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METALLURGICAL, PHYSICAL, AND ELECTRO-CHEMICAL RESEARCHES

By Weston A. Price, M. S., D. D. S., and Frank A. Fahrenwald, E. M., M. S.,
Cleveland, Ohio

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SPECIAL studies have been made in these departments under the following subjects:

METALLURGY

(1) General Review and Classification of the Available Literature of all Metallurgical Departments of Science and Art.

(2) Collection and Condensation of Data likely to be Required and Helpful in Future Dental Metallurgical Researches.

(3) Researches for finding Substitutes for Iridio-Platinum for Crown Posts, etc.

(4) For substitutes for Platinum Foil and for new Backing Metals.

(5) For new metal for making rigid Structure Frames of sufficient rigidity to prevent contraction distortion of Gold when casting.

PHYSICS

Repeating for correcting and checking studies of the physical properties of inlay and impression waxes, to determine particularly.

(1) Dimension Changes with Temperature.

(2) Elasticity.

(3) Practical Effects and Application.

ELECTRO-CHEMICAL

Studying the battery effects of various metals and combinations of metals.

(1) In Normal Saliva.

(2) In Acid Saliva.

(3) Alkaline Saliva.

METALLURGY

The special researches being conducted for the Commission during the past year in thes departments have been carried on in Cleveland and largely in the various departments of Case School of Applied Science, which privlleges have been placed, gratuitously, at the disposal of the Commission. These facilities have included the exclusive use of a private room equipped for general metallurgical researches, with the privilege of access to, and use of, the large quantity of microscopic, and photographic apparatus of their extensive metallurgical department. Also the use of special apparatus of the Electro-Chemical and Physical Departments. We are greatly indebted, for material, assistance and counsel, to Dr. Charles H. Fulton, head of the Department of Mining Engineering and Metallurgy; Dr. Albert W. Smith, head of the Department of General Chemistry; Dr. W. R. Veazey, head of the Department of Electro-Chemistry, and Professor Dayton C. Miller, head of the Department of Physics.

Having as our task the problems outlined above, we were immediately embarrassed from the fact that there was very little dental metallurgical literature and almost none bearing directly on the metallurgical problems in hand. It became necessary, therefore, to acquaint ourselves with the literature on these subjects and to make a reference index to it in order that we might avoid duplicating, unnecessarily, researches that had already been recorded. This entail-

ed an enormous amount of work, which fell almost entirely upon our competent associate, Mr. Fahrenwald. It envolved the collection of data on the properties of practically all the metals that might have been available in solving the problems with which we were engaged. A great deal of this data is put in definite and permanent form and so completely condensed as to be included in the table known as Figure No. 3 in this text. By carefully studyiug the key any student can readily ascertain the general effect, as expressed in physical properties, of each of tbe most available metals when melted with one of the others, bence the available binary alloys.

It bas been our purpose to so present the result of these studies, of various combinations of meals, that the charts would carry tbe informatlon that will be desired for other metallurgical problems as they may arise in dentistry, and while many of the combinations here illustrated are not available for the special purposes for which they were studied, tbey may be for others, and their retention, in the files of the members of the profession, should be of great value to mauy.

There are probably no metallurgical problems, confronting the dental profession, of so great importance as the finding of substitutes for the platinum alloy whicb will be botb stronger and much less expensive. It has heen stated by a good metallurgical authority that one-third of the platinum used in the world today is used in the arts and science of dentistry, variously estimated around one and one-half millions of dollars worth per year. The reasons for its use in dentistry is not based on the same kinds of standards that have brought it into use in jewelry. It is because platinum alloys will stand high temperatures, are not oxidized, will receive the alloys of gold as solders, are not effected by the fluids of the mouth, do not lose their stiffness entirely when heated, the coefficient of expansion corresponds to that of porcelain, etc. It is clearly evident that if metals can be produced, furnishing these physical properties at a fraction of the expense of platinum, they will afford a great saving to mankind and to our profession, and if it can be that they shall have these desirable physical properties in greater degree, they will become just so much more to be desired. Inasmuch as the gold solders require a base of higher melting point than silver, and one with which they will unite, the qualities of tbe class of material that will be desired for backings and foil will differ chiefly from the metals to be used for post materials, in that they will require to be soft, or medium soft, while in the latter they will require to be very stiff, even after heating. These two problems are, therefore, so closely related tbat they will be studied together. Before studying alloys in detail we should note some of tbe characteristic physical properties of the available metals, which are shown in Figure No. 1. In these studies the Centigrade temperature unit will be used, assuming that the dental profession is ready to adopt that temperature scale in harmony with general science. You will kindly note in this tahle, Figure 1, the relative melting points, Ceutigrade, Silver 961°; Gold 1063° (1945° Fahrenheit); Copper 1084°; Palladium 1550°; Platinum 1755°; Molybdenum 2500°; Tungsten 3000°. Inasmuch as one of our constant embarrassments in dental metallurgical work is that of the contraction of the metals, we should note the difference in coefficient of linear expansion of these metals, which is nearly four times as great per degree with gold as for molybdenum, but since the rate of coefficient of linear expansion of gold increases rapidly as we approach its melting point, the difference in dimension change through the same range of temperature for these two metals is about six times as great for gold as for molyb·

Figure 1

Metal	Melting Point. °C	Boiling Point. °C at 760	Coefficient of Linear Expansion	Tensile Strength Lbs-sq.in.	Density[1]	Atomic Weight O=16.	Atomic Volume
Aluminium	657.3	1800.0	2550. x10^{-8}		2.74 / 2.60	27.1	10.4
Antimony	630.5	1440.0	.976. x10^{-6}	[3]1000.0	6.71 / 6.61	120.2	18.1
Barium	850.0	1580.0	———	———	3.78	137.37	36.6
Bismuth	268.0	1935.0	1575. x10^{-6}	[3]3000.0	10.34 / 9.80	208.0	21.2
Cadmium	321.0	778.0	2879. x10^{-5}		8.67 / 8.69	112.4	13.0
Caesium	26.37	———	———	———	1.85 / 1.88	132.81	70.6
Calcium	780.0	———	———	———	1.54	40.09	25.2
Cerium	623.0	———	———	———	7.04	140.25	19.9
Chromium	1489.0	2200.0	———		6.92	52.1	7.5
Cobalt	1490.0	———	1234. x10^{-6}		8.70	58.97	6.7
Copper	1084.0	2310.0	1669. x10^{-6}	[3]50000.0	8.91 / 8.93	63.57	7.1
Gold	1063.5	2200.0	1390. x10^{-6}	20000.0	19.32 / 19.32	197.2	10.2
Indium	155.0	———	4594. x10^{-6}	———	7.42	114.8	16.1
Iridium	2292.0	———	648. x10^{-6}		22.42	193.1	8.6
Iron	1520.0	2450.0	1110. x10^{-6}	[3]55000.0	6.88 / 7.82	55.85	7.1
Lead	326.9	1525.0	2756. x10^{-6}	[1]2800.0	10.32 / 11.37	207.10	18.2
Lithium	186.0	———	———	———	0.59	7.0	11.8
Magnesium	651.0	1120.0	2541. x10^{-6}	———	1.74	24.32	13.9
Manganese	1207.0	1900.0	———		7.39	54.93	7.4
Mercury	38.85	357.0	———	———	13.57 / 14.19	200.0	14
Molybdenum	2500.0[3]	———	360. x10^{-6}	800000.0	9.01	96.0	10.6
Nickel	1452.0	———	1359. x10^{-6}	55000.0	8.71 / 8.70	58.68	6.5
Osmium	2700.0[3]	———	679. x10^{-6}		22.48	190.9	8.4
Palladium	1549.0	———	1175. x10^{-6}	50000.0	11.9	106.7	8.9
Potassium	62.5	667.0	8300. x10^{-6}	———	0.875 / 0.851	39.10	45.9
Platinum	1755.0	———	982. x10^{-6}	50000.0	21.50 / 21.50	195.0	9.06
Rhodium	1907.0	———	858. x10^{-6}		12.1	102.9	8.5
Silver	961.5	1955.0	1846. x10^{-6}	[3]40000.0	9.50 / 10.50	107.88	10.2
Sodium	97.0	742.0	7200 x10^{-6}	———	0.97 / 0.96	23.0	24.1
Thallium	303.7	1280.0	3135. x10^{-6}	———	11.85	204.0	17.2
Tin	232.0	2270.0	2138. x10^{-6}	[1]6000.0	6.78 / 7.29	118.0	16.3
Tungsten	3000.[3]	———	884. x10^{-6}	600000.0	18.7	184.0	9.8
Zinc	419.0	918.0	2935. x10^{-6}	[1]6500.0	6.95 / 7.10	65.37	9.2

1. Cast Metal
2. Rolled Metal
3. Upper figure refers to liquid state: lower to solid state.

deum. You will also please note, under the tensile strength in pounds per square inch, the very great variation ranging from twenty thousand pounds for gold and fifty thousand pounds for platinum to three hundred thousand pounds for tungsten. This table should be of very great help for frequent reference. In making these studies we have constantly had in mind the embarrassment, above referred to, namely, that our profession has continually had difficulty in making cast reproductions which are not distorted because of the contraction of the metal envolved. This applies as surely to metal when fused under the blowpipe as in the construction of bridges by the ordinary methods, as all bridge workers know, and we have hoped to find either structure materials of sufficient strength, that a frame work into which gold would be cast would hold it from distorting, or, if possible, we might find an alloy which would have little change between the fluid state and normal temperature. These dimension changes of gold with its change of temperature, both from the molten state to its first crystaling form, and from this to normal temperature, were previously very exhaustively studied and reported.* These studies demonstrated that gold changed its dimensions in passing from normal temperature to its last crystaling form, before going into solution, 2.2% linear or 6.6% volume, (volume dimension equals three times linear dimension) and from its first crystaling form to a liquid state, with a change of temperature of less than one degree, it undergoes a dimension change of 1.9% linear or 5% volume, making a total change from its liquid state to normal temperature of 11.53% volume, which is the amount that water changes in passing from the liquid to the crystalline form but in the opposite direction. That this contraction quality of gold is an exceedingly constant embarrassment is demonstrated by the fact that so far as we know few, if any, members of the dental profession are able to make cast reproductions that are actually quite close in dimension to the size of the pattern with which they started. This will be discussed in the report of physical researches.

Our chief metallurgical researches have centered around the problem of finding an inexpensive metal, or combination of metals, that would be eminently suitable for the posts for crowns and for bridge supports, having all the desirable properties of iridio-platinum, and as many of these in greater degree as possible.

Mr. Fahrenwald has expressed these qualities, and the approach to the solution of these problems, in his laboratory notes as follows:

A material suitable for this purpose must meet the following requirements:

1. The melting point, if gold is to be the soldering material, should be above at least 1200 degrees C.

2. The material must be unaffected by the chemical compounds of the mouth, and should not oxidize at a soldering temperature.

3. It must possess sufficient strength to resist stresses tending to change its form while in place, and at the same time be sufficiently malleable and ductile to permit of its being worked to the required shape.

4. The coefficient of expansion must be small in order to easily produce desired dimensions in the finished work. (This is not important for a simple post where gold is cast or fused about it at one point as a cast crown base.)

5. It should be of such material as will solder readily with the filling material; in most cases, gold.

6. The cost of production, when compared with platinum-iridium, must be low.

*Weston A. Price, Dental Cosmos, March 1911. "The Laws Determining the Behavior of Gold in Fusing and casting."

Reviewing briefly the materials at present available: Condition 1 is met by all metals having a melting point above that of gold. In order to fulfill conditions 1 and 2, many of these are eliminated. Taking 3 also into consideration, there remain only a few which meet to a greater or lesser degree the first three conditions. These are, in the order of their melting points: nickel, 1452; cobalt, 1490; chrominum, 1510; iron, 1520; palladium, 1550; platinum, 1755; iridium, 2300; molybdenum, 2500, and tungsten, 3000. Introducing conditions 4 and 5 also, there remains only platinum, which, to a greater extent than any other single element, meets all of the above conditions. But, even platinum is not sufficiently strong to withstand stresses involved during casting and later, while in place. This difficulty to a certain extent, has been overcome by the addition to the platinum of about 10% of iridium, which, however, makes the material even more expensive.

In view of the fact that no other single inexpeusive metal is suitable, it is evident that further search for the desired material must lie within the realm of alloys; for if the proper combination can be evolved, of two or more of the above named metals, or any of the above with any metallic or non-metallic element, a very desirable material will result; as in the parallel case of the addition of small amounts or carbon to iron, forming steel. As in this instance, the physical properties of many metals may he radically changed by the addition to it of varying amounts of another element, or of several elements. This then admits to the list of possibilities other metals whose properties may be sufficiently modified in alloying; among them: silver, gold, copper, tin, zinc.

Before attempting a solution of this problem it was necessary to review all available literature referring to any work already done in studying the alloys and allowing properties of all elements which might find application in this work. Most of the material given, however, does not include information concerning such physical properties as are desirable in the material for which we are seeking. However, much work in the line of thermal analysis has been done, and in the diagrams of thermal equilibrium which will be given, the proportion and type of the different constituents of a series of alloys may be very easily detected.

The relation between the constitution of an alloy and its mechanical properties, is rather well defined, as will be shown later, and so it is possible to a certain extent, from a study of a certain equilibrium diagram, to interpret in terms of characterlstic mechanical properties, the terms given as constituents. In turn, the general properties, the terms given as constituents. In turn, the general properties of these constituents are often determined by those of their components, which are some form of the elements themselves.

For this reason, and in order to proceed in a proper manner with this work, certain established laws must be obeyed and the relatiou of the various elements to each other recognized. For those of the Dental profession who may be interested in following this investigation work, hut who are not metallurgically inelined, the following general outline of certain governing factors, is included.

THE ELEMENTS

In 1864, Newlands observed that if the elements were arranged in the order of tbeir atomic weights, similar elements occurred at approximately equal intervals. On account of the inaccuracy of the atomic weight determinations made at that time, the true regularity and relationsbip was not given the table constructed by him. The present form of the periodic table is due to Mendeléef and Lotber Meyer, who later, with more accurate data at hand, arranged tbe elements in such manner that their remarkable relationship is clearly shown.

Fig. 1 shows a table constructed in this manner. Several elements, not of metallurgical interest at present, have been omitted, so that the arrangement given allows for a better comparison of the metallic elements than does the complete chemical table.

Beginning at the upper left corner, the atomic weights show an almost uniform increase, when read from left to right in a transition group of three elements. Within any one group there is no sudden change in general chemical properties when passing from one element to the next in order.

Reading from left, thru any one group, the first is strongly base forming, and the last is strongly acid forming, while those intermediate may be either, depending upon their relative positions.

Figure 2

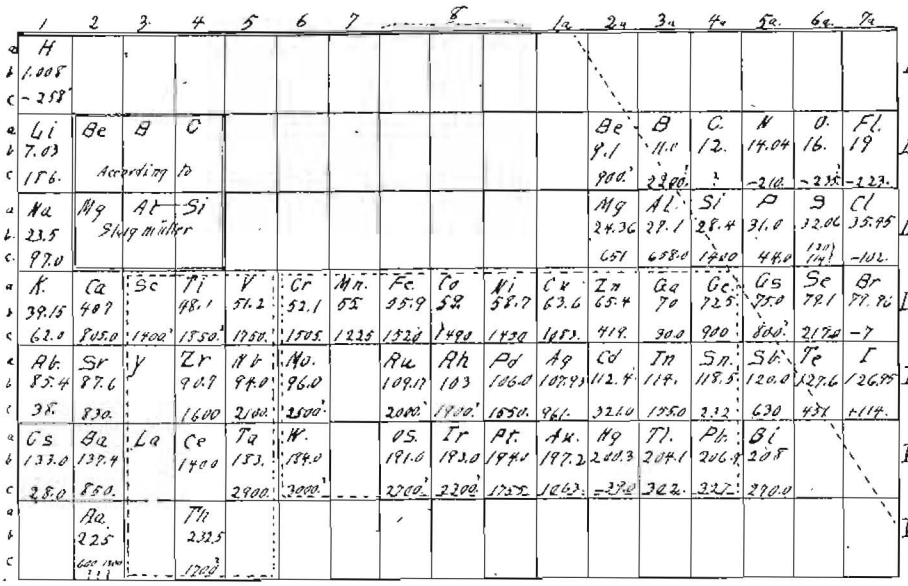


Fig Periodic Table - showing relationship of more common elements (according to Werner.)
a = Symbol for the element; b = atomic weight; c = melting point.

succeeding groups. Hydrogen, with an atomic weight of 1.008, is placed in group 1. Lithium, with an atomic weight of 7.03, comes first in group II; then follow berillium, 9.1; boron, 11; carbon, 12; nitrogen, 14.04; oxygen, 16.; and flourine, 19.0. Then in group III, sodium, 23.5; magnesium, 24.36; and in similar succession until thorium, with an atomic weight of 232.5, is reached. The horizontal rows represent periods or groups. A complete gronp contains seventeen elements arranged in two series of seven each, with Considering the two series forming one group; the first begins with elements which are strongly base-forming, and ends with strongly acid forming elements; e. g., potassium of column 1 and manganese, column 7. The second (sub. "a") series begins with elements which are only moderately base forming and ends with markedly acid forming elements; e. g., zinc in 1a, and bromine in 7a of the same group. The elements (8) connecting these series are intermediate, in their behavior, between the ele-

ments they connect; those of the first verticle column (iron, ruthenium, osmium,) forming both acids and bases; the others forming only acids.

However, in passing, with consecutive readings, from one horizontal group to the next lower, there is a sudden change in the chemical properties of elements of consecutive atomic weights. Thus, the last element of group 11, flourine, with an atomic weight of L9.0, is in complete contrast, in its chemical nature, to the next element sodium, with an atomic weight of 23.5, and which belongs in group III. Also, ionine, the last member of group 1II forms powerful acids, while caesium, the first member of group IV, is one of the most powerful base forming elements known.

Considering now the elements in a vertical column it is found that they are, on the whole, such as would naturally fall together in a classification of the elements according to their general chemical properties. Thus in first column are lithium, sodium, potassium, and caesium, —metals of the alkalies; in the second column are calcium, barium, and strontium,—metals of the alkaline earths, and so on.

It will be observed that the numbers of the columns of the table are repeated, running from one to eigbt and then beginning with 1a. There are, therefore, two columns represented by similar numbers. Between the like members of these two columns there is a general similarity of properties, although it is not so great as between members of tbe same column. Thus, the compounds of vanadium, niobium, etc., in column 5, bear considerable resemblance to those of phosphorous, arsenic, etc., in 5a. The especial property which is the most striking example of this, is that of the valency, or combining power of the elements. All the elements, of the two columns indicated by the same number, form in general, compounds of precisely the same formulæ. Take, for instance, the highest oxides of the two columns 5 and 5a. These are:

5	V_2O_5—Nb_2O_5—Ta_2O_5
5a	N_2O_5—P_2O_5—As_2O_5—Sb_2O_5—Bi_2O_5

This holds good for the other columns, each pair having its own combining capacity, which increases regularly from 1 to 8 and from 1a to 8a. The same sort of regularity appears in the case of chlorides, bromides, etc.

It is time thus seen that from a chemical point of view the elements of a vertical column are very similar, and there is no radical change in the properties of consecutive elements of a group. It is therefore evident that there should be a general similarity among the elements grouped in any one part of the table. The rectangle at the left contains metals of the rare earths. The large rectangle contains most of the heavier metals which are of metallurgical importance. Bordering on this are the light metal, aluminum, and the semi-metals, antimony and bismuth. The elements enclosed in the triangle are usually regarded as non-metallic.

Thus it is evident that the general chemical properties of an element can be foretold, if its position in the periodic table is known.

Enough experimental work has been done to point to a similar relation and gradation for the physical properties of the elements. Tbis is shown quite clearly in the case of the melting points, which have been included, for comparison, with each element in tbe above periodical table. It will be seen that almost without exception, these range quite regularly from low to high, or from high to low, in any given column, and in reading througb any horizontal group it will be noted that successive figures do not represent very great contrasts. This same general relationship governs the other physical properties of the metals. Take, for instance, malleability or ductil-

ity; these will increase or decrease from the upper to the lower quite regularly. Column 1a is a good example of this. Copper is very easily drawn or otherwise manipulated; silver, the next in the same column, is much more malleable and ductile; while gold, at the bottom, is the most malleable of known metals.

Hence, if a certain metal possesses special properties which make it valuable for industrial purposes, it is reasonable to suppose that those metals which occupy adjacent positions on the periodic table, may possess this same property to some extent at least, and would, therefore, bear investigation, especially if it came within the same vertical column.

These same general laws must be recognized when the alloying properties of the metals are under consideration.

ALLOYS

When two metallic substances are brought together in the liquid state, or melted together, the conditions possible are very similar to those found when two ordinary liquids are mixed. As when water and alcohol are poured into the same receptacle a complete solution of one in the other takes place. Alloys of gold and silver are good examples of this. Or, they may act like oil and water, separating into two distinct layers, with the heavier substance on the bottom. Thus it is impossible to form alloys of iron and silver. This condition is, however, not so commonly met with, as most metals will disolve varying amounts of another. A condition frequently met with is one similar to that which is encountered when ordinary salt is dissolved, to saturation, in water. In the liquid state there will be uniform homogeneous mass. When the temperature is lowered, however, salt or water will crystalize out until the saturation point at the freeziug temperature is reached, when both freeze as a conglomerate of the separate crystals, each practically free from the other.

This point is known as the eutectic, and in this case, as in that of metallic alloys, the freezing point is lower than that of either component or of any alloy of the series of different composition. Thus the lowest possible temperature is reached with ice and salt or water and salt, when they are present in eutestic proportions, i. e., about 20% of salt to 76% water, which freezes at -23.0 degrees C. (about 9.0 degrees below zero F.) The silver-copper series is a good example of this.

Then again, the two substances may have a chemical affinity for each other, and when melted together, form definite compounds. This is usually the case when the metallic elements are brought in contact with those which are much less metallic. There is still another condition, one involving two or more of the above in the same alloy. Two metals may be mutually soluble to a limited extent, and may form compounds at the same time, which also may be soluble in the excess material. Also it is common for two components to form a small amount of eutectic which collects between the crystals of the excess metal.

By comparing the properties of different alloys containing different constituents, it has been proven that certain constituents impart certain characteristic properties to the alloys of which they form a part. In fact, the relation between the constituents of an alloy and its Industrial application may be predicted for certain alloys, if its constituents are definitely known. Conversely if a certain application is desired, a definite limit may be placed upon the number and amount of constituents permissible.

Fortunately, the number of constituents which may be present in an alloy is limited to the four as outlined above: (1) pure metals, (2) solid solutions, (3) compounds, and (4) eutectics. Without going into a detailed theoretical review

of these, a short summary of their imparted characteristic properties will show clearly the value of any information regarding their presence. A great number of binary alloys of the more common metals have been studied by melting together those of one series in different proportions, and noting all critical points by means of an accurate and sensitive thermo-couple and galvanometer. When all related points are joined, the resulting diagram, giving percentages on a horizontal line and temperatures vertically, is divided up into areas showing definitely the range of certain constituents as defined by their critical points. These constituents are verified by microscopical examination and by chemical analysis. Therefore, knowing the properties of the constituents, it is possible to predict, to a certain extent, the mechanical properties of a binary alloy of any composition, by observing on the equilibrium diagram, just what constituents are present at the given composition. As stated above, the number of these constituents is limited to four, which will now be taken up in order, giving their characteristics as far as known.

(1) Pure Metals are present in an alloy of which the components possess only limited solubility or which form eutectics or compounds to a limited extent only and which are insoluble in the metal. It is evident that they tend to impart their own properties to the alloy, when this is not counteracted by the character of the matrix.

(2) Solid Solutions. In these, each individual crystal is made up of molecules of the different components. These may replace each other by varying amounts. and the presence of eveu a few molecules of one metal arranged among the molecules composing a crystal of another metal may cause a profound change in that metal. However, solid solutions possess similar properties to those of the elements of which they are composed. If the elements possess these properties, the solid solutions of these will also be soft, malleable, or ductile, etc. It may be pointed out that all industrial alloys which are capable of being cold rolled, drawn, or otherwise worked, consist of a single solid solution. Brass, bronze containing less than 8% of tin, coinage bronze, aluminum bronze containing less than 7.5% of Al., copro-manganese, cupro-nickel, German silver, standard gold, Magnalium, and some of the nickel and steels are examples of ductile alloys consisting of a single solid solution. Standard silver may be regarded as an exception to the rule, but the quantity of eutectic here present is very small; also, the silver-copper eutectic is exceptionally ductile when compared to other eutectics. Alloys of two solid solutions are usually less ductile, but are still capable of being rolled and worked while hot. Muntz Metal, manganese-bronze, delta metal, and a number of special bronzes and brasses examples of this latter type.

(3) Compounds are harder, usually, than the metals of which they are composed, and nearly always brittle. They decrease the ductility of an alloy and tend, usually, to lower its tensile strength. On the other hand, the presence of compounds may increase the compressive strength of the alloy, a property which is of great value in certain cases. The industrial alloys of this class include bronzes containing more than 8% of tin, cast phosphor bronze, all the white metals, anti-friction alloys, and the aluminum alloys containing copper, nickel or tin.

(4) Eutectics are usually quite brittle and possess lower melting points than either of their components. Eutectics of more than two metals have a lower melting point than those of only two, and advantage is taken of this fact in making the various fusion alloys, for safely plugs, etc. Owing to the fact that eutectics melt at a low temperature, this part will be the last to solidify, and so will

form between the crystals of the other constituents, forming a network, or cement, with the result that the strength and ductility of the alloy are practically the same as that of the eutectic portion.

It follows, then, that alloys containing eutectics are, with one or two exceptions, unsuited for constructional work. Their principal employment is probably in the form of solders, in which the difference in melting point of the constituents enables them to be manipulated in a semi-fluid, or pasty condition. The eutectic, or eutectoid, of carbon and iron, known as pearlite, is an exception to this rule, and is unique in that it forms after the steel is completely solid. The result of this is that the crystals of iron are not surrounded by eutectic, but the eutectic itself is surrounded by free iron, so that the formation of pearlite in steels is rather more comparable, as regards its influence on the mechanical properties, with the formation of compounds in other alloys. Alloys containing eutectics are sometimes rendered useful by chilling, so that the eutectic is not permitted to solidify between the crystals, but is evenly distributed throughout the mass.

Theoretically, when alloys containing more than two constituents are considered, the subject becomes much more complex. From a practical point of view, however, the difficulties are not greatly increased, for these alloys contain as before, metals, solid solutions, compounds, and eutectics. A solid solution of three metals may differ in hardness, strength, or ductility, from a solution of only two, and it is true that a eutectic of three or four metals has a lower melting point than one of only two, but the general characteristics of the constituents are the same. Solid solutions are the ductile constituents; compounds are the hard and brittle constituents; eutectics are usually rather hard and brittle, and tend to solidify between the grains of the alloy, thus destroying its ductility.

From this it would seem that present research should be confined pretty closely to those alloys made up of solid solutions only, or to those containing at least only a very small amount of compound or eutectic. Especially is this true where malleability, tensile strength, and ductility are required.

There seems to be no general law applicable to the expansion of alloys with change of temperature. In general, when heat is applied to a body, it expands, and the proportionate increase in length, per degree centegrade, is known as the coefficient of expansion. That for platinum is .0000089, for tungsten it is .0000040, and for molybdenum it is only .0000036. For the other it ranges upward from about .000014.

Most of the available data on this subject is with reference to the nickel-iron alloys and the nickel steels.* In the nickel-iron alloys, those of about 37% Ni. have a coefficient of expansion, for ordinary temperatures, of practically zero. The explanation** given for this is briefly as follows: Iron may exist in one of three molecular modifications, depending upon the temperature.—(1) Alpha, magnetic; (2) Beta, non-magnetic; and (3) Gamma, also non-magnetic. Alpha iron is that form which is common at ordinary temperatures. This undergoes a molecular change at 780.° C., forming Beta iron, which in turn changes into Gamma iron at 880.° C. Now the presence of about 37.% of nickel has such an influence upon the molecules of iron that they are unable to change their state when cooling from the gamma state (above 880.° C.), and so remain stable as crystals of Gamma iron. As this Gamma iron has already undergone its normal expansion throughout the Alpha and Beta range, and does not lose this again on cooling (because this reversion is not permitted to take place again on

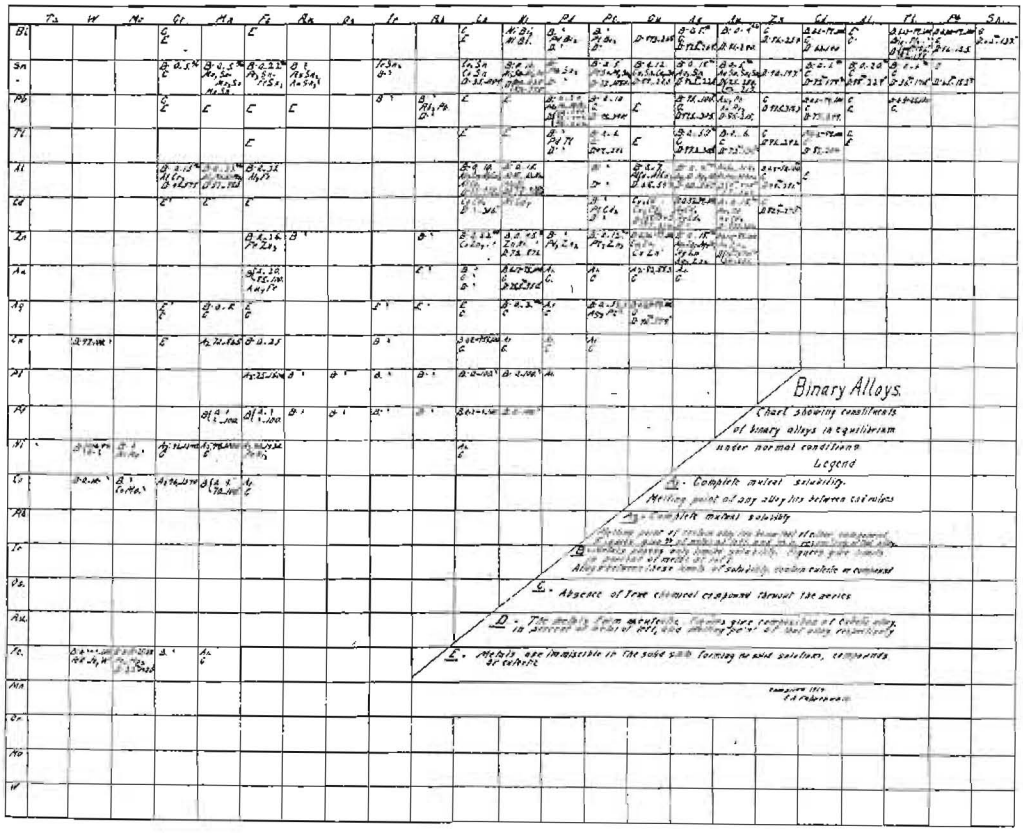
*Charpy and Grenet—Metallographist—6, 328.

**C. E. Guillaume, Non-expansive Alloys-Metallographist, 6,162.

cooling), it is natural that there should be no expansion upon reapplication of heat, until the normal Gamma temperature is again reached.

In this series the change in coefficient of expansion is due to the presence of a

Figure 3



transformation point, i. e., a change from one allotropic state to another—but this does not necessarily mean that the coefficient of expansion cannot be modified in alloys formed of metals having no transformation points. However, sufficient data is not available from which to formulate governing rules.

The above discussion has in a very general manner outlined the relationship of the elements when arranged in the periodic order of their properties; it has pointed out the similarity of elements in each vertical column, natural families they may be called; and has shown that there is no radical difference in the properties of succeeding elements of a horizontal row. The general properties of an alloy have been shown to depend upon the constituents of that alloy, and, in turn, these constituents have been briefly discussed with reference to their characteristic physical properties, and with reference to the probability of the occurrence of similar constituents in alloys of closely related metals. In many cases

not enough experimental work has been done to define their metallurgical relation, but from their relative position in the periodic table, this relationsbip may, to a large extent, be assumed. Thus, in column 6 (Fig. 1) tbe alloying properties of chromium have been fairly well worked out, while regarding those of molybdenum and tungsten very little is known. However, judging from their relative positions in the table, it may be reasonably supposed that a metal which forms a solid solution with chromium, will, with molybdenum, and perhaps tungsten, with certain properties greatly intensified or reduced. Nevertheless it is not safe to generalize in too broad a manner upon any assumed relationship between certain alloys which bave not as yet been tried out; but it would be impossible to make an intelligent search for an alloy possessing certain specific properties, without having definitely outlined the properties of the different elements and their relationship and behavior toward each other.

Fig. 2 is a table of all the elements with which this work will probably have to do, arranged in systematic order, showing so far as has been worked out, the types and amouut of constituents formed when any two of them are alloyed or melted together in any proportion. The blank spaces represent combinations which have not been investigated in systematic manner, or regarding whicb nothing definite is known. However, knowing the general relationship between the different groups these may be tentatively filled for purposes of comparison.

In attacking tbis problem the plan has been adopted of investigating all feasible combinations of one promising metal at a time. This metal will serve as a foundation to which such other elements, as would promise a proper modification of its properties, are added. It is obviously advisable to choose as such, a metal which lies in or adjacent to the squares containing the precious metals, or to use such of these as is least costly. The most promising are silver, palladium, and nickel, all having rather high melting points, and being very resistant to corrosive influences. Nothing quite satisfactory being found in one of these, in tbeir various combinations with other elements, the work bas been continued with tungsten, molybdenum, platinum, iridium, etc.

In accordance with this plan the alloys of silver will be taken up, giving first the equilibrium diagram, showing the constituent at any percentage composition, and at any temperature up to and above the melting point of the more infusible metal. This diagram will at once reveal the possibilities, which will be discussed briefly, followed by experimental results available.

Before the alloys are taken up a brief word as to methods and apparatus is thought advisable.

APPARATUS.

The metals used in making up all alloys were the purest obtainable, and before alloying were checked by careful chemical analysis in order to guard against impurities which might affect results. For the chemical analysis of the elements used, this laboratory is fairly well equipped, as it is for all melting operations, but for the more special work of the future, some special apparatus should be supplied.

The furnace used in melting the various alloys is that known as the "Gran-Annular Electric Furnace" and was presented for use, while in tbe present location, with the compliments of the inventor, Dr. Chas. H. Fulton, who is Dean of the School of Mining Engineering at Case. In this furnace, temperatures are available up to 2000.° C. (3600.00° F.) The atmosphere generated within this furnace consists of CO* and N. with a small fraction of one per cent of 0. This reducing atmosphere is ideal in all cases

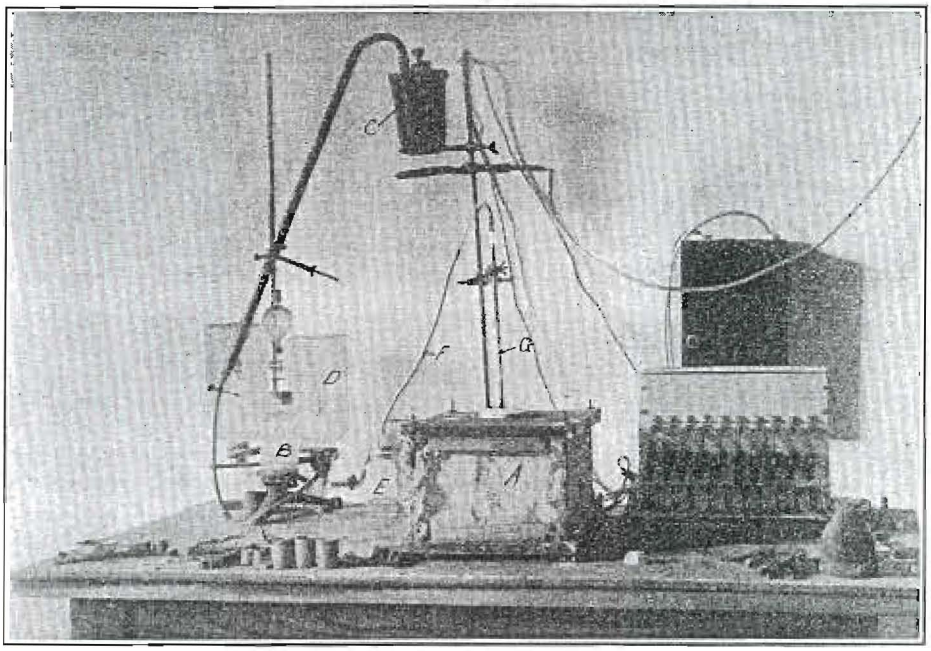
where the presence of CO is not objectionable. For use in melting the alloys of iron, nickel, palladium, platinum, etc., where C may not be present; an atmosphere of N or H may be used very easily.

Fig. 4 shows the set-up of furnace and connections. A. is the furnace; B. is the hydrogen generator; C. the nitrogen generator; D. pressure bottle for storing and maintaining pressure on gas. The gas

For microscopical work there was placed at our disposal the complete metallographic equipment of the metallurgical department of the Case School. This consists of all necessary grinding and polishing apparatus, and a microscopical set-up which is not excelled in this country.

As special precautions must be made at all times to prevent the introduction

Figure 4



to be used as an inert atmos. is conducted from bottle D. through wash bottle E.; then through ruhber tube F. to quartz tube G., which leads directly into the interior of the furnace.

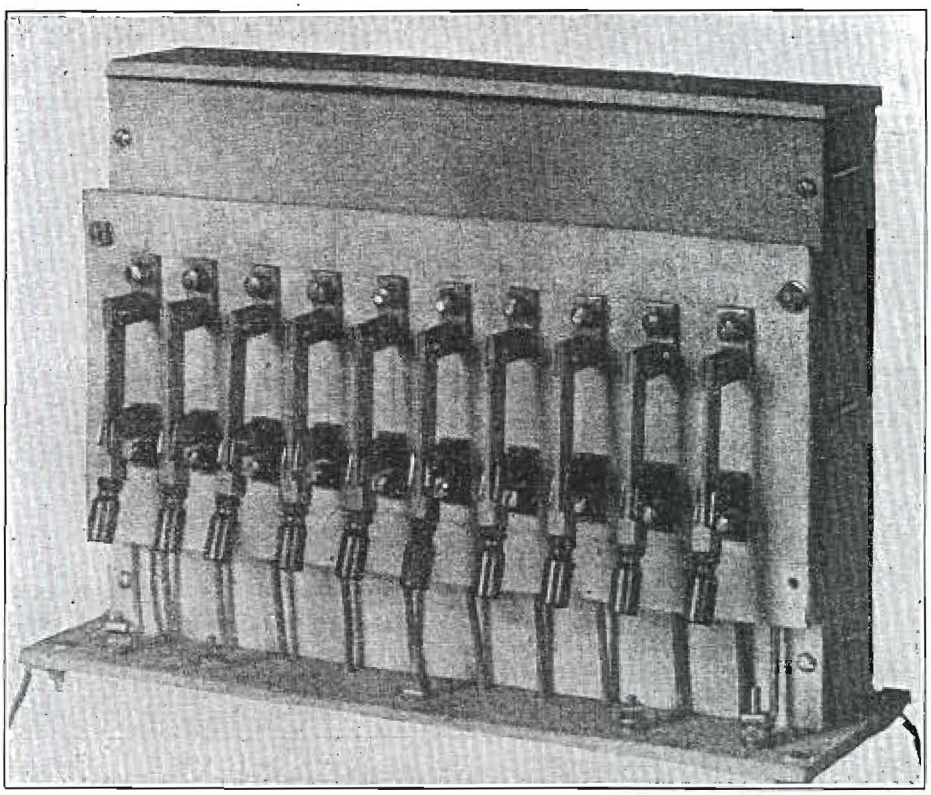
A current (D. C. or A. C.) of 20 to 35 amps. is necessary and to control this, a resistance box costing about $60 would be necessary. To avoid the burden of this additional expense to the commission, the control shown in Fig. 5 was designed. The cost was thereby very small.

of impurities, it was sometimes found necessary to make crucibles of special materials. Small amounts of carbon, silicon, etc., are very detrimental in some alloys, e. g. the nickel and palladium alloys. Alundum crucibles are splendid for many purposes, but, although there appears no record of a similar reaction, it was found that the Al_2O_3 was slightly reduced in several cases; as is testified by the fact that small amounts of Al. were found, and gave trouble in several alloys of nickel, which re-

quired a high temperature and a reducing atmosphere. Fig. 6 shows a special form of mould which was devised for use in making crucibles of magnesia, etc. In making these it was found necessary to first compress the Mg. O., then ignite at a very high temperature. This material was then reground and incorporated with a small amount of a suitable binder and again subjected to a very high pressure. In order to prevent the material from adhering to the surface of the mould, it was necessary to line the outer cylinder with a removable sheet steel jacket, which in turn was lined with a heavy greased brown paper. The piston was also coated with a heavy grease.

Table Fig. 7, 8, 9 and 10 give a list of the elements, together with the crucible material and atmosphere in which each may be melted. This gives the recommendations of the most advanced workers along this line.

Figure 5



ALLOYS OF SILVER.

Silver-Aluminum* 1. Fig. 11, shows at once the limitations of this series. The melting point of any alloy of the series lies below that of silver, so that unless the addition of a third or fourth

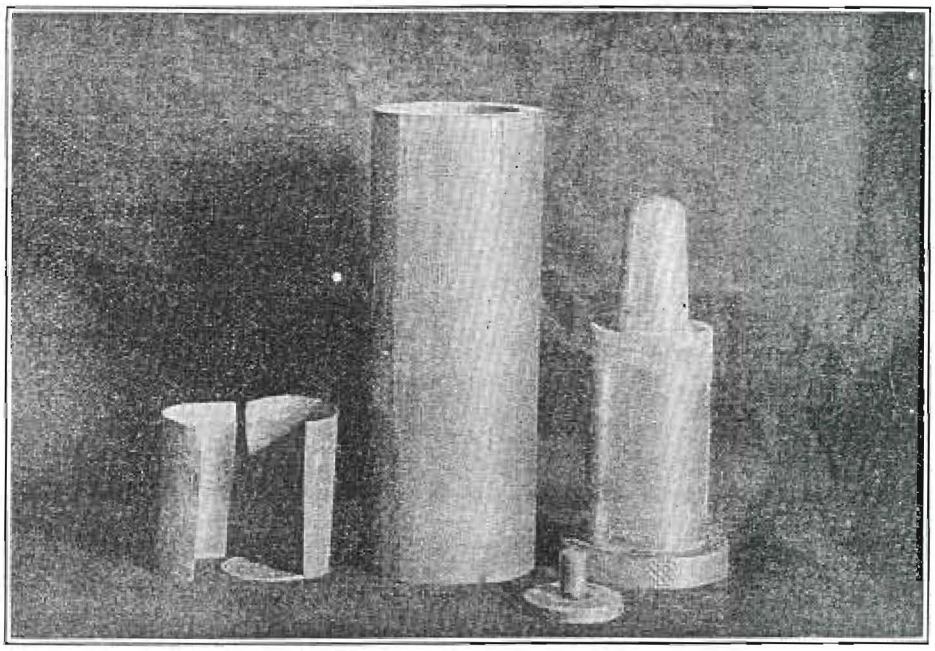
*1. Heycock & Neville, Phil. Trans. 189. A., p. 25.
Heycock & Neville, J. Chem. Soc. 73, 714.
2. Petrenko, Zeit. Aborg, Chemie. (1906) p. 133.

element would bring the m. p. up to amount 1200.° C. these alloys are not suited to hi-temp. work. Record of several Ag-Al alloys appears in the current literature, but their value has not been proved to such extent as to warrant their adoption in structural work.

tion. For standard, factory made parts, they might be of value.

In order to test the possibilities of those of high silver content, alloys of .5, 1.0, 2.0, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, 9.0, 10.0 per cent, respectively of Al. were made up. It was fouud that the alloys

Figure 6



Certain alloys of this class which are made up of about 95% Al., 3% Ag., 2% Cu. are used in the manufacture of beams and balances, and in various scientific instruments, in which light weight is of some advantage. The above composition, however, varies considerably. It is not likely that the high Al. alloys will be of much value in dental practice, on account of their difficult manipula-

containing over 1.0% of Al. were much less malleable and ductile than pure silver, and quite brittle, while those of under 1.0% were very similar to pure silver. This was to be expected, as the addition of even a small amount of Al forms a chemical compound, which, when dissolved in the excess silver, decreases the ductility and malleability to a marked extent.

Figure 7

Metal	Crucible Material	Protective Cover	Inert Atmosphere
Na	Porcelain, coated with oil and graphite. Jena glass, up to 800°C. Iron - wrought or cast preferably.	Vaseline with benzine or paraffin. Petroleum.	H_2, also the hydride is formed
K	Porcelain, is not reliable. Jena glass - also a black coating is formed. Iron - wrought or cast may be used, - also Ni-Cr alloys are fair.	As above - but with vaseline and paraffin the molten globules are very together with difficulty. Petroleum is especially good	As above.
Li, Rb, Cs.	Similar to K. Jena glass is strongly attacked by Li	As above	As above
Ca	Porcelain - not recommended. Iron - satisfactory below its fusion temperature.		CO_2, N_2, H_2 have not given satisfaction. Vacuum is recommended
Ba, Sr.	As for Ca		As for Ca.
Mg	Graphite, is good, but with slight reaction, better lined with mag nesia. Porcelain should all be used - better glass, at low temperatures. Magnesia crucibles are too porous	NaCl + KCl, good for Ag alloys. Pure Mg, fluids on the above fusion so it is better to use a mixture of KCl + LiCl.	CO_2 - cannot give good results. H_2 should be used

Figure 8

Metal	Crucible Material	Protective Cover	Inert Atmosphere
Al	Porcelain - may be used for certain alloys. Jena glass - may be used for quick fusions. Alundum is good but very porous. Fire clay	KCl + NaCl - also some salt may be recommended. NaCl. Better fused without cover.	H_2 and N_2 are recommended. Oxygen must be eliminated, or pieces cannot be melted together.
Rare Earth Metals	As for Al	As for Al	As for Al.
B.	Graphite, Porcelain, or earthy material) not recommended. Boron crucible might be used	O_2 O_3	H_2
C	Charcoal or Graphite	2 BaCl, 1 KCl	H_2 or N_2
Si	Graphite, or magnesia lined crucibles may be used for quick fusion		H_2 or N_2
Ti, V	Similar to above		As above
U, W, Mo, Cr	Carbonaceous material not permissible. Magnesia lining may be used. Magnesia crucibles may be used if not exposed to gaseous Ag crucibles or by CO_2 or CO		H_2 or N_2

Figure 9

Metal	Crucible Material	Protective Cover	Inert Atmosphere
Mn	Magnesia - or a lining of magnesia is recommended. Porcelain is rather strongly attacked. - The presence of silica or carbon is to be avoided. Alundum should find application here.	Charcoal must not be used. $BaCl_2$ may be used	H_2 N_2 CO_2 - must not be present.
Fe.	Porcelain is recommended. Magnesia Graphite with Mg lining. Carbon or silica should not be in contact with fusion. Alundum - is good, but very porous.	$BaCl_2$ KCN will carburize. $NaNH_2$ + MnO_2 - Gypsum. Charcoal powder is not permissable	H_2 N_2 - forms the nitride. CO or CO_2 will carburize iron
Co.	As for iron except that porcelain is strongly attacked by the oxide formed	As for iron	H_2 N_2
Ni.	As above - Small units of Al have been fused in Mg melted in an Alundum crucible in reducing atmos. -	As above	H_2 N_2
Ru, Rh, Pd, Os, Ir, Pt.	Carbonaceous material had best be avoided. Magnesia. Alundum.	Glass	H_2 forms alloy with Pd.

Figure 10.

Metal	Crucible Material	Protective Cover	Inert Atmosphere
Cu.	Charcoal, Graphite Porcelain, Fire Clay Magnesia - Silica Alundum.	KCl + NaCl B_2O_3 - Borax, KCN, Charcoal	H_2, N_2, CO. CO_2, Illuminating gas free from Sulphur
Ag.	Nickel, Iron, Fire Clay, Graphite, Porcelain. Alundum	KCl + NaCl KCN, Borax	H_2, N_2, CO_2 Illuminating gas.
Au.	Practically any non-metallic crucible.	As in silver not necessary.	
Zn.	Jena glass Graphite	KCl + NaCl. $NaNO_3$ + MnO_2. Gypsum Charcoal powder.	H_2 Illuminating gas
Cd, Hg, In, Tl.	Jena glass. Graphite, Porcelain.	KCl + NaCl or LiCl. Vaseline oil with benzine Charcoal powder.	H_2 N_2 CO_2, CO.
Pb, Bi, Sn, Sb.	Graphite. Charcoal	Borax, Glass, KCl + NaCl or LiCl. KCN, Charcoal.	H_2 N_2 CO_2, CO
As, P.	Magnesite - Silica	$BaCl_2$, B_2O_3 Borax reacts KCN, Charcoal.	N_2; CO_2 - CO. H_2 reacts at high temp.
Te, Se	As above	Borax does not react, as above	H_2; N_2; CO_2; CO.
S.	As for As. and P.	As for As. + P.	As above

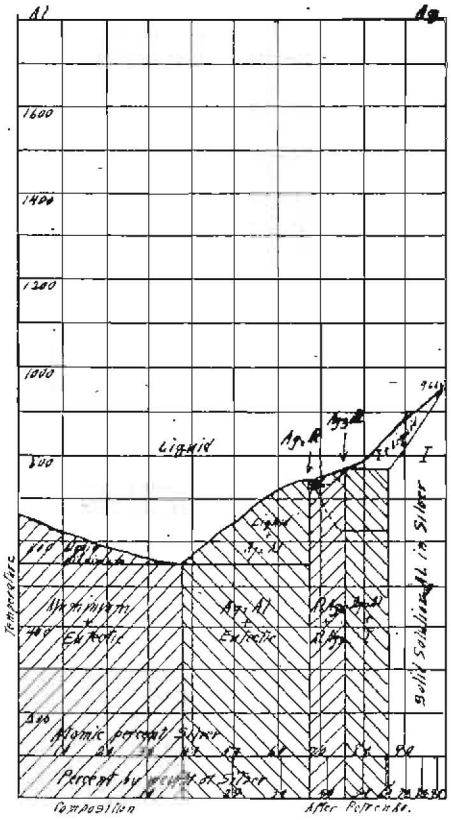
Silver-Bismuth* 1. Fig. 12.

The nature of these alloys are very clearly shown by the diagram. Silver dissolves bismuth to the extent of about 4. -5. %. Larger amounts of bismuth go to form an eutectic with this saturated mixed crystal. (That is, the crystals are made up of a homogeneon mixture of molecules of Ag and Bi). While this series might give something of use for amalgams for filling purposes, it does not offer any points of interest in connection with the post and pin problem. These alloys are especially susceptible to the influences of sulphur compounds.

Silver-Cadmium* 3. Fig. 13.

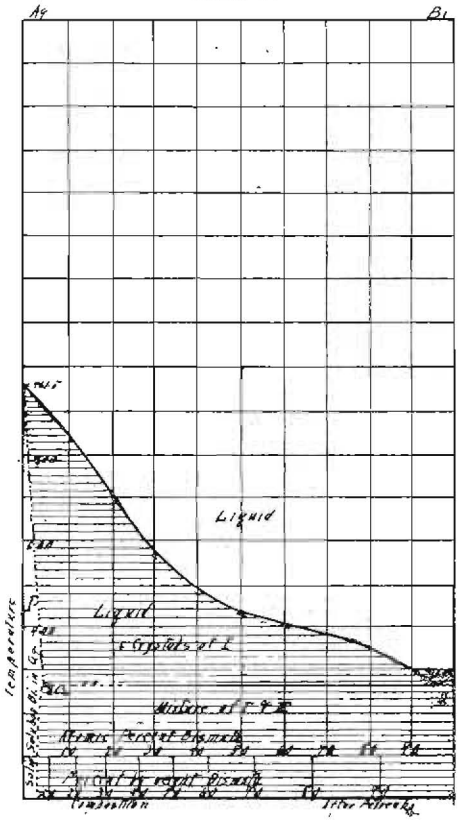
Cadmium, silver, and tin are ingredients of some soldering compounds, and certain amalgams. Silver alloys containing up to 30.0 % Cd. are very malleable, although not quite so tough as pure silver, and should furnish alloys which may be suitable for cast filling purposes. As shown in the diagram, a low m. p. is characteristic of these alloys. They

Figure 11



Silver-Aluminum Series.

Figure 12



Silver-Bismuth Series.

*1. Heycock & Neville, Ternare verbindungen. J. C. S. 65, 65.
Heycock & Neville, J. Chem. Soc., 62, 888.
Heycock & Neville, Chem. News, 62, 280.

2. Petrenko, Zeit. Anorg. Chemie, (1906) p. 136.

3. Kirk-Rose, Proc. Royal Soc. 74, 218.

would, no doubt be quite susceptible to sulphiding influences.

Silver-Chromium. Fig. 14.

Although silver and chromium seem to be very slightly miscible in the molten state, they crystalize out in two distinct layers of the pure metals, and as silver will not dissolve chromium in the solid state, there is small chance of raising its m. p., or of changing its physical properties in any way hy the addition of chromium in the binary form.

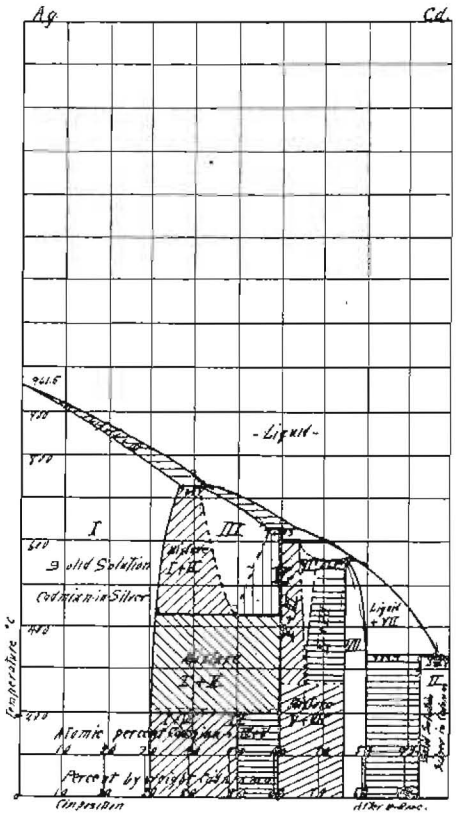
Silver-Cobalt. Fig. 15.

These metals are immiscible in both the liquid and solid states, and offer no alloys which as a binary, would be of any value.

Silver-Copper* 1. Fig. 16.

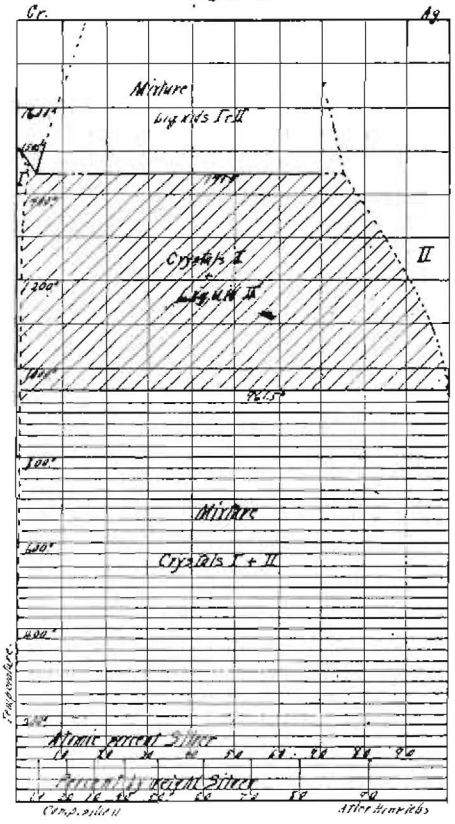
Silver will dissolve up to about 6% of copper, retaining this amount as a solid solution. A perfectly homogeneous alloy of this composition is only obtained by maintaining the material at a temperature near its melting point for a number of hours. Small amounts of copper harden silver quite appreciably, making it

Figure 13



Silver-Cadmium Series.

Figure 14



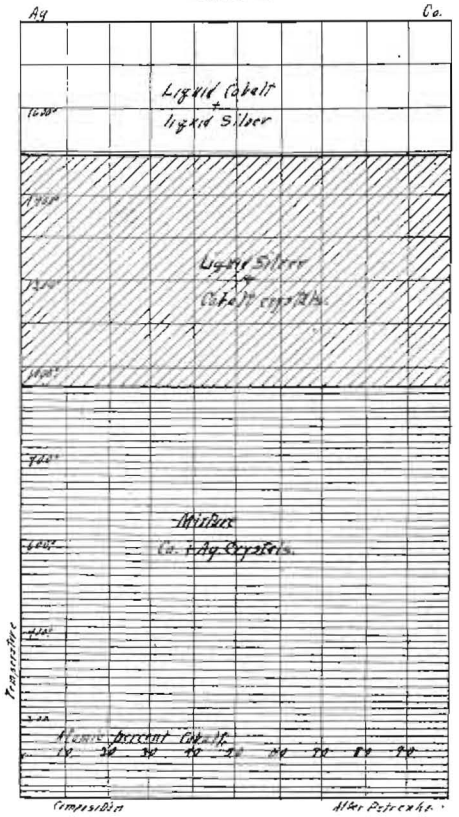
Silver-Chromium Series.

*1. Heycock & Neville, Phil. Trans., (1897) p. 786.
Lepkowski, Z. Anorg. Chemie, 59, 285.
Friedrich & Leroux, Metallurgie, 4, 297, (1907).

more resistant to mechanical abrasion. This fact is taken advantage of in the manufacture of coins, etc.

The eutectic alloy melts at 778.° C. and is quite hard and brittle.

Figure 15

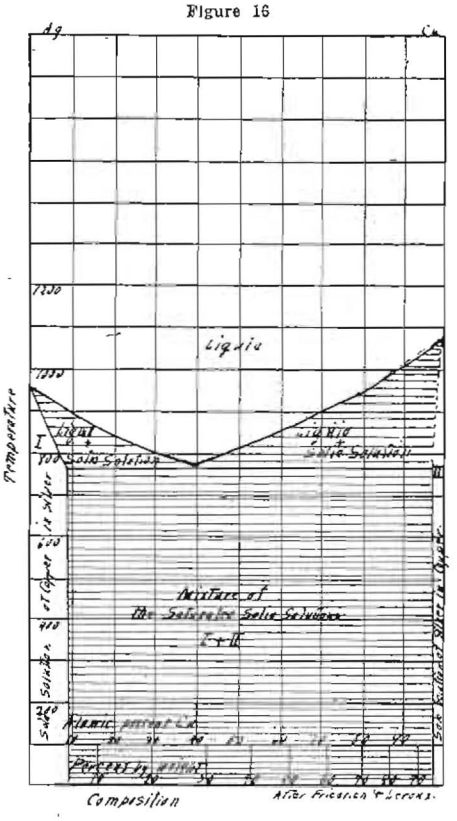


Silver-Cobalt Series.

Silver-Gold* 1. Fig. 17.

The diagram shows a complete series of solid solutions. These are slightly harder than their components and have general physical properties which lie between those of gold and silver. The most remarkable thing shown on the melting point curve is the high fusing point maintained up to about 60.0% of

Figure 16



Silver-Copper Series.

silver. During this range the drop is not over 12.0 degrees C. below the melting point of pure gold. On the other hand, the addition of a small amount of gold raises the melting point of silver considerably.

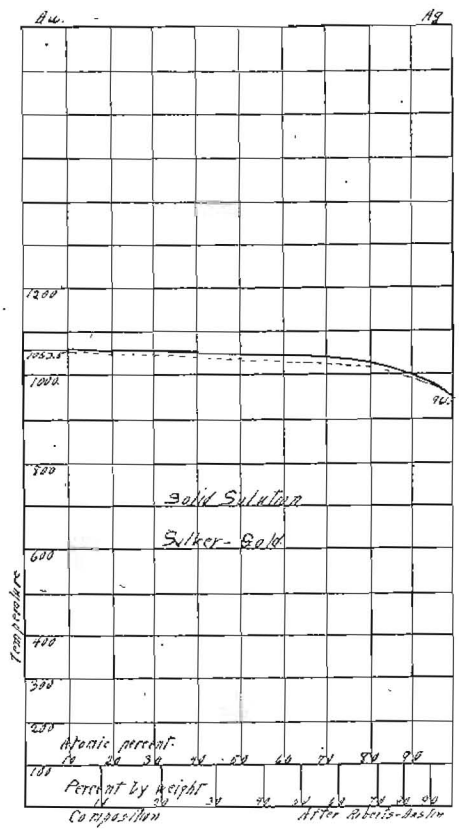
The melting point of any alloy of this series may be raised to a very high degree by adding platinum or palladium, without destroying certain desirable properties, as will be shown later. The addition of even a small amount of base

*1. W. Campbell, Jour. Franklin Inst. (1902) pp. 131, 201.
C. Hatchett, Phil, Trans. (1903) pp. 43-93.
Hershkowski, Zeit. Phys. Chem., 27, pp. 123, 894.
Heycock & Neville, Phil. Trans. 189 A. 225 (1897).
Roberts-Austin & Kirk-Rose, Proc. Roy. Soc. 71,161.
Roberts-Austin & Kirk-Rose Chem. News, 1, 151.

2. Roberts-Austin, Phil. Trans., 187 A., J. B. p. 23, (1896).

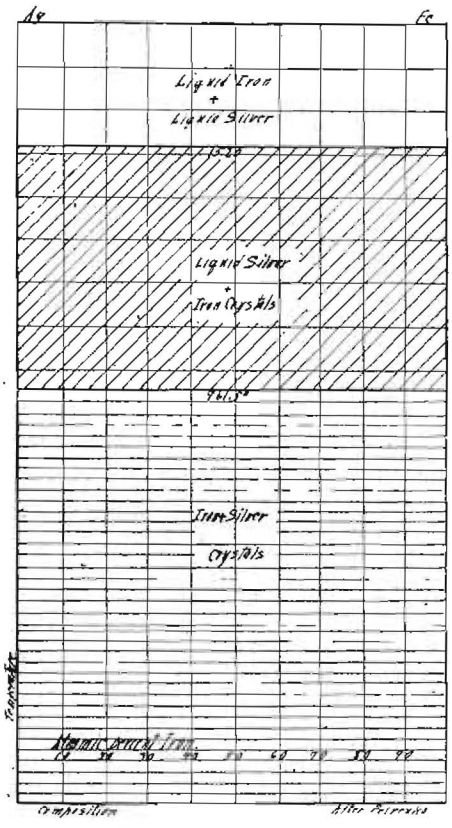
metal causes these alloys to be very susceptible to oxidation at high temperatures. The addition of such metals as nickel or cobalt produces a coarsely crystalline material which does not promise much. Those alloys of over about 30.% Au. are not easily darkened by sulphide compounds.

Figure 17



Silver-Gold Series.

Figure 18



Silver-Iron Series.

Silver-Iron. Fig. 18.

Silver and iron have not been found to alloy under ordinary conditions, at any temperature.

Silver-Lead* 1. Fig. 19.

This series offers nothing of interest in the present problem.

Silver-Manganese. Fig. 20.

Manganese dissolves a small amount of silver in the molten state, which lowers its melting point by about 6.0° C. Upon solidifying they crystalize as a conglomerate of pure silver crystals and crystals of II.

*1. Heycock & Nevillo, Phil. Trans. 189-A. p. 3. (1897).
Friedrich, Metallurgie, 3, 396.

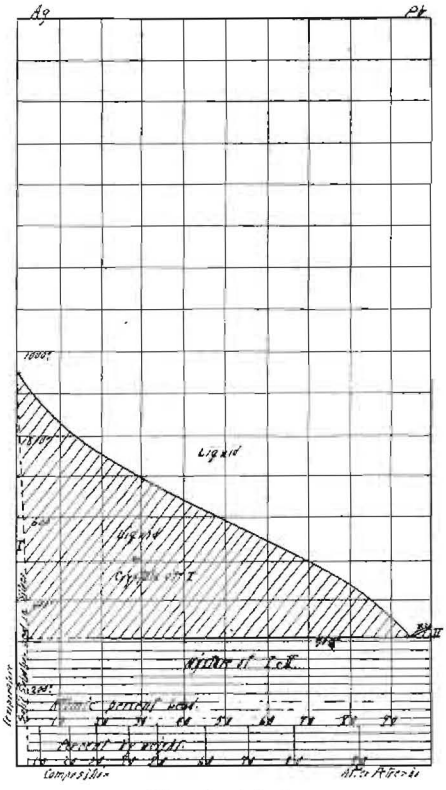
Silver-Magnesium* 2. Fig. 21.

Promise of entirely negative results have been predicted for these alloys from a structural point of view.

Silver-Nickel* 3. Fig. 22.

These are practically immiscible in the solid state; nickel retaining about 2.0% of silver in the solid state. This small amount does not seem to enohle the baser material to any extent. As a binary, these alloys promise very little.

Figure 19

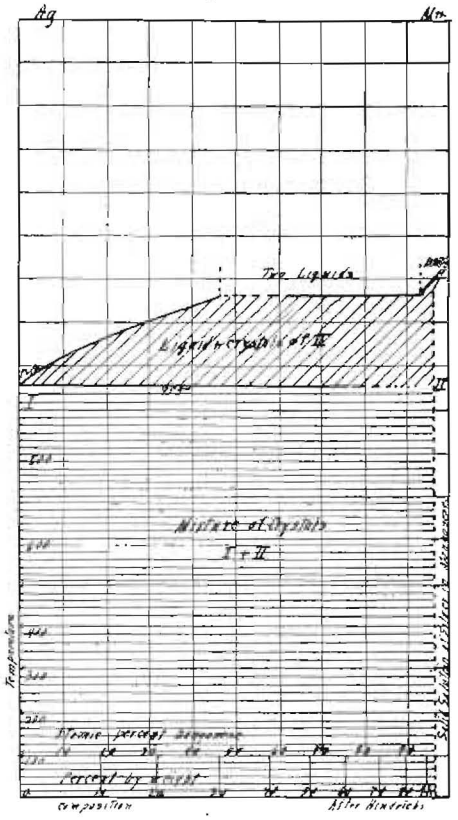


Silver-Lead Series.

Silver-Palladium* 4. Fig. 23.

According to the equilibrium diagram, silver-gold series. As is shown on the freezing point curve the alloy having 70.% Ag. and 30.% Pd. melts at about 1200.° C. These alloys are said to be very hard, and to take a very high polish. However, the specimens made up in this laboratory showed physical properties ranging between those of silver and palladium, especially with respect to the hardness. The alloys of over 20.% Pd. have one characteristic feature which might be made use of. These alloys showed no coloration when immersed for several days in the same sulphide solution which blackened pure silver very rapidly. An alloy of this type could be made at about $5.00 per c. c. as com-

Figure 20

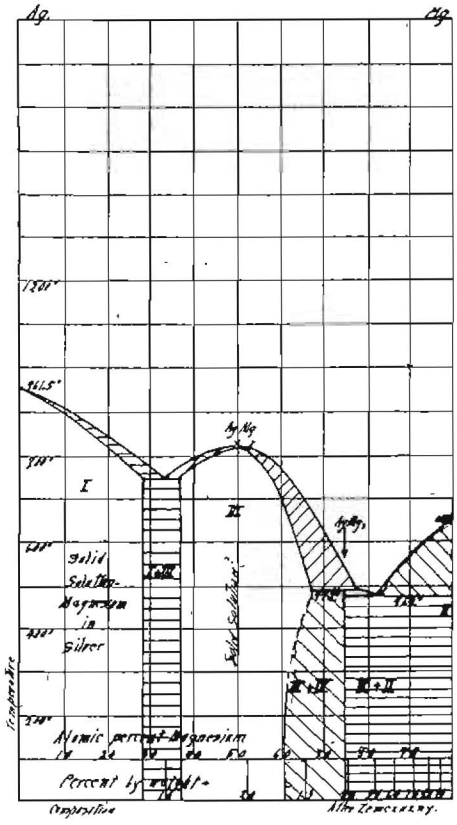


Silver-Manganese Series.

2. Zemczuzny, z. An. Ch., 49, 400. Parkinson, J. Am. Ch. Soc. 20, 17.
3. Petrenko, Z. An. Ch. 53, 212, (1907). Petrenko, Z. An. Ch. 53, 200.
4. Ruer, Zeit. Anorg. Chemie. 51, 315.

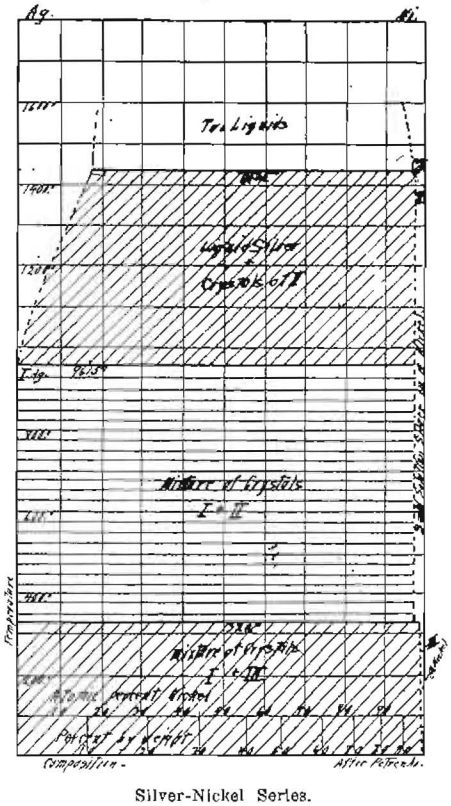
pared to $12.50 for gold. This series might also serve as a basis for ternary alloys, as palladium is one of the best solvents for a great many metals, including nickel, iron, cobalt, tungsten, molybdenum, etc. These will be taken up after the binary alloys of silver have all been considered. It is possible that the addition of small amounts of another metal will impart the necessary hardness, even though it would not alloy in any proportions with silver alone.

Figure 21



Silver Magnesium Series.

Figure 22



Silver-Nickel Series.

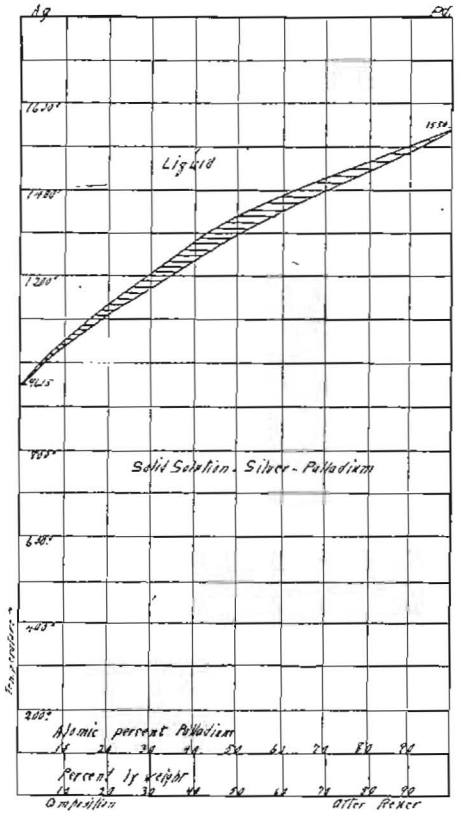
Alloys ranging from 1.% to 95.% Pd. were made up in this laboratory. and all showed very valuable properties. All samples were so soft and malleable as to permit of being rolled into very thin foil. In this operation, however, precautions must be taken to anneal frequently during the first stages of the rolling, as the ingot material shows a tendency to fracture quite readily. After the material has been reduced to sheet form this tendency seems to have been overcome, and the material may easily be reduced to thinest foil.

This foil is apparently as soft as Pt. foil and as the m. p. can be varied between 961. and 1551. ° C. it should serve as a very acceptable substitute. Tests made showed it to be unaffected by saliva solution, or by a sulphide solution. It is insoluble in HCl; very slightly soluble in H_2SO_4, and practically insoluble

in Aqua Regia. It is soluble only with difficulty in HNO_3.

This alloy will also solder very readily onto any of the metals or alloys used in dentistry. Therefore, these silver-palladium alloys should form a practical substitute for the pure platinum foil,

Figure 23



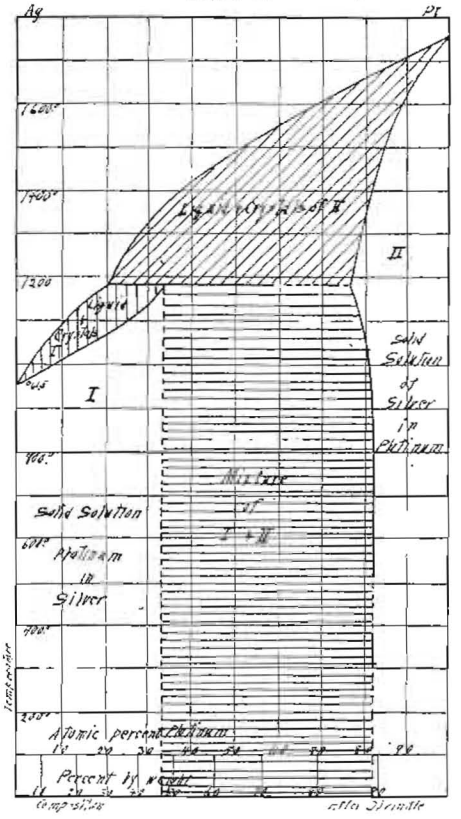
Silver-Palladium Series.

which often costs from $30. to $50. per cc., while this material could be made for from $5 to $15 per cc., depending upon the grade of alloy. These alloys will be summarized at the end of this chapter.

Silver-Platinum* 1. Fig. 24.

The diagram for the Ag. Pt. alloys shows two series of solid solutions, to which may be confined any alloy of industrial importance. Of these, series I should be of special interest. Series II alloys are of over 90.% Pt. content and so are too costly to permit of consideration. The alloys between 47.5% and

Figure 24



Silver-Platinum Series.

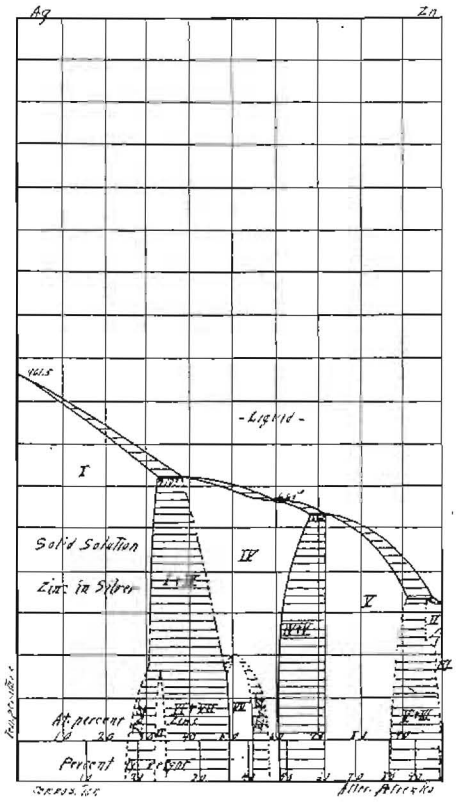
88.0% of platinum are probably made up of a mixture of crystals I and II (crystals I, silver saturated with platinum, and II platinum saturated with silver). Those alloys lying near the saturation point of I should possess the most marked properties, as to hardness, etc., while those between I and II should be, and are, very brittle.

To determine the applicability of these

*1. Miller, J. Am. Ch. Soc. 28, 1115.
2. Doerinkle, Z. An. Ch. 54, 338.

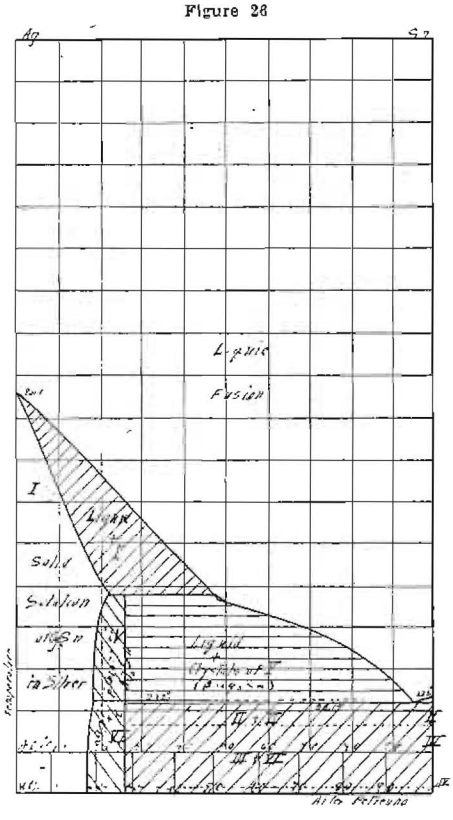
alloys to the problem in hand, a series of alloys were made up, varying by 5.% of Pt. The addition of small amounts of Pt. to silver increases the hardness considerably, and at 10.% could still be drawn although the resulting wire did not possess great strength. Above this

Figure 25



Silver-Zinc Series.

Figure 26



Silver-Tin Series.

Pt. content further addition seems to increase the hardness at the expense of tensile strength and workability. The Ag.-Pt. alloys are also quite resistant to action of sulphides, especially when the material has been quenched in dil. HNO_3, which dissolves the silver from the surface. Alloys of about 25. -30.% of Pt. are practically insoluble in any acid, or in Aqua Regia. In the case of acids the material is protected by the Pt., and where Aqua Regina is used the insoluble coating of AgCl., prevents further action. However, as a substitute for the Pt. Ir. alloys this series does not offer much. While the addition of Pt. to silver causes the m. p. to rise practically as much as does the addition of an equal amount of Pd., the hardness imparted would make the alloy worthless as a foil material, in which malleability and softness are necessary. The material of sufficiently high m. p. is too brittle for posts and pins. These alloys are in no way equal to the silver-palladium alloys. The

binary alloys of silver with zinc and with tin are shown in Figs. 25 and 26.

Silver-Tungsten. Silver-Molybdenum.

No reference has been found relative to these alloys but from experiments made in this laboratory, they appear to follow the group tendencies as shown by the Ag-Cr. series. These fusions must be made in an atmos. of H. or N, as the presence of small amounts of O seems to tend toward the formation of tungstate or molybdate of silver, which apparently is dissolved in the silver. Microscopical analysis of specimens which were made in an atmos. of nitrogen, showed the unalloyed particles of tungsten or molybdenum, imbedded in the silver matrix.

SILVER ALLOYS—SUMMARY.

Neither the time or the necessary apparatus were available with which to carry out exhaustive tests of the physical properties of each series of alloys made up, and which would have given really very little additional information of value from a practical consideration of their application in dentistry. Their physical behavior, when drawn out under the hammer or through draw plates, together with microscopic examination, gave sufficient evidence as to their probable value. If certain alloys passed these first tests, their general physical properties and chemical behavior during corrosion tests were noted. The corrosion tests were made in different acid and alkali solutions, and also in saliva solutions. In determining the corrodability of an alloy it was placed as one element of a series of couples, e. g. with gold, zinc, Pt., etc., in order to reproduce as nearly as possible such conditions as would be found in practice. The results of experiments started under another division, gives quantitative values for the corroding tendencies of different materials, and when complete will be of very great value in that they should decide definitely the question of what metallic combinations are permissible in dental work.

It is apparent that systematic work on ternary and more complex alloys should not be taken up until all information and data regarding the binary alloys employed in these different systems has been collected. Several of the binary silver alloys give promise of being a suitable foundation on which to base a ternary investigation, especially the silver alloys. None of this series would seem, however, to promise much in the line of a hard steel-like material for posts and pins. For cast filling purposes, the alloys of silver with cadium, zinc, tin, and a few others possibly, may be adjustable to require conditions. Reference to the amalgams has been purposely omitted, as work along this special line will be taken up later. Very little data is available with reference to the alloys of silver with osmium, iridium, ruthenium, etc., and owing to the costliness of these elements, they were not included in the experimental work.

A proper summary of the results of the investigation of any series of alloys in connection with this work should consist, perhaps, in a concise statement of what has been accomplished to benefit the members of the dental profession. Although research has been especially directed, during this year, to the solution of the Pt.-Ir. substitute problem, other applicable properties of any alloys tester, cannot be overlooked.

Recent statistical reports indicate that one-third of the world's platinum supply is used by the dental profession and hence is lost. A part of this is in the form of thinnest foil, which is used for the purpose of taking various impressions. This material must be especially pure, and as such, often costs as much as $80.00 per ounce. Under the silver-palladium head was brought out the fact that these alloys were very soft; were very resistant to corrosive and sulphid-

ing influences, and also that the m. p. could be varied between that of silver, 960.° C, and that of palladium, 1550.° C; depending upon the relative amounts of each present. In spite of the fact that all records of previous experimentors state these alloys to be quite hard, they were found to be practically as soft as Pt., when reduced to thin foil. At first they require frequent annealing.

As all metals are usually listed at cost per pound, or per ounce, a very erroneous idea is generally prevalent as to the actual relative cost of the different available materials, when applied to a given purpose. A certain tooth cavity, for instance, will require a certain volume of material, and is independent of the weight, which depends directly upon the sp. gr. or density of the filling material. Suppose the volume of this cavity to be one cubic centimeter. To fill this with platinum will cost about $30.00; with gold, about $12.50; and with palladium, about $22.00. This is certainly not the general conception of the relation between the cost of these elements when compared by weight; gold $20.67 per oz.; Pt. $48.00 to $60.00; and Pd. about $60.00 per oz. This same relation holds good for any of the materials used in dentistry, a certain volume being necessary in all cases, irrespective of the weight.

Referring again to the Ag-Pd. series; an alloy of about 25.% Pd-75% Ag. will have a melting point of about 1200.° C, and can be made for about $5.50 per cc. A 42.% Pd.-58.% Ag. alloy will melt at about 1300.° C and will cost about $9.00 per cc. With 63.% Pd.-37.% Ag. the melting point will be about 1400.° C. and will cost about $12.50 per cc., or the same as pure gold, but with a m. p. of over 300.° C. higher.

Tests made showed that the material melting at 1200.° C. could be used for taking an impression of a cavity and have the gold fused or cast directly into it.

ALLOYS OF GOLD

The alloys of gold with the base metals, with the exception of copper, have never been of much importance in the arts or industries. Gold has an abnormal tendency to form complicated compounds with most of the less metallic elements, and so produce alloys, which, from the point of view of their mechanical properties, are worthless. Their constituents are clearly shown in the accompanying equillbriums. As is seen, small amounts of Al., Bi., Cd., Sb., etc., greatly lower the melting point of gold, and in many cases are combined with gold to form easily fusible solders. The mechanical possibilities of these alloys have never been worked out, in the special case of their application to dentistry, and so it will hardly do to limit the probabilities, in theory only. The alloys of, say Al. Au. or Ni-Au. may show properties of special value in this connection.

The alloys of the Gold-Copper series are quite widely used, as are those of the Gold-Platinum series. However, very little has been done in connection with this latter series in the way of determining the relation of their physical properties to chemical composition or the relation of mechanical treatment to physical properties. For instance, no method or retaining or restoring the temper, or springiness, of certain dental appliances after annealing, or soldering, is known. The melting points of the Au-Pt. series increases quite rapidly from gold to platinum, as is shown in diagram Fig. 27. All of these alloys are barder than pure gold, while those of about 50% Pt. are harder than pure Pt.

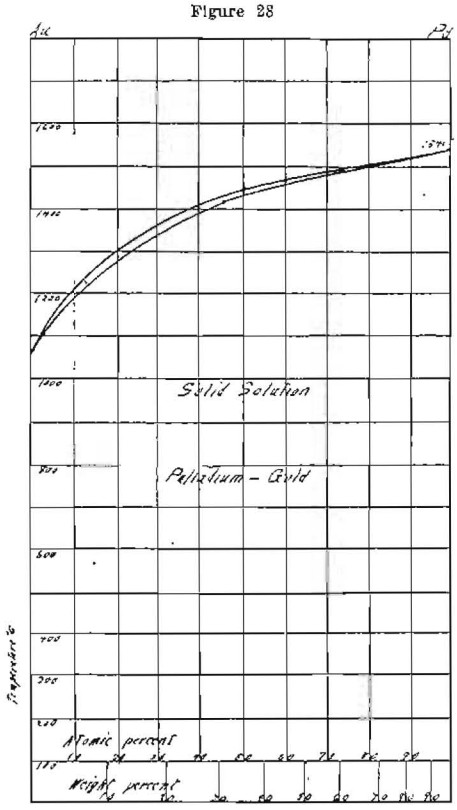
Gold Palladium. Fig. 28.

There is practically no evidence on record regarding the mechanical properties of these alloys. This series has been investigated rather thoroughly during the past year in this laboratory, and without going into a detailed description,

their value may be summarized as follows:

The addition of small amounts of Palladium to gold causes a greater rise in temperature than does a like amount of Pt., so that a certain fusing tempera-

Figure 28



Gold Series.

ture is reached with less cost by using Pd.

The Pd-Au., alloys are very soft and ductile, much more so than those of the Pt-Au. series.

A small per cent of Pd. in gold foil increases its melting point to such extent that it can be used for foil impressions, and cast and fused fillings made directly therein. Foil for this purpose is as soft as pure gold, and is much softer than Commercial Pt. foil.

One per cent of Pd. darkens gold perceptibly, while those alloys of 2% to 3% are a bronze color. At 5% Pd. the alloy is almost the color of silver, and above that point the color of Pd. is present.

Tests made, show these alloys to be absolutely unaffected by chemical compounds of the mouth.

They will solder as well as pure gold, and without being so easily fluxed, or melted.

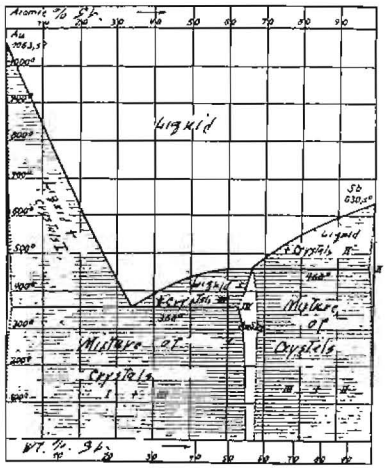


Fig 29 Gold - Antimony.

This foil is well suited for baking porcelain upon.

The alloys of gold, with antimony, bismuth, copper, lead, magnesium, nickel, thallium, platinum and tin, show characteristic physical properties which are easily read directly from the temperature and physical charts, (figures Nos. 29, 30, 31, 32, 33, 34, 35, 36, and 37) aud while they do not offer substitutes directly for platinum alloys, the information contained in these charts will be of value to the dental profession in later researches in the ternary alloys. We are, therefore, including them with the binary alloys in their proper place in the text.

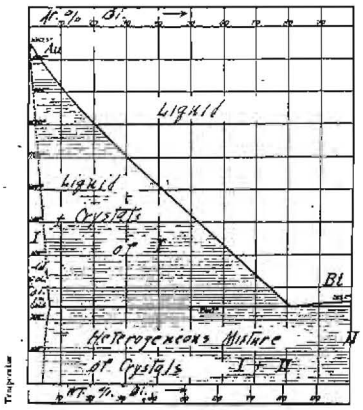


Fig. 30. Gold - Bismuth

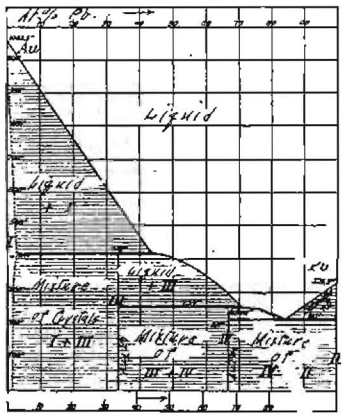


Fig. 32. Gold - Lead

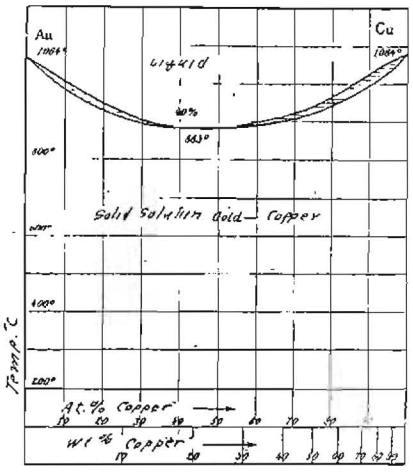


Fig. 31 - Gold. Copper

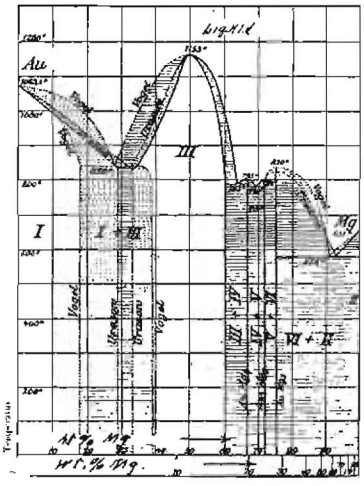


Fig 33 Gold. Magnesium

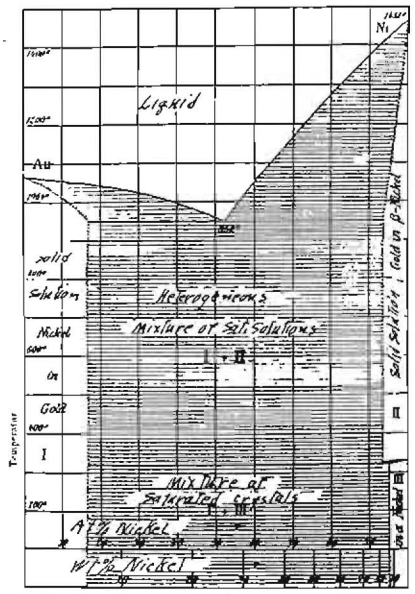


Fig. 34 Gold - Nickel

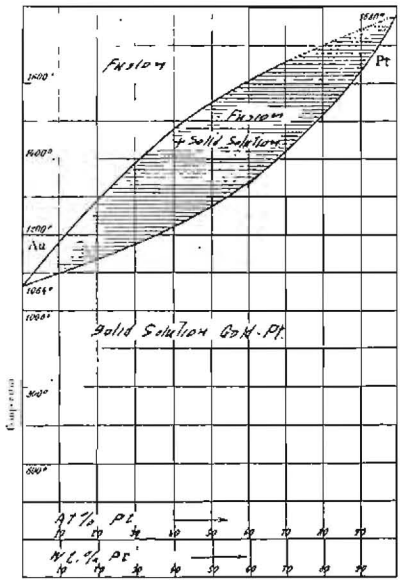


Fig 36 Gold - Platinum

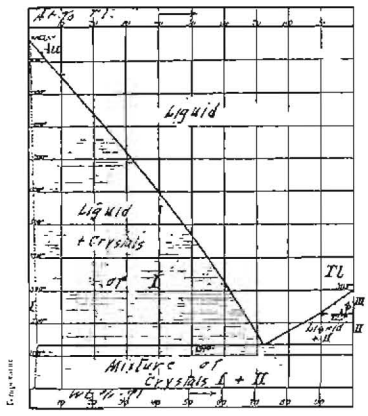


Fig 35 Gold - Thallium

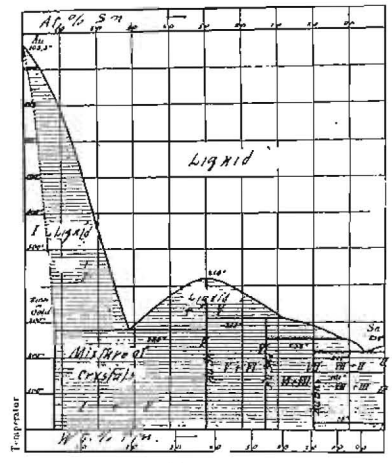
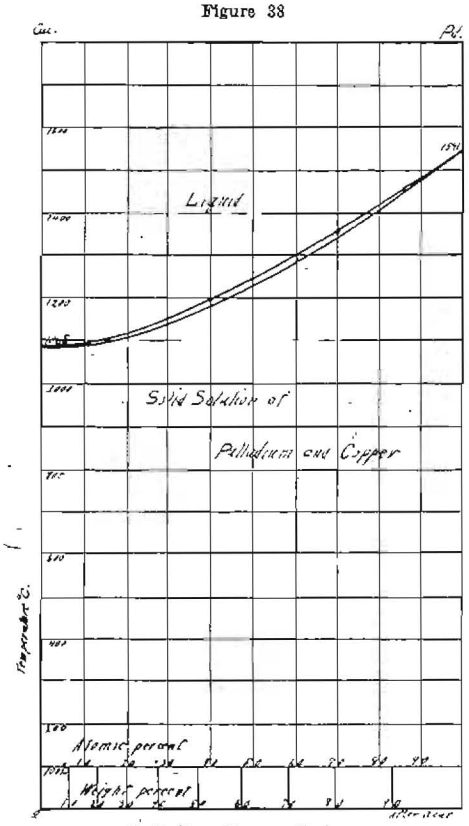


Fig 37 Gold - Tin

PALLADIUM.

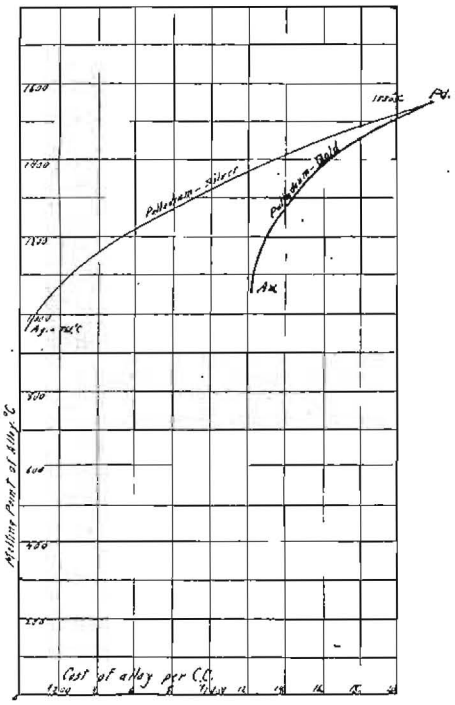
On account of its high resistance to carrision and sulphiding influences, palladium has long been used for making or coating the works of high grade chronometers, for making parts of very sensitive balances, and for electroplating reflecting mirrors of high grade telescopes. Its general properties are too well defined in any standard text on chemistry to take space for that purpose here. Suffice to say that it is insoluble in mineral acids, except strong HNO_3, and is unattacked by organic or alkali reagents in general. The remarkable properties of Pd from a metallurgical point of view, is its great solvent power for other elements, forming solid solution in perhaps more cases than any other element. This feature, coupled with its other valuable physical properties, makes this a particularly promising element for our purpose. With many of the metals of low m. p. its alloys are also of low m. p. except those of high Pd. content. This is true in the case of Zn. Sn., etc. Some of these, however, may be modified so as to he suitable for a casting material. In this present report only those combinations will be taken up that would promise a fairly infusible (above at least 1200.° C and non-corrodable alloy.

Figure 38



Palladium-Copper Series.

Figure 39



Curves showing relative cost of Pd-Ag and Pd-Au alloys having equal melting points.

Pd.-Ag.—These have been described under Palladium.

Palladium-Copper, Fig. 38.

Copper, with palladium, forms a completed series of solid solutions, as would be predicted, providing the properties of both Cu. and Pd. These are splendid soft, ductile, alloys whose properties parallel those of the Ag.-Pd. serles. The Ag. Pd. alloys, however, are superior in every way, apparently, in that both components are noble metals, and hence form alloys which are much more "noble" in their properties. Even if the melting point was the criterion, the silver-palladium alloys have the advantage, in that a certain m. p. is reached with a smalled relative addition of pd. than is necessary with copper, thus in every way, so far as considered in this work, the Ag. Pd. alloys will take the place of corresponding Cu. Pd. alloy, at a smaller cost of production and with more valuable properties.

Figure 39 shows curves giving graphically the comparision of the cost of production of Pd-Ag. and Pd.-Au. alloys of a given m. p. This gives the advantage to the Ag. Pd. series. By reading across from any desired temperature to tbe respectlve curves and then following down the perpendicular to the base the cost is read directly.

Palladium-Nickel.

The melting points of alloys of this series average apparently (no means was available for measuring the temp.) between that of nickel and Pd.

All alloys of this series are ductile and malleable, and those of above 30.% Pd. are not readily oxidized. They are all softer than nickel and hence do uot offer a pt-Ir. substitute. The foil would be inferior to Ag.-Pd. or Au. Pd. for dental purposes.

Palladium has proven to be a good solvent for nickel, iron, chronium, etc., so naturally its solubility for tungsten and molybdeum might be inferred. Experiments have proven this to be true. The addition of W. or Mo. to Pd., however, seems to offer no special properties of value. The opposite was shown in specimens made up, but this points to possibilities along a different line of attack, as will be taken up under tungsten and molybdenium.

The temperature and physical charts for other alloys are given here in the

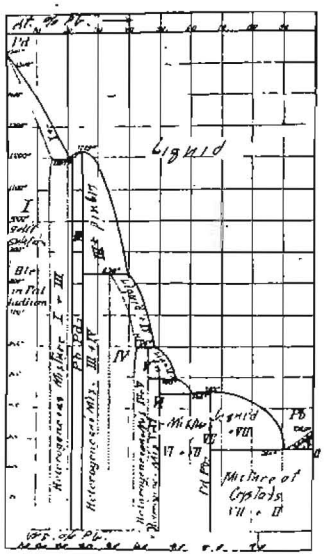


Fig. 40 Palladium Lead

binary group for later reference, as follows:

Palladium and lead, Fig. 40.
Platinum and iron, Fig. 41.
Platinum and lead, Fig. 42.
Platinum and Thollium, Fig. 43.
Platinum and tin, Fig. 44.
Platinum and Antimony, Fig. 45.
Platinum and Copper, Fig. 46.

So far, no binary alloy of the common metals has given promise of being successfully substituted for the iridio-platinum "hard metal". However, in the

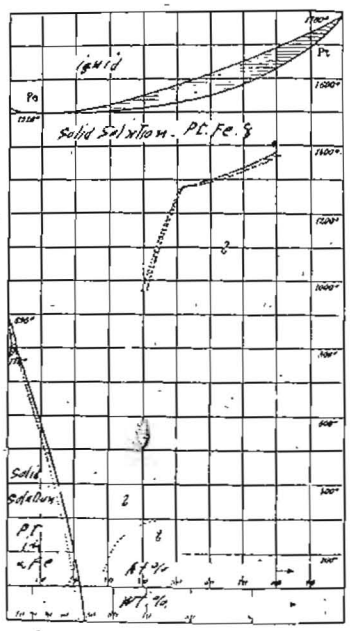


Fig. 41 Platinum - Iron

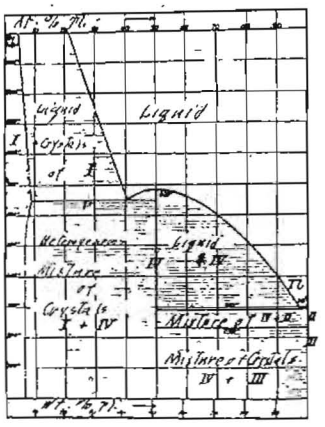


Fig. 43. Platinum - Palladium.

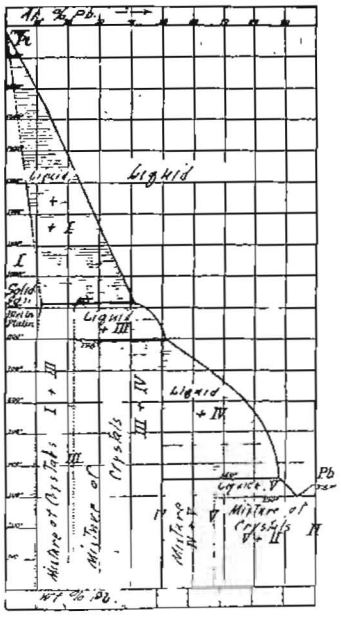


Fig. 42. Platinum - Lead

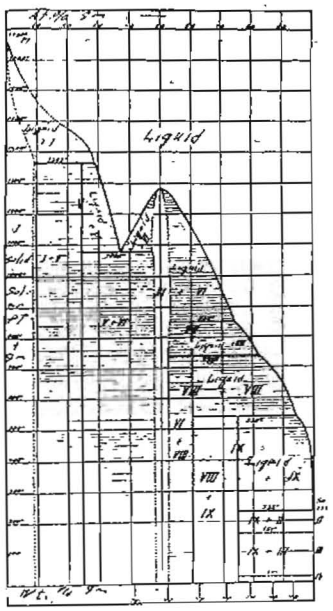


Fig 44 Platinum - Tin.

work carried on Pd. and Pt alloys, during the past year, several discoveries have been noted, and our field of possibilities thereby enlarged, chiefly among the elements regarding which little is known and which present a new field for research as to their application, these are Tungsten and Molybdenum.

Tungsten is popularly known only in its application in the manufacture of incandescent lamps. The newly developed

Electric laboratory furnaces with W. (tungsten) resistors are of two types; in one a W. wire is wound on an alundum tube in an air-tight box in an atmos. of H.; in the other a tungsten tube takes the place of the helical resistor in the Arsem vacuum furnace. Tungsten gauze is used successfully for filtering acid liquors, and where fumes are encountered. Tungsten is also well suited for standard weights since it can be

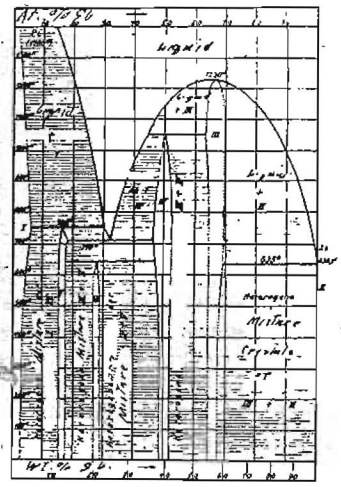


Fig 45 Platinum - Antimony

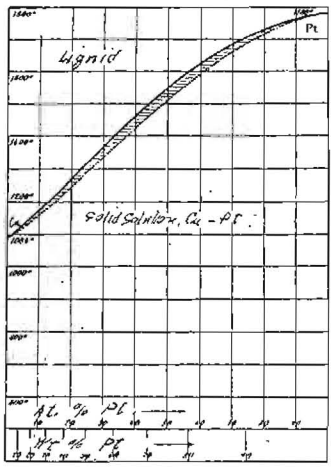


Fig. 46 Platinum - Copper

ductile metal is practically insoluble in any of the common acids, its melting point is higher than that of any other metal, its tensile strength exceeds that of steel, it is para-magnetic, it can be drawn to smaller size than any other metal, and its specific gravity is 70% higher than that of lead.

Wrought tungsten has been substituted with success for Pt. and Pt-Ir. as contact points in spark coils, voltage regulators, telegraph relays, etc. The service for exceeds that for Pt. and Pt-Ir. contacts, due to greater hardness, higher heat conductivity, and lower vapor pressure as compared with Pt.

made so hard that it will scratch glass and still be ductile. The density is also high, and it is unaffected by the atmosphere.

Among other applications partly worked out, or suggested, is for galvanometer suspension, cross hairs in telescopes, strings for musical instruments, etc. It has also been suggested to use the fine wires in surgical operations in place of the coarser gold and silver.

Acid proof dishes and tubes are also made of tungsten. Since W. is paramagnetic and is very elastic it may be used for springs for various purposes. Out of this material watch springs could be

made which would never become magnetized:

Tungsten pen points, drawing dies, knife blades, etc, are also possible.

The following gives an outline of its general physical and chemical properties:

Density=19.3-20.2.

Tensile strength,=322-427 Kg. per. sq. mm. (up to 650,000 pounds per sq. in.

Young's modulus of elasticity,= 42,000.00.

Steel=20,000.00.

Thermal conductivity=0.35 gm. cal. per. sec. per. degree cent. (Pt. =0.166).

Coefficient of expansion=4.3 times10-6 4.3 times 10(Pt. =8.8-6).

Resistivity, 6.2 ohms per c. c. (hard); 5. ohms (soft-anneale).

Temp. coef. of res. .=0.0051 (0.170° C.)

Hardness, 4. 5-8.0 (Mohs scale.)

Relative to the chemical properties of tungsten, the following is taken from a paper by W. F. Ruder, J. Am. Ch. Soc., 34,387. "In the following experiments the samples of metal used were all of the same shape and size. They were discs, of sheet tungsten, such as are now being used for X-ray targets, and are 18 mm in diameter by about 2.5 mm. thick. The surface area was 650 sq. mm. on the average. The weight according to thickness, was 9. to 12. grams.

Solubility in HCl wrought tungsten is insoluble in hydrichloric acid of and concentration at room temperature and only slightly so at 110.° C. After 45. hours the hot concentrated acid showed no effect upon the tungsten. After 175. hrs., however, the material was covered with a coating of oxide and the metal lost 0.5% in weight. In dilute acid at 110.°, it lost 0.05% after 22 hrs., but showed no further loss after 50. hrs. After 175. hrs. the metal was coated with tungstic oxide and there was a gain in weight of 1.% due to oxidation. This oxide formed an adherent coating protecting the metal against further loss.

Solubility in H_2SO_4. At room trmp. this acid has no effect upon wrought W. mor has the dil. acide at 110.°. Concentrated acid attacks it very slowly at 110.°, the loss in weight being 0.1% after 18 hrs. and 0.16% after 40. hrs.

Solubility in Nitric Acid.

Concentrated nitric acid at 110.° showed no action on tungsten after 48. hrs., other than a dulling of the bright metallic surface. The dilute acid, however, produces the yellow ovide on the surface. There is a slight gain in weight after 15. hrs. and then no further change after even 175. hrs. immersion.

Solubility in Aqua-Regia. Aqua-Regia at room temperatures, oxidize the surface to tungstic oxide. After 215. hrs. the loss in weight was .31%. If this coating is allowed to remain, continued boiling with fresh equa-reria had not further effect upon the metal.

Solubility in Hydrofluoric Acid. This acid, hot or cold, did not attact tungsten, even to the extent of dulling its polished surface, during frequent evaporations of the acid.

Solubility in Potassium Hydroxide. Potassium hydroxide solution of any concentration does not attack tungsten but the fused alkali attacks the metal slowly. In this case there was 21.= loss after 15. hrs., and after 40. hrs. the disc had all dissolved.

Solubility in Alkali Carbonate. In fused alk. carbonate, potassium carbonate, or mixtures of the two, tungsten dissolves slowly. About 2.5% was noted after four hrs. Addition of KNO_3 hastens the solution considerably.

In other experiments a saturated sodium hypochlorite solution was found to attack tungsten at the rate of about 4.% in 24 hrs. A mixture of H_2SO_4 and chromic anhydride did not act upon the metal. A mixture of hydrofluoric and nitric acids dissolves tuugsten very rapidly with evolution of nitric oxide and the production of tungstic oxide. Exper-

iments made in this laboratory has shown that tungsten is quite soluble in hydrogen peroxide, and this action is hastened by the presence of NH_4OH.

The following is taken from the same paper by W. F. Ruder as that above, on tungsten. "In the following experiments small strips of molybdenum, 30.X9.X.4 mm. were used, having a total surface of 540. sq. mm.

Hydrochloric Acid, diluted, slowly dissolves molybdenum, at 110.° to a brown solution with some black oxide, probably M_2O_3. The loss in weight was 20.% after 18. hours. The more concentrated acid has a much slower action. After keeping the metal in acid of 1.15 sp. gr. for 18 hours at 110.° the loss was only .34%, and the surface was still bright.

Sulphuric Acid, diluted, at 110.° does not attack Mo. The concentrated acid (1.82) does attack it very slowly at this temperature. Only 0.29% was dissolved after 18. hours. With elevated temperature, however, (200.-250.° the metal dissolves rapidly to a green solution, with evolution of SO_2.

Nitric Acid, concentrated (140) dissolves Mo. slowly with the formation of MoO_3, which deposits on the surface of the metal, retarding further action. The more dilute acid (1.15) attacks the metal rapidly.

Aqua Regia also dissolves the metal rapidly, especially if heated.

Hydrofluoric Acid (hot or cold) does not attack molybdenum.

Potassium Hydroxide solutions do not attack Mo. but it is soluble in the fused alkali.

It will be noted that both W. and Mo. are, to a certain extent, acid resisting, and this is due principally to the formation of an acid resisting coating of oxide. Tungsten is attacked most readily by fuming H_2SO_4 and this only to the extent of 1.2% in 8 hours. Molybdenum is much more easily dissolved than tungsten. It resists concentrated HCL and H_2SO_4 at moderate temperatures fairly well and is untouched by hydrofluoric acid.

With two exceptions, this metal is superior to any Iridio-platinum alloy possible. These properties of tungsten which make it unsuitable for dental purposes are: its oxidation at soldering and casting temperatures, and its practically zero affinity for gold, silver, etc., at ordinary temperatures.

During previous investigation it was discovered that both W. and Mo. were easily soluble in palladium and less so in platinum. This led to the partial investigation of these series, which did not promise much in the way of an alloy. It does, however, open up a new field. If tungsten is so soluble in Pd. why not put a coating of Pd. on the tungsten wire, thus combining the valuable properties of W. as to tensile strength, low coef. of expansion, hardness, etc., with those of Pd, which can be readily soldered, is not oxidized, or affected chemically during manipulation and while in use.

Experiment along this line led to the production of such a wire. Further work proved that the Pd-Ag. or Pd-Au alloys of sufficient Pd. content, could be used as well as pure Pd. Using this alloy, very little is added to the first cost of the tungsten itself.

This coated wire should serve as a more desirable material than Pt. or the Pt-Ir. alloy. This coated wire cannot be softened by repeated heating to ordinary temperatures (I. e. heating does not remove the temper or springiness as is the case with other materials). It has many times the tensile strength of Pt-Ir. and has six times the bending strength of a 30% Pt-Ir. wire of the same size. It can be easily soldered or cast onto; it will not oxide or be affected chemically. The wire cannot easily be deformed while cold, but if heated in the open flame slightly it can be bent to any desired shape.

The Availability of Tungsten.

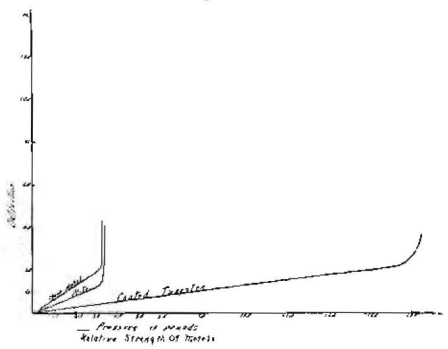
The enormous amount of detail, incident to these studies, and very large difficulties to be overcome have made it impossible in the limited time to bring these studies to a degree of perfection where we can state positively relative to the price of metals and their combinations, or of the purity and constancy of their properties as they will first become available. It has been impossible, most of the time, for us to get tungsten for our researches, not because of its scarcity but because of the care with which it is guarded. It is used, as is generally known in the manufacture of lamp filaments and since it draws into such infinitely fine wire, one-thousandth of an inch or less, a relatively small piece of tungsten rod would make enough of the filament for one thousand dollars worth of tungsten lamps. Its manufacture is guarded both by patents and secret process and the sources from which it can be secured in this country seem to be limited to the General Electric Company. It was only by making a special trip for a conference with the management that we were able to arrange for its commercial use by the dental profession, as well as secure samples for our research work. It will be necessary for the tungsten to be cut into lengths, probably not exceeding three or four inches, before it can be marketed to our profession. The general Electric Company will not sell it direct to individuals of the profession but after your research department has endorsed a quality of material, they will make it available to the dental jobbers. It is exceedingly difficult to change tungsten from the powdered form, in which it is easily obtained commercially, to the metallic bar and wire. The change is accomplished by compressing the powder under the high pressure, producing a rigid rod through which an electric current of high amperage is passed, thereby heating it to a very high temperature, in which condition the particles, though not fused, are sufficiently softened so that under the swaging process the particles become attached and the piece takes on a metallic appearance. It is then heated and while hot drawn through drawplates, which in effect elongates the particles or grains. This must be done in an atmosphere free from oxygen. The more it is drawn the more ductile it becomes, though at all times it must be drawn hot until small sizes are reached, though after it becomes more ductile it need not be even red hot. The physical property of the final bar, when crushed or broken, is that of bundle of small thread like crystals and the strength of the final bar depends quite largely on the number of drawings and may range from a hardness and stiffness exceeding that of hard steel to a softness comparable to medium steel wire. In its harder form it withstands abrasion probably better than any known metal, as is illustrated by the fact that a reproducing point for a phonographic needly, when made out of tungsten, will outwear two hundred of the standard hard steel points. This indicates a great possibility for this metal for the future as a cutting tool for dental uses, however, a very great difficulty in its manufacture arises out of that quality. Grades of tungsten that are as hard as the above are very difficult to mall and require to be ground. It is not improbable, however, that all these difficulties will be overcome.

We have spoken in the first part of this report of the enormous strength of tungsten as compared to that of other metals, it having a tensile strength thirty times that of gold and five and one-half times that of iron. It is practically uneffected by the acids or by fluids of the mouth and specimens that we have placed at the points of abrasion on the occlusal surface of fillings have shown a phenomenal resistance to wear. The melting point of tungsten is so enormous-

ly high, namely, over 3000° C. and 5400° F. that it is exceedingly difficult to fuse other metals on to it under ordinary conditions. This, however, can be done readily by methods which we shall review. While tungsten so perfectly resists oxidization at ordinary temperatures, it does oxidize rapidly under an open blowpipe flame at high temperatures, thus making it impossible to flow the ordinary metals on to it under ordinary conditions, even though they do so readily when in a non-oxidizing atmosphere. Consequently, it is not difficult to coat the tungsten perfectly with any of the suitable noble metals, or combinations of them, and the golds and solders can be readily flowed on these with the ordinary blowpipe flame. For this purpose pure gold, or preferably an alloy of pure gold, and palladium answer admirably, though silver and palladium is satisfactory. This coating is so thin that it need not add more than one per cent to the weight and, consequently, adds very little expense to the cost of the tungsten. The tungsten bars thus coated will probably cost from fifteen to twenty per cent as much as platinum to start with and if the judgment of metallurgists is correct, the price of tungsten must go down to a few dollars a pound.

Figure No. 47 illustrates in chart form the relative strength of the coated tungsten bars to that of iridio-platinum and of clasp metal of the same sizes. The horizontal line expresses an increase up to eighteen pounds and the verticle line illustrates deflection in tenths of an inch before bending and the pressure at which bending occurs or where elasticity is overcome. The length of these bars between supports was one-half inch. The clasp metal and iridio-platinum both bend at a trifle over three pounds at one and one-half and two-tenths inches deflection respectively, and the coated tungsten bent at eighteen pounds at about two-tenth deflection, giving tungsten approximately six times the stiffness of the iridio-platinum or clasp metal, which means that the factor of safety, when a bar of the same size of tungsten will be used as a post for a crown, would be six times as great as when iridio-platinum or clasp metal are used, and also means that a much smaller size post may be used and still have a much greater strength. All will recognize the very great advantage of this in small rooted teeth, like upper laterals, and all lower incisors. Also for individual roots of molars where great strength is required and the tooth structure material is already the minimum and elas-

Figure 47



ticity by being heated to ordinary temperatures which quality suggests a large usefulness for orthodontia appliances and for which use we are making studies, which will be reported later.

We have found tungsten as coated to be a very great advantage as a frame work into which we will cast cold alloys and thus hold gold from distortion due to its natural contraction. In other words controlling the location of the contraction by actually stretching and holding the gold. We have found that bridge abutments made of the coated tungsten, consisting of posts entering roots and united with bars of coated W by means of high fusing gold and platinum solder, will permit of the wax being moulded directly around this frame work, includ-

ing the inlay restorations for the abutments and the facings in position, and after the removal of the facings the entire piece cast at once with only a fraction of distortion produced when the same coating is made without this frame work. It is desirable for this use to use a threaded bar, or one specially roughened, to prevent the gold from sliding upon it. These bars are similarly used and with great advantage in controlling the contraction of MOD restorations, as previously announced. Molybdenum has some very desirable qualities and some less so. It is naturally much softer than tungsten but like tungsten is oxidized at high temperatures in the open blowpipe flame and requires to be coated with some of the noble metals, as we have just suggested. Our researches will be continued with it and reported more in detail later. It probably will be made a component of a ternary alloy with splendid qualities.

There are many reasons why our profession should make extensive use of palladium. In the first place because volume for volume it is about one-third cheaper than platinum. Its relative density, as compared with platinum, is approximately as eleven is to twenty-one, which means that when you buy an ounce you get approximately twice as many square inches, or linear inches, according to the form of the material. In color, surface and softness it compares very favorably and while its coefficient of expansion is slightly higher, namely, as eleven is to nine approximately, it is very satisfactory for many uses with porcelain. While we have not done so we are informed that porcelain dentures have been baked on it with beautiful success, it apparently behaved in every way as satisfactory as platinum. There is reason to believe that it may come to be one of the most used metals in dentistry, largely because of the fact that it enters into perfect solution with nearly all metals and in which record it stands unique among metals. Its present cost of approximately $60.00 an ounce, or $22.00 a cubic centimeter, will probably be very greatly reduced in the near future and we have been advised by competent metallurgists that if a good demand can be created for this metal, it could be produced as low as $10.00 an ounce. It is a by-product in the production of copper and has very little demand. The dental profession alone could use enough of it to warrant competent capitalists making special efforts to increase the supply. The alloys of palladium and silver and palladium and gold have so important a place in modern dental practice that we feel confident that those who use them will continue their use, both because of their being so much less expensive than platinum and its compounds and because they have all the softness of pure platinum in practically all proportions of either palladium and silver or palladium and gold, provided the ingot is frequently annealed during its first rallings. Palladium and silver, though both are white metals, have a slight but beautiful lemon tint when polished and the palladium has the remarkable property, not only of very rapidly raising the melting point of gold but of very rapidly absorbing its color so that ten per cent by weight, (not volume) of palladium and gold not only increases its melting point from 1065° C. to nearly 1300° C. but produces an entirely white metal like the palladium itself. This proportion can be used almost any place that platinum foil will be used as a backing for gold and would cost a little over $14.00 a cubic centimeter, considerably less than half the price of platinum. We have found it worked beautifully for taking impressions for porcelain inlays and for matrices for which to flow, or cast, gold in various other uses for which platinum is adaptable. The addition of even one per cent

of palladium to gold increases its tensile strength very greatly and even two or three per cent will raise the melting point sufficiently that when gold is cast upon it it unites without melting it, thereby producing a margin which, though practically as soft as pure gold for burnishing and finishing to the tooth, is much stronger and tougher than the 24K gold and likewise more pliable than the 20K gold, or less. Its use as a gold plate has some distinctly desirable qualities. The palladium can be purchased in the open market from the dealers in platinum and noble metals and should be supplied to the profession without difficulty. It is destined to have an important place in dental metallurgy as a ternary alloy, in which role it will be reported later.

METALLURGY.

(Closing Sentences.)

The director of these Metallurgical Researches greatly desires assistance and helpful criticism from the profession, relative to those various metallurgical products, that are and may be suggested for dental uses, and will undertake to send samples to such as shall desire them, with the understanding that we are to have the benefit of your helpful criticism and the expense incidental to preparing and sending the samples. We shall, also, be glad to advise all members of the trade where and how they may secure and prepare these products, upon request for this information. We shall expect to furnish additional information in these columus as fast as it becomes practicable.