beauty to the fullest extent; *that* is why we call them the precious stones. The semi-precious gems are less rare, or less durable, or possess in somewhat smaller degree some of the characteristics we have just enumerated.

#### BEAUTIFYING CONSTITUENTS

It is very striking to observe that the quality distinguishing one gem from another or of a gem itself from an otherwise simply interesting mineral, is, in most instances, caused by the presence of a small amount of some material that imparts color, or other pleasing characteristic. The few idiochromatic, or self-colored stones, are exceptions. The asterism, so highly prized in the star sapphire, is caused by minute inclusions that reflect the light in such a manner as to give this star effect. These included or color-imparting materials are rated as the minor constituents

in the composition, and are often called the impurities. I myself much prefer to speak of these minor constituents which, for instance, change an otherwise almost worthless bit of beryl into that most valuable of gems, the emerald, as the *beautifying constituents*.

Thus, as we correlate the chemical structure with the pleasing characteristics that give gems their value, we find that we are interested in two ways: First, in the chemical composition of the mineral to which the gem belongs, and second, in these beautifying constituents or so-called impurities. The diamond possesses in an unexcelled degree the characteristics that we have enumerated as gem qualities. Chemically, the diamond is one form of the element carbon, but even here in very unusual instances we will find the most prized diamonds to be those which have a gorgeous color superimposed on the usual fine gem characteristics of this form of carbon. We will possess, for example, in the rare red or blue diamond, a stone with color added to the usual luster, and fire, and transparency. This color is caused by the presence of the beautifying constituent in very small amounts and of unknown composition. Certain other gems, such as azurite, lapis lazuli, malachite and turquoise, have the beautifying color actually a property of the chemical constituting the gem. But, on the other hand, the vast majority of stones owe their gem interest to the presence of a small amount of this beautifying constituent, quite apart from the main chemical compound composing the mineral background. For instance, if the pure compound which gives the fundamental properties of hardness or luster, or the like, to the sapphire, topaz, emerald or zircon were present as an absolutely chemically pure product, these stones, and many others, as you see, would be colorless, with very little character, and would lose a very large proportion of their value as precious stones. But when there appears, superimposed upon the composition of the mineral, a small amount of these beautifying constituents, we have the wonderful blue of the sapphire or the gorgeous red of the ruby or the soft brown tints of the topaz.

These beautifying constituents occur in relatively small amounts and, because of their influence in changing these minerals otherwise of little value to gems of great value, it is asserted that they create more actual worth than anything else in the world of the same weight. The beautifying constituent of the emerald is  $1\frac{1}{2}$  per cent. of chromium, which added to the colorless goshenite makes the emerald, and by so doing changes the almost valueless goshenite into that most valued of all gems—imparting a value of frequently more than \$1,000 for each carat of emerald. At this rate the value imparted by the chromium as beautifying constituent figures out to the rate of \$150,000,000 per pound of the chromium. Is it any wonder

that I call these often rated impurities the beautifying constituents? Actually by making the minerals less perfect they enhance the beauty and increase the value. The imperfect becomes the more valuable! These beautifying constituents, comparatively minute in their percentage yet imparting the magnificent color to most of our gems, may be looked upon as the most interesting and indeed the romantic feature of the structure of these jewels. Our eye all along has seen this sumptuous beauty; may our mind be trained to conceive its cause!

In our study of gems we have found out much about the different ones that are pleasing to us, and we shall arrange these according to their chemical structure in a number of classes, and point out their beautifying constituents when these are known, as shown in the following sections.

#### ELEMENTS

In this group is the leader before all gems—the diamond. It is usually in a pure form, indeed the very purest form of carbon, and its outstanding properties of luster, hardness and fire are conferred upon it by the inherent structure of this form of carbon. Yet, even here the value is enhanced in certain very rare instances by the presence of some beautifying constituent that adds color, as when we have the rare red or other colored diamond. This gives an exceptionally pleasing combination, with color added to the diamond's usual superior qualities of brilliance, hardness and fire.

#### OXIDES

*Silica:* The common or ordinary sand of our shores falls within the classification of silica. Likewise under this heading are a great many varieties of gems, and indeed the very purest form of silica is our rock crystal, which furnishes such beautifully crystal-clear brilliant beads and ornaments. In this group, in a superlative degree, the beautifying constituents come into play, adding a broad range of color and texture to these stones.

We do not know what all these beautifying constituents are, but we have ascertained that a small amount of ferric iron present in crystal silica furnishes citrine, or, as it is generally called, false topaz, or simply topaz.<sup>2</sup> A little manganese gives the beautiful, soft tints of the rose quartz, and also a little iron probably furnishes the much-prized amethyst. In certain instances, inclusions add the particular beauty to the quartz, such as the opalescent appearance of milky quartz, caused by minute liquid-filled cavities, or the Venus hair stone, wherein the needle-like crystals of

<sup>2</sup> This name should not be used for citrine, but only for the rare real or precious topaz.

rutile or actinolite or even tourmaline lend interest and distinction to this special form of quartz.

There is a variety of quartz which lacks the clear crystalline form of our rock crystals, possessing a fibrous structure. This, in its soft gray tone, is recognized as chalcedony or, when a little ferric oxide comes in, evenly distributed as a beautifying constituent, we have the reddish carnelian; while with agate we have the same basic material, colored unevenly with this same ferric oxide, and as sardonyx we recognize a banded material with red and white layers. When manganese oxide is found in with the chalcedony in a dendritic or tree-like form, we call it moss agate.

Finally, in our silica family, when water occurs as an integral part of the gem, setting up strains and internal irregularities, we possess that most beautiful and most highly prized of all varieties of silica, the opal. If one takes such a stone and looks at it by transmitted light, there is little or no color, but the reflected rays are broken down by interference into the rainbow hues which are the glories of our opals. This same phenomenon also causes the play of color when a thin film of oil floats on water. Depending upon how the internal irregularities of the opal are arranged, we have different varieties of this lovely stone which we call by various names, such as fire opal, black opal or harlequin opal. Because these stresses sometimes exceed the natural bond or coherence of the gem, we lose an occasional fine opal by cracking. Thus does the cause of the breath-taking beauty of the opal sometimes carry also its own fragility! But this should rather lead us to prize more truly such changing and radiant colors.

*Corundum*: The mineral corundum in composition is aluminum oxide or alumina. A somewhat similar product is manufactured on a large scale out of bauxite or the raw material for aluminum. Corundum occurs crystalline in nature in various forms. When perfectly pure it is the white sapphire. On the other hand, when very impure, mixed with magnetic oxide or iron, we call it the abrasive, emery. When nature adds the impurities, or beautifying constituents, to the white sapphire, with discretion we may say, we get some of our most beautiful jewels. The gorgeous ruby is pure crystalline corundum, or white sapphire, carrying 1 per cent. or 2 per cent. of chromium oxide as the cause of its unusual beauty. The blue sapphire is colored with oxides of titanium and iron. The rare, but very attractive golden, or yellow sapphire owes its color to iron oxide alone, and there are many others of the so-called fancy sapphires which occur in various colors, such as violet, pink and even green.

It is here that the synthetic chemist has exercised his chief skill and knowledge, for he has taken the pure alumina and mixed with it these various beautifying constituents, and then by passing this mixture

through the intense heat of the oxyhydrogen flame has made synthetic sapphires and rubies which are duplications of those found in nature. Thus does synthesis confirm analysis. Furthermore, in the controlled operations of a factory, man has made other synthetic gems, such as are not found in nature, wherein the coloring constituent is a small amount of materials, as oxides of uranium or vanadium, which give effects somewhat different from the naturally occurring materials. Man has brought the coloring constituents into the sapphire base which have never happened to come into juxtaposition in nature.

*Spinel*s: When magnesium oxide occurs with aluminum oxide we have spinels. These resemble the corundum gems, sapphire and ruby, except that they are not quite so hard and melt a little lower. On the other hand, they give very gorgeous stones. The ruby of the Black Prince in the crown of England, one of the most famous gems in the world with a recorded history of half a thousand years behind it, is really a ruby spinel. Because of the slightly lower melting point one has been able more easily to synthesize spinels, and we find among our man-made gems many examples of the skilful use of unusual constituents to impart beauty of color to the otherwise clear and white magnesium aluminate or spinel. A fine example of this is the cobalt colored synthetic blue spinel, which has a clearer and deeper coloration than the natural blue spinel.

*Chrysoberyl* is a combination of beryllium oxide with aluminum oxide, and again the pure mineral is colorless. However, one of the rarest and most beautiful of all gems, the alexandrite, is chrysoberyl with the beautifying constituent believed to be chromium oxide, which causes the change in color characteristic of the alexandrite, showing green by daylight and red by artificial light. When the structure of the chrysoberyl is so arranged in fibers that a beautiful light streak appears across the mineral, we recognize this added beauty as furnishing the cat's eye, or cymophane, a highly prized gem.

*Hematite*: Common, ordinary iron oxide, source of so much of our steel, does occasionally carry crystals in such hard dense masses, with black metallic luster, that it has been employed for minor jewel use. Unlike the case with our other oxides, the color is due to the inherent nature of the compound, and not to a mixture with any lesser constituent. We speak of this type of coloration as being idiochromatic.

#### CARBONATES

With copper carbonates, malachite and azurite, the cause of green and blue color is due to the structure of the mineral and is another example of idiochromatic or self-colored gem. In other carbonates there are present beautifying constituents, or a variation in the

physical structure, causing such lovely iridescence as is found in the pearl.

#### SILICATES.

A large proportion of the ordinary rocks that make up the fundamental structure of the globe are silicates. Among some of the specialized silicates occur magnificent jewels, such as the emeralds and aquamarines, jades and zircons, topazes and tourmalines.

*Beryl*: Pure beryllium aluminum silicate is colorless, and this form is known as the mineral, goshenite; but when beautifying constituents are present we have the green emerald, the green-blue aquamarine, the golden beryl and the pink morganite. The emerald is our scarcest and most valuable gem, a small amount of chromium being considered to be the beautifying constituent that imparts this color so greatly desired. The scarcity of these emeralds can be comprehended when it is recognized that many of the fine emeralds are those that were found when Pizarro conquered Peru, centuries ago, and that even now the same Andean mines are supplying high-priced jewels.

*Garnets*: These are quite complicated silicates, embracing almost every color but blue. Some varieties of garnet when pure are colorless, as is true of the ordinary pyrope garnets employed in Bohemian jewelry. Presumably here the beautifying constituent is iron oxide.

*Jade*: A stone that is indeed venerated by the orientals is jade; even the names applied to the different varieties have a romantic sound, such as "mutton-fat" jade or "imperial" jade or "melting-snow-of-camphor" jade. The jades consist of the minerals jadeite and nephrite and are complicated silicates. Quite frequently ferrous iron is the beautifying constituent, imparting the soft green color so highly prized.

*Zircons*: Pure white zircon is incorrectly called the "mature diamond." It is that gem, next to the diamond, with the highest brilliancy and fire, due to its high index of refraction and high dispersion. But zircons are comparatively soft and should be repolished occasionally. Brown, and particularly blue zircons, are much sought after. The beautifying constituents are not recognized, but iron oxides do play a part in these splendid gems.

*Topaz*: Most of us think of the topaz as possessing a warm brown color, but this alumino fluosilicate when pure is colorless. It is often pale blue, wine yellow and occasionally pale red. We know very little about the coloring and beautifying constituents of this gem.

The coloring matter is comparatively unstable, and pink topazes are frequently made by simply heating. However, alteration does not take place under ordinary conditions of use. Because of such change of color of the topaz we do not believe it is due to the metallic oxides, but to some colloidal constituent.

*Tourmalines* are borosilicates with beautifying constituents present to furnish a great variety of colors, which may be pink, rose red, green, dark blue or colorless. Sodium and lithium occur in the rose red rubellite, though there may be even here another still unknown constituent that imparts this color. If much iron is present there occurs the black non-gem variety known as schorl.

#### PHOSPHATES

*Turquoise* is another gem wherein the color is caused by the copper-bearing nature of the mineral. This color does change somewhat with the ratio of copper-iron, wherein the variance will go from blue, due to copper, to green, where ferric iron is present.

#### SULFATES

*Satin Spar*: Crystallized calcium sulfate is quite soft and it must therefore be handled carefully and polished frequently, yet the irregularities in the growth of its fibrous structure imparts that chatoyant luster to this mineral which leads to its use in such semi-precious jewels as beads, and the like, wherein the wear is not very pronounced.

We have traveled from one gem to another, and seen something of their various types of beauty—and the cause of all this! Is there not as much romance and seeming mystery in the flaming colors of an opal—caused by imperfections—yes, cracks in its structure; or in the gorgeous greenness of the emerald, resulting from the presence of but a small amount of chromium; or in the limpid magnificence of a pearl, based here also on irregularities of composition—are not all these as romantic as the conquest by the Normans or the love wanderings of Evangeline or the landing of the Pilgrims?

We now take leave of our jewels—jewels born in travail of heat, fire and stupendous forces—jewels born not in a few hours, but in the processes of the ages—jewels born in the recesses of the earth—jewels revealed only by man delving deep into the secret places of the world or by the natural disintegration of these hidden deposits by the slow action of wind and water, heat and cold.

## OBITUARY

### CHARLES WILLIAM WOODWORTH

CHARLES WILLIAM WOODWORTH,<sup>1</sup> entomologist,

<sup>1</sup> E. J. Wickson, *Pacific Rural Press*, 102: 353 (front), portrait, 1921. E. O. Essig, "A History of Entomology," pp. 800-802, portrait, 1931.

mathematician, physicist, chemist and inventor, was born at Champaign, Illinois, on April 8, 1865, and died at his home in Berkeley, California, on November 19, 1940. He was educated in the public schools of Illinois