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SECTION IV: DENTAL PHYSICS, CHEMISTRY, RADIOGRAPHY, AND METALLURGY

# REPORT ON
# THE THEORY OF PRESSURE CASTING

By WESTON A. PRICE, D.D.S., M.S., Cleveland, Ohio, U.S.A.

This subject will be discussed within a rather strict interpretation of the title submitted to us, accepting the definition of *theory* as being "The general or abstract principles of any body of facts" (Webster).

Inasmuch as I am instructed to limit this discussion to a twenty-minute presentation, it is clearly impossible to review the bibliography pertaining to the development of the subject as it presents to-day; nor would such be desirable in anything but an historical review, since most of the early deductions have been abandoned, even by those who made them, for they were clearly based on wrong premises. The "general body of facts" from which we are to make our deductions, pertain to the processes involved in the construction of a body of metal which shall have a physical form and dimension which reproduces a part of a human tooth, whether accomplished by any one of several methods. The steps of this process are:

(*a*) The forming in the cavity of the tooth of a mass of material, usually wax, which mass shall not be distorted when withdrawn, because that chamber is shaped to allow it to draw. (This applies to either patterns carved in the cavity for a direct method or to impressions taken for an indirect method.)

(*b*) The reproduction of this pattern, or impression, either in the form of a mould in investment material for a direct method or as a model for an indirect method.

(*c*) The casting into this mould, or a model, of a metal which is to fit the chamber in the tooth from which the impression or pattern was taken. (This includes, also, patterns made in the model and removed therefrom for casting.)

Inasmuch as our deductions are to be based on a "body of facts" pertaining to these various processes, it is necessary for us to analyse and study in detail the important changes which actually occur in these various processes. These are as follows:

(*a*) The changes in the wax or material with which we make a record or pattern of the cavity dimension, produced chiefly by its changes of temperature between the time it is in the cavity in contact with all surfaces, and the time it produces the outline and dimension of the mould by the setting of the form, or investment material, around it, including a model for an indirect method.

(*b*) This record of dimensions may be changed by the process of setting or by changes of temperature, &c.

(*c*) Presuming that the gold is placed directly into this record, or mould, it will change in dimension with its change of state, from liquid to solid, and with its change of temperature from molten to normal temperature.

A more detailed analysis of these changes will show definite variations dependent upon the materials and conditions under which they are used as follows:

(*a*) The formula of the wax, or pattern material.

(*b*) The temperature at which the wax is moulded in the cavity.

(*c*) The temperature at which the wax is removed from the cavity.

(*d*) The temperature at which the wax is invested.

(*e*) The factor of stress, or elastic strain, retained in the wax and the extent to which this elastic strain is released.

(*f*) The quality of the investing, or model, material.

(*g*) Its behaviour when heated.

(*h*) Its temperature at the time it receives the molten metal.

(*i*) The relative size in cross-section of the neck of the sprue and the relative amount of gold left in the sprue gate, as compared with the casting proper.

Of these varying changes, only two are relatively definitely fixed, namely, the contraction of the gold from its freezing-point to normal temperature, which is approximately 2·2 per cent. linear or 6·6 per cent. volume or cubical change, and the change in volume of gold as it changes from liquid to solid, which is 1·6 per cent. linear or 3·9 per cent. volume. (Price, *Items of Interest*, May 1908; Price, *Cosmos*, March 1911.) The effect of these variations in the various steps of this process will be in part as follows:

(*a*) If the wax forming the pattern is invested at a temperature lower or higher than that at

which it was removed from the eavity, it will have a different dimension, which will go forward as an error, dependent upon the formula of the pattern material and on that ehange of temperature.

(*b*) If the wax eonstituting the pattern is under a condition of retained elastic stress and the temperature is later increased sufficiently to release this elastic stress, a definite distortion will be produced according to that elastic content.

(*c*) If the investment material is of a formula which expands when heated, the size of the mould will be changed in proportion to that temperature ehange, and if that temperature is taken to a point at which the investment ceases to expaud, and instead eontracts, the dimension will again be changed.

(*d*) If the pressure of the gold, as it enters the mould, is sufficient to distort the investment media, an error will be produced in the cavity formed, which faet makes the pressure available for any given set of conditions, dependent, in part, upon the formula of the investment material.

Inasmuch as practically all of the material related to these various operations have relatively quite definite rates of expansion and contraction, with increase or decrease of temperature, it is possible so to relate the procedures that errors will be produced in some of the steps that will approximately counteract or correct other steps in the procedure. The factors that have large change are :

(*a*) The wax pattern material, which may change as high as 4 or 5 per cent. linear within the ranges of variation in temperature with which we will use it (*see* Price, *Cosmos*, March 1911).

(*b*) The investment material which may be expanded under most favourable eonditions, 8 of 1 per cent. or may be contracted 5 per cent. aceording to its treatment and formula.

(*c*) The gold which will always have a relatively constant change in dimension, according to its temperature, of 11·53 per cent. volume or 3·8 per cent. linear between its molten condition and normal temperature, and of 6·6 per cent. volume or 2·2 per cent. linear between the point of crystallization or freezing and normal temperature.

Inasmuch as we eannot utilize the change of the dimension of gold except as a diminishing dimension, it may be considered as a fixed faetor to which we must adapt for correction our other available faetors, namely, the changes of dimension of wax and investment. The change of dimension of investment material, as compared with that of the wax pattern materials, is relatively small and under most favourable conditions cannot eounteract even half the uncontrollable contraction of the gold. This makes it clearly most feasible for us to seeure the correction for the fixed error or contraction of the gold by so manipulating the wax pattern material that we shall make its change of dimension eompensate for, and correct the uncontrollable ehanges of the gold.

Inasmuch as that change in the dimension of the gold, which oceurs with its change of state from liquid to solid, can easily be compensated for, by having uew liquid gold enter the mould to fill the vacancy caused by the change of state of the gold already within the mould, we need only to consider as a fixed error for the gold 6·6 per cent. volume or 2·2 per cent. linear. Nearly all of the pattern and impression waxes, and particularly the former, have dimension changes within their working range of temperature of over 6 per cent. volume or 2 per ceut. linear, and some have an amount as great as 15 per cent. volume and 5 per cent. linear within extreme working ranges and 9 per cent. volume or 3 per cent. linear within easy working ranges.

The problem of the application of this method of correction would be exceedingly simple, were it not for the fact that wax pattern materials, such as are available on the market, are eapable of retaining with low temperatures and releasing at high temperatures a large amount of elasticity. This is one of the very large sources of error and one which the profession seems to have appreeiated but little, though it can be so easily demonstrated by any person desiring to do so. Fig. 1 illustrates this elastic quality of wax very graphically. In Figs. *a* and *b*, we have a difference in length between the two arms of 18 per eent. by the following technique : Take two pieecs of inlay pattern wax, of most any make, and warm them to their low working range. Stretch one like a piece of rubber and place it in eold water while stretehing. While it is cold, it will remain stretched. Take the other piece and condense it at its low working range, like condensing a piece of rubber bar the same shape, and chill it as the previous piecc. From each of these cold sections cut a pieee one inch long and adapt them to a sprue former, as shown in Fig. 1. If thesc were now invested in a cold investment, of course the two arms would be cast the same length, but instead, invest them in a warm investment, which for that wax will be its high working range, and proceed to cast. The effect of the warm investment will be to relcase the elasticity of the wax like thawing a frozen piece of stretched rnbber, allowing these masses to take a relaxed statc. The one that was stretehed will shorten, the one that was condensed will lengthen, producing the changes shown in *a* and *b*, Fig. 1. This quality of the elasticity is a constant factor of practically all waxes, though it varies with different waxes and different formulas. This quality of elasticity, and the distortion it will

produce in practical work, is graphically illustrated in Fig. 2, which shows four castings of an MOD cavity, to which we will refer later, in which *a*3 and *a*4 had the wax inserted in the form of a ball of stiff wax pressed into place with a large ball burnisher, and as the wax was forced into the mesial and distal areas of the tooth form a condition of elastic stress was placed in the wax when it was chilled. This stretched elastic condition of the wax in the long arm of the pattern was followed by a relaxation when these patterns were all invested in warm water, producing the distortion and apparent contraction shown in pattern *a*4. Pattern *a*3 was treated precisely as pattern *a*4, as to the technique of placing the wax in the cavity, but before investing the elasticity was released by the method to be described later, and it did not distort. B1, of the same Fig. 2, had the wax put in the same mould by bending a piece at its low working range, in the form of an open horseshoe, passing the arms into the mesial and distal parts of the cavity and chilled, and when this wax pattern was invested in a warm investment, its elasticity was released and it took a relaxed position, which threw its arms out, as shown. This is distortion, not expansion. B2 was made by placing the wax in the pattern precisely as in the case of Fig. B1, and later the wax had its elasticity released, as we will explain, before being placed in the warm investment. It did not distort.

*Please Note.* All of these patterns were adapted to a sprue former at the same time, at which time they were all of the same shape and dimension, namely, the shape of the cavity in the tooth form and were without distortion. They were all invested together in a warm investment, near the high working range of this pattern wax which was S. S. White's Black. (Almost all waxes will produce the same result.) The effect of the warm investment was to release the elastic strain, like thawing a frozen piece of stretched rubber, and before the investment had time to set, the wax patterns had taken their relaxed shape and form, as shown.

It is clearly necessary, if we would prevent this distortion error, due to the release of the elasticity of the wax, that we shall release that elasticity while the wax is in the form, which is done by heating the wax to, or above, its high working range while it is in the form or tooth, which may be done by passing a warm instrument through it or by surrounding the entire mass with warm water. This will be spoken of in more detail later.

It is very clear that if we take a piece of wax, in its chilled state, having the shape and dimension of a cavity we wish to reproduce, and expand it by heating, we could introduce a dimension change ample to take care of the contracting gold, but it is clearly impossible for us to place the wax into the cavity in the tooth at this low temperature, say 67° F. or 20° C. In other words we must expand it and enlarge its volume because we must heat it to place it in the cavity. This change of volume can be readily seen by anyone, by observing that the wax pattern material of some pattern waxes, when placed in warm water, goes quickly to the bottom, having a specific gravity considerably greater than that of water. But before becoming very soft, it rises to the top, at which time it has a specific gravity less than that of water, having changed its volume in some instances with this small variation of temperature as much as 15 per cent. volume or 5 per cent. linear, according to the temperature of the water and the formula of the wax. It is this change in volume that we wish to utilize to counteract, or correct, the change in volume of the gold.

At this point we must discuss another phase of our problem. It is very clear, from personal observation to all who have done practical work, that restorations, to restore inside dimensions, are free from the embarrassments encountered when we undertake to make a casting to restore an outside dimension, and it will be apparent to all that we should use a different technique when we wish to produce quite accurately each of the following :

(*a*) A restoration for inside dimensions only.

(*b*) One for outside dimensions only.

(*c*) One for restorations involving both inside and outside dimensions. For example, if our restoration is for an inside dimension and we have a contraction error of 4 per cent. linear in our wax pattern before investing it and a 2 per cent. contraction error by the contraction of our gold, this 6 per cent. contraction error does not prevent the inlay from going to place, for it allows it to go more freely into the cavity and if it is prepared with bevel margins, and particularly with a wide bevel, it will enter the cavity enough farther to still rest on the bevel. If the bevel is not of wide angle, it will seat on the floor of the cavity, which is easily corrected by grinding the base of the inlay. If, however, a restoration, for outside dimensions only, is made by the same technique, this contraction error of 6 per cent. linear would entirely prevent the piece from going to place, as represented by a gold base for a porcelain crown, or a gold crown, &c. If, however, this same restoration is for a condition involving both inside and outside dimensions, those dimensions going within walls will not interfere, while those going over walls will interfere If, now, we use a technique that produces a gold restoration larger than the form from which our pattern was made, as by sufficient expansion of the wax, it will go over the outside dimensions but will not go within the inside dimensions. If, however,

the walls of these surfaces have an angle to each other of wide bevel or draw, this same amount of interference may not prevent the inlay to appear to be nearly seated, and if it is made of a soft material, like pure gold, it can often be stretched sufficiently to he forced nearly to place, which is the prineiple and practice usually resorted to.

It is clear from this observation that were we to produce just the proper amount of expansion of our wax to permit us to make relatively exact restorations, where we have both inside and outside dimensions to restore, it would be essential that our cavity surfaces be sufficiently free to allow the piece to go to place. This supposed condition of smoothness of tooth surface and inlay surface and of fluidity of the cement is greater than we are able to provide and, also, means that any defect in the form of a bead or nodule, though exceedingly small, on the eavity snrface of the gold, would prevent the piece from going to place. It is practically essential that we provide, in our technique, for small defects on the surfaces of the east gold, in other words for a freedom on all cavity surfaces. This is accomplished in different ways as follows :

(*a*) By working the pattern in and out of the cavity, and thereby planing off and reducing the friction at the points of bearing, thereby producing a clearance.

(*b*) By adding a very thin layer to the surface of the model, if we cast directly into a model which is a reproduction of the tooth, or casting a pattern made in the model as an amalgam model. (I use the term model in this case, in preference to cast, to prevent confusion with the gold cast that is to be made into the model.)

(*c*) The removal of part of the wax from the cavity surfaces of the pattern by dissolving, carving or melting.

It is possible to accomplish this by another technique that is very simple and incidental to the procedure for expanding the wax pattern to compensate for the contracting gold, which is as follows : Let us suppose we have an MOD cavity to restore in a molar tooth and that we have a matrix in place on the tooth. If we will place the wax in the cavity, at any temperature convenient, and chill it cold in the tooth, we will, of necessity, produce an elastie strain by the wax contracting over the outside dimensions iuvolved. Note that this elastic strain would not be revealed if the pattern were invested cold immediately, or at any time while that strain was retained, because of it being frozen in the wax. It being our desire to heat a wax pattern, and thereby expand it, it is necessary for us to release this elastic strain, if it exists, for it is necessary for us to produce a pattern which occupies or fills at low temperature the space of the ehamber we are to fill and at the same time be free from elastic strain. We will accomplish this by one of two methods. If we will remove the wax pattern from the tooth, at any temperature at which we can handle it without chilling, and then after removal, chill to room temperature or in ice water, its dimension will be too small to go over the outside dimensions, but if we will, at this stage, break it across the occlusal and place the two pieces back into the cavity, the contraction of the wax in the mesial and distal parts of the cavity, in other words the parts involving the inside dimensions, will produce a desired cavity freedom and we will have a distinct open space between the two broken sections, in which we can put additional wax by taking a pointed instrument in one hand and a piece of wax, pointed like a lead pencil or wedge in the other hand, and after drying the surfaces of the chilled wax while they are replaced cold in the tooth, we will heat the surfaces of these separated masses of wax and plunge the taper or wedge-shaped piece directly into the opening. This will give us enough additional wax, across the occlusal surface, to produce sufficient expansion, when heated, to allow our casting, when cast, to go over the outside dimensions. If, however, our inside dimensions have relatively parallel walls, this same expansion would prevent those parts of the inlay which are restoring inside dimensions from going to place, which condition we will correct by the following technique. Having placed the wax in a tooth cavity at any convenient temperature, pass a warm instrument into the wax in all parts of the cavity, or throw a stream of warm water upon it for some time, or have the patient hold very warm water in the mouth for sufficient time to heat all parts of the wax, to or above its high working range. There is no objection to literally melting it. This accomplishes two purposes, namely, to release all elasticity and to expand the wax, making the excess move out, in order that we may have freedom on all eavity surfaces when our pattern is completed. The excess of wax will, of necessity, bulge out of the cavity. Before chilling the wax, cut it across in one or two places across the occlusal, according to the shape of the ocelusal part of the eavity, and chill by throwing cold water upon it. (Cold water must not be thrown upon the wax until after the wax has been divided to permit the contraction to open up places into which new wax ean be placed, as already directed.) Fill the opening, caused by the contraction of the cooling wax, and note it is not necessary to cut so as to destroy the feather edge of the bevel at the margius which part will be stretched.

We now have a wax pattern with the following qualities :

(*a*) It is at room temperature, or lower, and therefore has a low dimension.

(*b*) It has its elasticity released.

(*c*) We have a large contraction of material in diameters where our filling must restore inside dimensions, producing the desired cavity freedom referred to above.

(*d*) We have additional wax in the diameter controlling the freedom over the outside dimension.

This pattern must be removed from the cavity, without allowing to warm, and when it is invested in a warm investment, made by putting the investment material into warm water, this wax pattern will immediately enlarge uniformly in proportion to the change in temperature and without distortion because it has been relaxed if it has approximately the dimension of the cavity at room temperature, 67° F. or 20° C. and is heated to 110° F. or 45° C., it will expand from 2 to 4 per cent., according to the formula of the wax. If no error is introduced as a contraction in our investment material by overheating, or cooling after over heating, the dimension of our gold will be 2·2 per cent. less than this pattern was at the time it was expanded in the warm investing material, or 1 per cent. larger than the outside dimensions of the cavity if our wax was expanded 3·2 per cent. thereby producing a surface freedom over the outside dimension. The elastic content of the wax is corrected or released by a molecular flow which takes place slowly even in wax at a temperature ranging from 45° to 60° F. if the wax is held to prevent its bending. *See* Table No. 3. This Table shows that bent bars of wax containing elasticity will lose that elasticity even when kept chilled. At the following rates, practically the entire amount in ten days, 90 per cent. in three days, and 75 per cent. of it in one day.

Space will not permit of a detailed review of the behaviour of the investment materials, but a summary of the best conditions can be given in a few words. Those desiring a detailed study of this matter are referred to "Price, *Dental Cosmos*, March 1911." Inasmuch as we cannot obtain, under most satisfactory conditions, a very large expansion of our mould by heating it, at best less than 1 per cent. and inasmuch as the cavity surface of our filling will be impaired by casting into a hot mould, as compared with one not very hot, or even cold, it is better for us to get our correction for the unpreventable contraction of the gold by expanding the wax, rather than by expanding the investment.

With some waxes, however, having a very low co-efficient of expansion, it is necessary to use the expansion of both wax and investment to compensate for the contraction of the gold.

It is possible, by knowing precisely the behaviour of the wax we are using, and the proper technique, to produce restorations for either inside or outside dimensions, or for cavities involving both, to reduce the embarrassment, due to the contraction of the gold, to a very small amount and in order that any person may be able to see it and plan just what technique he should use with any of the inlay pattern waxes that the writer has been able to secure in the open market, we have prepared both a table and chart, illustrating the expansion and contraction of the waxes, during their working ranges, as compared with that of gold These are shown in Figs. 4 and 5. The first shows the expansion and contraction of the waxes between room temperature at 67° F. or 20° C., and their lowest and highest working ranges; the first two columns show minimum and maximum working temperature; the second two the contraction of the lowest working range to 67° F. given in thousandths of an inch or per cent.: the third two the expansion between 67° F. or 20° C. and the highest possible working range; the fourth two the maximum possible expansion available; the fifth two the elasticity change, return or bend after heating to a higher temperature. The chart, Fig. 5, shows graphically the relative linear expansion and contraction of the various waxes, as compared with gold through their working ranges, where the dimension is one hundred times the unit on the scale from one hundred to one hundred and one. The line at hundred on the scale, representing the length of the wax or gold bar at 67° F. or 20° C. There are two columns for each, the short representing the dimension of the wax at its lowest working range, the longer of the pair the dimension of the wax at its highest working range. From this you will see the first wax, S. S. White's crown sticky wax, is 1 per cent. longer at its lowest working range than at room temperature and is only one and one-half units, or per cent., longer at its highest working temperature. The second, representing S. S. White's inlay wax, is 2 units, or 2 per cent. longer at its lowest working temperature than at room temperature, and $3\frac{1}{2}$ units, or per cent., longer at its highest working temperature than at room temperature. Bird and Moyer's inlay wax is $1\frac{1}{4}$ per cent. longer at its lowest working range and $3\frac{6}{10}$ per cent. longer at its highest working range.

Van Horn's Inlay Wax:
$1\frac{1}{4}$% longer at its lowest working range.
$2\frac{7}{8}$% ,, ,, highest ,, ,,

Taggert's Green Inlay Wax:
$1\frac{1}{4}$% longer at its lowest working range.
$2\frac{1}{4}$% ,, ,, highest ,, ,,

Security Inlay Wax:
$1\frac{1}{4}$% longer at its lowest working range.
$2\frac{7}{8}$% ,, ,, highest ,, ,,

Caulk's Inlay Wax:
$1\frac{5}{10}$% longer at its lowest working range.
$2\frac{6}{10}$% ,, ,, highest ,, ,,

Consolidated Inlay Wax:
$1\frac{1}{2}\%$ longer at its lowest working range.
$2\frac{3}{4}\%$ ,, ,, highest ,, ,,
Kerr's Inlay Wax:
$1\frac{1}{16}\%$ longer at its lowest working range.
$2\frac{7}{16}\%$ ,, ,, highest ,, ,,
Klewes' Inlay Wax:
$1\frac{5}{16}\%$ longer at its lowest working range.
$2\frac{7}{16}\%$ ,, ,, highest ,, ,,
Cleveland Dental Inlay Wax:
$1\frac{3}{16}\%$ longer at its lowest working range.
$3\frac{1}{8}\%$ ,, ,, highest ,, ,,
Standard Inlay Wax:
$1\frac{5}{16}\%$ longer at its lowest working range.
$3\frac{1}{8}\%$ ,, ,, highest ,, ,,
Price's for Stone Model:
$\frac{5}{8}\%$ longer at its lowest working range.
$1\frac{1}{16}\%$ ,, ,, highest ,, ,,
Peck's Inlay Wax:
$1\frac{7}{16}\%$ longer at its lowest working range.
$2\frac{3}{4}\%$ ,, ,, highest ,, ,,
S. S. White Black:
$2\frac{1}{16}\%$ longer at its lowest working range.
$3\frac{1}{2}\%$ ,, ,, highest ,, ,,
S. S. White Crown Sticky:
$1\frac{1}{16}\%$ longer at its lowest working range.
$1\frac{9}{16}\%$ ,, ,, highest ,, ,,

Some waxes have, as you see, three times the expansion co-efficient that others do. The column at the extreme right in this chart represents the linear contraction of gold from the fluid state to room temperature, and the short heavy column next to it represents the linear contraction of gold between its crystallizing or freezing-point and room temperature, which is the amount of error that remains fixed with all methods of procedure, unless we hold the gold as it contracts, thereby compelling it to streteh. By comparing this column with the columns of the various waxes, it will readily be seen at a glanee what technique will be necessary with each wax to produce an expansion sufficient to correct for the error due to the contraction of the gold, and it will also be seen that some of the waxes even at their maximum expansion, which means the highest temperature to which they could be heated without danger of their ehanging form by actually melting, have not sufficient expansion to counteraet the uncontrolled contraction of gold, and with which it will be necessary to introduce an additional expansion by heating the investment.

By making a direct applieation of the information of this chart to the preceding, we will see that it would be impossible to use S. S. White's crown stieky wax, which is not a pattern wax, and obtain sufficient expansion to correct for the contraction of the gold. If we use S. S. White's black inlay wax, it will be necessary for us to have it fill the chamber at a dimension which it will have at a temperature lower than its low working range, in order that, by heating it to its highest working range, we may expand it 2·2 per cent. If, when using this wax, we shall have it at a dimension that it will have at room temperature and still be without strain in the cavity, which would produce an elastic stress to be released later, and will heat it by investing it in a warm investment to its highest working range, say 128°, it will have an expansion of $3\frac{1}{2}$ per cent. which is $1\frac{1}{2}$ per cent. more than the contraction of our gold.

For the purpose of establishing the facts in detail, which constitute the casting process, and to find the best method that is at present available, the writer has offered a series of prizes to be granted to the persons first producing east reproductions of chambers with a specified minimum amount of error. The first was for $150.00 in three prizes for the first dentists of the Cleveland Dental Society who would cast a gold base for a porcelain molar crown where the bevel of the root preparation and of the crown preparation, over which the gold should be cast, should be 1 per cent., and the reproduction must permit the equivalent of the porcelain going to place in the gold base, and the base to place over the root within one-fiftieth of au inch. The conditions that would reproduce the ahove were decided by a committee of five, four of whoun were dentists and one a Professor of Physics from the Western Reserve University of Cleveland. Inasmuch as the gold base for a porcelain crown and coping for a root requires a restoration to both inside and outside dimensions, the committee decided that a taper column one-fourth an inch in diameter, polished to a 1 per cent. bevel, provided the conditions for the root and porcelain on their external surfaces and a ring of metal surrounding this column, at a little distance from it, provided the conditions of inside dimensions. A number of castings were made by the profession of Cleveland, the best oue of which lacked about one-half inch of going to place on the 1 per eent. taper column and the others stood higher on the column, some as high as two inches from the base. Fig. 6 shows the instrument accepted by the committee as fulfilling the conditions required of a gold base for a porcelain erown. Fig. 7 shows the same with the best casting in placc on the mandrel, instead of having an error of one-fiftieth of an inch, it has an error of one-half of an inch. Some stated that they did not cast gold bases for porcelain crowns, but that they could cast an inlay of any shape without error. Others stated that if the gold had not had a hole in the centre, it would not have contracted. Others, while acknowledging they could not cast a ring without error, stated that they could cast aceurately half a ring. To make the test as fair as possible, the form and conditions were changed to those of a large mesio-occlusio-distal eavity in a molar, as shown in the form in Fig. 8. The prizes were made available for the first to make a restoration that would go to place within one-fiftieth of an inch in this form when the pulpal walls had a bevel of 1 per

cent. The best inlay cast in this is shown in Fig. 9. It lacks one-fifth of an inch of going to place. The objection was made that this is larger than any MOD cavity inlay in a molar, and that the wax was inserted from the side instead of from the end as in a molar. Accordingly, the committee and author of the prize spent much pains in designing a reproduction in steel of a molar tooth with a mesio-occlusio-distal cavity. It was designed, so that all walls had a bevel of 1 per cent. to a common perpendicular for both those surfaces forming inside and outside dimensions for the inlay. The prizes were renewed to include this form as well as the others. The reproductions made in this form, which was the size of a normal molar tooth, did not go to place better than the reproductions made on the previous forms. Fig. 10 shows the instrument, and Fig. 11 shows the best inlay that was cast for it. The dentists of Cleveland had exclusive competition for this prize from May 1912 to January 1, 1914, when it was thrown open to anyone.

In testing the application of the principles laid down in this paper as being the foundation facts underlying the theory of pressure casting, we have adapted them and tested them on all these three forms and in which the profession had failed with their ordinary technique, and we have found that it is possible to cast restorations in which the normal contraction of the gold has been corrected for by an equivalent expansion in the wax within the limit of error required for the tests. We have also found that wax rings, or reproductions for any of these forms where the expansion technique is used without a special technique for preventing or correcting the elastic content of the wax, do not go to place, not because the wax has not expanded, but because of distortion. This is graphically illustrated in Fig. 2, B1, and A4, previously described in detail. The result of a large number of tests in these exacting forms seems to establish quite definitely the foregoing conclusions as being the basic facts underlying the behaviour of the various elements and processes involved.

There is another method available, under certain circumstances, for controlling the location of the contraction that is normal in gold, namely, by holding it with sufficient rigidity to compel it to stretch between the points we wish to have as fixed. This is illustrated in Fig. 12, in which are shown two rings, cast at the same time in the same investment and attached to the same sprue, except that one had investment material, plaster and silica filling its interior, and the other had a hard model material, called artificial stone, (any strong substance will do) which was of a formula that expanded slightly on heating. The rings are of pure gold. The ring that was cast over the stone model passes over the end of the brass column on which the wax pattern was formed. The one that was cast over investment material had its normal contraction and does not go closer than one and one-half inch to the base of the column. This principle of holding the gold, by this method, to prevent its contraction, is not available for a large variety of conditions. We have found in MOD cavities that a bar of metal placed in the mass of the wax in the occlusal part of the cavity and allowed to remain so that the gold will be cast about it, will, if of a suitable material and large enough proportion, as compared with the mass of the metal, largely hold the metal from contracting in that diameter. With this method, iridio-platinum bars threaded will control about 50 per cent. of the contraction of pure gold. In our research for other metals suitable for use in this capacity, we have found that tungsten with a total contraction for the same range less than one-fourth that of gold and molybdenum with a contraction less than one-fifth that of gold, are very much more efficient than iridio-platinum and by constructing a frame-work of these materials, which later are to be included in the central part of a mass of gold constituting a bridge, will permit the casting of bridges with the inlays, and bridge all made at once, with only a fraction of the distortion that occurs where gold or its alloys are used alone, in which the contraction is prohibitive. The high melting-point of these metals gives them a very great advantage—tungsten melting at 5600° F. or 3300° C., and molybdenum a little lower 4500° F. or 2500° C.

Space in this paper does not permit of a more detailed report on these important new metals, which will be found reported in considerable detail in the report of the Scientific Foundation and Research Commission of the National Dental Association of America, July 1914.

On the presumption that the foregoing paragraphs contain what are approximately the "general body of facts" underlying pressure casting we believe that a fair "theory" of their successful utility is embodied in the adaptation of these facts to practice as herein stated.