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The Laws Determining Casting or Fusing Results, Their Control, and a New and Rational Technique.

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To every one with high ideals there certainly has frequently, if not continually, come a consciousness that gold and its alloys when built into large pieces for dental restorations, whether cast or fused, did not produce either exact or uniform restorations. This has been particularly serious and annoying in bridge work, and the extent of the error has been in proportion to the size of the piece, while the distress it gave the operator was in proportion to the height of his ideals. This constant error has been chiefly produced by the contraction of the metals on cooling, and the contraction of the investment on heating, granting that the operator's technique has been faultless.

The writer has undertaken to accurately determine the extent of these expansions and contractions of the principal metals and investing materials, though it has proven an enormously difficult task. So far as we have been able to ascertain, there have been no previous determinations of the extent of the contraction of the metals we use on cooling from their melting or freezing point to ordinary temperature. The Bureau of Standards, Washington, informed me that, "It is a known fact that metals do contract when cooled, and this contraction may amount to a considerable percentage of the original volume if the metals are cooled from the melting point to ordinary temperatures." They could not give any more definite information.

(*Reprint from* Items of Interest.)

There have been some determinations made as to the rate of the expansions, per degree, at low temperatures, which, however, gives little light because of the increasing rise in rate with the rise in temperature, and also the total distance from the melting point. None of the alloys of gold we use have even had these observations made.

Tests of Contraction of Gold.

Our first method was to construct an instrument that would magnify the change in dimensions 1,000 times, and in it bars were measured for shrinkage which had been cast from wax models made on iridio-platinum pins which fitted tightly into holes in the short arms of this instrument. After producing many bars of each of the many gold alloys and of pure gold, it became very apparent that some error was being introduced, since no two bars of the same metal were exactly alike, and often had a very large variation. This error proved to be due to two factors, chief of which was the change in dimension of the mold in the investment; in other words, was due to the shrinkage of the investing material. To eliminate this error entirely required an investment or form to cast into, which would have an exceedingly slight change in dimension due to change of temperature. The best substance available for this proved to be fused pure quartz, a new and scarce product of science. A box was ground into this material one inch in length and the 24 k. gold and its alloys were in turn cast into it and measured. For measuring these changes of dimensions and those of the various investing materials at different temperatures a very sensitive instrument was specially constructed. It will measure with great accuracy changes of dimension to the hundred thousandth part of an inch, and has an electric heating device, and a pyrometer reading to 2,800 degrees F. to show the temperature of the piece being heated and measured. With this the expansions were recorded for all the various metals and alloys up to the sagging point, which was usually several hundred degrees below their melting point. These are shown in Table I. Curves were plotted for each and extended to the melting point, as shown in the last line. At this time the fusing points are not accurately known, but will be published later.

Bars of gold or its alloys cast in this fused quartz chamber, which itself had a relatively very constant dimension, showed in some cases close agreement to the total contraction as estimated from the readings of the expansions up from normal, but to my great disappointment different casts of the same metal showed different total contractions, which clearly indicated that another unsuspected source of error existed, for if conditions are the same results must be the same. This difference in dimension of the various casts of the same metal or alloy made into

Expansion per linear inch for gold and its alloys, and silver, platinum-iridium, aluminum, copper and zinc from 0 to 1,000 degrees F., expressed in thousandths of an inch.

Temperature	Gold 24 K.	Gold 22 K.	Gold 18 K. Clasp Metal	Gold and 5% Platinum	Gold and 20% Platinum	Gold Solder 18 pt. Gold 2 " Silver 2 " Copper Zinc	Silver Pure	Silver Sterling	Platinum Iridium Alloy	Aluminum	Copper	Zinc
Air (75°)	0	0	0	0	0	0	0	0	0	0	0	0
100	.2	.3	.1	.3	.4	.4	.3	.3	.2	.5	.3	.3
200	.5	1.2	1.	1.	1.3	.9	1.5	1.5	.4	1.7	1.	1.4
300	1.5	2.3	2.	2.	2.2	1.7	3.	2.8	1.	3.	2.1	3.3
400	2.5	3.4	3.1	3.4	3.2	3.	4.4	4.	1.7	4.1	3.2	5.3
500	4.2	4.5	4.5	4.6	4.2	4.3	5.6	5.4	2.3	6.2	4.4	8.
600	5.7	5.7	5.7	5.4	5.2	5.8	7.	6.9	3.	7.8	5.7	10.
700	6.9	6.8	6.8	6.4	6.4	7.2	8.4	8.2	3.7		3.7	12.
800	8.	8.	8.	7.3	7.3	8.3	9.9	9.4	4.3	Metal Softened	7.8	
900	9.	9.2	9.1	8.1	8.1	8.9	11.1	10.5	5.		8.8	Metal Softened
1000	10.	10.3	10.3	9.	8.9	9.2	12.8	12.	5.9		10.	

**Expansion estimated to fusing point from these expansions.*

Gold 24 K.	Gold 22 K.	Gold 18 K. Clasp Metal	Gold and 5% Platinum	Gold and 20% Platinum	Silver Pure	Silver Sterling	Copper	Zinc
22.	22.	21.	22.	23.	24.	21.	22.	14.

Total contraction per linear inch of bars of gold and its alloys, and silver, cast under definite pressure, expressed in thousandths of an inch.

Pressure of Molten Gold on Bar	Gold 24 K.	Gold 18 K. Clasp Metal	Gold Solder 18 pt. Gold 2 " Silver 2 " Copper Zinc	Silver Pure	Gold and 10% Platinum
0.	22.5				
1/50 oz.	20.5		18.		
1/10 oz.	18.				
3 lbs.	14.			20.	
5½ lbs.	13.	15.5	15.		14.

* The fusing points for the alloys are not definitely determined yet.

TABLE I.

the chamber of the fused quartz proved to be due entirely to the difference in casting pressure, and it was proven that any given pressure will produce constant results, other essential conditions remaining constant. For example, pure gold cast under one pressure contracted eighteen thousandths to the inch, and under another pressure only fourteen thousandths; and under another and very low pressure twenty thousandths. Eighteen k. gold solder at a given high pressure contracted fifteen thousandths, and at a given low pressure eighteen thousandths on repeated tests. The great significance of this will be apparent to every one as well as its natural lesson, viz.: if we are to get constant results we must use constant pressure as well as have other conditions constant, and to secure least contraction we must use as high pressure as possible without producing distortion of the investment, an important point to be taken up later.

Effects of Pressure on Cast Metals.

It also suggests that there is a very great difference in actual results produced by the various casting devices because of the great difference in the actual effective pressure, which varies through enormous ranges with some casting investments. Where the pressure is obtained from gas or air it is equal to the cross section area of the inlay or mold, not the gate or sprue, in fractions of a square inch divided into the pressure per square inch of the gas. For example, if the cross section area of the inlay is 1-8 of an inch square, it will be the 1-64 of a square inch, and the pressure 16 pounds per square inch the actual effective pressure will be 1-64 of 16 pounds, or 1-4 of a pound, less the back pressure of the gas retained in the investment behind the gold, and the leakage of the pressure around the gold, for if the pressure can get away through the investing material easily from behind the gold, it can easily get past around it in the same way; which means that there would be considerably less pressure than 1-4 of a pound, depending largely on the compactness of the investing material and the leakage of the closing device over the molten gold. The writer believes the effective pressure under the above conditions to be less than 1-8 of a pound actual pressure. The weight of the mass of molten gold exerts only the pressure of the weight of a column of gold the size of the inlay.

With a centrifugal machine the actual effective pressure is the weight of the mass of molten gold, for our purpose irrespective of its shape, multiplied by the square of the velocity of the gold in feet per second, divided by the radius in feet (not diameter) of the circle it moves in, divided by 32 to change poundal units to pounds pressure.

For example, if 1-2 ounce of gold, which is 1-24 pound troy, is revolving at the rate of ten revolutions per second, which is 600 per

minute, in a circle of a diameter of ten inches, the velocity in feet is 10x3.14x10 ÷ 12=26.17 feet per second, and the pressure 1-24 pound multiplied by 26.17 squared, the velocity, divided by 5-12 the radius in feet, divided by 32=2.14 pounds actual pressure on the inlay, and if the revolutions are twenty times per second, which is 1,200 per minute, the actual effective pressure is 8.56 pounds, or if only five revolutions per second .53 or 1-2 pounds. Remember the pressure increases as the square of the velocity. If this pressure is on an inlay 1-8 inch square it is equal at five revolutions per second to 34 1-4 pounds per square inch, at ten revolutions per second to 137 pounds per square inch, and at twenty revolutions per second to 548 pounds per square inch, and without decrease for back pressure or leakage as in the case of a gas pressure. If an ounce of gold is used instead of one-half ounce the pressure is double the above. The friction of the gold on the tapering walls of the gate will make but little correction of the above figures if the gate walls are not at a wide angle to each other, which they are not in practice. This reduction of force would, however, be in part counterbalanced, while the gold is in motion, by the inertia of the gold producing an increased pressure in the gate, like the tide in the neck of the Bay of Fundy.

With the casting machine giving 1-100 of a pound actual pressure on the inlay, the total contraction on cooling of pure gold will be about twenty thousandths per inch, or two per cent., and with the machine giving 5 1-2 pounds a contraction of about thirteen thousandths. The latter pressure, please note, requires a harder investment to keep a smooth surface, but other conditions being equal it is seven thousandths, or seven-tenths of one per cent., or one-third nearer a perfect fit than the inlay made at 1-100 of a pound pressure, which will amount to a considerable factor in casting a long bridge. This you will see is a very important method for reducing the contraction and is accomplished by replacing the contraction with new gold from the gate by means of the pressure on the semi-fluid gold whose contraction is greatest nearest its liquid point. There is another possibility of correcting, at least in part, this error in our work due to contraction of the metal, though it is now very often a means of increasing instead of diminishing it, namely, the investing material.

Errors Due to Manipulation of Investment.

The writer is sure that few dentists realize the enormous errors that may be and are generally introduced by the manipulation of it. For example, if any typical ordinary investing material is mixed very soft and allowed to set and dry out for a day or two, or over a slow, long continued heat, it will contract an extent as much as twenty-five thousandths. If the gold is cast into this at a low pressure, the

total decrease in the size is over forty thousandths, or over four per cent. Even this enormous error will not readily be seen in small inlays because of the lap on the margins. It would, however, show in bridges. To correct this error by forcing the cast under high pressure means only to make it so-called "tight," or "too large," by producing distortions or beads. I have, with very much labor, tested the actual expansion or contraction of all the available investing materials, both in the process of setting and drying out and heating, and find a great variation with different investing materials under the same conditions, and of most of them under varied conditions. It will be clear to every thinking operator that to make even a relatively perfect reproduction we must have an expansion somewhere that will compensate for the uncontrolled contraction of the gold or alloy. Theoretically this can best be done by expanding a model of the cavity or bridge as by soaking a cavity model in material containing agar agar or gellatin; but practically it is most easily done by expanding the investment. At this point the distortion of the shape of the mold or cavity by heating the investment should be discussed, but space will not permit. It may be considerable, however, if the cavity is large in proportion to the thickness of the walls of investment around *it, if heated unevenly and rapidly, or this distortion will be small if the volume of the investment is large everywhere as compared with the size of the cavity or mold and heated evenly and slowly.* This is very important; a large cast MUST NOT be made in a small investment cup. Notwithstanding the fact that some investing materials on the market are "guaranteed not to contract or expand on heating," they fortunately do expand. Some contract, some do both, but unfortunately none expand enough to correct the error of the contracting gold. Table No. II gives the expansion or contraction shown by plus or minus sign of the various investing materials that the writer could obtain, first, from the mixing initial set to a thirty-minute set; then heated slowly in the electrically heated sensitive thermo-micrometer and readings of dimensions taken for every 100 degrees F. rise in temperature. I have taken the inch and Fahrenheit scales instead of the metric and Centigrade because they are more familiar to all.

It will be noticed in general that plaster alone, or as a binder for other materials, has an initial expansion to about 300 degrees, and then a very marked contraction, the plaster disorganizing at about 1,100 degrees, from which point the contraction is exceedingly rapid, making it impracticable to heat any investment in which it is the binder up to or above that temperature. An actual effective pressure on the inlay of 5 1-2 pounds will reduce the contraction of the cooling gold from twenty

Expansion and contraction shown by + and − in thousandths of blocks of one-inch cube of the present investment materials.

Temperature degrees F.	Pelton and Crane	½ Pelton and Crane ½ Plaster	Brophy's Imperial	½ Imperial ½ Plaster	Sump	½ Sump ½ Plaster	Dendrolite	½ Dendrolite ½ Plaster	Fyrite	½ Fyrite ½ Plaster	Peck's	½ Peck's ½ Plaster	Plaster Paris Medium Stiff Mix	Plaster Paris Thin Mix	I. D. L. Investment Composition	½ I. D. L. ½ Plaster	Dr. Taggart's	½ Dr. Taggart's ½ Plaster	Plaster set for 15 minutes	Plaster set for 15 hours
Started	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30-minute set	+1.8	+1.	+ .9	+ .8	+ .9	+1.	+ .9	+ .5	+1.	+ .5	+ .7	+ .7	+1.3	+1.	+ .7	+ .8	+ .7	+1.	+ .5	0
100	+1.8	+1.4	+1.2	+1.	+1.4	+1.3	+1.1	+ .9	+1.	+ .8	+ .9	+ .9	+1.4	+1.3	+1.1	+1.2	+1.3	+1.3	+ .9	+ .1
200	+2.5	+2.5	+2.2	+2.8	+2.9	+2.4	+2.3	+2.1	+2.4	+1.9	+3.1	+2.2	+2.6	+2.5	+2.	+2.8	+2.3	+2.5	+2.4	+ .6
300	+3.2	+4.	+3.1	+3.	+4.	+3.5	+3.5	+3.6	+3.8	+3.3	+3.7	+3.1	+4.5	+3.	+3.2	+3.6	+5.1	+3.2	+2.6	+1.5
400	+4.	+4.	+4.	+3.4	+4.	+3.4	+3.3	+3.6	+3.8	+3.4	+4.5	+3.2	+4.5	+2.5	+3.8	+3.8	+lost	+3.4	+2.5	+1.9
500	+4.8	+3.8	+4.4	+3.4	+3.8	+3.	+2.8	+3.5	+3.3	+3.2	+5.1	+3.	+4.3	+1.9	+4.1	+3.5	+6.2	+3.2	+2.2	+2.1
600	+5.2	+3.7	+4.4	+3.3	+3.5	+2.5	+2.4	+3.4	+2.9	+2.8	+5.7	+3.	+3.9	+1.	+4.6	+3.4	+6.8	+2.9	+1.5	+1.7
700	+5.7	+3.6	+4.5	+3.	+2.8	+1.7	+1.5	+3.2	+2.	+2.5	+6.4	+2.9	+3.4	— .1	+5.2	+3.	+7.3	+2.5	+ .8	+1.
800	+6.3	+3.6	+4.6	+2.8	+2.1	+1.	+ .5	+3.	+1.4	+2.1	+6.9	+2.8	+2.6	—2.	+5.5	+2.9	+7.7	+2.3	— .2	+ .4
900	+6.7	+3.5	+4.8	+2.5	+1.2	0	— .5	+2.9	+ .6	+1.3	+7.2	+2.5	+1.4	—3.8	+6.	+2.5	+8.3	+ .7	—1.5	— .3
1000	+7.1	+3.3	+5.	+1.8	+ .2	— .9	—1.8	+3.5	— .5	+.3	+7.8	+2.	0	—6.5	+6.6	+2.	+8.5	+1.4	—3.3	—1.
Tot'l contraction on cooli'g	—5.	—11.	—10.	—12.	—15.	—14.	—35.	—14.	—12.	—15.	—7.	—11.	—18.	—24.	—8.	—15.	—6.	—11.	—18.	—15.

TABLE II.

thousandths to about thirteen thousandths of an inch per inch, and less pressure will in proportion, which error we should be able to correct to any definite known pressure we are using by simply heating the investment a few hundred degrees to a definite temperature, and the lower the better, since the surface is usually injured by high heating.

It will be seen that the best that any of the investments now available will do is to expand 8.5 thousandths as a maximum at 1,000 degrees F., which is an extreme temperature, and we should have an expansion of at least 15 thousandths at not to exceed 700 degrees, at which temperature all are very far short, and the best have only half expansion enough, and those that are highest have so little strength that high pressures are likely to distort them if used pure without the addition of more plaster, which, as you see by the chart, rapidly decreases the expansion. The writer has effected a combination with excellent working qualities and smoothness of surface and density that expands 12 thousandths at 700 degrees, which will be discussed later, and which can probably be still considerably increased. Note in Table II that all the investments have a very large total contraction on cooling after being heated. We regret space will not permit of a discussion of the remarkable data shown concerning our present investing materials.

Unfortunately one of the most difficult parts of the usual procedure of producing a cast restoration is the securing of a wax model that is closely accurate because of the conditions under which it is made and the nature of the substance. Many of the most desirable restorations to be made in this manner, such as bridges fixed and removable, cannot be produced as a complete wax model in the mouth, the methods of the most skilful so far as I can learn being to construct in parts or units, and assemble and braze together. Aside from these extensive wax models it is exceedingly difficult, and in many cases quite impossible, to produce a really closely accurate wax model of simple cavities, and largely because of the sliding tendency of semi-fluid masses unless supported on all sides equally at the same time, which conditions we can not effect under the circumstances and methods of its making. This is not simply a source of possible error, but one of certain error in many, if not most, cases; and in some of the so-called best operators' hands, unless his ideals are very high, it does not always seem to alarm him.

An ideal procedure, both from the standpoint of the comfort of the patient and operator and of exactness of results, requires that the least possible of the detail be accomplished in the mouth, and that the results be as exact as possible, which means very exact in fit, contour, occlusion and approximate contact, the latter of which is particularly difficult

to obtain accurately by the present method of the wax model. Except for the inconvenience of removing the tooth, or teeth, in question and replacing them, the ideal method from the standpoint of perfect technique would be to be able to take the teeth involved and surrounding tissues and petrify them, and cast the restoration directly into the cavities themselves, but even this, though it were possible, would not correct the error of the contracting metal, which is an absolute barrier in exact bridge restorations except by building up in sections which simply diminishes it.

The Author's Artificial Stone Model.

Based on the foregoing data and the conditions involved the writer has developed a technique which so far reduces the errors and eliminates the discomforts that it has entirely revolutionized his methods, and has eliminated more discomfort to his patients than anything in his experience, and so far as he knows it is entirely new. In brief, it is the reproduction of all the parts involved in an artificial stone that is almost as hard as the teeth themselves, and harder than some of them. It has an expansion on heating that nearly corrects the contraction of the cooling metal. The filling is contoured in warm wax, and the metal is cast directly upon this model, and is not removed until completely polished ready for cementing. It withstands a temperature above that of an alloy of half platinum and half gold, and heat only hardens it. The margins of the frail walls are reproduced as strong almost as the tooth itself. Some of the many advantages are as follows: Reducing to a minimum the work in the mouth; completing the adjustment of the occlusion and contact points outside the mouth; having a dry non-vital structure to design and construct upon with perfectly free access to all sides and aspects, including the gingival margins, both for constructing and finishing; a rigid model or mount to hold your piece upon for finishing, eliminating the danger of distortion of margins and discomfort from heat in polishing, or of the inlay being caught upon the polishing disks, etc.; a hard, smooth surface to cast upon that will withstand any pressure desired without possibility of pitting or distorting, allowing of very high pressure in casting; a model so strong as to reduce the contracting tendency of the gold in part by withstanding it, causing the metal to stretch where it is held by the model; a rigid reproduction of the tissues and surrounding parts which are always with the piece being restored and an important aid in designing and finishing; a model upon which porcelain can be designed, formed and fused without removal from its surrounding relations.

The detailed procedure is as follows: An impression of the cavity desired and surrounding parts is secured by one of the following methods as is best adapted to the particular condition. A simple occlusal, or buccal, cavity not involving a contact or occlusion point can

be most quickly produced by a platinum lined wax impression made by pressing platinum foil of one five-thousandths of an inch, and not exceeding one three-thousandths in thickness into the cavity with cotton and removing and annealing and filling with an excess of a medium low heat, hard, sticky wax. Replace in a nearly chilled condition, and press to place with oval headed burnishers, and by the patient biting on rubber which forces the very thin platinum into every detail; chill with cold water and remove without making any effort to shape the exposed surface of the filling. A large excess of wax is desired. Have the platinum

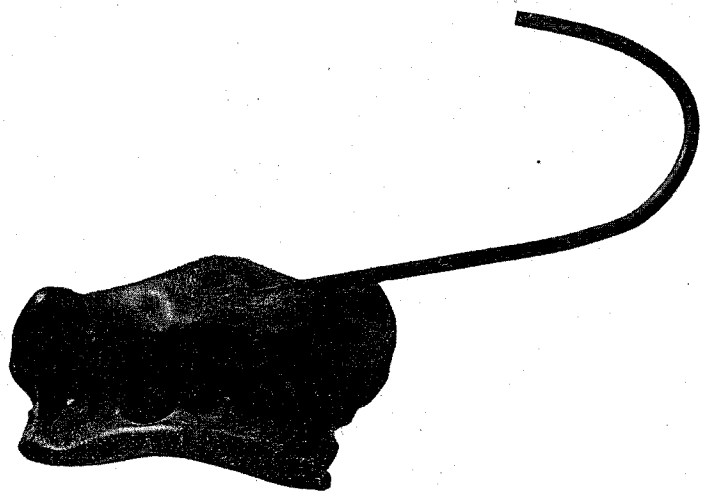


FIG. 1.

extend beyond the cavity to give contours of the surroundings, and have it well supported with the wax. Fill the back of the impression with the artificial stone and place over the heat. Soak up and burn the wax, and in three or four minutes you can fuse pure gold into the platinum to suit, and polish completely on this hard model as if in the cavity. Always expect to burnish the margins, or maybe dress slightly, but both yourself and patient will be delighted to see how often only the burnisher is needed, for I believe no method yet produced approaches this for exact margins and restorations.

Accurate Impressions of Cavities.

This same simple cavity could as well, if desired, be filled by taking an impression of it in the following or some other quite exact manner, producing the model as before, filling the cavity with

melted wax and casting into the model and polishing on the model as before; but this procedure of so simple a case takes a little more time.

Suppose the conditions to be large approximal cavities involving the mesial surfaces of the lower first molar and second bicuspid. It is always understood that the cavities themselves are so prepared that they will draw perfectly free. A wire is bent the shape of a shepherd's crook, to pass along the buccal surfaces and through these cavities, and either forward or backward a short distance on the lingual surface. On this wire frame a ball of warm impression compound, preferably a hard variety, is placed and the patient allowed to bite on it with the wire in the position stated. This, after quickly chilling, is removed and becomes the impression tray (Fig. 1). Nothing is done to the side which is the impression of the upper teeth, which is perfect enough for an articulating model since on it you do not require sharp cusps so long as they are exact in length; in fact, better not in order to allow for natural side motion. The lower side of this bite is dried with a blast of compressed air with or without drying first with alcohol, and into this dry mold, which is now the tray, drop from the stick a few drops of hot orange sticky wax enough for a thin layer; then place quickly into the mouth and have the patient bite into natural position again, which forces the soft wax into every indentation of the cavities, even under the free margin of the gum.

After chilling remove and pour both sides with the artificial stone, with or without mounting on an articulator as the nature of the occlusion may require. There are many little points, but important, which might not generally be thought of, but space forbids mention now, such as the caution not to allow the impression to extend to places that will disturb its drawing perfectly from the cavities, and also hold it tightly in contact with the teeth on the jaw with the cavities, while the patient is removing the teeth from the other side of the impression. If the gingival margins of these cavities are not free of gum tissue a procedure to be described later is employed.

When the models are hard, which takes an hour or two, and are removed from the impression, they are exceedingly perfect reproductions of the cavities and surrounding parts. These two cavities could be flowed full of wax and cast together and cut apart, thus destroying the contact points; a bad procedure. A beautiful piece of technique at this point is possible. With wedge cutters fracture the model between the teeth to be filled, thus exposing the approximating surfaces and the fine gingival margins. Fill the cavities with wax and shape to liking with perfect ease, and get the contact points by placing the fractured surfaces together again, and also to adjust the contour and occlusion with the articulating model of the other jaw. Now cast each filling separate from

the other, but direct into the models, which are invested in the usual way. Their fillings are then polished completely on the model, and their contact and occlusion points again verified, and I believe you will have a moist eye from gratitude at the ease and perfection with which those cervical margins can be polished to correct lines and ideals of contour that are entirely impossible under the conditions in the mouth, for as you

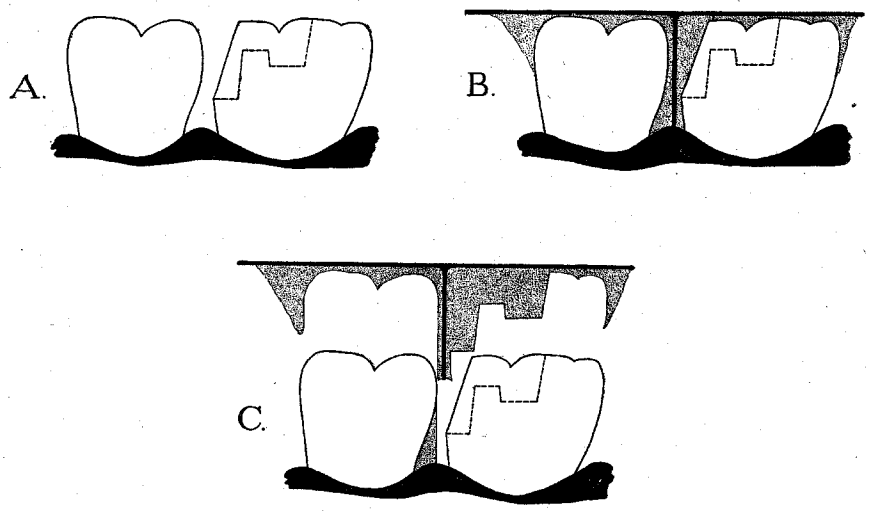


FIG. 2.

hold the model carrying the inlay in its place, you are able to see unobstructed all relations, and produce results that are entirely impossible in the mouth. The gratitude of your patient will be beyond money values.

A more difficult class of cases is where there is an undercut under the contact point of the adjoining tooth, a class of cases that has given much trouble for all restorations by impressions or wax models. A simple device has made this hardest of cases one of the simplest. A piece of brass 22 gauge, say one-half inch wide by an inch or two long, as desired, is the foundation for the tray. To this a partition of thin brass, say No. 28, is fastened with soft solder and is wide enough to reach the length of the crown to the gingival tissue and slightly press it. Suppose the condition to be a cavity in the distal surface of the first lower molar with the second in good condition, and its mesial surface

forming an undercut which ordinarily of necessity would distort any impression of the cavity that included all these surfaces. This is shown in Fig. 2A. The impression material is in place in Fig. 2B and, as shown, the partition entirely separates the pressure influences of the opposite tooth walls. The mass in the undercut below the contact point of the second molar is removed from the impression on its withdrawal, and can be of no use to us (Fig. 2C). When this model is completed, all the desired information and conditions are supplied and the wax filling is molded to the contact point as desired and then cast. The second molar on the model will be fractured off for polishing, and may as well be

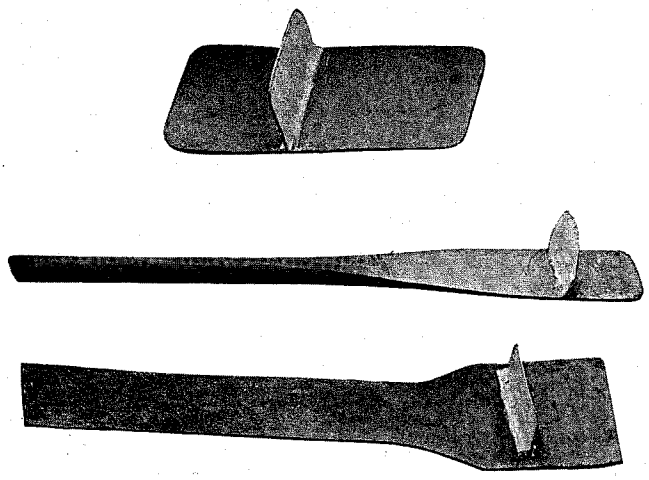


FIG. 3.

before casting, but temporarily replaced for correcting the contact point. A number of these trays made especially for practical cases are shown in Fig. 3. It took three minutes to make two of the trays recently. You can not fully estimate the great advantage of this procedure until you try it and note the exact result made possible with little labor.

For crowns this method is particularly adaptable. A cast base is made for a porcelain crown with all the surrounding structures reproduced and always in place. If both of the adjoining teeth have undercuts as the last case, two of these partitions are placed to prevent distortion of the impression and yet preserve the contact points.

Restoration of Incisal Angles.

Probably no class of dental restoration is as difficult for the operator to satisfactorily make as the broken incisal angles of the centrals, because the opportunity for anchoring is so limited and the exposure to hard strain so great for all porcelain fillings in this position. With this method the teeth involved and the adjoining ones are reproduced on the stone model along with the ones containing the cavity. The anchorage for such a case must be on the palatal surface. This angle is restored by a compound metal and porcelain filling. Gold and 10 per cent. platinum alloy is cast to reproduce all the lost structure except that when the wax model filling is built, a cavity is cut in the labial surface almost entirely occupying the visible portion. It will be readily seen how much more easily this angle can be constructed of proper shape with the teeth complete in position showing all relations and dimensions. After casting and polishing this gold and platinum hollow faced filling, porcelain of the selected shade is baked directly into this cavity, which has undercuts and is not disturbed, hence needing no cement. All this baking is done with the filling in place on the stone model and the adjoining teeth in position, which all practical porcelain workers will appreciate as being of incalculable value and advantage.

Electric Centrifugal Casting Machine.

I should discuss casting principles in the light of this research work, but can only do so in brief. After designing and making seven different kinds of casting machines for my own use on different principles, I am convinced that the best machine is one with the following requirements, viz.: the pressure is easily adjusted and controlled through a wide range, that is, to a high pressure; with a pyrometer to determine the temperature of the gold and to cast at a uniform and high pressure and high temperature simultaneously, that is, one with a construction that allows the metal to flow into the mold only at the moment it has its high pressure and highest temperature. To accomplish all of these items I have designed an electrically heated centrifugal machine, the crucible of which is left upright until the gold is at the proper casting temperature as shown by the pyrometer, at which time the motor is started and when the speed has attained the point where the pressure desired is obtained, the crucible and investment cup trip and take a horizontal position still revolving at the same speed, and the gold goes into the mold at its known pressure and temperature, which are indicated by the pyrometer and speedometer. Its simplicity and exactness make it possible for any one to make the casts with uniform results, and in the light of our present knowledge of conditions, with

maximum efficiency. The writer has no connection or financial interest in their manufacture, but has confidence in recommending them.

Technique of Making Exact Models.

Another most important development in the writer's hands is a method for making exceedingly exact models that are dense and free from the air bubbles which form so easily when filling an impression or placing the investment material around a wax or other model.

It is very simple and is accomplished as follows: When the impressions of any kind are poured, and the model material is still plastic, they are coated with wax or vaselin and put into a metal chamber containing water, and the top closed tight and a screw piston turned into an appartment of this chamber, thus displacing and compressing the water to a pressure of 1,000 to 1,200 pounds per square inch. Since the pressure is equal on all sides of the impression material and the model material is still plastic it is forced into every nook and crevice without destroying the impression, and the law of the volume of gases that the volume is in inverse proportion to the pressure if we increase the pressure ten times we decrease the volume of the air bubbles to one-tenth. When we increase the pressure to 1,200 pounds, which is shown by the gauge, the actual decrease in the bubbles' size is the proportion of 1,200 to the atmospheric pressure, or 1,200 divided by 14.2 (the mean pressure at Cleveland), or 1-84 its original size. This produces a model of great density and smoothness of surfaces, and when applied to an investment around a wax model has a most beautiful effect on the surface of the cast gold, and the greatly increased density produces a harder investment, and one with greater expansion, as will be shown later.

Special Cement for Cavity Models.

While the writer fully realizes that he probably could turn the control of the composition and manufacture of this model material to considerable financial gain, it would be poor compensation for midnight oil compared to giving it as unhampered and quickly as possible to the profession and humanity, whom he believes will be saved more suffering and discomfort through its means than the writer could relieve in a score of lifetimes binding up wounds. A dozen manufacturers through competition will produce greater improvements and higher perfection than a single one, and the writer will gladly assist in testing results for actual efficiency. This material is of a structure between Portland cement and the so-called silicate cements, the former of which has a large per cent. of calcium, and the latter a small per cent. Both are produced by heating together alluminum silicate and calcium oxid, or hydrate and usually a magnesium oxid or silicate to a definite very

high temperature. The former, Portland cement, forms a cement by the formation of the hydrate by adding water; the latter a compound phosphate on the addition of phosphoric acid.

The writer is familiar with the detail technique and chemistry and analyses of the various silicate cements, and zinc and copper oxids, and the varieties and formulas and manufacture of Portland cements, and has made a very large number of special cements, having entirely different properties from any of the Portland or silicate cements, neither of which have the properties we require. The former are generally free from contraction, but set far too slowly; even without the retarder that is put in by the manufacturers they do not get hard enough within a reasonable time. The latter, the so-called silicate cements, have too much contraction and will not withstand high temperatures, nor will the zinc or copper oxid cements, and all have a very large contraction notwithstanding claims to the contrary. This artificial stone is a modified silicate cement, and is made by fusing, as cement makers will know how to do, a highly vitrified alluminum silicate in excess for reaction with the calcium and magnesium oxy-silicates. A product is obtained which forms, with orthophosphoric acid of correct specific gravity, an artificial stone, exceedingly hard and having a constancy of dimensions almost equal to that of the best Portland cement, viz.: a shrinkage on setting which is very low, in some cases as low as two-thousandths per linear inch, and having an extreme density and withstanding a temperature of 2,700 degrees F., very far above the silicate cements, which have a contraction on setting dry and warm of from thirty to forty-thousandths per linear inch and fuse at about 1,300 to 1,600 degrees F. I appeal to the manufacturers of cements, for their own profit and for humanity's sake, to furnish the above in quantities and at prices that will allow of its becoming the almost universal product in the profession's hands for models for all purposes, and chiefly for casting upon. It should be put up in gallon cans, not ounce bottles, for its use, if of right quality at a fair price, will be very large. If the profession appreciates the needs for it, and demands such a material, it will soon come, and competition will soon adjust the price. Patients will bless you over and over again.

Deductions.

Some information that should be apparent to every one from the above data is that, to get uniformly the best results, we should use definite uniform temperature and pressure, and keep the pressure on not only until the metal crystalizes, but until its temperature is considerably below that. In a centrifugal machine a definite excess of gold for the sprue or gate, say half an ounce, should always be used; this is very important. Do not heat an investment containing considerable plaster above

400 degrees F. Use as hard and dense an investment material, especially for the base or contact surface of the inlay, as you can; one that will give a very smooth surface, and use as high a pressure as consistent with it. Universal conditions will produce universally good results. This is not simply theory, but is demonstrated by results. Do not conclude from the fact that platinum and irridium have less expansion per degree of heat than gold and its alloys, that they will shrink that much less when cast, but remember that their high melting points give them a longer range through which to contract, making the total shrinkage more nearly equal to the lower fusing metals that have greater expansion per degree. See chart of expansion of metals.

Some of the many advantages of the stone model are that you have as nearly as possible a reproduction of the tooth and cavity and adjoining teeth in a close casting, on which your inlay is designed, formed, cast and polished, thus exchanging the difficult procedure of making a removable wax model under the hampered wet conditions in the mouth for the simple one of melting and molding the wax into a dry model, where all parts and positions are accessible, even the temporary or permanent removal of the adjoining teeth to give access to the cervical margin, which is of incalculable advantage, and also for producing an ideal contact point and occlusion. In this mold or cavity the filling is cast with any degree of pressure. If done with low pressure it will drop out due to its shrinkage, and if done with high pressure will stick tightly. With the inlay in place in this model it can be finished to more perfect lines and contours than it could be even in the mouth, because of the accessibility, and no one is suffering from the heat of polishing, and it can not fly away, nor can you grind or polish away too much without knowing it, thus enabling the operator, with easy precision, to produce a restoration which, in fit, contour, correct contact with the adjoining tooth, and occlusion with opposing teeth, is very perfect, requiring only to be cemented and the margins burnished, thus freeing the patient from all the detail and discomfort except the few minutes for cementing. Incidentally it will greatly increase the operator's possible service.

This paper, because of its length, will be followed by a short one in the next issue on the relation of the size and shape of the cavity or mold to the investment under various conditions, and the authority for the application of the physical laws as they have here been made.