A manual on dental metallurgy / by Ernest A. Smith.

A MANUAL

ON

DENTAL METALLURGY

BY

ERNEST A. SMITH

ASSOCIATE OF THE ROYAL SCHOOL OF MINES, LONDON; FELLOW OF THE
CHEMICAL SOCIETY AND OF THE SOCIETY OF CHEMICAL INDUSTRY;
LATE ASSISTANT INSTRUCTOR IN METALLURGY, ROYAL COLLEGE
OF SCIENCE, LONDON

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PREFACE.

THE present manual is based largely upon the new syllabus of dental metallurgy, 1897, issued by the Royal College of Surgeons of England, and is primarily designed for the use of students preparing for their examination.

In the preparation of the manual I have also endeavoured to place in the hands of dental students an outline of the scientific principles involved in the extraction of the metals from their ores, their physical properties, and their application to the requirements of the dentist. Attention has been drawn to the fact "that metallurgy has not received hitherto its due share of attention at the hands of the dental student, and of its importance to him there can be no doubt." * While the properties of all the metals which have any application, directly or indirectly, in the dental laboratory have been dealt with, special consideration has been given to those most frequently used by dentists.

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* Howard Mummery, Esq., M.R.C.S., L.D.S. In an Address delivered at the Prize Distribution, National Dental Hospital, London, 1897.

Full descriptions of metallurgical processes are out of place in a text-book of dental metallurgy, and must be sought in metallurgical text-books. Only such condensed outlines, therefore, have been given as are sufficient to explain briefly the methods by which the metals are obtained in a state suitable for industrial purposes. An elementary knowledge of chemistry and physics on the part of my readers has been taken for granted.

Although I have endeavoured to present to the student a condensed and succinct account of the physical properties of the metals and their chief alloys, it must be borne in mind that the mere reading of a text-book will never give the student a practical knowledge of these properties. It is only by handling the metals and their alloys, and subjecting them to various mechanical tests, that he can become acquainted with the toughness, hardness, fusibility, and other qualities of the metals and know, as a result of his own observation, for what purposes each is best suited. Acting upon this principle I have divided the book into two parts.

Part I. contains a brief sketch of the metals, their properties and alloys, their special application in the dental laboratory, and other details required in the syllabus of the Royal College of Surgeons. In this portion of the book special attention has been given to the preparation and properties of alloys for amalgams, as this subject now occupies a conspicuous place in dental practice. Although the literature on this subject is extensive, much experimental work yet remains to be done; it is hoped, however, that the matter given in the present work will prepare the student for a fuller comprehension of the subject.

Part II. consists of a series of simple experiments which can be readily performed, thus enabling the student to acquire a practical knowledge of the properties of the metals and their alloys.

I have omitted all chemical equations and detailed descriptions of the chemistry of the metallurgical processes for extracting the metals, confining myself merely to a short mention of them in a few general remarks at the commencement of the various chapters.

The author cordially acknowledges the assistance kindly rendered by Mr. Oswald E. Smith and Mr. A. Jarman in executing some of the drawings, and by Mr. F. J. Padgett in reading the proof-sheets. His thanks are also due to Messrs. Claudius Ash and Co. for the loan of several blocks.

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PREFACE TO SECOND EDITION.

A SECOND edition of this volume having become necessary, the opportunity has been taken to correct the few typographical and other errors of the first edition, and to completely revise and amplify the work.

The additions will be found principally in the chapter on the physical properties of the metals. Several new illustrations have also been introduced. Great advances have been made in the study of the structure of metals and of alloys during the past five years, and reference has been made to these in the new edition.

In revising the work several valuable suggestions have been offered by Mr. A. McWilliam, A.R.S.M., especially with regard to iron and steel, and these the author gratefully acknowledges.

The chapter on iron and steel has been rewritten and brought up to date.

The Author hopes that this edition may meet with the same cordial reception as that which was accorded to the first edition.

E. A. S.

ASSAY OFFICE, SHEFFIELD.

CONTENTS.

PART I.

CHAPTER I.

PHYSICAL PROPERTIES OF THE METALS.

CHAPTER II.

ACTION OF CERTAIN AGENTS ON METALS.

CHAPTER III.

ALLOYS.

CHAPTER IV.

THEORY AND VARIETIES OF BLOWPIPES.

CHAPTER V.

MELTING APPLIANCES, FURNACES, AND FLUXES.

CHAPTER VI

GOLD.

CHAPTER VII.

MERCURY.

CHAPTER VIII.

DENTAL AMALGAMS.

CHAPTER IX.

SILVER.

CHAPTER X.

PLATINUM AND IRIDIUM.

CHAPTER XI.

PALLADIUM.

CHAPTER XII.

ZINC.

CHAPTER XIII.

LEAD.

CHAPTER XIV.

TIN.

CHAPTER XV.

COPPER.

CHAPTER XVI.

CADMIUM.

CHAPTER XVII.

BISMUTH.

CHAPTER XVIII.

ANTIMONY.

CHAPTER XIX.

IRON.

CHAPTER XX.

ALUMINIUM.

CHAPTER XXI.

NICKEL.

PART II.

EXPERIMENTS RELATING TO—

A MANUAL ON
DENTAL METALLURGY.

PART I.

INTRODUCTION.

When only a few of the metals were known they were divided into two classes, viz.—noble or precious metals and base metals.

Noble Metals.—Those having a very feeble affinity for oxygen, which renders them incapable of rusting or tarnishing by oxidation in the air at common temperatures or on heating.

Base Metals.—Those which lose their metallic lustre or are oxidised at an ordinary temperature or by heating.

The term "noble" or "precious" is applied to gold, silver, and platinum (and some of the rarer metals found in combination with platinum), as none of these metals rust or oxidise at the ordinary temperature or on heating; on the contrary, the oxides of these metals cease to exist on heating, the metal being set free and the oxygen given off. Mercury is also included sometimes as one of the noble metals. Thus it will be seen that the number of so-called noble metals is very small in comparison with that of the so-called base metals.

Occurrence and Distribution of Metals.—The majority of the metals are sparingly distributed in nature, and some are only of rare occurrence and are of little practical importance.

Native Metals.—Only a few of the metals occur in nature in the free or uncombined state, the majority being generally found in combination with oxygen, sulphur or some other non-metallic element. Those that occur in the metallic state are gold, silver, copper, platinum (and its allied rarer metals), mercury, bismuth, antimony and iron. Lead and zinc are also stated to have been found in the uncombined state, but their occurrence requires confirmation.

Ores.—As above stated, metals usually occur in nature in combination with non-metals forming a series of bodies known as *metalliferous minerals.* Native metals are also generally included under this heading. Those mineral substances which contain a metal in sufficient quantity and in such association as to admit of their being advantageously treated for the extraction of that metal are known as *ores.* The proportion of metal necessary to constitute a mineral an ore will vary with the nature of the mineral and the value of the metal. It is usually necessary to subject the mineral which contains the metal to mechanical preparation to free it from the valueless mineral matter or "gangue" with which it is invariably associated. Metallurgy is the art of extracting metals from their ores and preparing them for the uses of the artisan and manufacturer.

Methods of Extraction.—The processes employed for extracting the metals from their ores may be divided into two classes, viz.—Dry processes and Wet processes.

Dry Processes.—Those which are conducted in furnaces, or their equivalent, at a relatively high temperature. The operation of extracting metals from their ores by fusion in a furnace with suitable fluxes is known as *smelting*.

The metallurgical operations conducted at a high temperature require the use of furnaces built or lined with some material capable of withstanding excessive heat and the wearing action of the materials with which it comes in contact.

Wet Processes.—Those in which the metal is extracted by a suitable solvent after being, in some cases, first converted into a more readily soluble compound.

Metallurgical Furnaces.—The various forms of furnaces employed are conveniently divided into (i.) Blast furnaces; (ii.) Reverberatory furnaces; (iii.) Muffle furnaces; and (iv.) Crucible furnaces.

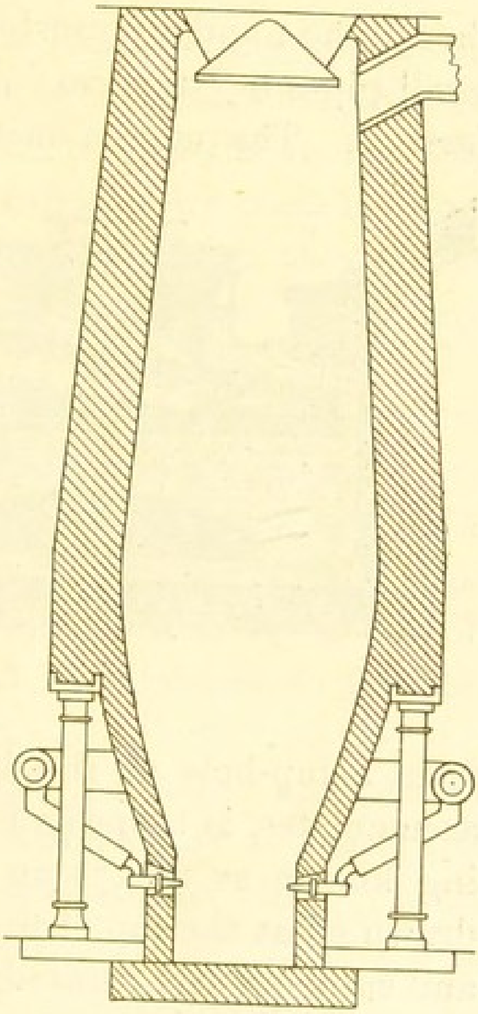
FIG. I.

(i.) **Blast Furnace** (Fig. 1).—The construction of the modern blast furnace varies much as to shape, size, and the proportion of its parts, according to the nature of the ore to be smelted and of the fuel employed. For iron smelting it consists essentially of a vertical chamber or "stack" (about 80 feet high), circular in section, and formed as illustrated in Fig. 1. The charge of ore and fuel is admitted at the top by means of the cup and cone arrangement, which closes the furnace, and a powerful hot blast is forced through small pipes or "tuyeres" placed round the base of the furnace. The molten metal is drawn off at intervals from a tap-hole at the base, while the "slag," as it accumulates, is tapped off at intervals through an opening known as the "slag hole." The waste gases are drawn off at the top of the furnace through a side tube, and subsequently utilised for heating purposes. Blast furnaces, rectangular in section, are largely used for lead and copper smelting.

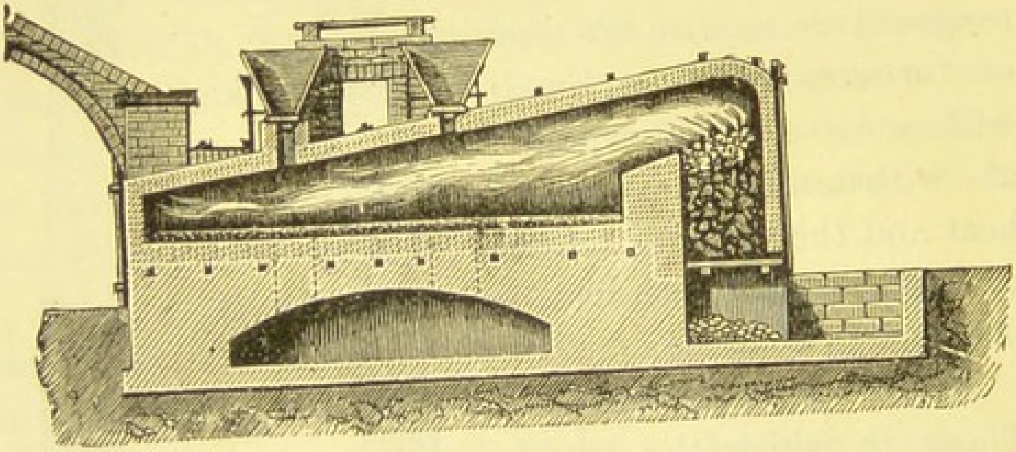

FIG. 2.

(ii.) **Reverberatory Furnace** (Fig. 2).—This is a horizontal furnace, "consisting essentially of three parts—a fireplace at one end, a stack or chimney at the other, and a bed between the two, on which the material is heated. The fireplace is separated from the bed by a low partition-wall, called the "fire-bridge," and both are covered by an arched roof. On the sides of the bed are openings through which the ore may be stirred when necessary. The flame in its course from the fireplace to the stack is reflected downwards or *reverberated* on the ore spread over the bed, whence the name *reverberatory* furnace." *

(iii.) **Muffle Furnaces.**—The essential characteristic of these furnaces is that the material being heated does not come into contact either with the fuel or the products of combustion. The furnaces are made in many forms according to the purpose for which they are to be used. As a type, the assay furnace on p. 75 may be taken.

(iv.) **Crucible Furnaces.**—Furnaces of this class are chiefly used for melting metals and alloys. They consist essentially of a closed fire-brick chamber with fire bars at the bottom, and a small flue at the top. The ashpit is usually fitted with a door by means of which the draught is regulated. The laboratory furnace on p. 73 is a type of this class.

Useful Metals.—Although a large number of metals are known, about twenty-one only of these are of any considerable industrial importance, viz.:

Aluminium.
Antimony.
Arsenic.
Bismuth.
Cadmium.
Chromium.
Cobalt.
Copper.
Gold.
Iron.
Lead.
Magnesium.
Manganese.
Mercury.
Nickel.
Platinum.
Potassium.
Silver.
Sodium.
Tin.
Zinc.

Of these, only about thirteen (those printed in Roman type) are employed in the metallic state for industrial

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* Percy, "Metallurgy," vol. i. p. 45.

purposes or in the dental laboratory. Of those printed in italics a few are used to a small extent in the metallic state, while their various compounds are extensively used in the arts as colouring pigments, or for other purposes. The application of metals to dental purposes cannot be regarded as of recent origin, as "gold was employed in Rome for the purposes of fixing artificial teeth more than three centuries before the Christian era, and a law of the Twelve Tables makes exception with regard to such gold, permitting it to be buried with the dead." *

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* Cic. de Leg., ii. 24. "Metallurgy," Phillips, p. 2.

CHAPTER I.

PHYSICAL PROPERTIES OF THE METALS.

ALTHOUGH the division of the elements into metals and non-metals does not admit of exact definition, yet the metals as a class possess certain generic properties which the non-metals either do not possess at all or exhibit only in a very slight degree.

All metals, with the single exception of mercury (a liquid), are solid at the ordinary temperature; they possess a high power of reflecting light; they are opaque except in the thinnest possible films, in which state they allow light to pass; they are better conductors of heat and of electricity than the non-metals, and, as a rule, they have higher densities than these, and are, with few exceptions, malleable and ductile. The metals differ widely from each other both in their physical and in their chemical properties, and are accordingly adapted for different uses.

The most important physical properties possessed by the various metals, rendering them fit for purposes which could not be fulfilled by non-metallic substances, are as follows:

Lustre and Colour.—One of the most characteristic properties possessed by metals is that of a high reflective power whereby a peculiar bright glittering appearance is presented, known as the *metallic lustre.*

When in a state of fine division the metals frequently appear in the form of black or grey powders, and the metallic lustre is not noticeable, but it can readily be observed when the powder is rubbed with a hard substance, such as polished steel or agate.

The peculiar lustre characteristic of metals is, however, not wholly confined to these substances, as certain compounds and some of the non-metals exhibit a closely similar lustre ; graphite is an example.

Although the light reflected from polished surfaces of most metals is nearly white, yet frequently there is a slight tinge of colour, which is best seen when the light is repeatedly reflected from the metallic surface. Thus, whilst tin, silver, platinum and other metals have a nearly pure white colour, and appear alike when equally polished, lead and zinc have a distinct bluish shade, iron a greyish hue, and bismuth a slightly brownish tint.

When light is repeatedly reflected from a gold surface, the characteristic pale yellow tint is deepened to a full orange-red, which may be readily seen by looking obliquely into an empty metal vessel which is gilded internally. The red colour of copper is also deepened, by reflection, to a bright scarlet.

Certain metals in the form of very thin leaves are transparent, and when viewed by transmitted light possess colours different to those possessed by the metals in mass. Thus, gold-leaf transmits green light and silver-leaf appears blue by transmitted light.

Taste.—A few of the metals when applied to the tongue leave a peculiar " metallic " taste, which is probably due to the action of the saliva. Copper possesses a characteristic faint nauseous taste. Zinc also has a slight metallic taste. The majority of the metals, however, are tasteless when pure.

Specific Gravity or Density of a metal may be defined as the weight of a certain bulk of such metal as compared with the same bulk of water.

All metals are lighter when molten than when in the solid state, with the exception of bismuth, which attains its maximum density just before solidifying (see p. 30).

The density of a metal is dependent on the intimacy of the contact between the molecules, and is influenced by the purity of the metal, by the mechanical treatment, by the temperature of casting, and by the rate of cooling.*

The density of a metal is increased by mechanical treatment, such as hammering, wire-drawing or rolling. Thus the density of platinum in the cast state is 21.21, which is increased to 21.45 by hammering.

Alteration of temperature also affects this property, as expansion is caused by increase of temperature; a given bulk of metal will therefore weigh less at a higher temperature than at a lower one.

Advantage is sometimes taken of this property of density in extracting metals from their ores. The extraction of platinum and gold are examples. The following table contains the principal metals, arranged according to their densities, referred to water at its maximum density at 4° C. (39° F.). To facilitate comparison the densities compared with aluminium, the lightest of the common metals, is also given in the second column.

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* Roberts-Austen, "Introduction to Metallurgy," p. 14

SPECIFIC GRAVITY OF METALS.*

	Water = 1.	Aluminium = 1.		Water = 1.	Aluminium = 1.
Heaviest.					
Iridium	22.4	8.3	Copper	8.9	3.3
Platinum	21.5	8.0	Cadmium	8.7	3.3
Gold	19.4	7.3	Nickel	8.5	3.2
Mercury, solid, − 39° C.	14.4	5.4	Iron	7.8	2.9
Mercury, liquid	13.6	5.1	Tin	7.3	2.7
Palladium	12.0	4.5	Zinc	6.9	2.6
Lead	11.4	4.2	Antimony	6.8	2.2
Silver	10.5	3.9	Aluminium	2.7	1.0
Bismuth	9.8	3.7	*Lightest.*		

Hardness is the resistance offered by a substance to the penetrating action of another substance.

Great differences are observable between the degrees of hardness of the various metals in common use.

Lead is so soft as to admit of being scratched with the finger-nail, while others can only be scratched by very hard substances. The hardness of metals is important in considering their applications to industrial purposes; gold used in the manufacture of jewellery and for coining into money is invariably alloyed with some other metal, such as copper, to harden it, as pure gold would be too soft to resist the attrition to which coins and articles of jewellery are exposed. Gold used

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* The specific gravity of a metal is determined by first weighing it in air, on a delicate balance, and then weighing it in water by suspending it to the balance by means of a piece of fine silk. The metal will weigh less in water, and the difference between the two weighings gives the weight of water displaced by the metal. The weight in air divided by the difference of the weight in air and in water is the specific gravity of the metal.

for artificial dentures is also hardened by the addition of other metals for similar reasons.

The property of hardness is one of importance in selecting a metal for dies to be used in swaging metal plates, as a die must be sufficiently hard to stand the necessary force applied to it in stamping up the plate to the required shape without becoming deformed to any material extent. It is partly on this account that zinc has been selected as a suitable metal for dies, as it possesses *hardness* as well as most of the other properties necessary for a die.

On the other hand, preference is usually given to lead in the formation of a counter-die, mainly on account of its greater softness, this property in a counter being of practical importance.

The hardness of metals diminishes with an increase of temperature. The following table gives the relative hardness of the more important metals compared with the hardness of the diamond as 100.

To facilitate comparison, the hardness of the metals when compared with lead, the softest metal in common use, is also inserted.

HARDNESS OF METALS.

	Diamond = 100.	Lead = 1.		Diamond = 100.	Lead = 1.
Hardest.					
Diamond . .	100.0	6.3	Silver . .	32.9	1.8
Nickel . .	46.8	2.5	Gold . . .	32.5	1.7
Iron . . .	45.6	2.4	Bismuth . .	30.2	1.6
Copper . .	45.2	2.4	Aluminium .	27.5	1.5
Palladium . .	41.6	2.2	Cadmium . .	25.2	1.4
Platinum . .	36.8	2.0	Tin . . .	21.6	1.2
Zinc . .	35.8	1.9	Lead . . .	18.9	1.0
Antimony . .	33.8	1.8	*Softest.*		

The hardness of metals may be approximately ascertained by cutting them with a good steel knife.

Malleability is the property of permanently extending in all directions by pressure, as by hammering or rolling, without rupture. Most metals possess this property in a greater or less degree. Gold is the most malleable metal, and may be hammered into leaves $\frac{1}{282000}$th of an inch in thickness, each grain of which will cover a surface of fifty-six square inches.

One grain of silver may be extended to a greater extent and made to cover ninety-eight square inches, but on account of the lower density of silver the leaves are *thicker* than those of gold.

Iron has been beaten into leaves $\frac{1}{2500}$th of an inch in thickness. Malleability is often affected by the presence of impurities, even when present in very small quantities. Thus the addition of $\frac{1}{2000}$th part of lead or of bismuth would render gold quite brittle: and similar effects on the malleability of many metals are produced by small admixtures of other metals.

The malleability of nearly all metals is impaired when they are subjected to long-continued hammering or rolling, but this property may be restored by *annealing*, which consists in heating the metal to a uniform red heat and allowing it to cool either rapidly or slowly—usually the latter. In some cases, as with copper for example, it is immaterial whether the metal be cooled rapidly or slowly in the annealing process. It is on account of this impairing of the malleability, by hammering, &c., that plates for artificial dentures have to be frequently annealed during the process of swaging in order to render them more pliable. The molecules of the metals are forced into unnatural positions by hammering, &c., and require occasional annealing or softening by heat to bring them back again to their normal condition. The relative malleability of metals is determined by the degrees of thinness of the sheets that can be produced by hammering or by rolling *without annealing*. The more important metals are arranged according to their malleability in the following table:

ORDER OF MALLEABILITY.

Most Malleable.

1. Gold.
2. Silver.
3. Aluminium.
4. Copper.
5. Tin.
6. Platinum.
7. Palladium.
8. Lead.
9. Cadmium.
10. Zinc.
11. Iron.
12. Nickel.
13. Mercury (frozen).

Least Malleable.

14. Bismuth } brittle.
15. Antimony } brittle.
16. Iridium } brittle.

Brittleness.—When the metals are void of malleability, and have a tendency to fly to pieces when hammered or rolled, they are said to be brittle.

Antimony and bismuth are characteristic brittle metals at all temperatures.

Some metals which are very malleable at one temperature are brittle at another. Zinc, for example, is brittle at ordinary temperatures, but when heated to between 100° and 150° C. (212°–302° F.) it becomes malleable and can readily be rolled into thin sheets, whilst at 200° C. (392° F.) and upwards it again becomes brittle and can easily be powdered in a mortar. Other metals which are malleable at ordinary temperatures become brittle when heated to a temperature just below their melting-points; lead, tin, copper, and aluminium are examples.

Bearing in mind these properties of zinc and lead at elevated temperatures, care should be taken in the preparation of dies and counter-dies for swaging metal plates to remove them carefully from the moulds, and not allow them to fall when hot, otherwise the dies may be broken owing to their brittleness.

Flow of Metals.—"When a malleable metal is extended by mechanical processes such as rolling, stamping, hammering, &c., a true flow of the particles of the metal occurs, analogous in all respects to the flow of viscous fluids. The pressure exerted upon the surface of the metal is transmitted in the interior of the mass from particle to particle, and tends to produce a *flow* in the direction where the resistance is least." *

The application of this fact, that solid metals flow like viscous fluids, is of great importance in industrial art, and the production of various complicated forms by rolling, punching, &c., entirely depends on the flow of the metal when suitably guided by the artificer.

The manufacture of jelly-moulds, from a single sheet of copper or other metal, and the striking of a coin are familiar instances of this property, the metal, under pressure, being made to flow into the sunken portions of the die without fracturing, thus producing a true impression. The flow of metals is of much importance in the dental laboratory, as it is this property which is utilised in swaging metal plates for artificial dentures, the metal being made to flow by force, so that it may accurately conform to all parts of

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* Percy, "Fuel," p. 22; and Roberts-Austen, *Proc. Roy. Inst.* vol. xi. p. 395 ("On Certain Properties Common to Fluids and Solid Metals").

the die. It is also this property which enables seamless crowns to be struck in one piece from the sheet metal.

Ductility is the property of permanently extending by traction, as in wire-drawing, and is closely allied to malleability. All ductile metals are necessarily malleable, but they are *not necessarily ductile in the exact ratio of their malleability.* Thus iron is very ductile, and may be drawn out into very fine wire; but it cannot be hammered or rolled out into such thin sheets as some other less ductile metals. Tin and lead are fairly malleable metals, but they are not sufficiently ductile to be drawn into very fine wires.

Wire is manufactured by passing a cylindrical rod of metal through a steel plate known as a *draw-plate*, which is pierced with a series of conical holes gradually diminishing in diameter (see p. 78). It is generally necessary to anneal the wire from time to time (see p. 12), otherwise it becomes hard and more or less liable to break after having passed through a certain number of holes. In certain cases, however, the annealing is reduced to a minimum, in which case the wire is said to be *hard-drawn.*

The following metals are arranged according to their ductility:

ORDER OF DUCTILITY.

Most Ductile.

1. Gold.
2. Silver.
3. Platinum.
4. Iron.
5. Nickel.
6. Copper.
7. Palladium.
8. Cadmium.
9. Aluminium.
10. Zinc.
11. Tin.
12. Lead.

Least Ductile.

Tenacity is the property a metal possesses of resisting fracture when subjected to a tensile or stretching force. This is one of the most important properties of the malleable metals in connection with their application to industrial purposes. With an increase of temperature the tenacity of a metal is usually diminished. The relative tenacity of different metals is determined by taking bars of pure metals and of exactly the same diameter, fixing them firmly at one end and applying weights at the other, the load being gradually increased until the *utmost weight* which each bar is capable of suspending without breaking has been exactly determined.

The approximate tenacity in tons per sq. in. of the common metals in the cast state is given in the following table:

ORDER OF TENACITY.

Most Tenacious.	Tons per sq. in.		Tons per sq. in.
1. Steel, special	90–100	9. Palladium	6.9
1. „ ordinary	25–65	10. Aluminium	6.7
2. Nickel	38	11. Zinc	3.0
3. Iron, wrought	20–26	12. Cadmium	2.5
4. Platinum	18.0	13. Tin	2.0
5. Iron, cast	5–15	14. Bismuth	1.2
6. Silver	10.0	15. Antimony	1.0
7. Copper	8.5	16. Lead	1.0
8. Gold	7.0	*Least Tenacious.*	

As the tensile strength of metals is very greatly affected by variations in their purity, structure, and temperature, the values given in tables of tenacity must not be regarded as constants.

The tenacity is usually greatly increased when metals are hardened by mechanical treatment, such as rolling, hammering, wire-drawing, &c. Thus, when copper is worked, the tenacity may be raised to over 18 tons per sq. in. Annealing will usually reduce the tenacity to that of the cast metal.

The ratio in which each metal possesses the properties of malleability, ductility and tenacity may be seen from the following table, in which the numbers represent the order given in the preceding tables:

Metals.	Malleability.	Ductility.	Tenacity.
Gold	1	1	6
Silver	2	2	4
Aluminium	3	9	8
Copper	4	6	5
Tin	5	11	11
Platinum	6	3	3
Palladium	7	7	7
Lead	8	12	14
Cadmium	9	8	10
Zinc	10	10	9
Iron	11	4	2
Nickel	12	5	1
Mercury (frozen)	13	—	—
Bismuth	14	—	12
Antimony	15	—	13

Elasticity is the power a substance possesses of resuming its original form after the removal of the force which has produced a change in that form.

The elasticity varies considerably in different metals; good steel possesses it to a very high degree, but lead scarcely exhibits a trace of this quality.

Within recent years advantage has been taken of the elasticity or "springiness" of various metals, more especially of "pianoforte wire," for regulating the teeth. The elasticity of metals is also utilised in matrices, and is a matter of importance in clasps employed as a means of retaining partial dentures in the mouth.

66

The operations of wire-drawing, rolling, hammering, &c., generally increase the elasticity of metals, whilst annealing generally diminishes it. Gold wire possesses very little elasticity, but by gentle hammering this may be increased and the wire made "springy." In this state it is sometimes employed for regulating purposes in place of steel wire, as it keeps its colour better and does not blacken the teeth, as pianoforte wire has a tendency to do; but it is not so universal in its applicability, as it can only be used where great elasticity is not necessary. The elasticity of a metal is often developed by combination with another metal (see Gold, p. 103).

There is a limit, however, to this property of metals beyond which they are incapable of regaining their original form, or even break. This point is known as the *limit of elasticity*.

Fusibility.—All metals when heated sufficiently pass into the liquid state, but the temperatures required to melt them differ considerably.

Mercury is solid at − 39° C., but above this temperature it assumes the liquid form, and is therefore always fluid at ordinary temperatures. Some metals are readily fused below or at a red heat, while platinum and a few rare metals can only be melted by the highest attainable heat of the oxyhydrogen flame or the electric arc. Metals are usually considered as easily fusible when they melt at temperatures below a very bright red heat, or about 1000° C., and those melting above that point as difficult of fusion or *refractory*.

It is somewhat difficult to judge the high temperatures required to melt metals from the terms commonly used to indicate different degrees of heat, such as red heat, white heat, &c.; but some idea of these temperatures may be gained by regarding a bright domestic fire as bright red heat about 900° C. (1652° F.).

The following is a convenient practical classification of the metals, founded on their degrees of fusibility:

Melting-points of Metals.[*]

		Cent.	Fahr.
	Mercury	− 39°	38.2°
Fusible at or below a red heat	Tin	+232°	449°
	Bismuth	268°	514°
	Cadmium	320°	608°
	Lead	325°	617°
	Zinc	415°	779°
Fusible above a red heat and at temperatures easily attained in furnaces: bright red heat to white heat	Aluminium	625°	1157°
	Antimony	632°	1170°
	Silver	960°	1760°
	Copper	1050°	1922°
	Gold	1061°	1942°
Fusible only at the highest temperature attained in furnaces: bright white heat	Palladium	1500°	2732°
	Nickel	1600°	2912°
	Iron	1600°	2912°
Fusible only by the oxy-hydrogen flame or the electric arc	Platinum	1775°	3227°
	Iridium	2500°	4532°

Some metals, such as zinc, cadmium, and antimony, are readily converted into vapour when heated, and all metals can be volatilised by the use of either the oxy-hydrogen flame or the electric arc.

Effect of Cold.—It has been pointed out by Dewar[†] that when metals are exposed to the very low temperature of −180° C., the tenacity is greatly increased. For instance, the strength of steel and of German silver is nearly doubled at this low temperature.

In some cases brittleness is produced by exposure to

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[*] "Introduction to Metallurgy": Roberts-Austen.

[†] Lecture before the Royal Institution, London, 1894.

cold: thus, ingots of tin, when exposed to the rigour of a Russian winter, fell into powder.

Fracture.—The appearance of the fractured surface of a metal is of importance as giving in many instances an indication of the purity or impurity of the metal. Thus the fracture of an ingot of pure zinc presents bright crystalline surfaces set at various angles, while the presence of the frequent impurity iron is indicated by a number of black specks on the faces of the cleavage planes and the duller and greyer appearance of the fracture. The fracture depends partly on the nature of the metal and partly on the manner in which solidification occurred.

The following terms are used in relation to the fracture of metals, but these appearances can only be satisfactorily and thoroughly learned by practice:

Crystalline.—Zinc, antimony and bismuth are characteristic examples.

Granular.—(Differs from the last only in the smaller size of the crystals.) As in grey forge pig-iron.

Fibrous.—Good wrought-iron partly broken by nicking with a chisel and bending double.

Silky.—Tough copper bent backwards and forwards until it breaks presents a silky lustre.

Columnar.—Observed in the grain tin of commerce. (It resembles common starch.)

Conchoidal or Vitreous.—(Glass-like.) Presented by certain alloys such as zinc 2, copper 1. (Percy.)

Crystalline Character.—Much attention has been given in recent years to the molecular constitution of metals. When the molecules of a substance are arranged in a certain definite and regular manner the substance is said to be *crystalline.* When growth in this manner has been free and uninterrupted, geometrical forms are developed externally, characterised by the constancy of the angles between similar faces in all individuals of the same species (*e.g.*, the same metal). These definite forms are called *crystals* and the substance exhibiting them is said to be *crystallised*. If, as in the mass of a cooling metal, the boundaries of the individuals are the result of their mutual interference the definite external forms cannot be developed; but, as on examining the polished and etched surface of the metal the same regular internal arrangement is seen to exist, each individual is still spoken of as a crystal and the mass is said to be crystalline.

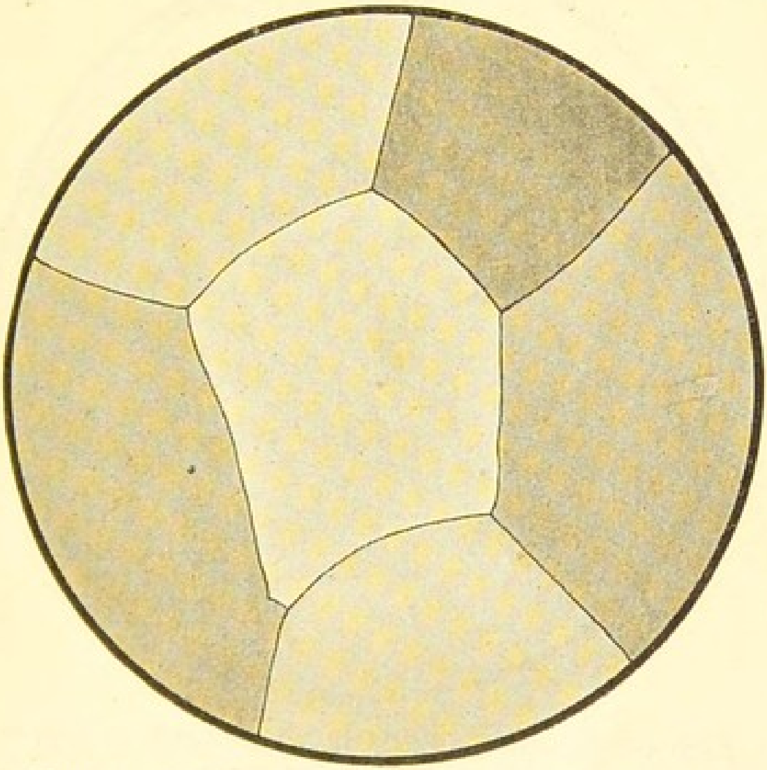

FIG. 3.—Pure Gold. Magnified 42 diameters.

Thus, Fig. 3 is taken from a micrograph * of the polished surface of a section of pure gold etched with

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* Taken by Mr. McWilliam from the original sections kindly lent by Prof. Arnold, Sheffield: see *Engineering*, February 7, 1896.

aqua regia and shows the crystals of the metal bounded by their lines of interference. Fig. 4 represents the appearance of a similar section of gold alloyed with 0.2 per cent. of copper. It will be noticed that the copper had apparently remained in the mass of the crystals as no difference can be seen between the two structures excepting the size of the crystals, and the metal in the mass is still practically as malleable and ductile as before. Fig. 5, however, shows the appearance under the microscope of a similar section of gold containing 0.2 per cent. of lead, and here the bright yellow crystals of gold are seen as before, but they are now separated by thin walls of a brownish-coloured substance. This latter is a very fusible and brittle alloy of gold and lead, and the gold having solidified and crystallised from centres while this alloy was

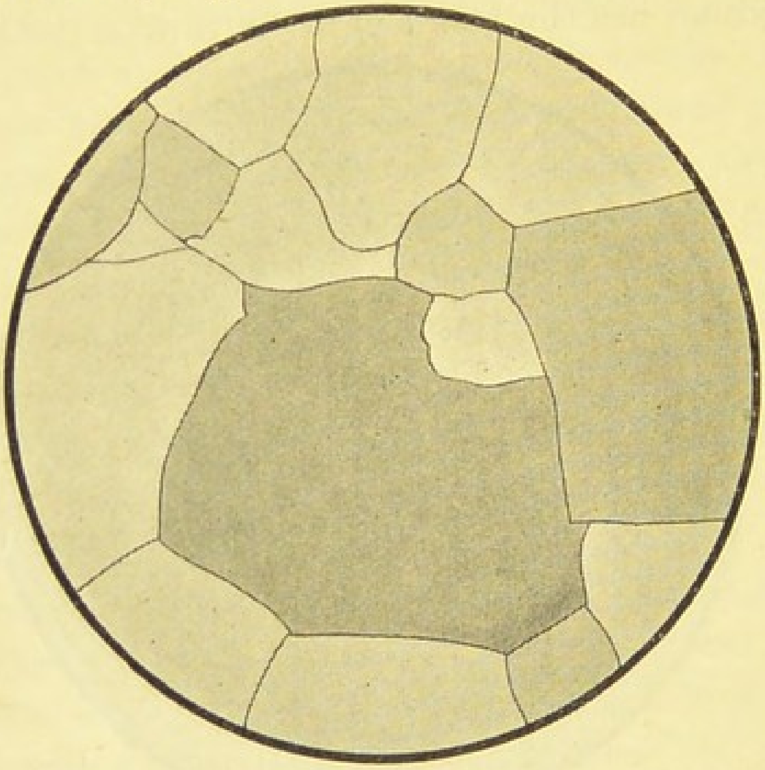

FIG. 4.—Gold alloyed with 0.2 per cent. of copper. Magnified 42 diameters.

liquid, the still thoroughly malleable crystals of gold are surrounded by an envelope of brittle alloy, and thus the whole mass is quite brittle. To show that the individual crystals are still thoroughly malleable, a portion of this sample was pounded in a mortar, and one of the grains was beaten as thin as ordinary gold-leaf. Gold with 0.2 per cent. of silver (an element of high melting-point) has a structure similar to that shown in Fig. 4, while gold with 0.2 per cent. of tellurium (an element of low melting-point) is similar to Fig. 5.

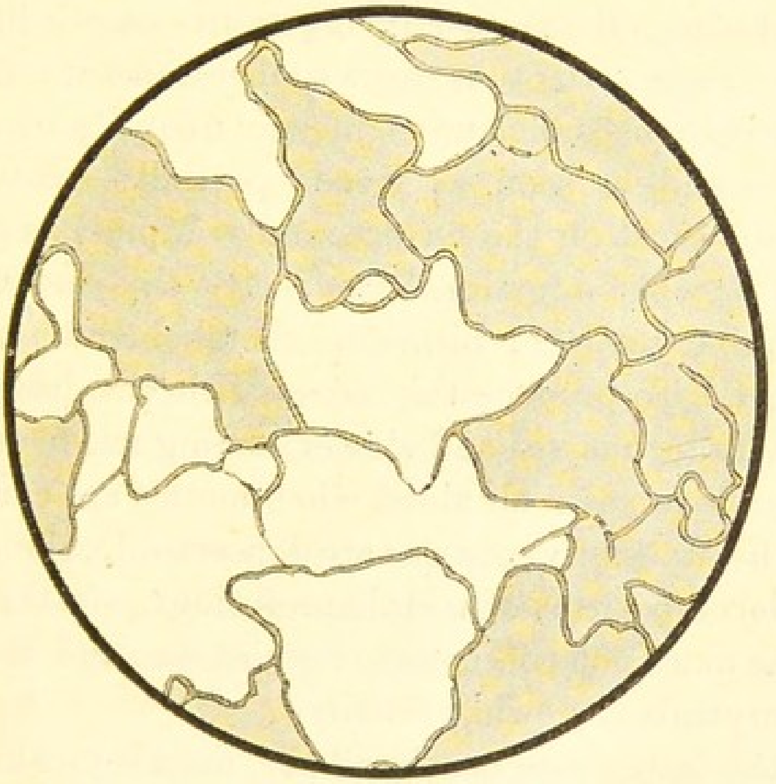

FIG. 5.—Gold alloyed with 0.2 per cent. of lead
Magnified 42 diameters.

In the case of metals showing a fibrous or a silky fracture the crystals have clung together and drawn out into the thread-like forms seen on the ruptured portion, while in those showing a "crystalline" fracture the crystals have not drawn out and the rupture has taken place along planes of weakness, sometimes apparently along crystal junctions, and sometimes as true cleavage, and hence the crystalline appearance of the fracture.

All metals under favourable conditions may be obtained in the form of definite crystals. Many metals —particularly gold, silver, and copper—occur crystallised in nature, and are found most frequently as cubes or octahedra. Metals usually crystallise on solidification after melting. In order to crystallise a metal artificially it is sometimes sufficient to melt a quantity of it in a crucible, and, as soon as it has partially solidified, to break the crust on the surface, and as rapidly as possible pour out what remains liquid. By this means very beautiful crystals of bismuth (rhombohedral) may be obtained. To produce this effect with the less fusible metals larger masses and slower cooling are necessary.

Crystals are also obtained when metals are condensed from the state of vapour or are deposited by the electrolytic decomposition of metallic solutions. In the former case the more volatile metals, such as zinc and cadmium, yield crystals somewhat readily.

In the latter case nearly all the metals yield crystals when deposited from their solution by electric currents of feeble intensity.

It also frequently happens that one metal may be precipitated in the form of crystals by placing a strip of another metal in a solution of its salts. In this way feathery crystals of lead (known as the "Lead Tree") are deposited when a piece of zinc is placed in a solution of lead acetate.

Micro-Structure.*—Much attention is now de-

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* For fuller details, see Roberts-Austen, "Introduction to Study of Metallurgy."

voted to the study of the structure of metals and alloys by the aid of the microscope, a method of investigation instituted by Dr. H. C. Sorby in 1864.

As the sections of metals, however thin, are opaque, they must be viewed by reflected light.

For this purpose it is essential that the surface should be perfectly smooth, and this is effected by careful grinding on emery and polishing with rouge. In most cases the structure of the metal or alloy is not shown by polishing only, and must be made evident by physical or chemical processes which produce different effects upon the different constituents.

These processes vary with the nature of the metals concerned. The carefully polished specimen is usually submitted to the action of a suitable reagent (such as very dilute nitric acid) in order to develop the structure.

A microscope fitted with powers varying from 30 to 350 diameters, and provided with special accessories for good perpendicular illumination, is generally employed.

By this method of investigation much valuable information has been gained as to the structure of metals, alloys, and amalgams. For example, the microscopical examination of the gold alloys has done much to show why the qualities of gold are greatly modified by the addition of very small quantities of certain metals (as described on p. 22).

In the author's opinion much of our future knowledge respecting the structure of dental amalgams will have to be gained by the aid of the microscope.

Conductivity of Heat and of Electricity.— The superior power of conducting heat and electricity is one of the most prominent characters possessed by the metals. The metals are the best conductors of heat and electricity among the solid bodies, but the power of transmission varies very considerably, being highest in silver and copper, and lowest in the brittle metals—bismuth and antimony.

It is on account of their conducting power that metals always feel cold to the touch. They are good conductors, and therefore carry away rapidly the heat from the part of the body with which they are in contact.

The order of conducting power of the metals for *heat* and for *electricity* is comparatively the same, as will appear from the following table,* in which the conductivity of silver is assumed to be 100 at 0° C.:

CONDUCTING POWER OF METALS.

For Heat.		*For Electricity.*	
Silver . .	100.0	Silver . .	100.0
Copper . .	73·6	Copper . .	97·8
Gold . . .	53·2	Gold . . .	76·7
Aluminium .	31·3	Aluminium .	65·5
Zinc . . .	28.1	Zinc . . .	29·6
Cadmium . .	20.1	Cadmium . .	24·4
Tin . . .	15·2	Iron . . .	14·6
Iron . . .	11.9	Platinum . .	14·5
Nickel . .	11.5	Tin . . .	14·4
Mercury (liquid)	13·5	Nickel . .	12.9
Palladium . .	—	Palladium . .	12.1
Lead . . .	8.5	Lead . . .	8.4
Platinum . .	8.4	Antimony . .	3·6
Antimony . .	4·0	Mercury . .	1.8
Bismuth . .	1.8	Bismuth . .	1.4

The relative values obtained for the electrical conductivity of metals at one temperature are not quite

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* Beckert, "Eisenhuttenkunde," p. 6.

the same as those obtained at another, as the conductivity is *diminished* by a rise of temperature, but not always at the same rate in each case.

Capacity for Heat, or Specific Heat.—Equal weights of different metals require different amounts of heat to raise them from the same to a higher given temperature. The amount of heat necessary to raise one part by weight of water from 0° C. to 1° C. being 1, the amount of heat required respectively to raise the same weight of the following metals from 0° C. to 1° C. will be as follows:

SPECIFIC HEAT OF METALS.*

Aluminium	0.2143	Tin	0.0562
Iron	0.1138	Antimony	0.0508
Nickel	0.1086	Mercury	0.0333
Zinc	0.0955	Platinum	0.0324
Copper	0.0952	Gold	0.0324
Palladium	0.0593	Lead	0.0314
Silver	0.0570	Bismuth	0.0308
Cadmium	0.0567		

From the above table it will be seen that the capacity for heat of the metals is very variable. If small balls of equal weights of the different metals are exposed for the same length of time to exactly the same temperature and then withdrawn simultaneously and placed upon a thin cake of wax, it will be observed that the metals having the greatest capacity for heat, such as iron, will "melt" their way through the wax much more rapidly than those having a smaller capacity for heat, such as bismuth.

The specific heat increases with an elevation of temperature and is greater as the metals approach their fusing-point. Any action, such as hammering,

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* Regnault, "Cours Élémentaire," ii. 28.

which increases the density of a metal, diminishes its capacity for heat, but it regains its original value after the metal has been again heated.

It is important to consider the capacity for heat of metals used for artificial dentures, as in the mouth they are exposed to varying temperatures and frequently to hot liquids.

The comparatively high specific heat of palladium, combined with its low conducting power, makes this metal suitable for artificial dentures, as these properties would prevent the sudden chill felt with a gold plate on drinking a cold liquid, and also in a similar manner would assist in preventing scalding with hot liquids. It is quite probable that palladium would be advantageously employed in prosthetic dentistry if its high price did not exclude it from the dental laboratory.

The great capacity for heat of aluminium, combined with its lightness, would render that metal also very suitable for dental plates, provided its other properties did not make it unsuitable.

Expansion by Heat.—Metals expand when heated, and, within certain limits, generally in a degree nearly proportionate to the increase in temperature.

In many industrial arts, and also in dentistry, it is very important to ascertain the exact amount of expansion which different metals undergo when their temperature is raised.

The figures in the following table represent the extension, in parts of its own length, of a bar of the given metal during a rise in temperature from the freezing-point 0° C. (32° F.) to the boiling-point of water, 100° C. (212° F.):

EXPANSION OF METALS BY HEAT.

Greatest Expansion.

Cadmium	$0.00306 = \frac{1}{326}$	Gold	$0.00145 = \frac{1}{689}$
Lead	$0.00292 = \frac{1}{342}$	Nickel	$0.00127 = \frac{1}{787}$
Zinc	$0.00291 = \frac{1}{343}$	Iron (malleable)	$0.00122 = \frac{1}{819}$
Aluminium	$0.00231 = \frac{1}{432}$	Palladium	$0.00117 = \frac{1}{854}$
Tin	$0.00223 = \frac{1}{448}$	Iron (cast)	$0.00107 = \frac{1}{934}$
Silver	$0.00193 = \frac{1}{518}$	Antimony	$0.00105 = \frac{1}{952}$
Copper	$0.00167 = \frac{1}{598}$	Platinum	$0.00089 = \frac{1}{1123}$
Bismuth	$0.00162 = \frac{1}{617}$		

Least Expansion.

The above table indicates the linear increase or coefficient of linear expansion—that is, the increase in one direction. Most substances, however, expand equally in each direction, and the cubical expansion may be taken as approximately three times the above fractions.

Change of Volume on Solidification.—All metals undergo a change of volume when they pass from the fluid to the solid state. With the exception of bismuth, which expands, all metals contract on solidification. This change of volume is a matter of great practical importance not only in the arts but in many branches of dentistry. It is one of the most important properties to be considered in the selection of a metal for the production of dies for swaging metal plates, as the successful adaptation of the plate depends to a large extent upon the die being an accurate representation of the precise form of the mouth. Owing to this general property of contraction it is impossible to obtain a metal which will give an exact reproduction of the mouth. The unavoidable shrinkage, however, is partially or wholly compensated for by the expansion of the plaster model employed, and the yielding condition of the soft tissues of the mouth. Although the contraction of zinc is somewhat greater than that of other metals, it is almost universally employed for the production of dies, as it possesses most of the other properties necessary for this purpose (see p. 44). The contraction of metals is often considerably diminished by being alloyed with other metals.

The following table gives the percentage of change in volume of metals on passing from the liquid to the cold solid state: *

CHANGE OF VOLUME ON SOLIDIFICATION.

Bismuth	increase of volume	2.30
Iron (cast)	decrease "	1.02
Mercury†	" "	4.85
Tin	" "	6.76
Copper	" "	7.10
Lead	" "	9.93
Zinc	" "	11.10
Silver	" "	11.20

Other metals in common use, such as gold and aluminium, undergo change of volume on solidification, the contraction being considerable in the latter case; but the exact amount of contraction of metals has only been determined in a few cases.

Galvanic Action.—When two dissimilar metals are immersed in a fluid, the chemical action of which is more energetic on one than on the other, and then brought into contact, a feeble electric current is produced known as *galvanic action*, which is analogous to the result obtained on heating the junction of a thermo-couple, such as bismuth and antimony.

If a silver coin be placed on the tongue, and a steel pen or iron nail under the tongue, and the edges

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* Roberts and Wrightson, *Proc. Phys. Soc.*, 5, 1884, pp. 97–104.

† Grunmach, *Chem.-Zeit.*, 1901, 25 [84], p. 919.

brought into contact, a feeble electric current is produced, giving rise to a peculiar bitter taste known as a galvanic taste. This galvanic action is sometimes experienced when different metals are in contact in the mouth, where they are continually bathed in the oral fluids. The amount of action is infinitesimal in healthy states of saliva; but in acid, or other unhealthy condition, a very efficient exciting fluid is in constant action. Many instances are known in which galvanic action has been experienced with combination fillings of gold and amalgam, the gold being found subsequently corroded at the line of junction of the two metals. In one case the action resulted from a pin on an upper gold plate striking an amalgam filling in the lower jaw.*

Seeing that electrical effects are always exhibited when different metals are in contact and moistened by exciting fluids, and that the wider apart metals are in their positive and negative character the greater will be the action developed, the selection of amalgam and metals for use in the mouth ought to be carefully considered and the contact of metals of wide electrical differences avoided.

The following list gives the principal metals, arranged according to their *usual* relative electrical position to each other in most liquids.

Commencing with the most *electro-negative* and passing regularly down to the most *electro-positive*, they have the following order:

NEGATIVE.—Gold, platinum, palladium, antimony, mercury, silver, copper, bismuth, lead, nickel, iron, tin, cadmium, zinc, aluminium.—POSITIVE.

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* Mr. Humby, *Journ. of Brit. Dent. Assoc.*, vol. xviii. p. 300, 1897.

In this series each metal is usually *negative* to all those below it, and *positive* to all those above it; consequently none are absolutely positive or negative. The above series can only be regarded, however, as a general arrangement, as the order varies slightly with every different liquid in which the metals may be immersed.

CHAPTER II.

ACTION OF CERTAIN AGENTS ON METALS.

Air.—With one or two exceptions, the metals undergo no change in dry air, and are not sensibly altered in moist air at ordinary temperatures, those most readily acted upon being copper, lead, zinc and iron. In *moist air*, in the presence of carbonic acid, copper becomes coated with a green layer of carbonate called *verdigris*. Lead and zinc are also acted upon, the surfaces of these metals becoming coated with a greyish-white film. Iron is readily oxidised, forming a brown coating known as *rust*.

When heated, the metals are more readily oxidised than at the ordinary temperature. Thus, tin under ordinary conditions retains its bright surface for a considerable time, but when heated it is quickly tarnished.

Sulphuretted Hydrogen.—In the presence of sulphuretted hydrogen certain metals are tarnished or blackened owing to the formation of sulphides. Silver and copper are readily blackened, while tin and lead are also tarnished. The surface of cadmium becomes slowly coated with a yellow film of cadmium sulphide. Sulphuretted hydrogen has very little or no action on the other metals.

Water.—Perfectly pure water has practically no action on the metals. When dissolved oxygen and carbonic acid are present as in ordinary water, copper, lead, iron and zinc are gradually corroded with the formation of a coating of an oxide or of a carbonate of the metal, which in some cases protects the surface from further corrosion.

Acids.—With the exception of gold, platinum and iridium (and other metals of the platinum group), all the metals are dissolved or more or less acted upon by acids. Gold and platinum are not soluble in any single acid (except selenic, which dissolves gold), but are soluble in some mixtures of acids, such as nitro-hydrochloric (aqua regia).

Nitric Acid.—Tin and antimony are converted into oxides by the action of nitric acid; all other metals, with the exceptions quoted, are soluble in the acid and form nitrates, some being readily soluble in the strong acid, while others are more easily attacked by the dilute acid. This acid is the best solvent for the majority of the metals.

Hydrochloric Acid.—This acid has no action on gold, platinum, iridium and mercury, and very little action on silver, lead, copper and bismuth. It dissolves the other metals with more or less facility, according to the strength of acid used, forming chlorides.

Sulphuric Acid.—Boiling concentrated sulphuric acid converts lead and antimony into lead sulphate and antimony sulphate respectively.

Bismuth, zinc, silver, aluminium and mercury are dissolved by concentrated sulphuric acid, but are not acted upon or are only very slightly affected by the dilute acid. All other common metals, with the exception of gold, platinum, iridium and palladium, are soluble in this acid, whether strong or dilute.

Acetic Acid.—Lead is rapidly attacked, and copper is slowly acted upon, by acetic acid (vinegar); but this acid has little or no action on the other metals.

Alkalies.—Comparatively few of the metals are acted upon by alkaline solutions; aluminium, however, is readily dissolved in solutions of caustic potash or of soda. Zinc, lead, cadmium and tin are also slowly attacked by solutions of the alkalies. Alkaline chlorides convert metallic silver into its chloride, which is dissolved in an excess of the alkaline solution. Ammonia slowly dissolves copper.

Effect of Exposure in the Mouth.—All the metals, with the exception of gold, platinum and palladium, are more or less acted upon by exposure in the mouth. Copper, silver and cadmium, on account of the affinity which they possess for sulphur, are the metals most readily acted upon when exposed in the mouth, owing to the presence of sulphuretted hydrogen. Carbonic acid, which is always present, acts with greater facility on zinc and lead than upon other metals, while aluminium is readily attacked by the alkaline fluids of the mouth. Although in some cases action is slow in healthy states of saliva, yet the presence of vegetable acids in articles of food, such as fruit, and of sulphuretted hydrogen, and the taking of drugs as medicine, greatly facilitate the action, causing the metals to become black in a comparatively short period. The action is also facilitated when two metals are in contact in presence of the acid fluids, thus giving rise to galvanic action (see p. 30). Soluble salts which are injurious to health are sometimes produced by the action of the saliva. The effect on metals possessing a strong affinity for sulphur may be modified in a few instances by the admixture of other metals. Thus, the addition of platinum to silver tends to minimise the affinity which the latter possesses for sulphur. On the other hand, the necessary admixture of other metals may accelerate the action. Gold in a pure state retains its colour in the mouth, but when alloyed with copper it becomes more or less tarnished, according to the quantity of base metal present.

Solvents for Metals.—The principal solvents used to effect the solution of metals are nitric, hydrochloric, sulphuric, and nitro-hydrochloric acid (aqua regia). This last is prepared, when required only, by mixing one part of concentrated nitric acid with three to four parts of concentrated hydrochloric acid. This mixture evolves chlorine, which attacks the metal and effects its solution.

The following table contains a list of the best solvents for the different metals:

Metal.	*Solvent.*
Aluminium . .	Hydrochloric acid.
Antimony . .	Nitro-hydrochloric acid.
Bismuth . .	Nitric acid.
Cadmium . .	Do.
Copper . .	Do.
Gold . .	Nitro-hydrochloric acid.
Iron . . .	Nitric acid (dilute*) or hydrochloric acid.
Lead . . .	Nitric acid.
Mercury . .	Do.
Nickel . .	Nitric or nitro-hydrochloric acid.
Palladium . .	Nitric acid (hot).
Platinum . .	Nitro-hydrochloric acid.
Silver . .	Nitric acid (dilute).
Tin . .	Hydrochloric acid (when heated).
Zinc . . .	Hydrochloric or sulphuric acid.

* Dilute acid = equal parts of acid and water.

CHAPTER III.

ALLOYS.

Most metals are capable of uniting with one another to form a class of bodies termed **alloys,** in which the physical properties are sometimes quite different from those of the constituent metals. Alloys, however, being composed of metals, will possess all the physical and chemical characteristics common to metals; they have the metallic lustre, are more or less ductile, malleable, elastic, and sonorous, and are good conductors of heat and of electricity. While retaining, however, these characteristics, the bodies produced are frequently so modified in some of their properties that they often do not resemble either of the constituents and may consequently be regarded as new metals, having characteristics peculiar to themselves.

The alloys most generally useful are frequently those whose constituents are most dissimilar in character. By means of alloys, therefore, the number of useful metals is multiplied, as it were, and usefulness sometimes given to such as are separately of little value.

Comparatively few of the metals possess properties such as render them suitable to be employed alone, but most of them have important applications in the form of alloys. Pure gold possesses many good qualities, but is seldom used alone, as it is too soft to resist wear and tear; copper is therefore added to harden it as well as lower its cost. Bismuth and antimony have little application in an uncombined state, but in combination with other metals they form a series of alloys of much value, several of which are used in the dental laboratory. It is not always possible to predict from the properties of the various metals employed what will be the character of an alloy formed from given proportions of each. Thus, it might be supposed that gold and lead, which are both very malleable metals, would produce a malleable alloy; but, although these metals unite readily in all proportions, the alloys obtained are in some cases very brittle and without utility in the arts.

Metals differ in respect to their affinity for one another, and do not therefore alloy with equal facility; thus, it is difficult to unite silver and iron, but the former combines readily with gold, copper, or lead.

The subject of the constitution of alloys has received much attention within recent years, and great progress has been made in connecting the behaviour of metallic alloys with that of solutions. As the result of research it has become more and more evident that alloys may be divided into two main classes:* (1) Those which are merely solutions of the constituent metals, and (2) those which contain compounds in solution, for while few alloys are regarded as true chemical compounds, most series of alloys hold in solution compounds to which some experimenters are disposed to attribute definite chemical formulæ.

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* Roberts-Austen, "Alloys": Cantor Lectures, Society of Arts, 1897.

As these compounds dissolve in all proportions in the molten mass of metals, it is very difficult to satisfactorily separate them for examination.

Although metals may be mixed in the fused state, it by no means follows that they will remain in admixture if they are allowed to cool slowly, or sometimes even rapidly. If lead and zinc be thoroughly mixed in the molten state, and slowly cooled in a deep mould, the two metals separate almost completely; the zinc, being lighter, rises to the top, leaving the heavier metal at the bottom. With other metals there is sometimes a tendency, on solidification, for one of the constituents to become concentrated in the middle or at the surface of the mass, thus giving a casting which is not perfectly homogeneous. It is now well established that most of the possible associations of any two metals have more than one point of solidification, and do not "freeze," as pure water does, at a single point. There is, however, in many series of alloys one particular association of the two metals which is more fusible than the rest of the alloys of the series. This alloy is called the *eutectic* alloy, and it possesses a single point of solidification, that is, when the eutectic alloy is cooled it sets sharply as a whole at a given temperature. Many associations of two metals contain an eutectic alloy and consequently have two points of solidification.

As a molten mass of alloy cools down it begins to solidify at a certain point, but the eutectic alloy on account of its low solidifying-point remains fluid, and entangled in the portion which has set, until the temperature falls to the solidifying-point of the eutectic alloy, at which temperature solidification of the mass is completed. There is, therefore, in many cases abundant opportunity in the interval between the initial point of solidification of the alloy and that of the eutectic for the mass to arrange itself in a peculiar way which frequently results in a want of uniformity of the mass.

A striking instance of this is afforded in the case of the alloys of the silver-copper series, all of which, except the eutectic alloy, exhibit divergencies in composition. The eutectic alloy of the series contains 71.8 per cent. of silver and solidifies at 778° C. The presence of the eutectic has been detected in standard silver (92.5 per cent. of silver) and in several other members of the series, and consequently these alloys have two points of solidification.

To take the case of standard silver, the initial solidifying-point of which has been ascertained to be 883° C. As a molten mass of this alloy cools down it begins to solidify at 883° C., but the eutectic alloy remains fluid, and entangled in the portion which has set, until the temperature falls to 778° C., at which temperature the mass sets sharply as a whole. During the interval between these two solidifying-points there is ample opportunity for the mass to arrange itself in a peculiar way, hence the want of uniformity of the mass.

The eutectic alloy in this and in several other series of alloys occurs exactly at a composition corresponding to a definite formula, and this has led to the conclusion, as previously stated, that eutectic alloys are chemical compounds.

The exact composition of the eutectic is, however, difficult to determine. The most recent experiments have shown that the composition of eutectic alloys does not in general correspond with simple atomic proportions of the component metals, and this fact, and the theory of the subject, point to the conclusion that the eutectic alloy is not generally a compound, and hence should not have a formula. Further research, however, is necessary before any definite conclusion on this point can be generally accepted. The tendency of the constituents to separate on cooling is known as *liquation*, and is a matter of importance in casting alloys for industrial purposes, as for dies, &c. In some instances where liquation has taken place a more homogeneous alloy may be obtained by breaking up the ingot and remelting (see also p. 175).

Physical Properties of Alloys.

Colour.—The strongly coloured metals, such as copper and gold, are very much modified in tint by alloying with metals of light colour, such as aluminium, silver and tin. Thus, when 5 per cent. of aluminium is added to copper the resulting alloy has a beautiful golden-yellow colour, and zinc when added to copper in certain proportions acts in a similar manner. The colour of gold is modified by the addition of only one-twentieth part of silver, and it is entirely destroyed when gold is alloyed with half its weight of silver. The colours of alloys, however, are not always dependent on those of the separate metals. For example, when thirty-nine parts of gold are added to eleven parts of aluminium an intensely ruby-coloured alloy is obtained. Antimony, also, when fused with an equal weight of copper produces a violet alloy known as "regulus of Venus."

Density.—The specific gravity of an alloy is rarely the mean of the densities of the constituent metals, being sometimes greater and sometimes less. When the density is increased it shows that *contraction* has occurred, and chemical combination has probably taken place between the constituents. When *expansion* takes place by the union of the metals, the density will be below that calculated from the densities of the constituents.

Fusibility.—In nearly all cases the melting-point of an alloy is lower than the mean melting-point of the constituent metals, and in some instances it is considerably lower than the melting-point of either of its constituents.

An alloy of two parts of bismuth with one part of lead and one part of tin melts at a temperature of 93° C. (200° F.), whilst the lowest melting-point of the constituent metals is that of tin, 232° C. (449° F.). By the addition of a small quantity of cadmium the melting-point is reduced to 65° C. (150° F.) (see Fusible Metals, p. 51).

Expansion by Heat.—The expansion of alloys is approximately in the ratio of the relative volumes of the constituent metals.

Specific Heat.—The capacity for heat of alloys is the mean of the specific heats of the metals which compose them.

Conductivity for Heat and for Electricity.—These properties in an alloy are found in some cases to be the mean of the conducting powers of the component metals, and in others to have apparently no relation whatever to such mean.

Hardness.—Alloys are generally harder than the mean hardness of the constituent metals.* This is

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* Calvert and Johnson, *Phil. Mag.*, 4th series, xvii. p. 114.

especially noticeable in the silver-platinum alloy known as "Dental Alloy" (see p. 174). In some cases, on the contrary, the hardness is slightly less than that calculated, tin-zinc alloys being examples.

Malleability and Ductility.—These properties are usually diminished and sometimes completely destroyed by alloying metals. The brittleness produced by the addition of lead to gold has already been mentioned.

Action of Solvents.—The action of solvents on alloys is sometimes very different from their action on the constituent metals alone. Thus, platinum is insoluble in nitric acid, but it is dissolved in this acid when alloyed with much silver; silver also when alloyed with much gold is not affected by nitric acid, but it is completely soluble when present in the alloy in large excess. Generally speaking, however, alloys are readily soluble in the acids which are solvents of the constituent metals.

Preparation of Alloys.—The method ordinarily adopted to effect the union of metals is by fusion—that is, melting them together, usually in a graphite crucible. To do this successfully, however, requires a knowledge of the properties of the various metals employed. Sometimes the constituents are mixed and melted together, but in other cases one of the metals is melted first and the others subsequently added to it, sometimes in the fluid state, but more often in the solid. A little charcoal powder should be placed on the surface of the charge to prevent oxidation, and the liquid metal should be carefully stirred with an iron or fireclay rod after each addition, and in such a manner as to secure most complete intermixture without liability to injure it by exposure to an oxidising atmosphere. The molten alloy should be poured at the lowest possible temperature consistent with the proper degree of liquidity, excessive heating always being avoided.

Alloys for Dies and Counter-Dies.—There are certain properties which it is indispensable that a metallic die and counter-die should possess in order to answer fully the requirements of the dentist. These may be summarised as follows:

1. A die should be sufficiently hard to resist any necessary force applied to it in stamping the plate during swaging without suffering any material change in the form of its face.

2. It should not to any material extent contract in the act of cooling.

3. It should be fusible at a low temperature.

4. It should not be brittle, but should be sufficiently cohesive to resist the repeated blows of a heavy hammer without cracking. No metal possesses perfectly these properties of hardness, non-contractibility, fusibility and cohesiveness, although metals possessing one or two of these are readily obtainable.

Much time and thought have therefore been expended in the effort to discover some alloy which shall possess more fully the several properties referred to, but although a large number of combinations of metals have been suggested, comparatively few of these are used. In selecting an alloy to serve as a die it is necessary to bear in mind that the nature of some alloys is changed by repeated melting, and that their physical properties are materially altered. Thus, an alloy may answer the requirements of a die for a time, but very much deteriorate by constant use. Some alloys also, when they solidify from a state of fusion, tend to "liquate" or even separate into two distinct layers of different composition, a property which may prove fatal to the die, as the bottom layer will fill up the deeper portion of the mould representing the most prominent part of the die, and may be soft and totally unfit for the purpose of swaging.

The alloys most frequently employed for dies or counter-dies are as follows :

Type Metal.—The better qualities of this alloy consist of three parts of lead with one part of antimony and one part of tin. In different proportions, however, these metals, sometimes with the addition of small quantities of copper and other metals, form different grades of type metal (see also p. 211).

This alloy is sometimes used for dies and less frequently for counter-dies. Richardson states * that "when used as a counter to a zinc die it is improved by adding to it an equal quantity of lead; it may also be used in the form of a die in connection with a lead counter after rough stamping with a zinc die." Type metal is considerably harder than lead, but a little softer than zinc, and gives sharp castings. It melts more readily than zinc, being more fusible than the average fusibility of the constituent metals, and the contraction is less than one-half that of zinc. It is somewhat brittle, and therefore needs very careful handling when used as a die. When the alloy is melted in contact with the air the antimony and tin are oxidised much more readily than the lead, even when all precaution is taken, thus the composition is very liable to alter after repeated melting. When preparing this alloy the

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* "Mechanical Dentistry," 1894 edit. p. 124.

lead and tin are first melted together, then the antimony added, a layer of charcoal being used to prevent oxidation. Excessive heating must be avoided.

Babbitt's Metal.—This is an alloy of copper one part, antimony two parts, and tin six parts ; the proportions, however, vary considerably with different makers. "The melting-point of this alloy is lower than that of zinc and somewhat higher than that of lead, so that counter-dies of the latter metal can be readily made to it with proper care." The alloy contracts but little on solidification and is nearly as hard as zinc, but somewhat brittle, and needs care in using. It is rendered less brittle by the addition of more tin.

The following proportions of the above metals are recommended by Fletcher for dental purposes : Copper one part, antimony two parts, tin twenty-four parts. This alloy melts at a little lower temperature than the above, and on account of the larger quantity of tin it is somewhat less brittle than Babbitt's metal of the proportion given above.

Haskell recommends the following alloy for dental work : Copper one, antimony two, tin eight. "This alloy is nearly as hard as zinc and has less shrinkage. It is used to finish the swaging of a plate after being nearly completed on the zinc model. As this alloy fuses at a lower temperature than lead, it is necessary to have a counter-die in which tin forms a constituent, such as lead five, tin one. The die should also be quite cold and covered with a quantity of whiting before inserting it in the molten metal."*

Babbitt's metal is best prepared by first melting the copper with half the tin, then adding the antimony and

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* H. Rose, *Brit. Journ. of Dent. Sc.*, 1895, vol. xxxviii. p. 531.

finally the remainder of the tin, stirring well after each addition and then casting into suitable moulds. Charcoal powder should be thrown on to the surface of the metal to prevent oxidation. This alloy is liable to waste and alter in composition by repeated melting.

Spence's "Metal."—This is not, strictly speaking, an alloy, but a compound obtained by dissolving metallic sulphides in melted sulphur. The sulphides of iron, lead, antimony and zinc are usually employed in varying proportions according to the quality of the product desired, which will naturally depend upon the use for which it is designed. The Spence's "metal" usually employed for dies is "sulphide of iron," made by melting iron with excess of sulphur. The compound melts at 160° C. (320° F.), expands slightly on cooling and gives very good castings; it is hard although somewhat brittle, and needs care in handling. This "metal" should be melted in a fireclay crucible and not in an iron ladle. By remelting, loss of sulphur is invariably occasioned and the composition of the mass altered.

Alloys of Zinc and Tin.—These alloys are frequently employed in casting dies for swaging plates, and are best prepared by melting the zinc and then adding the tin. According to Richardson, an alloy suitable for dental purposes, consisting of zinc four parts, tin one part, "fuses at a lower temperature, contracts less on cooling, and has less surface hardness than zinc. This alloy is also more rigid than zinc and less brittle."

Fletcher recommends the following proportions: zinc two parts, tin one part, and states that all alloys of zinc and tin are superior to zinc alone for dies.

It may be remarked, however, that in casting alloys of zinc and tin in which zinc predominates there is a tendency for the metals to separate at the bottom of the mould, and this tendency increases as the proportion of tin decreases.

The waste in melting is greater when zinc is in excess. All the alloys of zinc and tin give sharp castings, and on this account are largely employed for casting ornamental objects (see also p. 206).

Alloys of Tin and Antimony.—Alloys of these metals have also been used for dies. Richardson gives the following proportions: tin five parts, antimony one part. This alloy has a low melting-point, contracts but slightly on cooling, is harder than tin, and sufficiently cohesive. It is, however, readily oxidised on melting, and should be poured as soon as thoroughly molten. Alloys of tin and antimony are harder than tin but less malleable, and the tendency to become brittle is greater as the proportion of antimony increases (see also p. 217).

Brass.—" Before the introduction of zinc for dental dies, brass, an alloy of copper and zinc, was used for this purpose. It is generally composed of two-thirds copper and one-third zinc; a small percentage of lead being sometimes added when used for dental purposes. Brass may be melted and poured the same as zinc, but to ensure good results it is as well to have a good head of metal for the die to contract from. This can be effected by placing another casting ring full of sand on the one containing the model, and cutting a bell-shaped cavity in the upper ring, tapering down until it comes to the back of the plaster model. The model is then removed and the upper ring adjusted to the lower, and securely cemented to it by sand; the melted brass can then be poured through the opening on to the sand impression, and when hard and the casting removed and cooled the bell-shaped piece of brass may be sawn off. It must be mentioned that the sand impression should be smoked, and a good carbon surface produced on it by burning resin. This greatly improves the surface of the casting."*

Other Alloys for Dies.—A series of alloys of lead with tin, bismuth and antimony, having comparatively low melting-points and possessing other properties necessary for a die, are given by Austen in a paper on metallic dies.† His results are embodied in the following table, in which zinc is introduced for the purposes of comparison.

ALLOYS FOR DIES.

Lead.	Tin.	Bismuth.	Antimony.	Melting-point.		Contraction.	Hardness.	Brittleness.
2	1	3	—	200° F.	93° C.	.00133	2.7	7
5	3	8	—	200°	93°	.00200	2.5	8
1	1	1	—	250°	121°	.00066	2.3	7
5	6	3	1	300°	139°	.00266	1.7	9
5	6	—	1	320°	160°	.00566	1.9	6
1	2	—	—	340°	171°	.00500	2.2	3
2	3	—	1	420°	216°	.00433	1.4	7
2	1	—	—	440°	227°	.00633	2.8	3
		Zinc.		779°	415°	.01366	1	5

In the above table the hardness of zinc is taken as one, and the brittleness as five; those alloys having a hardness below five being malleable, and those above five being more brittle than zinc.

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* H. Rose, *Brit. Journ. of Dent. Sc.*, 1895, vol. xxxviii. p. 530.

† *Am. Journ. of Dent. Sc.*, vol. vi. p. 367.

Fusible Metals.

This name is given to a series of alloys which melt at very low temperatures, and consist chiefly of tin, lead and bismuth, with occasionally the addition of cadmium and mercury. Many of the alloys obtained by the union of these metals, in different proportions, melt at a temperature below the boiling-point of water and far below the melting-point of the most fusible metal entering into their composition.

Tin and bismuth both have low melting-points and they readily combine in all proportions when fused together, the resulting alloys being more fusible than either of the metals taken separately.

A very small quantity of bismuth imparts to tin more hardness, but the alloys become brittle as the proportion of bismuth increases. Alloys of tin, bismuth and lead are more fusible than those containing only two of these metals. It is difficult to obtain these alloys in a perfectly homogeneous state, as there is a tendency for the lead to separate somewhat at the bottom of the mass while solidifying from a state of fusion. They are rapidly tarnished in the air, and more so in boiling water. The alloys of the above metals are rendered still more fusible by the addition of cadmium, some of the resulting alloys being readily melted in boiling water. Cadmium, however, does not render the alloys so britle as bismuth.

The following table shows the composition and melting-points of a number of " fusible metals " :

FUSIBLE METALS.

Name.	Bismuth.	Tin.	Lead.	Cadmium.	Melting-point.	
Lipowitz alloy	15	4	8	3	145° F.	63°C.
Fusible metal	4	1	2	1	150°	65°
Wood's alloy	5	2	4	2	160°	71°
Fusible ,,	8	3	8	10	167°	75°
,, ,,	16	3	11	2	170°	77°
Rose's ,,	8	3	8	—	175°	79°
Fusible ,,	—	2	1	1	187°	86°
Dalton's ,,	10½	3	5	—	197°	92°
Onion's ,,	5	2	3	—	197°	92°
Darcet's ,,	2	1	1	—	200°	93°
Newton's ,,	8	3	5	—	202°	95°
Fusible ,,	3	2	—	1	203°	95°
,, ,,	1	3	3	—	310°	154°
,, ,,	1	1	—	—	320°	160°
,, ,,	1	2	—	—	331°	166°
,, ,,	—	2	1	—	338°	170°
,, ,,	4	12	15	—	341°	172°
,, ,,	4	12	16	—	352°	178°
,, ,,	1	4	—	—	392°	200°

All the fusible alloys are brittle and expand on cooling and are all more or less hard.

Preparation.—Fusible alloys are prepared by melting the constituents together under a layer of charcoal and well stirring with a stick of hard wood before pouring. Mercury is sometimes added to still further lower the melting-point. Thus, by the addition of one-sixteenth of its weight of mercury to "Darcet's alloy" a new alloy is formed which is fusible at the temperature of the human body. The addition of one to two parts of mercury to "Newton's alloy" also produces a very fusible alloy, and any of the fusible metals may be rendered more fusible by the addition of mercury. The mercury is added after the other metals are perfectly melted.

Uses in the Dental Laboratory.—In the dental laboratory fusible metals are mainly used for "fusible plugs" to vulcanisers, the composition of the alloys being such that the plugs will "blow out," *i.e.* melt, when the temperature exceeds about 350° F. or 177° C. Fusible metals have been used in crown, bridge, and vulcanite work, and novel methods have been introduced for accomplishing in a simple manner many kinds of dental work with fusible metals. In a very interesting paper read before the British Dental Association in 1891, R. P. Lennox of Cambridge drew attention to a number of uses for these alloys in connection with bridge work.

Mellotte has introduced the following fusible metal for crown and bridge work: bismuth 8, tin 5, lead 3.*

This alloy melts at 100° C. (212° F.) and expands on solidification. It is harder than tin, but not so hard as zinc, and is brittle. For obtaining accurate models with this fusible metal he uses a compound of potter's clay and glycerine known as "moldine," which retains its plasticity for months: it stiffens, however, with constant use, but may be made plastic by moistening with a little glycerine.

Determination of Melting-point of Fusible Alloys.—A very simple method for determining the melting-point of a fusible alloy consists in melting the alloy in a porcelain crucible over a Bunsen burner. When thoroughly melted the flame is removed and a thermometer held carefully in the molten mass.

The temperature at which solidification takes place is noted; this can be readily ascertained, as the mercury thread of the thermometer will remain stationary for some considerable time when this point is reached. The

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* Essig, "Dental Metallurgy," 1893, p. 263.

thermometer, which becomes embedded in the solidified alloy, is removed by again melting the alloy.

When due precaution is taken there is no risk of breaking the thermometer, but it is very necessary to avoid excessive heating of the alloy.

Another method is illustrated in Fig. 6. A small quantity of the alloy is placed in a glass test-tube, and the open end closed with a cork. This tube is attached to the stem of a delicate thermometer just above the bulb by binding it with thread or fine wire or by means of a small rubber ring slipped over the larger end of the thermometer stem. The thermometer and tube are placed in a glass vessel containing water and the vessel gently heated until the alloy melts; the lamp is then removed and the temperature at which the alloy *solidifies* accurately noted by the thermometer. The mean temperature obtained from several observations will give the melting-point of the alloy. During the process of heating the water should be constantly agitated. For determining the melting-points of alloys which melt at a temperature a little above that of the boiling-point of water, a liquid with a higher boiling-point, such as glycerine, may with advantage be employed instead of water. The alloys should be previously melted and cast on a flat surface in order to obtain a thin sheet. This should be broken up and a small portion only used for determining the melting-point.

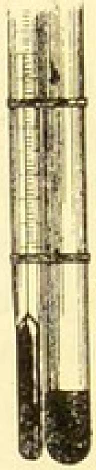
FIG. 6.

The melting-points of alloys which are not sufficiently fusible to test by the above methods may be approximately determined by placing a fragment of metal of known melting-point in the locality of the piece of alloy to be tested and carefully subjecting them to a uniform heat before the blowpipe, or by other means. Thus, a small piece of bismuth (melting at 514° F.) placed beside the alloy may melt before the alloy is fused, though a piece of lead (melting at 617° F.) may remain unmelted at the fusing-point of the alloy. It follows, therefore, that the temperature at which the alloy melts must be between 514° and 617° F.

Withing recent years very precise determinations of the melting-points of metals and of alloys have been made by means of pyrometers. The instrument now almost universally adopted is based on the fact that, when a junction of two dissimilar metals is heated, the electrical equilibrium of the system is disturbed, and the measurement of the difference of potential thus produced affords a means of estimating the temperature of the junction.* In its latest form the instrument consists of a thermo-couple of two wires, one of platinum and the other of platinum alloyed with 10 per cent. of rhodium, simply twisted at the ends, and connected with a dead-beat galvanometer usually of the suspended-coil type. An autographic recorder is used in connection with the thermo-couple whereby a photographic curve, of the cooling of a mass of metal or of alloy, is registered.

The pyrometer is calibrated by exposing the thermo-junction to certain known temperatures, such as the solidifying-points of salts or of readily fusible metals. As a mass of metal passes from the solid to the fluid state, the temperature remains constant for a short period, hence there is no difficulty in recognising the

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* For a description of this pyrometer, see "Introduction to Study of Metallurgy," Roberts-Austen.

melting- or the solidifying-points. By means of this instrument much valuable information respecting the molecular constitution of alloys has been obtained.

Solders.

This term is given to alloys used in joining metallic surfaces by fusing them upon the surfaces when in contact and allowing them to cool, thus obtaining a more or less firm joint at the point of juncture.

The alloys used must be necessarily more fusible than the metal or metals to be united and must possess the property of flowing readily. They must also consist of metals which possess a strong affinity for the substances to be soldered together. Solders should, if possible, be of the same colour as the metals to be joined, and should not discolour or undergo decomposition with age.

Solders for dental purposes must also be capable of resisting the action of the fluids of the mouth. When a solder has a high melting-point—*i.e.* at or above a red heat—it is said to be "hard." When, however, the melting-point is lowered by the addition of an easily fusible metal, or by the addition of a greater amount of the more fusible constituents of the alloy, the solder is said to be "easy" or soft. The term "soft solder" is usually applied to the alloys of tin and lead used for soldering (see p. 211).

Each metal requires, to a certain extent, a particular kind of solder; the alloys most suitable as solders are described under the different metals.

Preparation of Solders.—In making solders great care must be taken to secure uniformity of composition. They are prepared in the same manner as other alloys by melting the constituent metals under a layer of powdered charcoal and well stirring the molten mass before pouring. The metals used must be free from impurity, and may with advantage be employed in a "granulated" state. Many solders are used in the form of powder, obtained by filing the ingot of alloy; but silver and gold solders are usually rolled into sheets and "soft solders" are generally sold in sticks.

CHAPTER IV.

THEORY AND VARIETIES OF BLOWPIPES.

Theory of the Blowpipe Flame.—The blowpipe is an instrument which is used to direct a stream of air into a lamp or coal-gas flame in order to produce a more intense heat. The introduction of the air within the flame at once destroys its luminosity for the same reason that the luminosity of the gas-flame is destroyed in the Bunsen burner—viz. that when gas is mixed with a proper proportion of air before being burnt the oxygen of the air burns the whole of the carbon in the body of the flame, making it non-luminous. In a well-formed blowpipe flame two parts may be distinguished: the *inner flame*, which is blue and pointed, and around this an almost colourless flame known as the *outer flame*. The inner flame (Fig. 7, *b*) is often called the *reducing flame*, as it contains excess of carbon, and is therefore capable of deoxidising or reducing substances. The outer flame (Fig. 7, *a*) is known as the *oxidising*

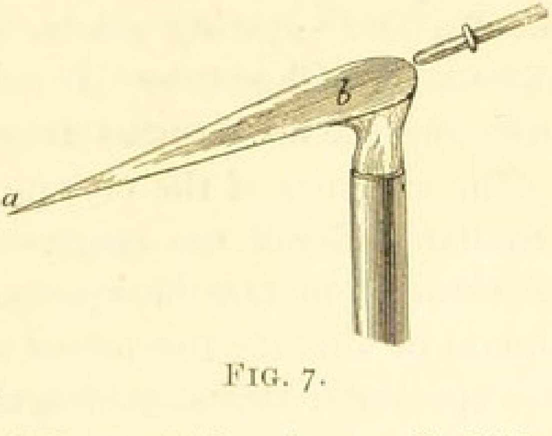


FIG. 7.

flame, as it contains excess of oxygen and readily changes metals into their oxides. The reducing flame is best obtained by placing the blowpipe nozzle in the edge of the flame; whilst the oxidising flame is produced when the nozzle is pushed much further into the flame and a stronger blast employed.

It is important in soldering operations to bear in mind the properties of the two flames, as the object to be soldered would become unnecessarily "dirty" if the oxidising flame were used, owing to the excessive oxidation of the base metals present.

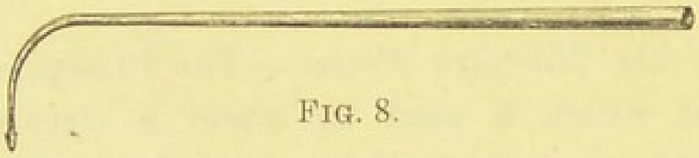


FIG. 8.

Mouth Blowpipes.—Blowpipes should be made of either brass or German silver, as these alloys are poor conductors of heat. The simplest form of blowpipe consists of a plain metal tube, 200–240 mm. long (8 to 10 inches), larger at the end applied to the mouth, and tapering gradually to a point at its other extremity. The tube is curved for convenience in directing the blast to the desired spot (see Fig. 8).

The aperture of the blowpipe nozzle should be quite circular and not too large. This generally requires adjustment in new blowpipes. The end of the nozzle should be slightly hammered over, in order to contract the aperture; this should again be enlarged by thrusting a large pin through it, until a perfectly circular opening is produced.

When a steady flame is continued for a long period moisture collects in the tube and is liable to be expelled by the pressure of the air, causing disturbances in the flame. To avoid this a hollow chamber is sometimes constructed about midway in the instrument to hold any moisture that may escape from the mouth (Fig. 9).

Another form of blowpipe for overcoming this difficulty is supplied by Letcher, of Truro. It consists of a brass tube fitting into a small chamber, which collects and retains the moisture, and the bottom of which is movable, so that it can be taken off and the moisture shaken out at the end of the operation (see Fig. 10).

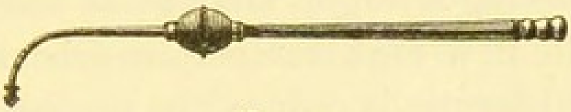


FIG. 9.

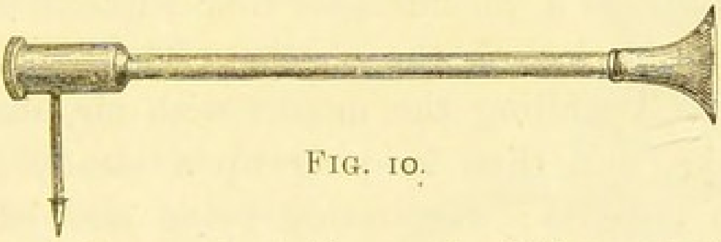


FIG. 10.

Hot-Blast Mouth Blowpipe.—Fletcher, of Warrington, has introduced a new form of blowpipe for obtaining temperatures beyond those attainable with ordinary blowpipes.

The hot-blast mouth blowpipe, as it is termed, is shown in Fig. 11. The improvement consists in coiling the end of the tube into a light spiral over the point of the jet. By this arrangement the air becomes

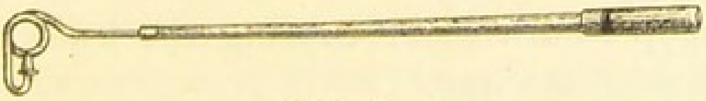


FIG. 11.

heated in passing through the tube, as the coil takes up the heat which would otherwise be wasted. The moisture also which may collect in the tube is converted into steam.

It is claimed that by the use of this instrument much higher temperatures are reached than is possible with the ordinary blowpipe, and that with the same amount of blowing a larger amount of work is accomplished, while, if a high temperature is not required, the labour of blowing is reduced in proportion.

The operation of blowing is not always readily acquired, but usually a few days' practice removes all the difficulty at first experienced in producing a continuous steady blast, and when once produced it may be continued for a considerable time without fatiguing even the muscles of the cheeks. The operation is commenced by filling the mouth with air, expanding the cheeks, and then keeping up a steady pressure with the muscles; respiration being allowed to go on as usual through the nose. To avoid tiring the muscles of the lips by continual blowing, the trumpet mouthpiece, shown in Fig. 10, which is merely pressed against the open mouth, has been recommended. The curvature of the mouthpiece should, however, correspond to that of the mouth and fit comfortably, otherwise it will require to be pressed very forcibly against the lips in order to prevent the escape of air. With this form of mouthpiece an uninterrupted blast may be kept up for a long period without causing the least fatigue to the muscles of the lips.

The length of the blowpipe is usually about 200 mm. (8 inches), but, as it is important that the object upon which the flame is directed should be seen distinctly, the length must be adapted to the eye of the operator; short-sighted persons require a short blowpipe, whilst for the long-sighted a longer one is necessary.

Bellows Blowpipes.—Many of the operations conducted in the dental laboratory require the application of a higher temperature than that obtainable with the mouth blowpipe. In order to effect this, special blowpipe burners are employed, while the necessary blast is obtained by means of a suitable blower.

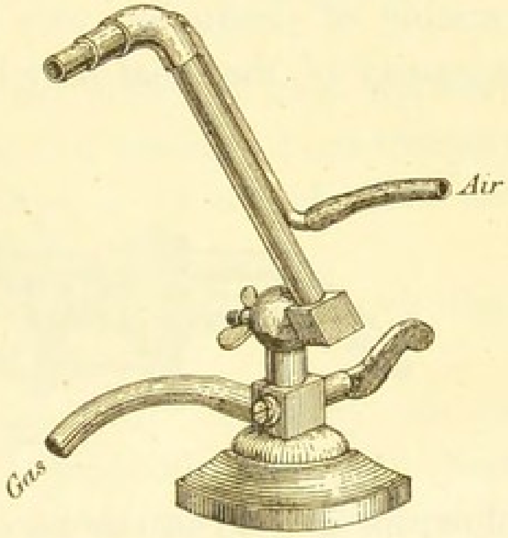


FIG. 12.

A form of burner commonly employed is represented in Fig. 12. The burner is capable of being adjusted so that the flame can be directed at any angle, and when necessary can be firmly fixed in position by means of a wing nut at the base. The jet of this blowpipe is removable, so that jets of any size can be fitted as desired. The tap lever is so arranged that it will turn the light out when pushed backward, and leave a small pilot light when drawn forward, thus avoiding the necessity of relighting for each operation. The burner is mounted on a heavy brass stand to make it perfectly steady when in use.

Owen's Blowpipe is also very frequently used. It consists of two separate brass tubes arranged as shown in Fig. 13, thus making the gas and air supplies independent. Each tube is fitted with an india-rubber valve, on which the thumb or fingers are placed in order to regulate the gas and air. By this arrangement the blowpipe flame is under perfect control.

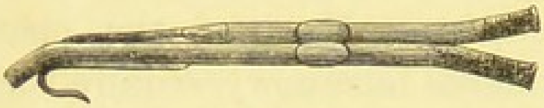


FIG. 13.

Automatic Blowpipe.—A very convenient hand blowpipe for many purposes in the dental laboratory is Fletcher's automatic blowpipe, shown in Fig. 14. This is a very manageable and effective instrument and is capable of producing very high temperatures, and the intensity of the heat may be graduated at will. The blowpipe is held in the hand and is provided with taps as shown, which are under perfect control, so that the supply of both gas and air can be readily regulated. Complete mastery over the character of the flame can be gained after a few minutes' practice. When burning at full power the blowpipe consumes about ten cubic feet of gas per hour.

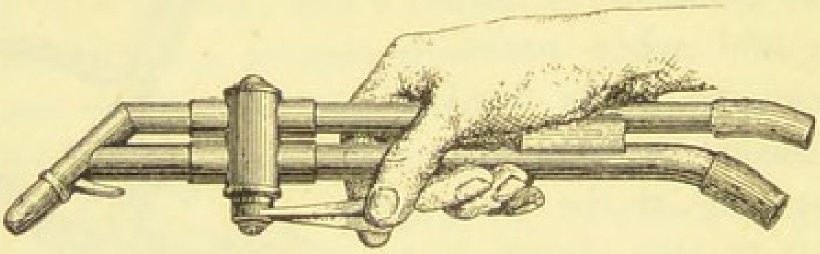


FIG. 14.

Other forms of automatic blowpipes well adapted for dental purposes have also been designed by Fletcher.

Hot-Blast Blowpipe.—For soldering operations in which pure gold is used, as in continuous-gum work, and other operations requiring a greater intensity of heat than that furnished with ordinary gas blowpipes, Fletcher's hot-blast blowpipe is sometimes used (Fig. 15). This blowpipe is so constructed that the air-pipe is coiled around the gas-pipe and both are heated by an independent Bunsen burner, the gas supply to which is regulated by a separate tap. By this simple device it is claimed that the power of the apparatus is about double that of an ordinary gas blowpipe.

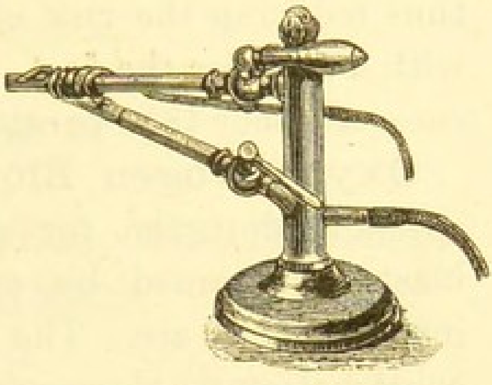


FIG. 15.

The advantage of the hot blast is only apparent when a pointed flame is required having a high temperature; under these conditions it is stated that thin platinum wire may be fused.

The blowpipe is also supplied with a bench light attached for convenience in working.

Blowing Apparatus.—The blast necessary for the production of the flame with gas blowpipes is obtained by means of a foot-blower, connected with the burner by a flexible rubber tube.

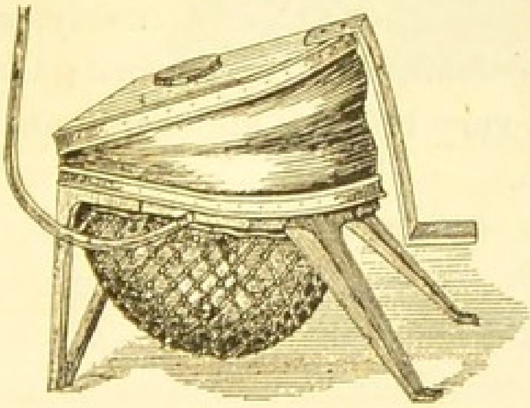


FIG. 16.

A simple and compact form of bellows for the purpose is shown in Fig. 16. With this apparatus a continuous, equable supply of air is obtained which is completely under the control of the operator. A disc of rubber is fitted beneath the bellows, which expands under the pressure of the air, while the bellows are in motion, forming a reservoir which holds the air and thus affords a very compact, powerful, and effective arrangement. The bellows are mounted on a stand, thus reducing the risk of injury to the disc, and fitted with a step for the foot, so that they can be used with ease, whether the operator is standing or seated.

Oxyhydrogen Blowpipe.—Blowpipes are now specially designed for dental purposes in which the blast is obtained by means of compressed oxygen instead of by air. The blowpipes are very similar in construction to those previously described for use with air blast.

The oxygen is supplied from a cylinder of the compressed gas. The cylinder should be fitted with a regulator for controlling the pressure of gas, as this is more satisfactory than a fine adjustment valve. When oxygen is not readily obtainable, nitrous oxide may be employed, but is not so suitable as it gives rise to a less steady flame.

Oxyhydrogen blowpipes are now being more extensively used in the dental laboratory than formerly, as they are well adapted to certain classes of work; the heat obtained, however, is very intense, and care must be exercised in using them.

CHAPTER V.

MELTING APPLIANCES, FURNACES, AND FLUXES.

Simple Ingot-Mould.—When it is required to melt a small quantity of gold or silver, the simplest form of apparatus for the purpose is that shown in Fig. 17. It is very easily and quickly made as follows:

A block of compressed charcoal or carbon is carefully cut in halves lengthways with a saw, in order to obtain two thin slabs, which are rubbed together until perfectly smooth surfaces are obtained. A circular cavity is cut in one of the slabs for the reception of the metal to be melted. At the other end of the slab an ingot-mould is carefully carved, the size and shape of which is made to suit the requirements of the case. A gutter or groove is then cut to connect the two cavities, after which the other slab is cut in halves and one half placed over the ingot-mould and secured in position by means

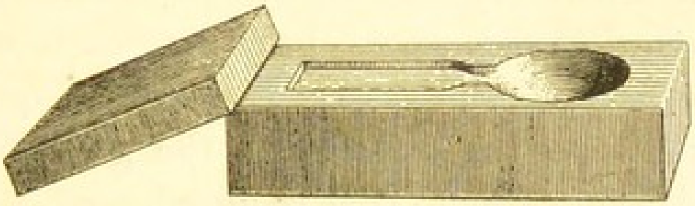


FIG. 17.

of thin iron or copper wire. The metal to be melted is placed in the cavity and the blowpipe-flame directed upon it, and when thoroughly fluid the charcoal is tilted so that the molten metal will run into the ingot-mould prepared for it. It is necessary that the charcoal should be perfectly dry before use, as the presence of moisture will cause the projection of the metal from the mould.

This simple and convenient apparatus is frequently employed in the dental laboratory and also by jewellers when only small quantities of metal have to be melted. A similar form of combined melting appliance and ingot-mould made of asbestos is obtainable at the dental depôts.

The author has made many similar moulds out of soft red Windsor brick, which is suitable for the purpose and is easily cut and shaped.

Melting Scrap.—When melting gold scrap for the dental laboratory care should be taken to prevent the admixture of old plates, backings, &c., containing portions of solder and scrap of doubtful quality, as these would lower the standard of the gold and give a plate of inferior carat to that required.

On this account it is usually safer to neglect scrap containing solder, and melt only clippings and filings from new plate. Care must also be taken to prevent the introduction of fragments of dental-alloy or of impure filings: lead is specially injurious, as it renders the gold brittle and useless.

Melting Apparatus.—A very convenient and useful form of apparatus, embodying the same principles as those described above, has been devised by Fletcher for quickly obtaining ingots of gold and silver without the use of a furnace. It is shown in the accompanying Fig. 18. **A** represents a moulded carbon block, supported in positon by an iron side-plate, which acts as a shallow crucible. **B** is an iron ingot-mould constructed in two parts, which slide on each other, to admit of ingots of any width being cast. By this arrangement the mould serves for both plate and wire.

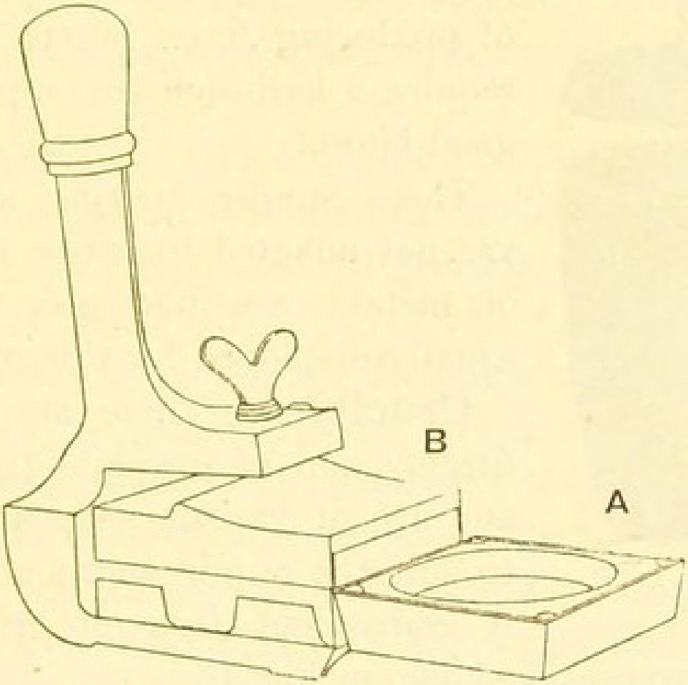


FIG. 18.

The apparatus is mounted on a rocking stand for convenience in tilting. The metal to be melted is placed in the shallow crucible and the flame of the blowpipe adjusted. When the metal is melted the whole apparatus is tilted in order to fill the ingot-mould. A sound ingot may be obtained in a few minutes by the use of this simple apparatus. The metal should be thoroughly molten before being run into the mould, but excessive heating should be avoided.

The ingot-mould is made sufficiently hot by the waste heat of the flame; it should, however, be oiled, or coated with lampblack by holding the inner surfaces over the flame of an oil-lamp or gas-jet before using. When very bulky scrap is to be melted it should be run into a mass in a moulded carbon block before being placed in the crucible. The melting appliance as usually supplied for dental purposes is capable of producing ingots of about 3 ozs. Similar appliances of larger size may be obtained capable of producing 20 oz. ingots, but these require a half-inch gas supply and a good blower.

These simple melting appliances are not adapted to large quantities of metal; crucibles are, therefore, usually employed for this purpose.

FIG. 19.

Crucibles.—These are made of fireclay and of graphite (plumbago) and are of various shapes and sizes to suit the requirements of the case. A convenient form of crucible for dental purposes is shown in Fig. 19.

Earthen crucibles are made of fireclay mixed with other infusible materials, such as sand or burnt fireclay, in order to counteract the tendency which raw clay possesses of shrinking when heated. The materials thus mixed with the clay expand slightly on heating, and therefore act in an opposite manner to the clay. Crucibles of these materials are capable of resisting a high temperature without softening.

Graphite or plumbago crucibles are made of varying proportions of fireclay mixed with powdered graphite or with coke dust. Good plumbago crucibles withstand the greatest changes of temperature without cracking, are highly refractory and the least corroded by the action of metallic oxides. They are, therefore, very suitable to the requirements of the dental laboratory, as with due care they may be used many times in succession. It is very important before using these crucibles to subject them to a careful preliminary annealing by placing them in a warm place in an inverted position, otherwise they will split when suddenly heated. The crucibles are usually provided with covers, as shown in Fig. 19.

Gold and its alloys should be melted in good plumbago crucibles, which when new should be rubbed inside with a little charcoal powder, to prevent any particles of metal adhering to the sides of the pot. When earthen crucibles are employed for the purpose they should be glazed inside with a thin coating of borax. This is done by placing a small quantity of borax in the crucible and exposing it to a high temperature until the borax is perfectly liquid. The crucible is then removed, held firmly in the tongs and carefully rotated in an inclined position in order to allow the molten borax to flow over the entire surface.

When thus glazed the crucible may be left in an inverted position until ready for use. By this means the pores of the crucible are closed and the retention of globules of metal during pouring is prevented.

Forms of Furnaces.—Melting operations may be conducted in any form of fire or furnace in which a sufficiently high temperature can be obtained.

The fire of an ordinary cooking-stove is often employed; where gas is available, however, the operation may be more effectually accomplished in a suitable gas furnace, such as those invented by Fletcher, which are very compact, convenient and effective. These furnaces are easily attended to, and work can be carried on with them in a very cleanly manner.

The choice of furnace to be used will depend chiefly on the degree of heat to be obtained, but the following furnaces will be found perfectly adapted to the requirements of the mechanical dentist.

Injector Gas Furnace.—Fig. 20 represents Fletcher's injector gas furnace. The furnace is constructed of a special refractory material, which is a bad conductor of heat and very light. It is enclosed by bands of hoop iron and contains an interior space sufficiently large to take crucibles with a capacity of six ounces to twelve pounds, according to the size of the furnace. The necessary temperature is obtained by injecting a mixture of air and gas into the furnace by means of a special burner, constructed on the principle of the Bunsen burner, the blast being obtained by a suitable blower, such as that described on p. 63. The burner is provided with a screw check, so that the supply of air can be easily adjusted. Extremely high temperatures can be obtained with these furnaces, half-pounds of cast iron being completely melted in seven to twelve minutes, but for rapid working and for high temperatures a free supply of gas is required.

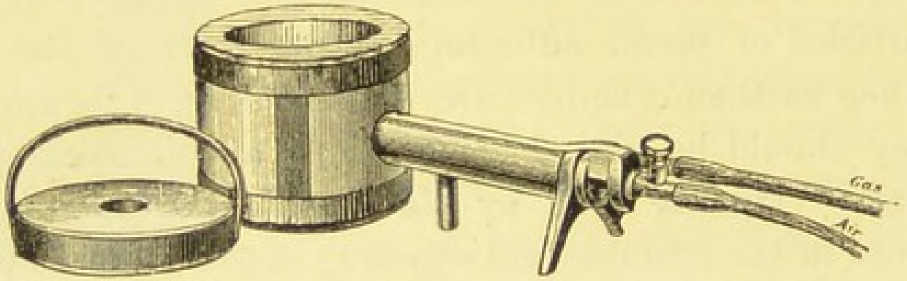


FIG. 20.

A thin layer of silver-sand is usually placed on the bottom of the furnace to prevent crucibles adhering when a white heat is employed.

These furnaces need a special gas supply, varying from three-eighths to five-eighths inch pipe, and the india-rubber tubing used for the connections must be smooth inside, the tubing made on wire not being suitable. The burner is liable to get very hot if the gas supply is insufficient.

To adjust a new furnace to its highest power, put the nozzle of the burner tightly up against the hole in the side of the furnace casing, turn on the full gas supply, light the gas in the furnace, and commence blowing, before putting on the cover of the furnace, with the air-way full open. If, when the cover is replaced, the flame comes out of the hole in the cover about two inches, the adjustment is correct.

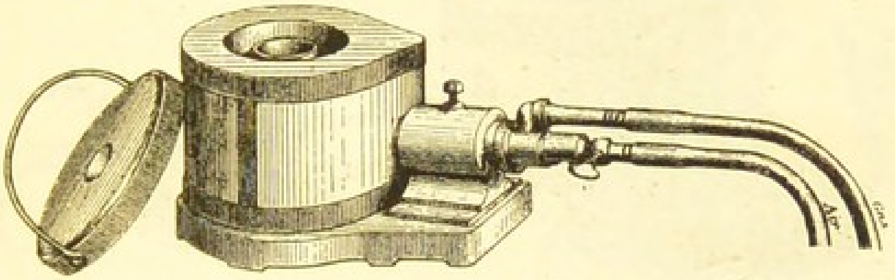


FIG. 21.

If the flame is longer, enlarge the hole in the air-jet until the proper flame is obtained, or reduce the gas supply. Before stopping the blower, draw the burner back from the hole.

Concentric-Jet Gas Furnace.—Fletcher has recently introduced a new series of concentric-jet furnaces, which are designed to supersede the injector furnaces above described. These furnaces (Fig. 21) are very similar to the injector furnaces, with the exception of the burner, which is specially constructed to avoid any cutting action or "cold spot" on the crucible.

There is no wire gauze in the burner to get choked or damaged, and the power is limited only by the air pressure and the gas supply available; it is also so constructed that it cannot light back. The burner and furnace are mounted on an iron stand, so that the former cannot get displaced when in use. The furnaces are supplied in four sizes with a capacity of from four to twelve pounds, and are in every way superior to the ordinary form of injector furnaces for use in the dental laboratory, where high temperatures and rapid working are required.

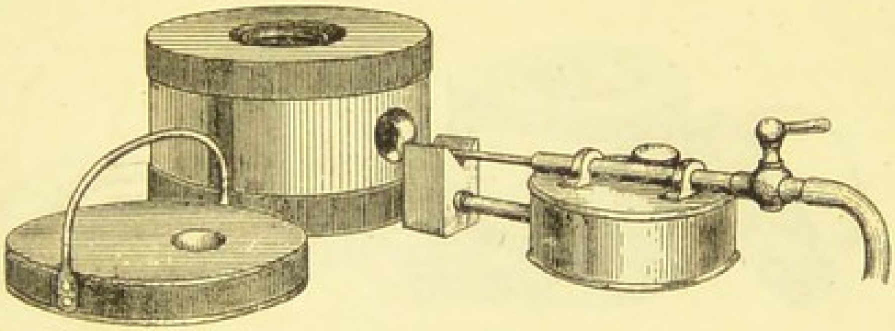


FIG. 22.

Injector Oil Furnace.—When gas is not obtainable the injector furnace can be fitted with a lamp for burning ordinary kerosene or petroleum oil, a burner having been designed by Fletcher for this purpose.

In using this the wick-holder of the lamp must be placed close against the hole in the furnace casing. The blast is supplied by means of a blower as before. The oil furnace (Fig. 22) is, however, inferior in power to the furnaces supplied with gas, but with a little experience in management a half-pound of cast iron can be melted in about twelve minutes, starting all cold.

Melting Furnace for Coke.—A very convenient and portable furnace for melting operations where a suitable supply of gas is not available is that illustrated in Fig. 23, made by Morgan and Co., Battersea, London. The furnace is constructed of fireclay, suitably bound with hoop iron, and is made in two parts for convenience in cleaning and repairing. The necessary draught is obtained by fixing an iron tube chimney to the socket *a*, and is regulated by means of the small door *d*. It is also very convenient to have a damper, *g*, fitted in the iron chimney for regulating the draught. An iron grate, *f*, is fitted at the bottom of the furnace, which is kept free from clinker by introducing a poker through the stoking-door *e*. The crucibles are introduced through the door *b* and placed on a small fireclay stand resting on the grate. The fuel usually employed is coke, which should be broken to pieces the size of an egg and well packed round the sides of the crucible, but not over it. The furnaces are made in several sizes to hold crucibles with a capacity of from four to thirty pounds.

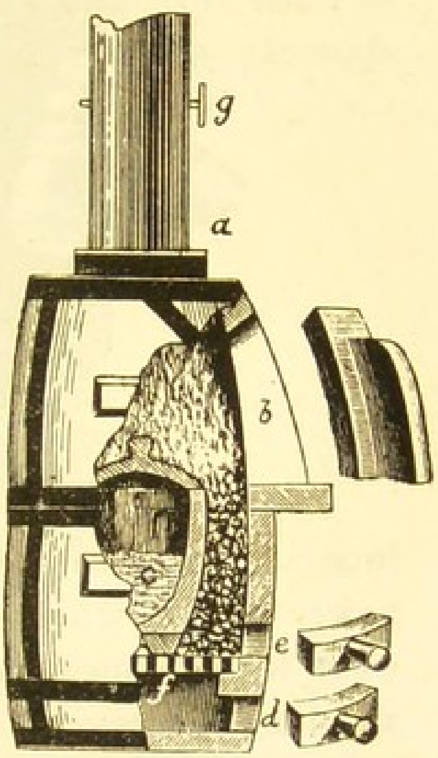


FIG. 23.

Ladle Furnace.—Fletcher has devised a new and substantial form of ladle furnace (Fig. 24) for melting zinc and lead, which is well adapted for the dental laboratory. The furnace will take ladles seven inches in diameter, and is heated by a special high-power burner, which is removable, and can therefore be used for boiling water and other purposes. The body and lid are arranged to admit the handles of different-sized ladles at various heights, to enable them to be kept perfectly level.

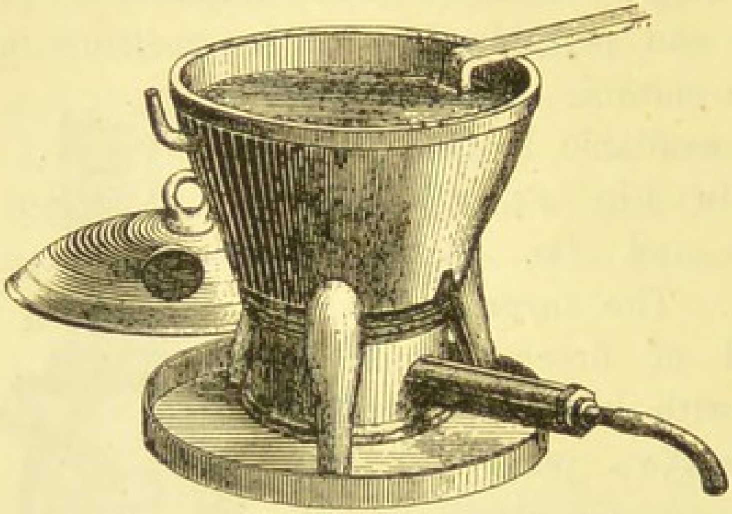
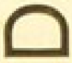


FIG. 24.

FIG. 25.

Ladles.—The ladles used with these furnaces are shown in Fig. 25. In order to insure perfect steadiness in pouring, the handles are fitted with a slide which is pushed to the cool end while the metal is being heated, and is, therefore, always cold. The ladles are made with cast-iron bowls for melting lead and with malleable iron bowls for zinc, the handle being so constructed that a new bowl can be fixed in a few minutes.

Muffle Furnace.—The muffle furnaces used in the metallurgical laboratory for the assay of gold and silver are very similar to those used for dental purposes; the muffles, however, are somewhat larger in the former case. The special feature of this class of furnace consists in the device for isolating the materials operated upon from both the fuel and the products of combustion. The muffle proper is a fireclay chamber shaped thus  in section, closed at one end, and fixed in the furnace in such a manner that it can be surrounded by the flame on all sides. The sides are perforated with a number of holes or slits through which the air is drawn, the muffle furnace being used chiefly for operations requiring the passage of a current of air, as in the processes of cupellation and scorification mentioned under Silver Assays.

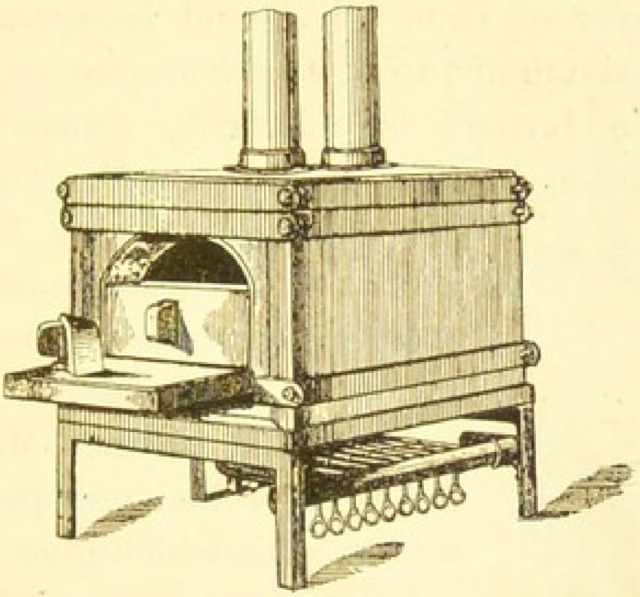


FIG. 26.

Gas Muffle Furnace.—A gas muffle furnace recently invented by Fletcher is shown in Fig. 26, This furnace has been designed specially for gold and silver assays, and ranks among the best of its kind for this purpose. It is designed to give the best results at the lowest ordinary day pressure of gas, and the temperature of the muffle is uniform from end to end, and can be adjusted to any extent. The muffle is closed by a door arranged in two parts, so that it can be partially opened when an extra supply of air is needed. A thin layer of bone ash should be spread over the bottom of the muffle to protect it in case of accident.

A muffle furnace fired by coke somewhat similar in construction to the furnace described on p. 73 is also made by Messrs. Morgan and Co., and will be found useful for assaying purposes when coal-gas cannot be obtained.

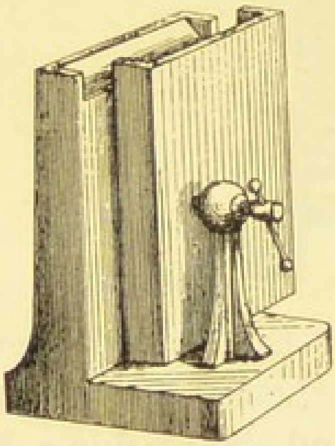


FIG. 27.

Ingot-Moulds.—Metals which are to be rolled into plate are cast into moulds which give a flat ingot suitable for passing through the rolls. The ingot-mould usually employed for this purpose is shown in Fig. 27. It is made of cast iron, in two parts, for convenience in removing the ingot, and should be slightly concave on the inner surfaces, to compensate for the greater shrinkage of gold in the middle than at the edges of the ingot. Before pouring, the moulds should be moderately heated and rubbed over with a well-oiled rag, or coated with a deposit of carbon by holding the inner surfaces over a gas or oil flame. Moulds are also frequently rubbed with blacklead powder, but when this is used care must be taken to remove all excess powder from the mould before pouring the metal. Ingot-moulds formed of soapstone are also employed for casting purposes and are preferred by some. As the metals for dental purposes require to be in the form of plate or wire, the ingot is subjected to rolling, &c., to fit it for the purpose required.

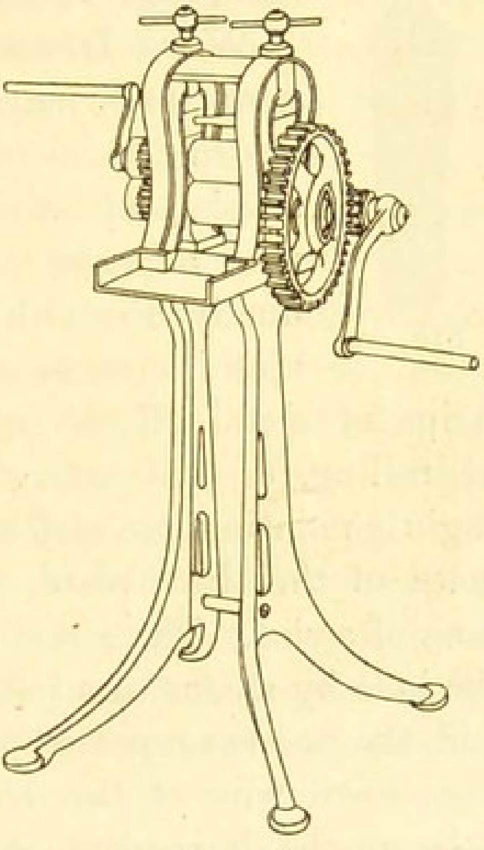


FIG. 28.

Rolling, or Laminating.—This is accomplished by passing the ingot repeatedly between two strong, highly polished cylindrical steel rollers. Many different forms of flatting mill are used for this purpose, that shown in Fig. 28 being frequently employed. These are so constructed that by adjusting the screws the rollers may be brought closer together every time the ingot is passed through. It is very important to keep the rollers perfectly parallel by very careful adjustment of the screws, otherwise the metal will twist and become unmanageable. As metals become hardened by rolling, the ingot should be frequently annealed during the process. The rollers for the purposes of the dentist should be from three to four inches in length.

Thickness of Plate.—The degree of attenuation obtained by rolling is determined by a gauge-plate, which is sometimes circular in shape and sometimes oblong, as shown in Fig. 29. The edge of the instrument is provided with a series of slits as shown, which gradually diminish in size and are indexed by numbers which correspond to regular fixed standards, which vary for the different countries. In order to determine when the plate has been rolled sufficiently thin it is repeatedly tested by the gauge during the operation of rolling.

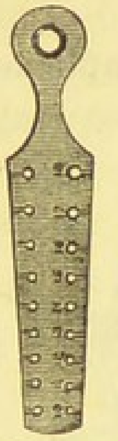


FIG. 29.

Wire-Drawing.—Thick wire or thin metal rods may be drawn into finer wire by passing them through a draw-plate, which consists of an oblong piece of steel pierced with a series of conical holes which gradually diminish in diameter. On a small scale, wire is readily obtained by cutting strips of metal off the rolled sheet in the direction of rolling, or by casting the metal into a thin rod, slightly pointing one end, and passing it into one of the holes of the draw-plate, which is firmly held in the jaws of a vice. The rod is then forcibly pulled through the hole by means of a pair of drawing tongs or pliers, and the process repeated with smaller holes in succession, until wire of the desired size is obtained. The holes in the draw-plate should be filled with grease or fat to facilitate the operation.

It is generally necessary to anneal the wire from time to time during the operation, otherwise it becomes hard and more or less liable to crack or break, after having passed through a certain number of holes. Draw-plates are also constructed for obtaining half-round, square, and other forms of wire.

Fluxes.

Definition.—A flux is a substance added when melting metals and smelting ores, for the purpose of combining with the infusible substances present or formed during the operation to render them fusible. The fusible body thus formed is termed a *slag*.

When metals or alloys are melted in contact with air the oxygen acts on the surface of the molten metal and converts it into oxide; if, however, a suitable flux is added it will combine with the oxide to form a fusible *slag*, which protects the surface of the metal from further oxidation. "In many cases of simple melting of metals it is desirable to remove base metals, which are present as impurities; it is then often advisable to add an oxidising flux, in order first to oxidise the impurities, in which state they readily combine with other fluxes to form a liquid slag." It is for this reason that nitre is added when melting impure gold (see p. 90). The chief flux employed in the dental laboratory is *borax*, which is principally used for soldering purposes, but also used occasionally when melting metals.

Borax (Sodium borate).—This substance fuses readily and is very fluid when in the molten state. In the crystallised or hydrated form it contains nearly half its weight of water, which is driven off on heating, causing it to swell up considerably. When strongly heated it fuses into a clear white glass known as *borax glass*. The inconvenience sometimes experienced by the swelling up of the hydrated borax may be avoided by the use of fused borax. The commercial material is frequently adulterated with common salt and alum.

Ammonium Chloride, commonly called Sal-ammoniac, is also frequently used as a flux. Several metals when in a molten state decompose this substance, forming metallic chlorides and liberating ammonia. Advantage is frequently taken of this property in purifying gold and also for purifying zinc which has become impure by frequent melting (see pp. 91 and 200).

A mixture of sal-ammoniac and charcoal is sometimes employed instead of the former alone.

Sodium Chloride, or common salt, is employed as a flux in melting operations, as it preserves the substance beneath from the action of the atmosphere and thus prevents oxidation. It is also used to moderate the action of substances such as nitre, which cause violent ebullition. It is for this reason that it is included in the charge for refining "lemel"—given on p. 120. It melts at a red heat in an open crucible and is very fluid when molten.

Potassium Nitrate, also called Nitre and Saltpetre. This substance is largely used as an oxidising agent, as it is decomposed on heating and yields a large volume of oxygen. It is specially useful when melting gold contaminated with small quantities of base metals.

Charcoal Powder is largely employed to prevent oxidation when melting metals. Flour and resin are also frequently used for the purpose.

Soldering.

The process of soldering is rightly regarded as a branch of mechanical dentistry, but as it deals with the melting of metals and the use of fluxes, a few notes on these points may be considered as coming within the scope of dental metallurgy.

Soldering is the process by which two or more pieces of metal are united by means of a fusible alloy termed a "solder" (see p. 55). It is chiefly confined in the dental laboratory to the use of gold solders, although occasionally "soft soldering" is found useful for several purposes.

In order to facilitate the soldering operation a "flux" is employed, which is usually borax.

When the various parts to be united are heated the surfaces become "darkened" by a thin coating of oxide, owing to the oxidation of the base metals present. If, however, borax is employed as a flux it will readily dissolve the metallic oxides which form, and also protect the metal from further oxidation by excluding the oxygen of the atmosphere. The flux is prepared by taking a lump of borax and rubbing it on a slab of ground glass, or porcelain, with clean water, until it attains the consistency of cream, after which it is applied to the surfaces to be united by means of a camel's-hair brush. A saturated solution of borax may also be used for soldering, the piece to be soldered being painted with solution where the solder is wanted to flow.

The conditions necessary for successful soldering are:

1. A solder which flows freely.
2. Contact of all the parts to be united.
3. Avoidance of excess of solder.
4. Exposure of a clean, bright surface in places over which solder is to flow.
5. A gradual and uniform distribution of heat.

As previously stated, the solders used should be more fusible than the metals to be united, should flow readily when fused, and should possess a strong affinity for the metals to be joined, in order that it may run into every part of the joint and thus effect a perfect union. The colour of the solder should correspond as nearly as possible to that of the plate on which it is used. As the solder is to be exposed to the action of the fluids of the mouth, in order that it may resist this action as far as possible it should be as high in quality as the plate will admit, without risk of melting the latter during the *fusion* of the solder.

Solders for dental purposes should be in the form of thin plate (about 0.75 mm. ($\frac{1}{35}$th of an inch) in thickness), which is cut up into pieces varying in size, depending on the extent of the surfaces to be united.

Very thin plate is objectionable, as it exposes a larger surface of base metal to oxidation, and consequently retards the flow of the solder and thus tends to weaken the joint. When solder is used in the form of filings it is first mixed with borax of the consistency of cream to form a paste, which is then applied to the parts to be united. The quantity of solder used should always be reduced to the minimum, as all superfluous portions have to be removed in the finishing process. When excess of solder is used the contraction which takes place on cooling is liable to cause the fracture of the teeth. Care should also be taken to avoid the use of excess of flux.

An *oxidising* flame should be avoided in all soldering operations, as this makes the surfaces of the metals unnecessarily "dirty," and renders it difficult to obtain a clean joint. It is also necessary that cleanliness be observed and care taken to prevent the surfaces to be soldered from contact with plaster-of-Paris, as this substance, on account of its infusibility, greatly interferes with the perfect union of the parts.

The gradual and uniform distribution of heat is of great importance in all soldering operations, and the failure to give proper attention to these points is frequently the cause of much delay and want of success. The temperature should be raised gradually at first, to prevent the displacement of pieces of solder by the swelling up of the borax used as a flux. The heating process for an artificial denture should also be conducted gradually, as a sudden elevation of temperature will cause displacement of the plaster owing to the too rapid expulsion of moisture and will tend to cause the fracture of the porcelain teeth.

In soldering a large piece of work the flame should be carefully directed until all parts are uniformly heated to the required temperature, and then the blowpipe-flame directed to the solder and parts to be united.

The process of soldering is a delicate operation to accomplish successfully, and needs to be undertaken with care and patience. With a little practice, however, the difficulties at first experienced are soon overcome, and neat and successful joints obtained.

Soft Soldering.—The method of soldering by means of the blowpipe is known as "hard soldering"; but when *soft* solders—*i.e.* those with very low melting-points—are used, the process is termed "soft soldering." The solders used for this process are usually alloys of tin and lead in varying proportions (see p. 211), the "softest" or most fusible being those containing the largest proportion of tin, this being the more fusible constituent. These solders are cast into the form of thin, narrow strips. The fusion of the solder on the surfaces to be united is usually effected by means of a "soldering iron," instead of the blowpipe as in hard soldering. The blowpipe, however, is in some cases employed for soft soldering. The soldering-iron consists of a specially shaped piece of copper, known as the "bit," which is attached to an iron stem and securely fixed in a wooden handle. In soft soldering a flux which is designated "soft soldering fluid" is used, and consists of a solution of zinc chloride, made by dissolving a small quantity of zinc in dilute hydrochloric acid. This solution is employed instead of borax to dissolve oxides or prevent oxidation of the surfaces to be united, and also to assist the "flow" of the solder. When the surfaces have been prepared the solder is melted and applied to the work by means of the soldering-iron. A novel application of "soft soldering" to dental purposes has been introduced by Mr. Baldwin * in connection with the repairing of bridges and crowns, the porcelain facings of which are broken. The process consists in soldering a "backed" tooth to the pre-existing "back," the new faces being attached with soft solder by soldering *in the mouth*. For this purpose a small clockmaker's soldering-iron is necessary, and in easy cases a fine quality of ordinary soft solder is used, while for more difficult cases, such as Richmond crowns, a solder with lower melting-point is required, that known as "pearl solder," which contains bismuth and mercury, in addition to tin and lead, being very suitable for the purpose.

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* *Dental Record*, 1896, vol. xvi. p. 489.

CHAPTER VI.

GOLD.

SYMBOL, Au (Aurum). ATOMIC WEIGHT, 197.

Occurrence.—Gold occurs very widely distributed in nature, and almost invariably in the metallic state, the native metal being found disseminated in veins in some of the oldest rocks. Formerly the most important deposits were the *alluvial* deposits, resulting from the disintegration of the ancient gold-bearing rocks by the weathering action of the atmosphere and running waters. The gold occurs in this gravel or sand detritus in rounded masses, and also in the form of fine grains or dust; the masses when of any considerable size being termed "nuggets," some of which have been found weighing as much as from a few pounds to two cwt.

Native gold invariably contains more or less silver; while copper and iron are also frequently present in small quantities. The purest specimens of native gold contain about 99 per cent. of gold. The Californian native gold averages 87 to 89 per cent., and the Australian from 96 to 97 per cent. of pure gold.

Preparation.—In order to extract the gold from alluvial deposits advantage is taken of its high density. The auriferous earth is washed in a "cradle" or pan in a stream of water, whereby the light particles of rock are carried away, and the greater portion of the metallic grains remains at the bottom of the washing apparatus, from which it is collected and melted into bars.

Gold is extracted from auriferous rocks by stamping the rock to coarse powder, then causing the powder to flow, by means of a stream of water, over inclined copper plates, the surfaces of which have been amalgamated—*i.e.* covered with a layer of mercury. The gold particles adhere to the mercury, with which they amalgamate, while the finely crushed rock is washed away. The gold amalgam thus obtained is carefully removed, placed in a retort, and the mercury distilled off, leaving the gold behind.

Another method adopted very largely within recent years is to place the crushed ore in large tanks, and treat it with a dilute solution of potassium cyanide, which readily dissolves out the gold. The gold solution is then run into boxes containing shavings of metallic zinc, which precipitates the gold; the precipitate is then collected, washed, dried and melted into bars.

Parting Gold from Silver.—Gold when extracted from its ores contains silver, and is frequently impure and brittle, owing to the presence of small quantities of base metals. In order, therefore, to separate these and render the gold malleable and fit for use it has to be refined or parted, and this may be effected either by a dry or wet method.

Miller's Process.—This dry method, which is frequently employed, consists in melting the gold in a crucible, glazed internally with borax, and passing a current of chlorine gas into the molten metal by means of a fireclay tube passing through the lid of the crucible. The silver and other impurities are converted into chlorides and rise to the surface and are partly volatilised. When the operation is complete, the crucible is allowed to cool, and when the gold has solidified the still molten silver chloride is poured off. The gold is cleaned from adhering chloride, and then remelted and cast.

Parting with Acid.—Gold is also purified from silver, copper, &c., by the wet process, termed "quartation or parting." In this case the gold is melted with from two to three times its own weight of silver, the molten alloy thus produced being poured into water in order to granulate it. The granules are carefully collected, and then boiled with strong sulphuric acid, whereby the silver and copper are converted into sulphates which dissolve in hot water, and the gold is left behind in a pure state as a brown powder. The gold powder is washed, dried and then melted and cast into bars.

The silver is readily obtained by placing sheets of copper in the solution, which precipitates the silver in the metallic state.

Nitric acid is sometimes employed for parting instead of sulphuric acid.

It is necessary to have the proportion of silver to gold about three to one, otherwise the silver would only be dissolved from the surface of the alloy, the large proportion and density of the gold present preventing the action of the acid throughout the mass and the complete removal of the silver when the proportion is less.

Preparation of Pure Gold.—Gold of extreme purity cannot be obtained by parting alone; when, therefore, gold is required of absolute purity it must be specially prepared.

Chemically pure gold is prepared by dissolving parted or standard gold in nitro-hydrochloric acid, the excess of acid being driven off by evaporation. The gold chloride thus obtained is dissolved in a large quantity of water and left at rest for about twenty-four hours to enable any precipitate of silver chloride to subside. The clear liquid is then carefully removed from the deposited silver chloride by means of a syphon, and the gold is precipitated by passing a current of gaseous sulphur dioxide through the solution, or by the addition of oxalic acid or other precipitating agent (see p. 96). The gold precipitate so obtained is washed repeatedly with dilute acid, then with ammonia and water, after which it is melted in a crucible with a little potassium bisulphate and borax and poured into an ingot-mould.

If a small quantity of platinum is present in the gold treated, alcohol and potassium chloride must be added to precipitate it before diluting the gold chloride with water.

Properties.—Gold has a characteristic yellow colour, but very thin leaves of the metal are translucent and appear green by transmitted light. It possesses a brilliant lustre and is susceptible of a high polish. Gold is one of the heaviest metals, its specific gravity being 19.4. Its hardness lies between that of aluminium and silver. In malleability (see p. 12) and in ductility gold exceeds all other metals, its ductility being such that a wire can be drawn so fine that 500 feet weigh only one grain.

It is a good conductor of heat and of electricity, though in these respects it is much inferior to silver. It is also capable of being welded together in the cold by the application of pressure. It is tenacious, though inferior in this respect to iron, copper, platinum and silver, the purest gold obtainable having a tenacity of 7 tons per square inch and an elongation of nearly 31 per cent.

Gold is not acted upon by atmospheric air, either at ordinary temperatures or when strongly heated ; neither is it tarnished by exposure to the action of sulphuretted hydrogen. Gold is not acted upon by any single acid (except selenic), but it is dissolved by chlorine or an acid mixture such as nitro-hydrochloric (aqua regia), which evolves chlorine. Selenic acid, even when moderately concentrated, has no effect upon gold in the cold, but the concentrated acid when used hot (230°–300° C.) dissolves the gold, forming gold selenate.* Alkaline solutions have no action on the metal. It melts at 1061° C. (1942° F.), and contracts considerably on solidification, and though practically a "fixed" metal it may be slightly volatilised at a very intense heat.

It will thus be seen that gold possesses, in an eminent degree, those general properties which render it peculiarly fit for the purposes to which it is applied in dental practice.

Use for Dental Purposes.—On account of its untarnishable nature, gold has long been employed in the dental laboratory. In the pure state it is used in the form of foil, as a filling for teeth and for other purposes. In combination with copper and silver it is largely employed for the base of artificial dentures.

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* V. Lenher, *Journ. Amer. Chem. Soc.* 1902, 24 [4], 354–355.

Effect of Impurities on the Properties of Gold.—The malleability and ductility of gold are materially influenced by the presence of only small proportions of other metals, such as tin, lead, zinc, antimony, &c. Gold alloys readily with *lead*, but a very small quantity of this metal is sufficient to impair the malleability and ductility of gold, rendering it quite brittle, and generally useless for any of the purposes to which gold is applied ; even $\frac{1}{2000}$th part of lead renders standard gold brittle and destroys its working properties. Having regard to this influence of small proportions of lead on gold, care should be taken, after annealing a gold plate, to prevent the plate while hot from coming into contact with any particles of lead, as this metal would at once be diffused into the plate and probably render it quite unfit for further treatment.

Antimony is particularly destructive to the malleability of gold ; .5 per cent. renders gold quite brittle, while quantities not exceeding .05 per cent. impair its malleability.

Bismuth alloys with gold, and is highly injurious, making it hard and brittle.

Zinc and *Tin* both form alloys with gold, the presence of these metals making the gold more or less brittle.

In the dental laboratory gold is very liable to become contaminated with particles of lead, zinc, and other metals. When, therefore, the gold scrap, &c., is to be reconverted into proper form for use, care should be taken to prevent the gold as far as practicable from becoming contaminated with base metals.

Brittle Gold.—Gold which is impure and brittle may be refined by melting it with a little borax in a crucible, and adding a small quantity of nitre (potassium nitrate). The nitre exercises a powerful oxidising effect on the base metals in the gold, and the resulting oxides form a liquid "slag" with the borax. Sal-ammoniac is sometimes sprinkled on the surface of the molten gold to remove the lead and tin after skimming off the slag.

Gold Foils.—For the manufacture of gold-leaf for industrial purposes the gold is usually alloyed with silver and copper, according to the colour required in the finished leaf; but gold foil for dental purposes is beaten from pure gold, on account of its superior welding power, which enables it to be pressed more readily into a compact form.

The metal is first melted and cast into small ingots, which are thinned by hammering, and then rolled until a ribbon is produced having a thickness of about $\frac{1}{300}$th of an inch; the gold requiring frequent annealing during this operation. The ribbon is then cut into pieces one inch square, weighing about six grains, about 150 of which are interleaved with sheets of vellum or parchment and the whole made into a packet. The "cutch" thus produced is beaten with a hammer until it has become extended to about four inches square or sixteen times the original area. If the sheets are intended for filling teeth the beating is not continued beyond this stage.

For application in the arts, however, the beating is frequently continued until the thickness of the leaves is about $\frac{1}{282000}$th of an inch. For this purpose the sheets are cut into four, and piled again between sheets of goldbeater's skin, thus forming a "shoder." The beating is then carried on for some time, after which the sheets are again cut up into squares, rearranged as before, forming a "mould," and the operation of beating repeated for about two hours until the leaves have acquired the degree of tenuity required for the purposes to which they are to be applied. From the finished leaves thus produced squares of about three inches are cut from the central portions by a piece of bamboo sharpened to a cutting edge. These are then piled in a book made of soft paper rubbed over with red ochre or red chalk to prevent adhesion, twenty-five leaves being usually placed in each book. Mechanical power has in recent years been substituted for manual labour in gold-beating. During the earlier stages of the process the blows are directed mainly towards the centre, which causes cracks and rents near the edges of the leaves; these cracks, however, become closed up again subsequently, the edges of the cracks welding together perfectly, so that the finished leaves exhibit no trace of them.

Gold for filling teeth is beaten into foils of varying degrees of thickness, the foils being generally numbered according *to the weight of the sheet*, the standard size of which is four inches. Each book of foil contains 60 grains ($\frac{1}{8}$ ounce) of gold, and the number of the foil indicates the weight of each full sheet.

For example, a book of No. 3 foils would contain 20 sheets, each four inches square and weighing three grains; a book of No. 5 foil would contain 12 sheets, four inches square, each weighing five grains; book No. 6, 10 sheets, four inches square, each six grains in weight, and so on. Foils ranging from No. 32 upwards are usually employed and are prepared by folding a sheet of No. 4 foil, so that it becomes equivalent to

No. 8 foil, and then folding it again to make it as thick as No. 16 foil, and then again to make it equal to No. 32 foil. When heavier foils are needed several sheets can be folded together.

Although the foils are generally prepared by beating, yet some of the heavier numbers, averaging from No. 20 to No. 60, are produced by rolling, and these are sometimes used instead of thin foils folded to the required thickness, as they are extremely cohesive and may be advantageously employed in extensive contour operations. The heavier foils, however, are not so easily worked and considerable practice is required in using them.

The advantages claimed for gold as a filling for teeth are that it is able to withstand the attrition to which fillings are exposed and that it retains its shape, and, therefore, forms a practically watertight plug; it has no preservative action, however, upon the tooth substances.

Cohesive and Non-Cohesive Gold.—There are two varieties of gold-foil used in dentistry, known as *cohesive* and *non-cohesive*. In the cohesive variety the characteristic welding property of pure gold is utilised, each piece of gold-foil introduced into the cavity of the tooth being carefully welded to the others already in position, principally by means of pluggers and mallets, thus consolidating the gold.

In the non-cohesive variety union does not take place between the pieces of gold introduced into the cavity, the gold being made to retain its position mechanically by wedging and intimately interlacing the pieces very tightly between the walls of the cavity.

The difference between these varieties of gold-foil is brought about by a slight alteration in the method of manufacture. Non-cohesive gold is so prepared that there is no possibility of one piece sticking to another. This appears to be attained by subjecting the leaves of foil to the influence of certain gases, such as ammonia gas. Graham has shown * that when pure gold is heated it has the power of occluding or absorbing gases, notably hydrogen and nitrogen. "The amount of hydrogen occluded by gold is sensible, but does not exceed 0.48 of its volume. Probably the most interesting point connected with the occlusion of gases by gold is presented by the fact that the metal *retains* 0.2 of its volume of nitrogen." It is, no doubt, the retention of nitrogen which destroys the cohesive property of gold. A pellet of cohesive gold may be made non-cohesive by exposing it to the atmosphere, or, more expeditiously, by submitting it to the action of ammonia gas. "If non-cohesive gold is annealed it will often be noticed that a vapour is given off, and then it becomes, as a rule, thoroughly cohesive. There are a few makes of non-cohesive gold which become so slightly cohesive on being annealed that this does not prevent their being worked non-cohesively. These foils, the character of which is only slightly changed by annealing, are often spoken of as 'true non-cohesive gold.' They *can* be worked cohesively, but it demands special care and manipulation. What it is that gives them this particular property is a trade secret. In some cases it is probably due to a very slight admixture of another metal; these true non-cohesive foils,

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* Percy's "Metallurgy," vol. i. p. 35; experiments recorded by Roberts-Austen.

however, seem also to have been subjected to the action of some vapour, for, as above mentioned, they are not so absolutely non-cohesive when annealed, and heating them causes a vapour to be given off just as with other makes of non-cohesive gold."* "In using cohesive gold, care should be taken to avoid touching it with the hands, since moisture, grease, and exposure to air destroy its cohesiveness. Though foils are sold as cohesive, it is always best to pass them through the flame before working, in order to anneal them and restore their cohesiveness, and for this purpose a spirit lamp should be used. A Bunsen burner leads sooner or later to failure, owing to the impurities contained in the gas. In annealing, care should be taken not to overheat the gold, since many varieties become harsh when exposed to a high temperature. Good cohesive gold can be annealed to a dull red-heat without becoming harsh."† The annealing is best effected by placing the foil upon a sheet of mica, which is held over the flame of a spirit lamp.

Much diversity of opinion exists with regard to the relative values of the two varieties of foil, the advantages claimed by the advocates of each variety being briefly as follows:

For Cohesive Foil.—That it makes a harder and more compact filling, although taking longer to work. That it adapts itself to the walls of the cavity as well as non-cohesive foil. That in any case exposed to mastication the filling remains smoother and the edges stand better.

For Non-Cohesive Foil.—That fillings are much more

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* Grayston, *Dental Record*, 1896, vol. xvi. p. 105.

† Smale and Colyer, "Diseases of Teeth," p. 193.

rapidly made, as larger pieces can be used. That the adaptation to the walls of the cavity is better than with cohesive gold, thus the preservation of the tooth is better. That it can be more thoroughly burnished to the edges on account of the greater softness which it possesses.

With due care either variety is capable of affording good results ; a combination of the two varieties, however, is extremely useful and often employed, the advocates of this combined method claiming that a better joint is obtained at the cervical edge than with cohesive foil.

Cohesive foil is the variety most generally employed, the gold being consolidated by hand pressure or by means of a series of blows struck by a hand, electric, automatic, pneumatic, or engine mallet.

Precipitated and Spongy Gold.—Metallic gold may be precipitated from a solution of gold chloride in the form of fine powder, in scales, in a more or less crystallised state, or in a spongy condition, according to the nature of the precipitating agent employed, and also on the strength of the solution and mode of operating. The gold chloride solution is prepared by dissolving metallic gold in aqua regia as described in the preparation of pure gold (p. 87).

Owing to the facility with which gold chloride is reduced to the metallic state, a large number of different reagents may be used for precipitating the gold.

The reagents most frequently employed are sulphurous acid, oxalic acid, and ferrous sulphate.

By Sulphurous Acid.—When an excess of sulphurous acid is added to a hot solution of gold chloride the gold is precipitated in the form of a brown powder which is more or less scaly.

By Oxalic Acid.—This acid is a very useful precipitant and will give gold of several forms, from sponge-like masses to the different crystalline or powdery forms, according to the strength and temperature of the gold solution. Its action, however, is somewhat slower than that of other precipitants and the solution requires heating.

The crystallised oxalic acid is dissolved in water and then added to the gold solution, when carbonic acid gas is evolved, owing to the decomposition of the acid, and the gold is precipitated.

By Ferrous Sulphate.—This reagent precipitates metallic gold, either at once or on heating the solution, in the form of a very finely divided brown powder. The liquid in which the fine powder is suspended appears dark blue by transmitted light and reddish and turbid by reflected light. The solution is poured off after subsidence has taken place, and the precipitate is washed first with a little dilute hydrochloric acid and subsequently with water, and then dried.

By other Precipitating Agents.—The majority of the common metals will precipitate metallic gold from a solution of the chloride.

Many organic substances also readily precipitate the metal. Thus, when a solution of gold chloride is boiled with sugar the gold is thrown down first as a light red precipitate, which afterwards darkens in colour. As sugar is similar to oxalic acid in its action, the precipitation is capable of regulation, and various forms of gold may be obtained. "Lamm's so-called 'shredded gold,' somewhat extensively used by dentists for filling teeth during 1867 and 1868, was produced by the addition of sugar or gum arabic to an acid solution of gold."

When precipitated from its solutions, gold assumes a dark-brown colour, but on being rubbed with a piece of polished steel, or other hard substance, it readily assumes its characteristic colour and metallic aspect. Precipitated and finely divided gold are capable of being welded and united into a solid mass by the application of pressure.

The various forms of sponge and crystal gold used by dentists are frequently prepared by precipitation, but other methods are also adopted.

Crystal Gold.—When an electric current of feeble intensity is passed through a solution of gold chloride in which a plate of pure gold forming the anode is suspended, and a platinum plate, forming the cathode, the solution is decomposed and the gold deposited on the platinum plate in the form of crystals, which vary in size according to the strength of the solution and intensity of the current.

As the solution loses gold by deposition of the metal, it is replenished from the suspended gold plate, which is gradually dissolved. The crystal gold thus formed is generally very pure; it is collected, washed and dried, and is then ready for use.

The beautiful spongy form of gold known as "Watts' Crystal Gold" is produced in this way. It is a cohesive gold, and must be used strictly as such.

A crystallised form of gold is also obtained when an amalgam of gold is slowly heated until the whole of the mercury is expelled. When, however, a light spongy mass is required, the amalgam is first treated with nitric acid to dissolve out the excess of mercury. The aggregate of crystals thus obtained is then heated to expel the remaining mercury, thus leaving the gold as a light spongy mass, having a bright lustrous appearance.

Assay of Gold.—Alloys of gold are usually assayed by—

1st. Alloying them with silver by the process of cupellation (see Silver Assay, p. 178).

2nd. Parting the gold from the silver by means of acid.

For this purpose about ½ to 1 gramme (10 to 20 grains) of the alloy is carefully weighed and wrapped in a piece of lead-foil with pure silver equal in weight to 2½ times the quantity of gold assumed to be present in the weight of alloy taken for assay.

This is then subjected to cupellation, by which means the lead and copper are oxidised and absorbed by the cupel, while the silver and gold remain behind as an alloy on the cupel. The gold-silver bead is removed and rolled out to an oblong strip about 2 inches long, after which it is annealed and coiled into a spiral.

The spiral or "cornet," as it is termed, is placed in a glass flask, and "parted" by heating it, first with dilute nitric acid for about 15 minutes and then with stronger nitric acid, by which means the silver is dissolved out, leaving the metallic gold as a brown residue.

The acid is poured off and the gold washed with water, after which it is dried and then placed in a small crucible, and "annealed" in a red-hot muffle for a short time, when the gold acquires the usual yellow colour, with a considerable shrinkage in bulk.

The gold is allowed to cool, then carefully weighed and the percentage of gold present in the alloy calculated from the weight thus obtained.

After parting, the gold retains a very small quantity of silver, so that when very great accuracy is required a system of working with "checks" is adopted. In this case an amount of pure gold (approximately equal to that in the assay) is very accurately weighed and alloyed with the necessary quantity of other metals, in order that the check may correspond in composition to the alloy to be assayed. It is then treated simultaneously with the assay and exactly in the same way. If the gold left after parting the cornet from the "check" weighs more than the pure gold taken, the excess weight is deducted from the weight of the gold obtained from the assay of the alloy; and, conversely, if it weighs less the deficiency is added.

Assay by the Touchstone.—This method of determining the fineness of a gold alloy consists in rubbing the alloy to be tested on a small block of hard, smooth, dark stone, resembling slate, called a *touchstone*, and comparing the appearance and colour of the streak thus produced with those made by a series of small bars of carefully prepared alloys of definite composition, known as "touch-needles" (Figs. 30 and 31). The effect of the action of a drop of nitric acid and of dilute aqua regia on these streaks is also noted; the streak from the less pure alloy will be more readily acted upon, with the production of a more or less green colour, according to the proportion of copper present. Several series of touch-needles are usually employed, consisting of alloys of gold and copper, gold and silver, and gold, silver and copper, the alloys being made either to correspond to legal standards or in series in which the proportion of gold increases by carats or half-carats. For the sake of convenience, the touch-needles are frequently soldered to the points of a star-shaped piece of metal, as shown in Fig. 31.

The valuation of an alloy is made by determining to which of the touch-needles the streak it produces most nearly corresponds. In order to get correctly the streak of the alloy to be tested, the surface of the metal should first be slightly filed away, as this may have been made somewhat richer than the bulk of the alloy by boiling with acid to remove the base or inferior metal from the surface, as in the "colouring" process used by goldsmiths (see p. 116).

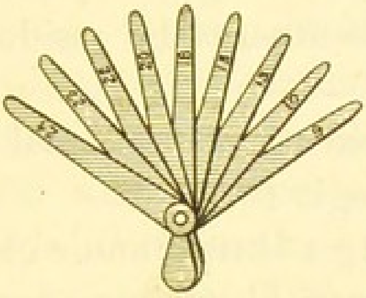

FIG. 30.

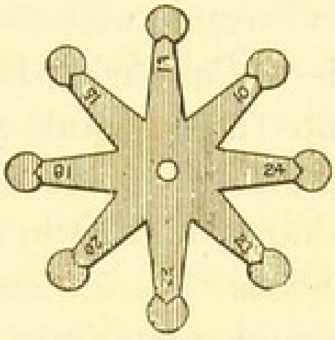

FIG. 31.

The touchstone is generally used for the approximate assay of small articles of jewellery, which it would be necessary to destroy in order to obtain samples for a correct assay; it is also of use to the assayer in determining the approximate fineness of gold bullion; but it cannot be relied upon for very accurate assay, although it yields sufficiently useful results for a preliminary test, and for some purposes is sufficiently exact. It requires, however, a sharp and very practised eye. "The trial is more sensitive for alloys below 750 fine (18 carat) than for higher standards. The amount of gold in alloys between 700 and 800 fine (17 to 20 carat) can be determined correct to 5 parts per 1000." *

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* T. K. Rose, "Metallurgy of Gold," p. 459.

Detection and Estimation of Gold in Alloys.—Alloys for dental amalgams are mainly composed of tin and silver, to which small quantities of gold and platinum, and sometimes other metals, are added.

DETECTION OF GOLD.—The presence of gold in these alloys may be detected by treating a small quantity of the alloy with nitric acid, when the gold will remain undissolved. As tin is invariably present in dental alloys, it will be converted into oxide by the nitric acid and remain with the gold, forming a purple residue (purple-of-Cassius). If gold is absent the residue will be white (metastannic acid).

The following are the usual tests for gold after obtaining a solution in aqua regia :

Stannous Chloride containing a little stannic chloride is a very characteristic test for gold, giving a beautiful purple precipitate (purple-of-Cassius), even in solutions containing extremely small quantities of gold.

Ferrous Sulphate is also a delicate test, producing either at once or on heating the solution a very finely divided precipitate of gold: the liquid usually appears bluish by transmitted light, and is always reddish and turbid by reflected light.

Sulphuretted Hydrogen gives a brown or black precipitate of gold sulphide.

ESTIMATION OF GOLD.—When tin is absent, the residue of gold obtained after treatment of a definite weight of the alloy with nitric acid may be filtered off and then heated to redness and weighed.

If tin is present the residue of "purple-of-Cassius" is filtered off and then fused with caustic potash, which combines with the tin, forming a compound (stannate of potash) readily soluble in water, leaving the gold as a fine powder. This is collected on a filter, then washed, heated to redness and weighed.

The gold in amalgam alloys may also be determined by submitting a small quantity to scorification, as described under Silver, p. 180, then cupelling and parting the gold-silver bead with nitric acid in the ordinary way as previously described. The gold present in these alloys usually varies from one-tenth per cent. to about 5 per cent.

Alloys of Gold.—Gold is capable of uniting with almost any of the metals, its alloys with other metals constituting its most important uses, as pure gold is too soft for application alone.

Gold and Copper.—These metals alloy well together in all proportions when fused. Copper increases the hardness of gold, the maximum degree of hardness being attained when the copper constitutes one-eighth of the alloy. The yellow colour of gold is deepened by the presence of copper, and when much copper is present the alloys become tarnished on exposure. The malleability of these alloys is scarcely inferior to that of gold if pure copper is employed, and does not exceed 10 to 12 per cent. Alloys of gold and copper are more fusible than pure gold.

The gold coinage of this country is made from 22-carat gold, or 916.6 parts of gold to 83.3 parts of copper, the alloying metal being copper. This alloy is termed *standard gold* (see p. 105).

An alloy of gold and copper of 18-carat standard is very largely employed for jewellery.

Gold and Silver.—These metals unite in all proportions when melted together, the resulting alloys being paler in colour than pure gold, the presence of one-twentieth part of silver being sufficient to modify the colour of gold. With 27 to 30 per cent. of silver the alloys have a green tint, but when the silver exceeds 50 per cent. the alloys are nearly white. The effect of silver is to give hardness to the gold without impairing its malleability, and to make it tougher and more elastic, while at the same time sensibly reducing the melting-point.

Gold-silver alloys do not oxidise on exposure to air, but are more or less tarnished in the presence of sulphuretted hydrogen.

Gold, Silver, and Copper.—These three metals are largely used by jewellers and by dentists for the production of alloys, which are tougher, more malleable and more ductile than when copper alone is used as the alloying metal.

Alloys of these metals, in varying proportions, are used as gold solders (see p. 110).

Gold and Platinum.—These metals unite by fusion, but require a high temperature to effect their combination, in consequence of the high melting-point of platinum. The effect of platinum on gold is to produce alloys which are ductile and elastic, but its presence makes the colour of gold paler.

Gold and Mercury.—These metals have a great affinity for one another, even at ordinary temperatures (see Gold-Amalgam, p. 134). If a piece of gold is rubbed with mercury it is immediately penetrated and becomes exceedingly brittle; care should therefore be taken to prevent globules of mercury coming into contact with gold plate in the dental laboratory.

Gold and Tin.—These metals form alloys which are usually brittle and of a paler colour than gold.

Carat and Fineness.—Gold is never employed in a pure state, but is almost universally alloyed with a certain proportion of copper or of silver, the alloys being made up to definite proportions or "standards."

Pure gold is described as 24 carats *fine*, and the fineness of gold, or its proportion in the alloy, is therefore expressed by stating the number of carats (or parts) of pure gold present in 24 carats of the alloy. The English gold coinage, or standard gold, consisting of an alloy of 22 parts of gold with 2 parts of copper, is accordingly described as 22 carats fine. 18-carat gold is an alloy consisting of 18 parts of gold and 6 parts of copper. In some cases part of the copper is substituted by silver; thus, the standard frequently employed by goldsmiths, though of 22 carats fine, contains in the 24 carats 22 of gold with 1 of copper and 1 of silver. In special cases the alloying metal may be platinum, as in 17-carat gold plate used for bands in dental work.

In England at the present time five legal standards exist for gold ware, viz.—22-carat, or standard gold; 18, 15, 12, and 9-carat gold. Gold plate and wire for dental purposes are made to standards of 22, 20, 18, 17, and 16 carat, while for gold springs and swivels 13-carat gold is employed.

The fineness of gold is also frequently expressed in decimals, in which case pure gold is described as 1000 fine. The English standard for gold coin, 22 carat, would therefore be 916.6 fine, and would contain this number of parts of fine gold in 1000 parts of alloy.

The standard of the American, German, and French gold coinage is 21.6 carats or 900 fine. The relation of the carat to decimals is shown in the following table:

——	Carat.	Decimal.
Pure gold	24	1000
English gold coin	22	916.6
American ,,	21 6	900
Dentist's gold	20	834
,, ,,	18	750
,, ,,	17	709
,, ,,	16	667
,, ,,	15	625
,, ,,	13	542
,, ,,	12	500

Gold Plate.—Pure gold is seldom employed in the dental laboratory, on account of its softness and flexibility. In order to obtain the degree of hardness, strength, and elasticity necessary to enable it to resist the wear and strain to which an artificial denture is invariably exposed in the mouth, the gold for dental purposes is alloyed with other metals.

These important properties are usually conferred upon the gold by the addition of copper or of silver, or both; or by copper, silver and platinum. Varying proportions of copper and silver are most generally employed, but gold plate, such as that used for bands, &c., is sometimes alloyed with platinum in order to give it additional elasticity. The quality of gold which is to be introduced into the mouth should not, as a rule, be less than 18 carat fine or much above 20 carat. Gold of low standard is much more readily tarnished, owing to the larger proportion of copper and silver present, and communicates to the mouth a disagreeable metallic taste, while gold of high standard will generally be found too soft and yielding and not capable of resisting the strain put upon it during mastication.

Higher grades of gold plate intended for dental purposes may, however, have the requisite amount of rigidity and strength conferred upon them by the addition of a small quantity of platinum. Gold plate suitable as a base for artificial dentures may be prepared according to the following formulæ;* the relative proportions of the various metals added to the pure gold or to the standard gold may, however, be varied to suit the requirements of the manipulator.

The approximate quantities are also given for the preparation of gold plate from the formulæ when English standard gold (coin) is used, (22 carats fine) instead of pure gold:

GOLD PLATE. 18 CARATS FINE.

	dwts.		dwts.	grs.
Pure gold	18	Standard gold	19	15
Copper	4	Copper	2	9
Silver	2	Silver	2	0

GOLD PLATE. 20 CARATS FINE.

	dwts.		dwts.	grs.
Pure gold	20	Standard gold	21	19
Copper	2	Copper	0	5
Silver	2	Silver	2	0

GOLD PLATE. 22 CARATS FINE.

	dwts.	grs.
Pure gold	22	0
Copper	1	0
Silver	0	18
Platinum	0	6

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* Richardson, "Mechanical Dentistry," 7th edit, 1898, p. 81.

The addition of a small amount of platinum to high carat gold, as in the last formula, furnishes an alloy rich in gold, while, as previously stated, it imparts to the plate a suitable degree of stiffness and elasticity and does not destroy the characteristic colour of fine gold nor materially impair its susceptibility of receiving a high polish. The richness of colour of the gold plate is, however, more or less impaired as the quantity of platinum is increased.

Gold plate 20 or 21 carats fine, in which the alloying metals are copper and platinum, is frequently used by dentists on account of its greater strength and power of resisting the chemical action of the fluids of the mouth. With reference to gold plates containing platinum, Essig remarks * that "owing to its increased strength and stiffness a much thinner and lighter plate may be employed without the additional labour and cost of doubling the plate at what would be weak points in partial cases composed of ordinary 18-, 19-, or 20-carat gold." An objection urged against the employment of gold plate containing platinum is the increased difficulty of swaging a plate of the alloy so that it shall perfectly conform to all the depressions of the die. Essig having invariably found, when the alloy contained any considerable percentage of platinum, that the ordinary method of swaging between zinc and lead was not effective, has for more than twenty years employed zinc for counter dies as well as for dies, thus entirely overcoming any difficulty in swaging.

Gold plate and wire used in making bands and clasps should contain a little platinum in order to

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* Essig, "Dental Metallurgy," 1893, p. 139.

render it sufficiently elastic to firmly embrace the tooth. 17-carat gold alloyed with platinum is frequently employed for this purpose. The following formula gives the quantities necessary for the preparation of 20-carat gold plate suitable for clasps, and whenever elasticity and additional strength are required:

GOLD PLATE. 20 CARATS FINE.

Pure gold	20 dwts.	Standard gold	22 dwts.
Copper	2 "	Copper	0 "
Silver	1 "	Silver	1 "
Platinum	1 "	Platinum	1 "

In France the following alloys are used for "dental" gold plate: *

	No. 1. 18 cts.	No. 2. 20 cts.	No. 3. 21 cts.	No. 4. For clasps.
Gold	18	20	21	20
Silver	2	2	1	1
Copper	4	2	2	2
Platinum	—	—	—	1

ALLOYS PREPARED FROM FRENCH GOLD COIN (900 FINE).

	No. 1. 18 cts.	No. 2. For clasps.
Gold coin	20	20
Silver	2	0.4
Copper	2	0.3
Platinum	—	0.75

Preparation of Gold Plate.—Alloys for gold plate are prepared by melting the constituents together in a plumbago crucible, which should be carefully annealed in an inverted position before use. A small quantity of charcoal powder should be placed on the surface of the metal to form a protective coating and prevent the oxidation of the copper;

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* Communicated to the author by André P. Griffiths.

the crucible should also be covered with a lid. The crucible is then heated in a suitable furnace at a good bright heat, and when the mixture is melted the whole should be stirred with an iron rod (previously made red hot) in order to promote more intimate union between the constituents of the alloy. The alloys of gold should not be over heated but poured immediately after complete fusion has taken place. The metal is cast into an ingot-mould (see p. 76) and subsequently rolled into sheets of the required thickness. The mould must be blackened or greased to prevent the metal sticking, and must be dry and warmed before use. Care should be taken to prevent the charcoal powder from running into the mould with the metal, otherwise it will cause a faulty casting. When melting up clean scrap for the production of plate the precautions given on p. 66 should be considered.

Gold Solders.—These are alloys of gold employed for effecting the union of the various parts of articles composed of pure gold or of gold plate.

To do this successfully the solder used must have a lower melting-point than the materials to be joined with it ; the fusing-point of the solder should, however, approach as near as it conveniently can to that of the material to be soldered, in order that a more perfect and more tenacious joint may be obtained.

Many varieties of gold solder of different degrees of "softness" and "hardness," *i.e.* of fusibility, are produced by adding to the gold variable proportions of the more fusible metals—silver, copper, and sometimes zinc.

Gold solders are very frequently made from the same carat gold as that of which the article to be soldered is composed, the melting-point being lowered by the addition of copper and silver, or of standard silver and sometimes of brass. In some cases gold plate of low standard may be employed as a solder for gold plate of a higher standard. As several standards of gold are used in dental work, solders of different degrees of fineness are employed, the solder most suitable for the work in hand being selected. The most desirable range for gold solders is from 20 to 12 carats, or from 15 to 50 per cent. of alloy, although many consider 12-carat solder too coarse for dental work. The presence of zinc renders the solders more fusible, but when employed it should only be in quantities sufficient to make the gold flow readily and evenly at a diminished heat; when used in excess it becomes objectionable. Gold solders containing zinc are always more or less brittle, and consequently difficult to roll into plate without breaking into many pieces.

The following alloys are largely employed in this country as gold solders for dental work. They are very fluid and flow readily in a state of fusion, and effect a perfect combination between the parts united by them.

No. 1. "Best Quality." 15-carat Solder.

Gold	15 dwts.	Standard gold	16.5 dwts.
Silver	4 "	Silver	4.0 "
Copper	5 "	Copper	3.5 "
	24 "		24.0 "

No. 2. "Medium." 13-carat Solder.

Gold	13 dwts.	Standard gold	14 dwts.
Silver	6 "	Silver	6 "
Copper	5 "	Copper	4 "
	24 "		24 "

No. 3. "Most Fusible." 12-carat Solder.

Gold	12 dwts.	Standard gold	13 dwts.
Silver	6 „	Silver	6 „
Copper	6 „	Copper	5 „
	24 „		24 „

The following formula * may be used in connection with 18- to 20-carat gold plate, and is 16 carat fine :

16-carat Solder.

Pure gold	6 parts or	16 dwts.	0 grs.
Silver	2 „	5 „	8 „
Copper	1 „	2 „	16 „
		24 „	0 „
Standard gold	6.5 parts or	17 dwts.	8 grs.
Silver	2.0 „	5 „	8 „
Copper	0.5 „	1 „	8 „
		24 „	0 „

The following formulæ will furnish 15-carat and 18-carat solders :

15-carat Solder.

Pure glod	15.0 parts	Standard gold	16.8 parts
Silver	3.6 „	Silver	3.6 „
Copper	4.2 „	Copper	2.4 „
Brass	1.2 „	Brass	1.2 „
	24.0 „		24.0 „

18-carat Solder.

Pure gold	18.00 parts	Standard gold	19.66 parts
Silver	2.66 „	Silver	2.66 „
Copper	2.66 „	Copper	1.00 „
Brass	0.68 „	Brass	0.68 „
	24.00 „		24.00 „

Borax is always used as a flux with gold solders.

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* Harris, "Dental Surgery," No. 3, p. 666.

Preparation of Gold Solders.—In preparing gold solders the metals are carefully weighed and then melted together in a plumbago crucible in a furnace at a bright red heat. A little charcoal powder is sprinkled on the surface to prevent oxidation. When complete fusion has taken place, the metal is stirred and then poured into an ingot-mould to obtain a thin ingot suitable for rolling.

When zinc or brass enters into the composition of the solders it should be added after the other constituents are completely melted, care being taken to avoid excessive heating. The alloy should then be well stirred and poured immediately.

The metals employed for the preparation of gold solders should be free from impurities, and great care should be taken to insure uniformity of composition.

Calculation of the Carat Fineness of Alloys.—The several calculations in connection with the carat fineness of various mixtures may be readily made by the application of a simple method devised some years ago by Mr. A. McWilliam, of the University College, Sheffield, for the calculation of all kinds of steel mixtures, and now extensively used by students and in the works.

A carat being one $\frac{1}{24}$th part (see p. 105), the number of ounces (or other unit of weight) multiplied by the carat fineness gives the number of 24ths of an ounce of fine gold present in an alloy, and this new unit ($\frac{1}{24}$th ounce) is termed the "carat ounce."

This new unit will be found very convenient in calculating the carat fineness of gold alloys, for it is obvious that in any alloy .

$$\frac{\text{carat ounces}}{\text{ounces}} = \text{carats.}$$

$$\frac{\text{carat ounces}}{\text{carats}} = \text{ounces.}$$

$$\text{ounces} \times \text{carats} = \text{carat ounces.}$$

The application of this method will be readily understood from the following examples:

I. To ascertain the Carat Fineness of an Alloy from a given Mixture:

Example I.—The following mixture is given for the preparation of a gold solder: Pure gold, 6 ozs.; silver, 2 ozs.; copper, 1 oz. Total, 9 ozs.

Ascertain the fineness of the alloy produced. 6 ozs. pure gold contain 6 × 24, or 144 carat ounces of gold, and as this is the amount of gold in 9 ozs. of alloy, the carat fineness of the alloy is 16.

$$\frac{\text{144 carat ozs.}}{\text{9 ozs.}} = \text{16 carats fine.}$$

Example II.—Again, take a gold solder in the preparation of which English standard gold has been used instead of pure gold, the quantities being 48 dwts. standard gold (22 carat), 16 dwts. silver, 12 dwts. copper. Total, 76 dwts. 48 dwts. standard gold contain 48 × 22, or 1056 carat dwts.

$$\frac{\text{1056 carat dwts.}}{\text{76 dwts.}} = \left\{ \begin{array}{l} \text{13.9 carats as the fineness of the} \\ \text{alloy from the given mixture.} \end{array} \right.$$

II. To Reduce Gold to a Required Standard:

The standard of a gold alloy may be lowered by the addition of copper, or of silver, or an alloy of these, such as silver coin.

Example I.—Reduce 4 ozs. pure gold to 16-carat gold. 4 ozs. pure gold contain 4 × 24, or 96 carat ozs.

$$\frac{96 \text{ carat ozs.}}{16 \text{ carats}} = 6 \text{ ozs.}$$

6 ozs. is the weight of the alloy of 16-carat fine, and as 4 ozs. of gold are used, 2 ozs. of other metal must be added to reduce the pure gold to 16-carat gold.

Example II.—Reduce 2 dwts. of 18-carat gold to 16-carat gold.

2 dwts. of 18-carat gold contain 2 × 18, or 36 carat dwts.

$$\frac{36 \text{ carat dwts.}}{16 \text{ carats}} = 2\tfrac{1}{4} \text{ dwts.}$$

Hence ¼ dwt. of other material must be added.

To Raise Gold to a Higher Carat:

This may be done by adding either pure gold or gold alloy of a higher standard than that to be prepared.

Example I.—Raise 10 dwts. of 18-carat gold to 20-carat gold.

The 10 dwts. must be raised 2 carats, and this will require 10 × 2, or 20 carat dwts.

The pure gold (*i.e.* 24 carats) added must be considered to retain 20 of its own carats, and hence there are only 4 carats available for enriching.

$$\frac{20 \text{ carat dwts.}}{4 \text{ carats}} = 5 \text{ dwts.}$$

5 dwts. of pure gold must therefore be added to raise 10 dwts. of 18-carat gold to 20-carat gold.

Example II.—Raise 10 dwts. of 18-carat gold to 20-carat gold by the addition of standard gold (22 carats).

Standard gold has 2 carats available for enriching.

$$\frac{20 \text{ carat dwts.}}{2 \text{ carats}} = 10 \text{ dwts. of standard gold to be added.}$$

Example III.—Raise 9 dwts. of 13-carat gold to 16-carat gold by the addition of 20-carat gold.

9 dwts. raised 3 carats = 27 carat dwts.

20-carat gold has 20 – 16 = 4 available carats.

$$\frac{\text{27 carat dwts.}}{\text{4 (available) carats}} = 6\tfrac{3}{4}\text{ dwts. to be added.}$$

Colouring of Gold.—This term is applied to the process by which a superficial film of fine gold is obtained on articles made of gold alloys to improve their appearance, and is effected by externally dissolving out the copper or other metal with which the gold is alloyed. In conducting the process the article to be coloured is first heated to dull redness in a Bunsen flame or flame of a spirit lamp, and then plunged into a weak solution of nitric acid or other acid bath, by which means the copper, &c., on the surface is dissolved, leaving behind a film of pure gold of a deep, rich, yellow colour.

The same effect is also frequently produced by a method known as "dry colouring," which consists in placing the article to be coloured for a few minutes in a paste, composed of a mixture of saltpetre, common salt and alum. Twelve-and-a-half to thirteen carat gold is the lowest quality that can be satisfactorily subjected to the colouring process, and retain a rich and uniform appearance without showing irregularities on the surface.

Gilding.—By this process articles of low standard or of base metal are made to resemble high carat gold by having a thin film of gold deposited on their surface. The method now usually adopted for this purpose is known as "electro-gilding," and is dependent on the fact that when a current of electricity is passed through a suitable solution of a metal decomposition of the liquid takes place, the constituents of the liquid being liberated and the metallic constituent deposited.

Large articles are gilded in cold solutions and smaller articles in hot solutions. A solution for electro-gilding small articles may be prepared by dissolving 15.4 grains of pure gold in aqua regia and evaporating nearly to dryness. The gold chloride thus formed is dissolved in water, and a solution of potassium cyanide carefully added as long as a precipitate of gold cyanide is given. The precipitate is allowed to settle, the clear liquid poured off, and the precipitate dissolved by the addition of more potassium cyanide solution. The solution is then diluted with water to one quart. The temperature of the bath should be about 165° F., and the current strength 2.0 to 2.5 volts.

The process is conducted by first thoroughly cleansing the article by immersing it in a hot solution of caustic potash, and sometimes in an acid bath, and also by means of a scratch-brush.* The article is then rinsed in water and transferred to the plating solution.

A plate of pure gold is suspended in the bath from a suitable support connected with the positive pole of a battery, while the article to be plated is suspended by thin copper wire connected with the negative pole. By this means an electric current is passed through the plating liquid, which causes the deposition of a film of metallic gold on the article.

The gold solution is kept hot during the operation (as above stated), and remains constant in strength

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* This consists of a bundle of fine, hard brass wire about 6 in. or 8 in. long, bound round very tightly with other wire, the ends being left free to form a brush.

owing to the gradual dissolving away of the gold plate. When sufficient gold has been deposited, the article is removed and well rinsed in water; the dull brown surface is then made bright and lustrous by burnishing. The electric current employed is usually derived from a Bunsen battery, and the proportion of gold cyanide, potassium cyanide, and water in an electro-gilding solution may vary very greatly without detriment to the process.

A process for making dental bases by electro deposition on the plaster cast, after suitable preparation, was patented by Ward in 1889.

Fire Gilding.—Articles are sometimes gilded by the old process, known as *fire gilding*. The article to receive the deposit of gold is first cleansed and then dipped into a solution of mercuric nitrate, by which means it becomes coated with a film of mercury. It is afterwards pressed upon a pasty amalgam of gold (see p. 134), a portion of which adheres to it. The mercury is then expelled by heat, leaving behind a deposit of gold which is subsequently burnished.

Recovery of Gold from Scrap.—Dental scrap consists chiefly of plate clippings and old plates. If proper care is taken to prevent the introduction of platinum, filings, or particles of base metal, and to keep clippings of definite standard together, the scrap only requires to be remelted and again converted into plate or other form for use.

When, however, the scrap is contaminated with mixed filings, platinum, and fragments containing solder, &c., the gold must be recovered before it can be worked up again into fresh plate.

For this purpose the scrap is first partially refined by melting with a little borax and nitre. It is then alloyed with from 2 to 3 times its own weight of silver and the resulting alloy granulated and parted as described on p. 87. If platinum is present and does not form more than 10 per cent. of the original alloy, it will be dissolved with the silver after prolonged boiling in acid. The silver is precipitated as chloride (see p. 169), and the platinum subsequently separated with zinc or ammonium chloride and converted into spongy platinum.

If more than 10 per cent. of platinum is present the operations of inquartation with silver and parting must be repeated, or the gold may be dissolved in aqua regia.

The solution thus obtained is evaporated, and potassium chloride and alcohol added to precipitate the platinum.

After allowing the platinum precipitate to settle the clear liquid is poured off and ferrous sulphate or other precipitating agent (see p. 96) added to precipitate the gold. The finely divided metallic gold is collected, washed, dried, and then fused in a crucible, with the addition of a little potassium bisulphate as a flux, after which it is cast into an ingot and is ready for use.

The platinum is recovered in a spongy form in the metallic state by strongly heating the precipitate obtained.

Purification of Sweep or Lemel.—These terms are applied to the material which accumulates in the dental laboratory and other places where gold is worked. It consists of fine metallic particles contaminated with dust and organic matter, such as wax, &c., and varies considerably in composition. A magnet is first passed through the filings to remove any iron which may be present. The lemel is then purified by burning off the organic matter, and melted in a fireclay crucible with suitable fluxes. These necessarily vary according to the quantity and nature of the impurity mixed with the lemel, but the following proportion may be conveniently taken :

Lemel	50
Sodium carbonate	5
Borax	5
Potassium bisulphate or nitre	1 to 2
Common salt	5

The lemel is well mixed with the fluxes, with the exception of the salt, which is kept as a cover for the mixture, as it prevents the mass rising too much and overflowing the crucible. Nitre, which oxidises the base metals, and potassium bisulphate should be sparingly employed. The crucible should not be more than half full to commence with, and should be gently heated at first, the temperature being raised gradually. Towards the end of the operation, when the violence of the action has nearly ceased, a more intense heat is employed, and when the whole mass is thoroughly liquid it is well stirred with an iron rod, after which the crucible is removed and the contents poured into an ingot-mould, care being taken to prevent the "slag" running into the mould. The ingot thus obtained will in many cases be in a suitable condition for rolling. If brittle, the alloy may be "toughened" by remelting with a little charcoal powder. When it is desired to obtain the gold, &c., in a pure state the ingot must be cleaned from any adhering slag, weighed, and alloyed with from two to three times its weight of silver, the molten alloy being well stirred and then granulated by carefully pouring into water.

The small granules of alloy are collected, placed in a suitable vessel, and parted in acid as described on p. 87.

If much platinum is present the alloy is best dissolved in nitro-hydrochloric acid, and the metals recovered as described for the treatment of scrap.

Purple-of-Cassius.—This compound is employed by manufacturers of porcelain teeth for obtaining the necessary pink tint; it is also used in the arts for imparting a rose or pink colour to porcelain, enamel, and glass. It varies in colour from violet to a purplish-red or brown, according to the method of preparation. It is obtained by adding a solution of stannous chloride ($SnCl_2$), containing also stannic chloride ($SnCl_4$), to a dilute neutral solution of gold chloride. By this means a fine flocculent purple precipitate is obtained, which is allowed to settle, then collected, washed, and dried. The exact nature of this precipitate is not thoroughly understood; it is supposed to be a combination of stannic oxide, coloured with finely divided gold or one of its oxides.

A very fine product is obtained by adding a solution of stannous chloride to ferric chloride, until the solution loses its yellow colour and becomes a pale green. This mixed solution is then added to the gold solution to produce the purple precipitate. Many other methods are also employed. The purple-of-Cassius used by the manufacturers of porcelain teeth, in the preparation of gum-enamel, is sometimes prepared by the following method.* An alloy consisting of

Silver	40 parts or	85.1 per cent.
Gold	4 "	8.5 "
Tin	3 "	6.4 "

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* Essig, "Dental Metallurgy," 1893, p. 150.

is prepared by melting the constituents in a crucible, under a cover of borax. The alloy is granulated by pouring into water, and the granules treated with nitric acid and gently heated, until all the alloy has been acted upon. The silver having thus been entirely dissolved, the solution is poured off and the purple residue carefully washed, until the last trace of silver solution is removed.

After several washings, the purple-of-Cassius is dried by gentle heating, and is then ready to be incorporated with the silicious materials for the preparation of gum-enamel.

CHAPTER VII.

MERCURY.

SYMBOL, Hg (Hydrargyrum). ATOMIC WEIGHT, 200.

Occurrence.—Mercury is frequently found in nature in the metallic state, almost pure, usually disseminated through its ores in small globules. It is also found in combination with iodine and chlorine, and in union with gold and silver, as native amalgams. Its combination with sulphur, constituting *cinnabar* (HgS), forms, however, the most important ore of the metal, and that from which almost the whole of the mercury of commerce is derived.

Preparation.—The method almost exclusively employed for extracting mercury from the natural sulphide consists in heating the ore in a suitable kiln or furnace, to which a series of large condensing chambers is connected. By the action of heat and air the ore is decomposed, the sulphur being oxidised to sulphur dioxide, and the mercury liberated and volatilised. The gases and mercury vapour in passing from the kiln are introduced into the condensing chambers, where the mercury condenses. The metal thus obtained is always more or less contaminated with other metals derived from the ores treated; it therefore needs purification. Small quantities of mercury may be prepared free from admixture of other metals by operating upon a pure compound of mercury, which is decomposable by heat. Thus, the red oxide readily yields mercury by simple distillation, while the sulphide (pure vermilion) is best treated after the admixture of an equal weight of lime.

Properties.—This metal, known also as *quicksilver*, differs from other metals in being liquid at ordinary temperatures, but, unlike ordinary liquids, it runs off non-metallic surfaces without wetting them, while with many metallic surfaces the mercury unites with the metal and deposits a film of an amalgam upon it.

It has an almost silver-white colour and possesses a strong metallic lustre. When pure, mercury is not tarnished by exposure to dry or moist air. If, however, other metals are present, oxidation rapidly takes place, and the surface of the metal becomes covered by a grey powder: this fact forms a ready method of detecting any considerable amount of impurities. If mercury be maintained in contact with the atmosphere at a temperature just below its boiling-point the metal is slowly oxidised to mercuric oxide. Mercury is very slowly tarnished in the presence of sulphuretted hydrogen, but it is unaffected by exposure to carbonic acid. Water and alcohol are without action on the metal. Mercury is not attacked by hydrochloric acid even when the concentrated acid is heated with the metal. It is scarcely affected by dilute sulphuric acid, but the concentrated acid with the aid of heat acts on it readily. Nitric acid is its best solvent, and dissolves it with great energy. Alkaline solutions have little or no action on mercury. Mercury solidifies when cooled to $-39°$ C., and in the act of freezing it contracts considerably, forming a tin-white, ductile, malleable mass that may be beaten out with the hammer or welded, and it is also capable of being easily cut with a knife. Mercury boils at 350° C., producing a colourless vapour which is very poisonous, giving rise to salivation. The density of the metal varies much with the temperature, owing to its high coefficient of expansion for heat. When mercury is shaken with oil, or when it is triturated with sugar, lead, and other bodies, the metal is obtained in a very finely divided state in the form of a dull grey powder. This operation is known as *deadening*, and is employed in the preparation of grey mercurial ointment.

Use for Dental Purposes.—Mercury is chiefly used in the dental laboratory for the production of amalgams for filling purposes. It is also used to a small extent as a constituent of "fusible" alloys. Compounds of mercury are used in the manufacture of dental rubbers.

Testing the Purity of Mercury.—It is very important that the mercury employed for dental purposes should be quite pure, otherwise it will not readily amalgamate with other metals. All doubtful specimens should therefore be purified before use. Mercury which has been squeezed out in the preparation of amalgams should not be returned to the mercury-holder, as it invariably contains small quantities of other metals derived from the alloy used. The mercury of commerce, unless specially purified, is frequently contaminated with small quantities of the volatile metals. Zinc and bismuth, which are sometimes present in mercury ores, are distilled over with the mercury, while lead, antimony, tin, and bismuth are added as adulterations to the metal. The comparative purity of mercury is readily observed by allowing a drop of it to run lightly down a slightly inclined surface, when it ought to roll as a perfect sphere and not elongate or drag a "tail" behind it. It may also be tested by briskly shaking a small quantity of the metal in a bottle with air, when it should retain its bright metallic lustre. If base metals are present, they are oxidised and form a grey or black powder upon the surface of the mercury.

Purification of Mercury.—The method most frequently employed for freeing mercury from these impurities is to distil it, the surface of the metal being covered during distillation with clean iron filings to the extent of about one-sixth the weight of the mercury used. The iron filings retain the impurities and also help to prevent the spitting of the mercury, which, however, cannot be completely avoided. For distilling small quantities of mercury a glass retort is used, while earthenware or wrought-iron is employed for large quantities. The retort, about one-third full of mercury, is carefully heated by imbedding it in a sand-bath, while the neck is inclined and made to dip beneath the surface of the water, with which the receiver is half filled. The receiver is still further cooled by placing it in a large vessel also filled with water. On the application of heat the mercury boils and distils over, and is condensed in the water, while the other metals are retained by the layer of iron filings. The mercury thus obtained is generally covered with a thin film of oxide, which is readily removed by treating the metal with a little hydrochloric acid, after which the mercury is well washed and dried at a gentle heat. A better method is to substitute coarsely powdered *cinnabar* for the iron filings, the former being added to the extent of about one-fifth the weight of the mercury used. The cinnabar suffers decomposition during distillation with the liberation of its mercury, while the impure metals are largely converted at the same time into sulphides, which remain in the retort. In distillation processes a small portion of the more volatile impurities is generally carried over into the receiver and condenses with the mercury; therefore, when very pure mercury is required, the separation of the impurities is effected by other means. The best method of effecting this is to treat the mercury with nitric acid diluted with from six to eight parts of water and expose it to a gentle heat of about 55° C. (131° F.) for some hours. The acid dissolves out the impurities and more readily oxidisable metals, while very little of the mercury is dissolved. In order to bring the mercury into intimate contact with the acid it should be exposed in thin layers in a shallow vessel or frequently shaken up with the acid. Another method consists in dropping the mercury in a fine stream through a high column of dilute nitric acid.

Mercury which has become contaminated with dust, or from which the impurities have been oxidised by shaking in air, may be cleansed by filtering through a cone of paper, the apex of which has been pierced with a pin. It may also be filtered by squeezing through a piece of chamois-leather.

Electrolytic Purification of Mercury.—Electrical methods have been recently introduced for the purification of mercury for dental and other special purposes, but the details of the processes employed have not been published.

Mercury may be obtained by electro-deposition from a solution of the metal in nitric acid or in sulphuric acid, with about 5 per cent. of free acid.

In a method devised by Johnson* commercial mercury is employed as the anode and carbon rods as the cathodes. The mercury is placed in a flat basin and the carbon cathodes suspended above it, the electrolyte consisting of a solution containing 17 per cent. of nitric acid and 4 per cent. of potassium nitrate. An E.M.F. of 1 volt is employed, the current being interrupted at suitable intervals to prevent mercury from going into solution. As long as the voltage is kept below 0.75 very little mercury leaves the anode, but the impurities, zinc, cadmium, copper, lead, &c., all pass into solution. The process is said to work best with very weak currents of long duration, the electrolyte being renewed from time to time. Six hours were found sufficient for the purification of about 2 lb. of the ordinary commercial mercury.

The theory upon which the process is based is that the ionising pressure of hydrogen is less than that of the impurities and greater than that of the mercury; the solution of the impurities is, therefore, assisted by the current.

Vermilion.—Mercuric sulphide, HgS. This compound of mercury is extensively used as a colouring pigment in vulcanisable rubbers and celluloid. The vermilion of commerce varies much in tint and purity of colour, slight differences in the details of its manufacture impairing or improving its colour.

Preparation.—Vermilion of fine colour and superior quality is made by the Chinese. The process of manu-

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* W. M. Johnson, from *Electric World and Engineer*, 37, 634, 1901.

facture consists in heating a mixture of one part of sulphur with four parts of mercury in a shallow iron pan, the mixture being stirred to effect combination. The product, which is a reddish or black powder, is placed in iron pans provided with earthenware domes and strongly heated for eighteen hours to sublime the sulphide. The vessels are then allowed to cool slowly, when most of the vermilion is found adhering to the surface of the dome, that attached to the iron pan being of inferior quality. The purest portion of the sublimate is finely powdered, then put into a large vessel containing water and allowed to settle, when the fine sediment or residue is collected and dried. The powder, which is of a very fine colour, is sifted through muslin and is then ready for sale.

Vermilion of good quality is also obtained by wet processes, one of the best being that of Brunner, which is frequently employed. It consists in rubbing together for some hours a mixture of 100 parts of mercury and 38 parts of flowers of sulphur, and then mixing the resultant mass with one part of potash dissolved in six parts of water. After heating this mixture for about eight hours the mass begins to exhibit a red colour, and when the right tint has been attained the mass is quickly washed with water to prevent further action, and is then dried.

Detection of Impurities.—Vermilion is sometimes adulterated with red lead, red oxide of iron, and frequently with gypsum and other impurities. The presence of these impurities can be readily ascertained however, as pure vermilion when heated in a glass tube is volatilised without leaving any residue. If a residue is left it denotes the presence of some impurity.

Properties.—When vermilion is brought into contact with silver, copper, and other metals having an affinity for sulphur, it is decomposed with the formation of metallic sulphides, and it is this fact which renders the combination of silver and vulcanisable rubbers impracticable.

Vermilion is unaffected by water, alcohol, or alkalis, and is insoluble in nitric, hydrochloric, and sulphuric acids. It is readily soluble, however, in nitro-hydrochloric: this mixed acid should therefore not be used in removing tinfoil applied as a coating for plaster casts in rubber work, which may adhere so tenaciously that it cannot be removed without the aid of a solvent. Hydrochloric acid is the only solvent that will accomplish the removal of the tinfoil satisfactorily without injury to the rubber. "Pure vermilion in combination with rubber is not likely to produce deleterious effects when worn in the mouth, nor is it probable that this compound can be decomposed chemically and converted into a poisonous salt of mercury or cause salivation by mere contact with the saliva." * The discomfort sometimes caused by wearing artificial dentures of vulcanised rubber is probably due to a certain extent to the presence of deleterious substances present in the vermilion used for colouring the rubber.

Amalgams.—When mercury is one of the constituents of an alloy the mixture is called an *amalgam*. Mercury unites with most of the metals when brought into contact with them, especially if the metals are in a fine state of division or in the form of foil. Many of the metals unite with mercury at the ordinary temperature, while others require the assistance of heat.

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* Essig, "Dental Metallurgy," 1893 edit. p. 223.

The facility with which combination often takes place at the ordinary temperature is probably due to the liquid condition of mercury, which facilitates its being brought into intimate or molecular contact with other metals. With most of the metals, union with mercury is easily effected; but with platinum, iron and nickel combination takes place only with difficulty. The formation of amalgams is sometimes accompanied by an evolution of heat, indicating the existence of a certain amount of chemical affinity: in other cases an absorption of heat takes place, but as a rule little or no thermal disturbance results from the combination of metals with mercury. The formation of amalgams of a few of the metals is attended with considerable diminution in bulk, while in some cases expansion takes place, but generally the union of mercury with other metals is accompanied by little or no change in volume. The amalgams of some metals are fluid like mercury, while others are solid or semi-solid. The solid amalgams appear to consist of metals united with mercury in atomic proportions, forming what are regarded by many as definite chemical compounds, while the liquid amalgams generally consist of a compound dissolved in an excess of mercury. This excess can frequently be separated by simple pressure through chamois-leather, the solid amalgam left behind most probably consisting in many cases of metals united in atomic proportions. The chemical affinities between the constituent metals, however, are only very feeble, as many amalgams in which the metals are united in atomic proportion may be partly decomposed by subjecting them to very great pressure, a part of the mercury being thus forced out, while an amalgam containing a larger proportion of the other metals remains behind. In many cases liquid amalgams acquire a crystalline form on standing, the excess of mercury being separated; the crystallised body thus formed is the true amalgam, and, as before stated, probably a definite chemical compound.

Although amalgams are usually obtained by the direct union of the metals with mercury, other methods are frequently employed for their production, especially for metals which do not amalgamate readily. Amalgams may also be produced—(1) by adding mercury to a solution of a metal; (2) by placing the metal to be amalgamated in a solution of a mercury salt; and (3) by the action of a weak electric current produced by placing the metal in contact with mercury and an acid. The properties of the amalgams of the common metals are as follows:

Aluminium Amalgam.—The union of aluminium and mercury cannot be effected readily at the ordinary temperature, but mercury is capable of combining with finely divided aluminium on heating, the union being attended by a considerable evolution of heat. Although mercury and aluminium are not oxidised by exposure to air at the ordinary temperature, yet after combination has taken place oxidation rapidly ensues, the resulting amalgam being readily covered with a thick film of white aluminium oxide. A very considerable increase of volume also accompanies the combination. When using aluminium instruments or apparatus, it is very important to remember the affinity of aluminium for mercury under suitable conditions, and also to avoid the use of aluminium in any form in the mouth in contact with amalgam fillings. The same results are experienced on bringing aluminium into contact with mercury salts.

Antimony Amalgam.—Antimony combines with mercury in the cold with great difficulty, but more perfectly when heated, producing a soft plastic amalgam. The amalgamation is also facilitated by the addition of a little dilute hydrochloric acid. The amalgam is soft, white and granular. When triturated or shaken in air the amalgam gives up the antimony in the form of powder.

Bismuth Amalgam.—Mercury is capable of dissolving a considerable quantity of bismuth without losing its fluidity, the union being readily effected, even in the cold, by simply mixing the metals. When heat is applied combination takes place more rapidly. With two parts of mercury and one part bismuth the amalgam is pasty; it hardens after standing and becomes more or less crystalline. Bismuth amalgam, when pressed in chamois-leather, passes through the pores like mercury.

Cadmium Amalgam.—Mercury and cadmium readily combine at the ordinary temperature; the union is, however, much more perfectly effected when mercury is added to molten cadmium. When mercury is completely saturated with cadmium a compound is formed consisting of 87.3 parts of mercury and 21.7 parts of cadmium, agreeing with the chemical formula Hg_2Cd. Cadmium-amalgam is a silver-white, crystalline, very brittle mass, heavier than mercury. When moderately heated it softens and can be kneaded like wax. From its property of gradually hardening it was formerly used as a stopping for teeth, but, owing to the action of the sulphuretted hydrogen in the mouth, the filling is readily covered with a yellow film of cadmium sulphide. Cadmium easily dissolves in warm mercury, giving rise to a solid compound, corresponding to the formula Hg_5Cd_2. An amalgam of one part by weight of cadmium with six parts of mercury has the low melting-point of 16° C. (60.8° F.).

Copper Amalgam.—This amalgam may be obtained by the direct union of copper and mercury. It possesses the property of becoming hard and crystalline when left for a few hours, while its soft and plastic character can be restored by continued kneading or pounding of the amalgam. It also becomes soft and plastic when gently heated or placed in boiling water, but recovers its hard crystalline character after standing. Copper amalgam crystallises readily: when hard it is malleable, and can be rolled or hammered. It admits of a good polish and retains its lustre well in air, but is readily blackened by sulphuretted hydrogen. The density of this amalgam is the same in the soft and hard states; therefore it does not expand in hardening, and thus fills cavities, when hard, into which it has been pressed in the soft state. Copper amalgam is used for stopping teeth, but is objectionable on account of its great tendency to blacken (see Dental Copper-Amalgam, p. 146).

Gold Amalgam.—Gold in a fine state of division is quickly dissolved by mercury, even in the cold; but if the mixture is slightly heated, amalgamation takes place much more rapidly, the mercury absorbing a considerable proportion of gold without losing its liquidity.

The amalgam of two parts of gold and one of mercury is white in colour, of a pasty consistency and readily soluble in mercury, forming a liquid mass. When this solution is strained through chamois-leather, the excess of mercury passes through together with a small quantity of gold, while a white pasty amalgam remains behind. It is probable that definite compounds of gold and mercury exist. When heated to redness, gold amalgam is decomposed, the mercury being distilled off, leaving a residue of gold.

Iron Amalgam.—An amalgam of iron cannot be obtained by direct union of the metal with mercury, but by introducing sodium amalgam into a clear, strong solution of iron sulphate a viscid amalgam is obtained, which, in small globules, is attracted by the magnet.

Lead Amalgam.—These amalgams may be readily formed by simply rubbing lead filings with mercury or by pouring mercury into molten lead. The amalgams are not entirely liquid ; they grow more and more pasty as the percentage of lead increases. By centrifugalising them in a chamois bag, crystals are obtained of the composition Pb_2Hg. When the percentage of lead has reached 65, the amalgam is entirely solid.[*] Contraction takes place during combination, the amalgam being denser than either of the constituent metals.

Nickel Amalgam.—Nickel does not amalgamate when rubbed with mercury, nor can a nickel amalgam be obtained directly. An amalgam may be obtained by adding sodium amalgam to a strong solution of a nickel salt.

Palladium Amalgam.—This amalgam is obtained by rubbing finely divided palladium with mercury. Union takes place at the ordinary temperature, but not with great facility. The combination is attended

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[*] Fay and North, *Amer. Chem. Journ.*, 1901, vol. xxv. pp. 216 231.

by an evolution of heat, leading in some instances to explosion. It is therefore probable that chemical union takes place between the two metals.

Palladium amalgam expands slightly on cooling. This amalgam is used as a filling for teeth, and is probably the most durable of all the amalgams for this purpose, although it is a little difficult to manipulate. It forms a good watertight filling, but has the disadvantage of turning quite black. It does not, however, lead to any staining of the tooth substance.

Platinum Amalgam.—Platinum in the compact form, such as plate or wire, does not amalgamate with mercury. By triturating spongy platinum (such as that precipitated from a solution of platinic chloride by means of zinc) with mercury in a warm mortar amalgam is obtained of a silvery appearance. The mercury is expelled from this amalgam on the application of heat, and a grey residue of platinum left behind. With 12 per cent. of platinum the amalgam is metallic in appearance and possesses a soft, greasy feel, but it becomes more solid as the proportion of platinum is increased. An amalgam of these metals does not harden well.

Silver Amalgam.—Mercury slowly dissolves silver at the ordinary temperature, but much more rapidly and perfectly on the application of heat. The more finely divided the silver the more rapidly does amalgamation take place. Silver precipitated from its solutions by means of metallic zinc or copper, then washed and dried, is in a very favourable condition for amalgamation (see Precipitated Silver, p. 171). When silver thus prepared is added to hot mercury combination takes place rapidly.

The affinity of mercury for silver is almost equal to that of mercury for gold, but there is a greater tendency towards crystallisation in the case of silver. The combination of silver with mercury is usually attended by an increase in volume, although in certain proportions the union appears to be accompanied by a contraction in volume. The amalgam varies in character, according to the composition and mode of formation, being soft, granular, or crystalline. It is readily dissolved in excess of mercury, but the excess can be separated from the pasty amalgam thus formed by squeezing through chamois-leather. The soft white amalgam left gradually becomes hard and brittle, and is generally regarded as a chemical compound. By adding mercury to a slightly acid and dilute solution of silver nitrate, the amalgam is obtained in a beautiful crystalline form, known as a "silver-tree" or *Arbor Dianæ*. Silver amalgam, if heated to redness, gives off the mercury, the silver, however, sometimes retaining traces of mercury.

The union of these metals in certain proportions is accompanied by a considerable elevation of temperature.

Littleton has pointed out * that when an amalgam of silver and mercury is moderately heated, considerable swelling takes place, and the mass becomes hard, brittle, and crystalline in structure. It was noted that this remarkable behaviour was most marked when the silver and mercury were present in the proportions corresponding with the formula $AgHg_4$, and that, when these metals were brought together, the silver in the state of a fine crystalline powder, and the mercury simply poured over it, there was very con-

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* *Trans. Chem. Soc.*, 1895, vol. lxviii. p. 239; and *Proc. Chem. Soc.*, 1896, vol. xii. p. 220.

siderable rise of temperature, amounting to 38° or 40° C., so that the amalgam could not be borne on the palm of the hand without pain. The amalgam, just after its production, is a soft, pasty, semi-fluid mass. Several native amalgams of silver and mercury have been found, which are compounds in which the constituents are combined in atomic proportions.

Silver amalgam has been used as a filling material for teeth, but it becomes discoloured owing to the action of sulphuretted hydrogen.

Tin Amalgam.—Tin and mercury unite readily, even at the ordinary temperature, but much more vigorously at the melting-point of tin. With small proportions of mercury the amalgams are brittle and granular; an amalgam of equal parts of tin and mercury is solid, while those with excess of mercury are more or less soft and plastic. With one part of tin and ten parts of mercury the amalgam is liquid, like mercury, but does not flow so readily. Tin amalgam has a tin-white colour and is more or less brittle and granular, according to the proportion of mercury present. When the excess of mercury is removed from a fluid amalgam by squeezing through chamois-leather a flexible mass remains, which hardens in a few days. The union of tin with mercury is attended by a considerable diminution in bulk. Tin amalgam was formerly used as a filling for teeth, but it hardens slowly and imperceptibly and also contracts, thus possessing a tendency to draw away from the edges of the cavity.

Zinc Amalgam.—Zinc amalgamates slowly with mercury at the ordinary temperature: but it combines readily if heated, and still more readily when mercury is poured into molten zinc.

The amalgam of one part of zinc with four or five parts of mercury is white, granular, and brittle.

When the mercury largely predominates the amalgam becomes pasty. Zinc is occasionally employed as a constituent in dental amalgams.

Iron } Sodium amalgam
Nickel } + Salt. of metal

Carrosive Sublimate Perchloride of Mercury
Colourless prismatic crystals When heated
it. Sublimes without leaving a residue
Preparing By Subliming Mercuric Sulphate
Sodium Chloride + black oxide of manganese
On heating an alloy of Silver + tin
with Carrosive Sublimate the tin is
volatalised in the form of the Chloride
+ Silver left

CHAPTER VIII.

DENTAL AMALGAMS.

AMALGAMS prepared from many different formulæ have been used in dentistry as fillings for teeth. The majority of the well-known alloys from which the dental amalgams are prepared are composed of tin and silver with small additions of other metals. It has been previously stated that the union of tin and mercury is attended by *contraction*, and that tin dissolves very readily in mercury, giving an amalgam which hardens slowly and imperfectly. On the other hand, *expansion* generally takes place when silver enters into combination with mercury, the union being effected with much less facility, and producing an amalgam which becomes very hard. The manufacturers of alloys for dental amalgams, therefore, use tin and silver in different proportions, utilising the good qualities in the one to counteract the inferior qualities in the other, with the object of obtaining an amalgam which will meet the requirements necessary for a filling material. The following qualities are necessary in an amalgam to be used for dental purposes:

1. Strength to withstand the force of mastication.
2. Sharpness of edge.

3. It should not expand or contract in setting.
4. It should retain its shape.
5. It should not become discoloured.
6. It should be free from metals liable to form soluble, injurious salts.
7. It should not stain the substance of the tooth.

In the formation of amalgam for dental purposes the best results will most probably be obtained by uniting the constituents in atomic proportions to form what are believed to be definite chemical compounds.

As previously stated, the solid amalgams appear for the most part to consist of metals united with mercury in atomic proportions, and capable of being dissolved in an excess of mercury.

When filings of an alloy are intimately mixed with a measured quantity of mercury by thoroughly kneading the mass entirely new compounds are formed, the mercury combining first with the metal for which it has greatest affinity. With some metals these compounds are produced very readily, while with others they are slowly formed. If sufficient mercury has been employed, the mass soon becomes of a soft, pasty consistency. After a short interval a process of crystallisation commences, which may be accompanied by a change in volume, the mass thickens slightly, and when pressed carefully between the fingers emits a peculiar grating sound, caused by the rubbing or grating of the crystals against each other. This mass may probably represent a definite chemical compound (or compounds) of mercury and the metals of the alloy in atomic proportions and crystallised, the whole being dissolved in an excess of mercury. In order to use this plastic compound as a filling material the excess of mercury must be removed. This can be done to a certain extent by straining through chamois-leather by compression with pliers. All the excess of mercury cannot, however, be satisfactorily removed in this way, and the mass left in suitable working condition.

From the most recent experiments * it appears that Dr. Bonwill's and similar methods † for removing the excess of mercury are those most likely to give the best results with this class of filling.

Tomes has recently shown ‡ the advantage of employing old amalgams for filling purposes; these should be first heated to soften them, and then used alone or rubbed up with a small quantity of freshly prepared amalgam. Amalgams which have set and become hard are softened to a workable consistency by gently heating; they harden again on cooling, a phenomenon which is ascribed to a state of amorphism, into which the amalgam passes from the crystalline condition in the process of softening. Old amalgams have the advantage of having undergone the shrinkage, alteration of shape, &c., which takes place, more or less, when fresh amalgam is used. Although there may be difficulties with regard to the manipulation of old amalgams

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* "Notes on Amalgams," C. S. Tomes, *Brit. Journ. of Dental Science*, 1895, vol. xxxviii. p. 242.

† Dr. Bonwill's method consists in inserting the amalgam fairly plastic, and squeezing it dry in the cavity with suitable instruments by the application of much pressure. Pads of bibulous paper are repeatedly placed over the cavity to absorb the mercury thus pressed out. The softer portions upon the surface of the filling, into which the excess of mercury has been squeezed, are also removed from time to time. In some cases gold-foil has been used instead of bibulous paper.

‡ *Brit. Journ. of Dental Science*, 1895, vol. xxxviii. p. 242; also 1896, vol. xxxix. p. 529.

on account of rapidity in setting, there can be no doubt that the use of ready-formed amalgams tends to give watertight plugs and very satisfactory results. When old amalgam is used for the whole operation of filling it should be heated in a spirit or Bunsen gas-flame, and then laid on a hot plate over the flame, in order to keep it soft. With the exception of copper and of palladium amalgams, silver-tin alloys form the basis of all the dental amalgams used at the present day. These alloys are composed of varying proportions of silver and tin, ranging from sixty parts of silver and forty of tin to forty parts of silver and sixty of tin. Occasionally alloys are made with a larger proportion of silver. "These alloys in the form of filings or shavings are mixed with varying proportions of mercury, which generally range in ordinary practice from 30 per cent. of mercury and 70 per cent. of alloy to equal parts of each by weight, a larger proportion of mercury being used in exceptional cases." * Silver-tin amalgams vary with regard to working properties, those containing most tin being usually soft and plastic and slow in setting, while those with excess of silver are quick-setting and much harder, "the quickest setting amalgam being that made from an alloy containing 72.5 per cent. of silver and 27.5 per cent. of tin." † The amalgam obtained after removing the excess of mercury becomes more or less hard within a few hours, but does not generally acquire the full degree of hardness for twenty-four to forty-eight hours. It is then a hard, brittle mass which may be dressed with a file and polished like other metallic bodies. The disadvantage of this

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* G. V. Black, *Dental Cosmos*, July 1895, vol. xxxvii.

† *Ibid.*, 1896, vol. xxxviii. p. 986.

material as a filling is that it has a tendency to alter in shape and is liable to become discoloured. As the silver-tin alloys do not possess all the qualities necessary for the production of a dental amalgam, it has been the practice of many manufacturers of alloys for this purpose to add other metals with a view of modifying or improving the chemical and physical properties of the resulting amalgam. The metals usually added are gold, copper, platinum, and occasionally zinc, cadmium and antimony. The composition of some of the alloys most frequently used for dental amalgams is given in the annexed table.

The effect of the presence of different metals in silver-tin amalgams is given in the following list. It must be pointed out, however, that the individual effects are greatly dependent on the quantity of metal added; thus, the addition of gold is usually very beneficial, but Dr. Bonwill has ascertained by experiment * that it is not desirable to add more than 7 per cent. of gold to silver-tin amalgam. The ratio between the main constituents of the amalgam is also of importance in connection with the addition of other metals. The presence of a small quantity of zinc may be beneficial in one silver-tin alloy, while a larger quantity of zinc may be a decided disadvantage in this particular alloy, but very advantageous in a silver-tin alloy of different composition. The effect produced by the addition of a small quantity of a certain metal is frequently very much modified when other metals, besides silver and tin, are also present as constituents of the amalgams. Thus, the properties of a silver-tin amalgam appear to be greatly impaired by the addition of platinum in any

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* *Dental Cosmos*, vol. xxiv. p. 422.

COMPOSITION OF ALLOYS FOR DENTAL AMALGAMS.*

—	Tin.	Silver.	Gold.	Platinum.	Copper.	Zinc.
Arrington's amalgam (S. S. White's)	57.50	42.50	—	—	—	—
Caulk's par-excellence alloy	61.75	27.25	0.15	0.25	10.60	—
" white alloy	55.00	43.65	—	—	1.35	—
Davis's standard amalgam	55.40	44.60	—	—	—	—
Eckfeldt and Dubois' standard dental alloy	40.60	52.00	4.40	—	3.00	—
Flagg's contour alloy	37.00	58.00	5.00	—	—	—
" submarine	35.00	60.00	—	—	5.00	—
" facing	35.00	57.00	5.00	—	—	3.00
Fletcher's gold alloy (old)	56.00	40.00	4.00	—	—	—
" perfected standard alloy †	62.30	30.30	5.76	1.60	—	—
Lawrence's amalgam (old)	47.00	47.00	1.00	—	5.00	—
" " (new)	50.43	44.06	—	—	5.51	—
S. S. White's globe	53.36	44.74	1.50	0.40	—	—
Townsend's (old)	58.00	42.00	—	—	—	—
" (improved)	54.50	44.50	1.00	—	—	—
Welch's gold and platinum alloy (old)	54.00	44.00	1.30	0.70	—	—
" " " (new)	51.90	46.00	1.70	0.40	—	—
" amalgam	51.52	48.48	—	—	—	—
Alloys used in France ‡						
Alloy Magitot	45.00	50.00	—	—	5.00	—
Gold alloy	45.00	45.00	10.00	—	—	—
Amalgam alloy	55.00	40.00	—	—	5.00	—
Common alloy for "stopping"	52.20	48.00	1.70	—	—	—

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* "American System of Dentistry," J. O. Keller, vol. iii. p. 813.

† Analysis by A. McWilliam.

‡ Communicated to the author by André P. Griffiths.

considerable quantity, except when gold is also present, in which case the platinum confers useful properties on the amalgam. The following list must, therefore, be regarded as giving only the *general* effect of the various metals when added to the silver-tin amalgam.

The effect of the presence of silver and of tin in the amalgam is also inserted for convenience in reference.

Effect of Different Metals in Amalgams.—*Silver.*—As the union of silver with mercury is usually accompanied by *expansion*, and the union of tin with mercury by *contraction*, the direct influence of silver upon an amalgam of tin and mercury is to lessen the contraction and increase the hardness. Silver has the disadvantage, however, of increasing the discoloration of the filling, owing to the formation of silver sulphide by the action of the sulphuretted hydrogen in the mouth. It also tends to stain the tooth owing to the formation of soluble silver salts.

Tin facilitates amalgamation and helps to prevent discoloration; but it causes shrinkage, slowness in setting, and loss of edge-strength.

Gold in amalgams renders them cleaner and easier to work, reduces the shrinkage, produces good edge-strength, and assists the filling to maintain a good colour. Its presence affects the power of setting.

Copper facilitates setting, diminishes shrinkage, gives great edge-strength, and exerts a preservative influence on the tooth structure. It largely increases, however, the tendency to discoloration.

Platinum in any considerable quantity appears to greatly impair the properties of a silver-tin amalgam, causing dirtiness in working, slowness in setting, and tendency to shrinkage. When, however, platinum is added to a silver-tin amalgam containing gold, it appears to confer the properties of setting quickly, great hardness, and retention of shape after hardening.

Zinc is occasionally employed as a constituent of alloys for dental amalgams. It appears to control shrinkage, add whiteness to the filling, and also helps the amalgam to retain its colour. But it causes rapid setting and a tendency to change of form. Amalgams containing it possess good edge-strength.

Cadmium was at one time used as a constituent in amalgams, but it is now generally condemned for that purpose. It causes quickness in setting and facilitates expansion. Amalgams containing it are very white and make good fillings, but they readily discolour owing to the formation of yellow cadmium sulphide. The tooth substance is also stained an orange-yellow on account of the formation of soluble salts of cadmium.

Antimony has been occasionally used as a constituent. Its presence appears to facilitate amalgamation and control shrinkage, but it makes the amalgam soft and very dirty to work.

Palladium as a constituent of silver-tin amalgams has been condemned, experiments* having proved that it makes the amalgam very dirty to work, gives leaky plugs, and is altogether unsatisfactory. It is stated that amalgams containing palladium blacken to a greater extent than those from which it is absent. (See also Palladium Amalgam, p. 135.)

Bismuth greatly facilitates amalgamation and the working properties of the amalgam; it also reduces expansion. But it makes the amalgam very dark,

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* Fletcher, *Brit. Journ. Dental Science.*

lessens the edge-strength, and greatly reduces the hardness: hence it is seldom used as a constituent.

Lead is never employed in dental amalgams unless accidentally present as an impurity in the metals employed. Its action appears to be similar to that of bismuth.* It facilitates amalgamation, but causes slowness in setting and makes the amalgam very dark.

Aluminium has not been used as a constituent in dental amalgams, but from recent experiments † its presence appears to give a soft pliant mass which is slow in setting. It also greatly increases expansion and the tendency to alter in shape, and would facilitate the action of the fluids of the mouth on the filling. Heat is developed in mixing alloys containing it with mercury. (See Action of Mercury on Aluminium, p. 132.)

Change of Volume.—Much diversity of opinion exists with regard to the contraction and expansion of silver-tin amalgams, some claiming that contraction takes place,‡ while others state that the amalgam first contracts and then finally expands.§ The composition of the alloys and the quantity of mercury used will necessarily influence the results of experiments on these questions. The recent researches of Dr. Black ‖ appear to support the latter conclusion. He found that alloys containing less than 50 per cent. of silver first shrink and then expand. Alloys with 50 to 62

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* Experiment by G. V. Black, *Dental Cosmos*, 1896, vol. xxxviii. p. 989.

† *Ibid.*

‡ Hitchcock and Tomes, *Trans. New York Odont. Soc.*, 1874.

§ Kirby, *Brit. Journ. of Dental Science*, July 1888, vol. ix. part ii.

‖ *Dental Cosmos*, 1896, vol. xxxviii. p. 975.

per cent. of silver shrink only. Those with 65 to 75 per cent. of silver expand when *fresh cut*, but shrink when fully "*aged*." (See p. 156.) Alloys containing over 75 per cent. of silver expand only.

Methods of Testing Change of Volume.—The change of volume which takes place more or less with most dental amalgams constitutes one of the disadvantages of this class of material as a filling. The shrinkage or expansion is usually determined by carefully packing the amalgam into a small shallow glass tube until full and then making the surface perfectly level. When contraction has taken place the filling will frequently slide readily out of the tube, while expansion is seen with the aid of a lens by the projection of the filling above the mouth of the tube.

The contraction and expansion of silver-tin amalgams has been studied by Black,[*] who examined them under the microscope. For this purpose the amalgams were inserted in Wedelstaedt test-tubes, made of hardened steel one-half inch deep and one inch in diameter, with a cavity three-eighths of an inch in diameter and one-fourth of an inch deep. The top of the tube is ground flat, and the margin of the cavity brought to a perfect edge. The tubes are placed on the stage of the microscope, and so arranged that every part of the margin of the cavity is brought under the lens as the stage is rotated. A groove was cut in the inner wall of the tube at the bottom to hold the filling at that point, so that in case of shrinkage the surface of the filling sinks down into the tube. When comparative results are required the amount

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[*] *Dental Cosmos*, vol. xxxvii. 1895, p. 648

of contraction and expansion is measured with a micrometer.

Several forms of apparatus have also been constructed by different investigators for studying the change of volume in amalgams. One of these, devised by Kirby, consisted of a V-shaped metal trough (Fig. 32) having a movable end, to which a delicate screw micrometer was attached, and so constructed that any change of volume could be easily and accurately measured. The amalgam to be tested was made up in the way generally adopted for filling teeth, then placed in the trough and allowed to remain for some time. By means of this apparatus the most minute change, either of expansion or contraction, was readily indicated.

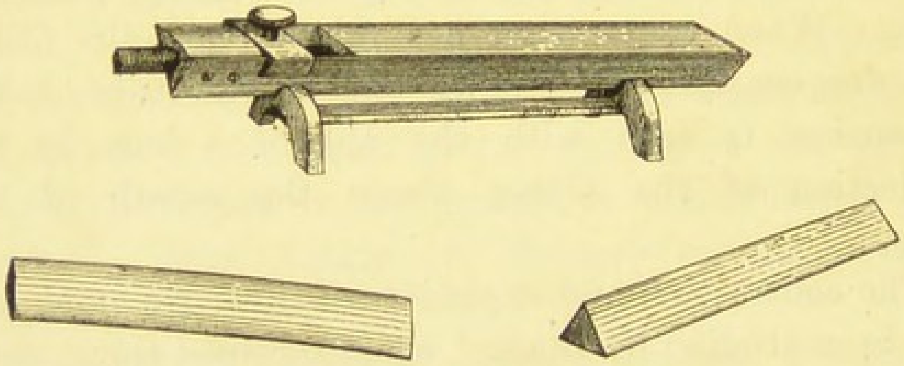

FIG. 32.

Other forms of apparatus, with micrometer adjustments, embodying the same principle, have also been devised.

"The advantage of the tube test over that of the amalgam micrometer is the possibility of doing a number of experiments in a limited time, as tube after tube can be packed and set aside for results, while with the micrometer each packing has to remain in the instrument until the result is obtained. This requires from several days to many months for each experiment; but while the tube test is *practical*, reliable micrometer work is more accurate." *

The change of volume is also ascertained by taking the specific gravity of the amalgam.

As previously stated, when the density of an alloy or amalgam is less than that of the mean of the constituents, it shows that expansion has taken place during combination, while an increase in the density denotes that contraction has accompanied the union of the metals.

For ascertaining the change of volume in amalgams by the specific gravity method † an exceedingly delicate balance must be used and a large number of precautions taken, in order to obtain accurate and concordant results, one of the most important being the consideration of the fact that *heat* is given out during the setting of some amalgams.

Alteration of Shape.—Much has been said with regard to the so-called "spheroiding" of amalgams or

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* Flagg, "Plastic Filling Materials," p. 72.

† A fallacious rule is frequently given for computing the specific gravity that should result from the alloying of given quantities of two metals of known densities, supposing no condensation or expansion of volume to take place. Thus, it is said that if gold and copper be united in equal weights the computed specific gravity is merely the arithmetical mean between the numbers denoting the two specific gravities. This, however, is incorrect; the computed specific gravity of the alloy is obtained by the following rule: "Multiply the sum of the weights by the product of the two specific-gravity numbers for a numerator; and multiply each specific-gravity number by the weight of the other constituent, and add the two products together for a denominator. The quotient obtained by dividing the said numerator by the denominator is the truly computed mean specific gravity of the alloy. On comparing with that density the density found by experiment, it will be seen whether expansion or condensation of volume has attended the combination."—Uré's Dict., vol. i. p. 92.

tendency to assume the spherical form. "The phenomenon from which this term *spheroiding* has been mostly derived appears to be the tendency of some amalgam fillings to rise in the middle and assume a convex form on the surface." * This alteration of shape, or tendency of some fillings to assume a convex form on the surface, after having been dressed flat, is probably due to a change of volume. The amalgam being firmly held down on all sides but one during expansion will tend to flow towards the point of least resistance, thus causing the surface to become slightly convex. Kirby is of opinion, as the result of his experiments, that it "is due to unequal distribution of mercury throughout the mass, and that the alteration is produced by the passage of the mercury from one part of the filling to the other, causing contraction in the portion containing excess and expansion in the drier portion. When the mercury is distributed equally throughout the filling, no change in shape takes place, since there will not be any passage of mercury from one place to another.†

The alteration of shape will be apparent in making tests for change of volume, and may be seen by the aid of a good lens.

Change of Colour.—Dental amalgams differ considerably with respect to their liability to darken by exposure in the mouth : copper and palladium amalgams being those which darken most rapidly. The addition of gold is an advantage in helping amalgams to retain their colour, while copper greatly facilitates discoloration. Fillings containing an excess of mercury are

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* *Brit. Journ. of Dental Science*, 1895, vol. xxxviii. p. 901.

† Smale and Colyer, " Diseases of Teeth," p. 186.

more liable to blacken than those which are drier when inserted. Discoloration is largely due to the formation of sulphides, resulting from the action of sulphuretted hydrogen in the mouth, produced by the decomposition of the oral secretions. Silver and mercury, under the conditions in which they exist in the mouth, both have a great affinity for sulphur. Discoloration is also due to the presence of vegetable acids in articles of food, such as fruit ; to the action of drugs taken as medicines ; or to abnormal conditions of the fluids of the mouth. The surface of many amalgam fillings may be kept bright by friction, whether produced by mastication or by a brush ; but such fillings will probably blacken if they occupy positions in which they are protected from friction.

An amalgam may become discoloured at the surface and yet fully preserve the teeth from further decay. On the other hand, an amalgam may retain its original colour and surface brightness and yet not protect the tooth, the tooth-substance being darkened, thus indicating chemical action at the edges. The darkening of the substance of the tooth is due to the formation of soluble salts, resulting from the action of the oral fluids upon the metals composing the amalgam.

Imperfect adaptation is frequently the cause of the discoloration of the tooth, as this favours the ingress of the oral fluids which form the eroding agent. Change of colour is usually tested by packing a small quantity of the amalgam into a small glass tube and covering it with a dilute solution of sulphuretted hydrogen water (about one part of strong solution with about four parts of water). In this way the filling is exposed to the action of sulphur in the form in which it exists in the mouth.

Gradual discoloration is seen better in dilute solutions than in strong.

Leakage.—One of the disadvantages experienced in using amalgams as fillings is the difficulty of getting absolutely watertight plugs.

The leakage is largely dependent on the method of packing used. Amalgams are tested for leakage by packing them into small circular holes, about one-eighth of an inch in diameter and a quarter of an inch in depth, bored right through slips of bone or of ivory, which are clamped to a flat surface of ivory whilst being filled. The slips are then plunged into ink, Draper's dichroic being frequently employed, and are left for some time. On being removed the plugs are split and the surfaces carefully examined for the ingress of the fluid used.

Human teeth have also been employed for the same purpose.

Edge-Strength.—This term is used to denote the degree of resistance the edge of an amalgam mass offers to a force which tends to fracture it. An amalgam used for filling purposes should always be sufficiently strong to retain its integrity of edge under the force of mastication. "The stress in the ordinary use of the teeth has been shown to be from sixty to eighty pounds upon the area of two molars of medium size. This, if evenly distributed, would give from seven and a half to ten pounds on a filling occupying one-fourth the area of one of these teeth. This would be a filling of ordinary size; but it frequently happens that the filling must bear all of this stress."* The edge-strength of amalgams is sometimes approximately

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* Black, *Dental Cosmos*, July 1895, p. 554.

determined by mixing the amalgam in the ordinary way, then forming it into a small " button " and testing the strength of the edge by breaking it with the thumb-nail when the specimen has hardened. This, however, cannot be regarded as a satisfactory method for comparative testing. For accurate and reliable work some form of dynamometer or instrument for measuring force is used. This usually consists of a carefully balanced and graduated metal beam upon which a sliding weight is placed. A chisel-shaped steel rod is also fixed to the balanced beam and so arranged that the pressure necessary for testing the strength of the amalgam filling can be applied to the chisel by moving the sliding weight along the graduated scale. The instrument is also provided with suitable screws for accurate adjustment. The amalgam to be tested is mixed as for ordinary fillings and made into small blocks in order to obtain the greatest edge-strength of which the specimen is capable. After allowing the amalgam to harden it is carefully secured in position upon the instrument, so that the point of the chisel rests upon the edge of the specimen. The sliding weight is then slowly pushed out along the graduated scale on the beam until the pressure produced is sufficient to break the edge of the specimen. In this way the position of the weight indicates the point at which "crush" or fracture occurs, and the relative edge-strength of various samples, with the accompanying toughness and brittleness, is determined.

Permanence in the Mouth.—The permanence of amalgam fillings in the mouth is necessarily largely dependent on the care bestowed on the manipulation of the material, on the proper preparation of the cavity, and on the condition of the tooth in which it is placed. It is also dependent on the metals present in the amalgam used, as each of these materially affect the character of the amalgam of which it forms a constituent. Careful observation and experiment with each amalgam can only satisfactorily solve the question of permanency in the mouth. Amalgams containing large proportions of metals possessing an affinity for sulphur, such as silver, copper, and cadmium, are more liable to waste or wear away, and are usually less permanent than those containing only small proportions of such metals.

Metals which are more or less readily acted upon by alkaline and acid fluids under ordinary conditions are sometimes protected from action when alloyed with other metals. Copper and zinc, if used alone, would be attacked by the fluids of the mouth, but when added in small quantity to other metals employed for amalgams they are largely protected from corrosive action.

The tendency of some amalgam fillings to shrink and draw away from the edges would be favourable to the ingress of the erosive fluids of the mouth, and thus possibly reduce the permanency of the filling.

Possible Action on other Metals in the Mouth.—When amalgam fillings come into contact with other metals in the mouth, galvanic action usually takes place, as described on p. 30. Galvanic action tends to facilitate the "wasting" of the amalgam filling.

Ageing.—This term is given to a peculiar change that takes place with the lapse of time in the working properties of silver-tin alloys for amalgams after being cut. In some cases amalgamation is facilitated after "ageing"; in other cases it is retarded. The "ageing" of alloys for dental amalgams has been attributed to the formation of a film of oxide, the silver-tin alloys being particularly susceptible to oxidation. Although this would greatly tend to retard amalgamation, the recent experiments of Black* in connection with this subject have demonstrated that the changes that occur in a cut alloy are largely dependent upon the temperature at which it is kept. He showed that the change known as "ageing" was universal in the silver-tin alloys, but varying in degree with different formulæ; also that it could be produced artificially, the temperature at which it was effected varying with the composition of the alloy. The explanation offered by Professor Black for the changes which occur in a silver-tin alloy by subjecting it to heat is that in cutting the alloy it is hardened and undergoes a molecular change. Heating the alloy anneals it and causes it to return to its normal condition.

That certain alloys undergo molecular change when subjected to mechanical treatment or to change of temperature has long been known and has been the subject of much experimental investigation. Some kinds of brass wire become extremely brittle in the course of time, at ordinary atmospheric temperatures, especially when kept in a state of tension or subjected to vibration. An alloy of tin and lead, which is comparatively hard, and is used in pattern-casting for brass foundry work, becomes after a time so soft as to be no longer fit for use.†

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* *Dental Cosmos*, vol. xxxviii. p. 976.

† Percy, "Metallurgy," vol. i. p. 21.

Quantity of Mercury needed.—The quantity of mercury used with an alloy to form an amalgam is very variable and necessarily differs with every alloy. The proportions usually vary from 30 to 50 per cent. of mercury. Sufficient mercury must be used to satisfy the chemical affinity of the metals present and thus form a true amalgam.

If insufficient is added the mass will consist of a mixture of amalgam with particles of unamalgamated alloy. The two methods most frequently employed for obtaining the right quantity of mercury are—1. To add filings or shavings of alloy to a globule of mercury until a mass of proper working consistency is produced. 2. To add excess of mercury and then remove the excess by straining through chamois-leather with the aid of pliers. By the first method there is no indication as to when the proper amount of filings has been added to exactly satisfy the chemical affinity of the quantity of mercury employed. The second method is objected to by some, as a small quantity of alloy is removed in solution by the mercury squeezed through the pores of the leather. This method is also open to the objection that it does not remove all the mercury in excess. The methods which appear to give most satis-

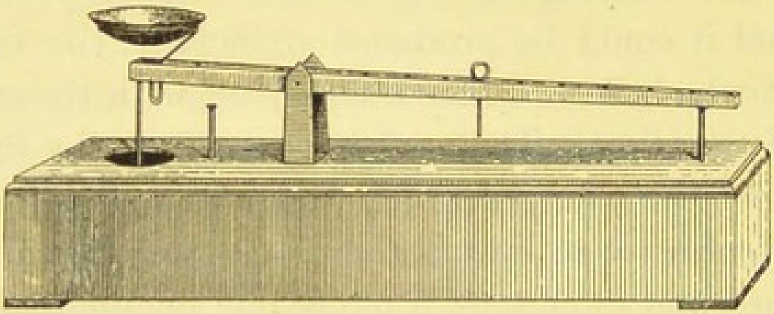

FIG. 33.

factory results are those in which sufficient mercury is mixed with the filings to give a fairly plastic amalgam and the excess forcibly squeezed out in the cavity and removed by means of bibulous paper or gold-foil.

In order to obtain the right quantity of mercury in preparing amalgams, after ascertaining the correct proportion to be used, balances are sometimes employed. Fig. 33 represents a balance designed by Kirby for this purpose, which turns to the fraction of a grain. The small metal pin acts as the weight and is inserted in the different holes on the balanced beam according to the quantity of mercury required.

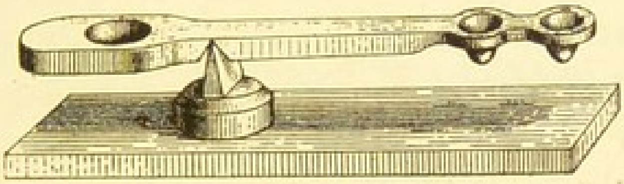

FIG. 34.

Another balance designed by Fletcher is represented in Fig. 34. The filings are placed in the large cup and the mercury in the two small cups, according to the quantity required.

Mixing Amalgams.—Different methods are employed for effecting the union of the filings or shavings of alloy with the mercury. That most frequently adopted consists in simply rubbing the filings and mercury together in the palm of the hand. This is perhaps the most expeditious way of effecting union, but it is open to the objection that the moisture or any film of dirt on the hand may retard amalgamation and possibly bring about failure in the result desired. Amalgamation is also effected by means of small porcelain Wedgwood mortars, but owing to the attrition of the pestle the particles of alloy become more or less burnished, and union is thus liable to be retarded.

Amalgamation is greatly facilitated, however, by heating the mortar. Several simple and effective appliances have been introduced for promoting amalgamation by percussive force. Fletcher has introduced the glass mixing-tube shown in Fig. 35. The required weight of filings is put into the tube, the mercury added and the tube well shaken for a few seconds, the open end being closed with the thumb. By the percussive force thus produced union readily takes place. If necessary, the tube may be gently heated to facilitate amalgamation. Another form of apparatus for mixing, introduced by Kirby, is shown in Fig. 36. It consists of two tubes provided with a handle for convenience in shaking, each tube being closed by means of a rubber stopper.

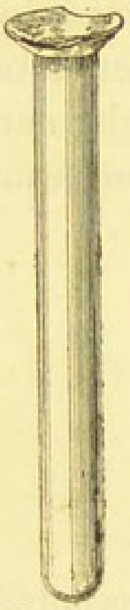

FIG. 35.

Preparation of Alloys for Dental Amalgams.—Alloys for dental amalgams may be readily prepared by melting the constituents in a graphite crucible heated in a suitable furnace, any of the forms previously described being well adapted for the purpose. As previously stated, the metals entering into the composition of alloys for amalgams are mainly silver and tin with small additions of gold, platinum, and copper. All these metals possess an affinity for one another, but they vary considerably with regard to the temperature required to melt them; the alloys produced are very easily oxidised, care is therefore needed in preparing them.

The constituent metals are placed in a crucible and a little charcoal added to prevent oxidation. The crucible is placed in the furnace and the temperature raised sufficiently high to thoroughly melt the metals and obtain a uniform alloy, but excessive heating should be avoided as it leads to loss, owing to unnecessary oxidation. The molten alloy is then well stirred and poured into a suitable ingot mould. Borax is frequently employed to prevent oxidation, but when using it care must be taken to prevent the molten "slag" from running into the mould with the alloy on pouring. If zinc is a constituent of the alloy it should be added in slight excess of that actually needed in the alloy, in order to allow for loss by oxidation, which invariably takes place. The ingot should be freshly filed off as required for use, a coarse file being employed for the purpose. It may be pointed out that, owing to the segregation which invariably takes place with these alloys during solidification, it is very difficult to obtain ingots which agree exactly in composition or correspond to a given formula, even when every precaution is taken.

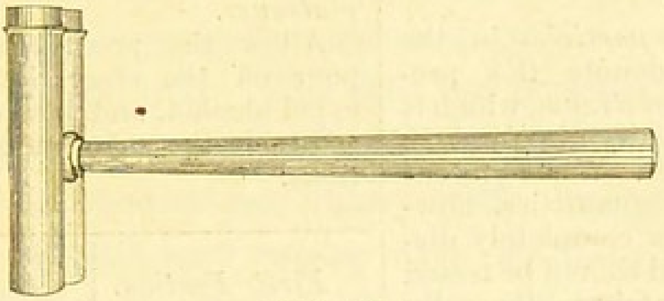

FIG. 36.

Qualitative Examination of Alloys for Amalgams.—It is important that the dentist should know how to ascertain the composition of the alloys used in the preparation of amalgams; the following scheme is therefore given for detecting the presence of the various metals usually present. A small quantity, about one gram (or 10 to 20 grains), is treated with nitric acid, gently heated until all action ceases and all red fumes are expelled, then diluted with water, the insoluble residue allowed to settle and filtered off.

<table>
<tr>
<td rowspan="2">RESIDUE.—May contain tin, gold, or platinum.
A <i>white residue</i> denotes the presence of <i>tin</i>, which is oxidised to metastannic acid.
A <i>purple residue</i> denotes the presence of <i>gold</i>, which is insoluble and forms purple-of-Cassius when present with tin.
<i>Black particles</i> in the residue denote the presence of <i>platinum</i>, which is only partially dissolved in some cases. When present in small quantities, however, it is completely dissolved and should be tested for separately in the solution as given.</td>
<td colspan="2">SOLUTION.—May contain silver, platinum, copper, zinc, cadmium: add hydrochloric acid: a white precipitate denotes the presence of <i>silver</i>.
Filter: evaporate the clear solution nearly to dryness: add some potassium chloride solution, then alcohol, and stir well. A yellow precipitate denotes the presence of <i>platinum</i>.
Allow the precipitate to settle, pour off the clear liquid, boil to expel alcohol, and then dilute.
Divide the solution into two portions.</td>
</tr>
<tr>
<td><i>First Portion.</i>—Add excess of ammonia: a deep blue coloration denotes the presence of <i>copper</i>.
Add to the blue solution a solution of potassium cyanide until colourless, pass a current of sulphuretted hydrogen. A bright yellow precipitate denotes the presence of <i>cadmium</i>.
<i>Note.</i>—If ammonia gives <i>no</i> blue colour, copper is absent and sulphuretted hydrogen may be passed at once.</td>
<td><i>Second Portion.</i>—Pass a current of sulphuretted hydrogen, filter off the precipitate of cadmium sulphide, then add ammonia to the clear solution. A white precipitate denotes the presence of <i>zinc</i>.</td>
</tr>
</table>

When old amalgam fillings are tested they should first be heated to redness to remove the mercury, the residue crushed to powder in a mortar and then treated with acid as previously directed.

Dental Copper Amalgams.

Sullivan's Amalgam.—This is prepared by mixing pure precipitated copper with mercury, but there are slight differences in the methods of manufacture.

The copper is generally prepared by placing rods of zinc or of iron into a hot dilute solution of copper sulphate and allowing the action to go on until all the copper is precipitated. The dull red flocculent precipitate of copper thus obtained is thoroughly washed with cold water and sometimes finally with alcohol or ether. It is next ground in a mortar with mercury, the combination being facilitated by the addition of water slightly acidulated with sulphuric acid. The amalgam is then washed with dilute ammonia to neutralise traces of acid, again thoroughly rubbed in the mortar, and subsequently washed with hot distilled water and dried. It is finally rolled into small pellets or lozenge-shaped pieces and allowed to set for about twenty-four hours before using. Care should be taken to thoroughly remove all moisture from the pellets before allowing them to set.

The precipitate is sometimes first moistened with a solution of mercuric nitrate, whereby it receives a thin coating of mercury, and then mixed with the required quantity of mercury. The amalgam usually consists of 3 parts of copper to 6 or 7 parts of mercury. It is stated that copper precipitated by iron is more serviceable and durable than that obtained with zinc, and iron is now usually employed for the purpose.

The copper should be freshly prepared when required, as it readily oxidises on exposure to air and becomes practically useless for amalgamation. This amalgam, in common with all copper amalgams, possesses the property of softening with heat and again hardening on cooling. This phenomenon, as previously stated, is ascribed to a state of amorphism, into which the amalgam passes from the crystalline condition in the process of softening. When one of the small pellets of amalgam is heated, small globules of mercury ooze slowly to the surface; then, more suddenly, a greater quantity is set free, sometimes accompanied by a hissing sound. If the heating is carried too far the mercury will be driven off and the copper oxidised or "burnt." When employed as a filling, one of the pellets is gently heated in a small iron spoon or ladle over the flame of a spirit-lamp, and then crushed and rubbed into a plastic, workable mass in a mortar.

With some varieties of this amalgam it is recommended, after rubbing in a mortar, to clean with water acidulated with sulphuric acid and then wash with water or dilute solution of common salt. Much diversity of opinion exists as to the point at which to stop the application of heat; some discontinue the heating when globules of mercury begin to appear on the surface; others continue till the excess is driven out. Dr. Black has shown * that the strength of the filling is seriously affected when the amalgam is removed from the source of heat on the appearance of globules. Great

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* *Dental Cosmos*, 1895, p. 738.

diversity of opinion also exists in regard to the merits and demerits of copper amalgams as a filling material. All copper amalgams, however, have the disadvantage that they discolour readily and stain the tooth substance. They also undergo a process of "wasting," resulting from the combined action of the acid and alkaline fluids of the mouth and of the sulphuretted hydrogen always present in the mouth to a greater or less extent. Copper amalgam is also said to possess therapeutic properties and thus arrest decay.*

Other copper amalgams are also used for filling purposes, but these only differ in slight alterations in the method of manufacture and in the addition of small quantities of other metals, mainly tin and silver, with a view to helping the amalgam to better retain its colour.

Filings of silver coin (alloys of silver and copper) are also employed for preparing amalgams for filling purposes.

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* For further details regarding the advantages and disadvantages of copper amalgam as a filling material, the student is referred to an interesting paper on the subject by Badcock, read before the Odontological Society of Great Britain (see *Proc. Odont. Soc.* (1897), vol. xl. p. 295).

CHAPTER IX.

SILVER.

SYMBOL, Ag (Argentum). ATOMIC WEIGHT, 108.

Occurrence. — Silver occurs in nature in the metallic state, occasionally in masses weighing several hundredweight, and usually alloyed with small quantities of other metals. It is also frequently found in combination with sulphur and chlorine. Silver is present in most ores of lead, notably with *galena* (lead sulphide), argentiferous lead ores constituting one of the main supplies of silver.

Preparation.—The methods employed for the separation of metallic silver from its ores are very varied; they may, however, be classed under three heads, namely:

1. Amalgamation processes involving the use of mercury.
2. Smelting processes involving the use of lead.
3. Wet processes.

Amalgamation Processes.—The finely ground ore is formed into a thin mud with water, and then well mixed with mercury, by which means a silver amalgam is formed. This is collected and the excess of mercury squeezed out; the residual amalgam is then heated in a retort to distil off the mercury, leaving behind the silver, which is melted and cast into bars.

Smelting Processes.—Silver ores are smelted with lead ores, whereby an alloy of lead and silver is obtained, from which the silver is extracted by a process known as *cupellation*, in which the alloy is melted in a furnace on a porous bed of bone-ash called a *cupel.* A blast of air is blown over the surface, which oxidises the lead and the oxide fuses and is partly absorbed by the cupel and partly flows away, whilst the silver remains behind.

A considerable portion of silver is also obtained by smelting argentiferous galena, the lead thus produced being subjected to a process for the concentration of the silver which is subsequently extracted from the enriched lead by cupellation.

Wet Processes.—The ore is roasted with salt to convert the silver into chloride, which is dissolved out of the roasted ore by means of a suitable solvent, such as hot brine. The silver is then precipitated either by placing strips of copper in the solution or by some other means, the "spongy" silver thus obtained being dried and melted.

Properties.—Silver possesses a pure white colour, has a very high metallic lustre, and is capable of taking a good polish. It is not acted upon under ordinary conditions by exposure to the air at any temperature, but in the presence of sulphuretted hydrogen the surface becomes rapidly tarnished owing to the formation of a black film of silver sulphide. Water is without action upon silver, and hydrochloric acid and dilute sulphuric acid have little or no action upon the metal. Hot concentrated sulphuric acid converts it into silver sulphate, while nitric acid is its best solvent, dissolving silver readily at the ordinary temperature. It is slowly attacked by alkaline solutions. In malleability and in ductility silver is only exceeded by gold, and is capable of being hammered into leaves of not more than $\frac{1}{100000}$th of an inch in thickness, which are capable of transmitting light giving a bluish or bluish-green colour. By hammering and wire-drawing the metal becomes more or less brittle, and requires more frequent annealing than gold under the same conditions. The presence of small quantities of other metals, such as antimony, bismuth, tin, zinc, and arsenic, renders silver brittle and liable to crack when rolled. Silver is harder than gold and softer than copper, and possesses considerable tenacity. Of all the metals it is the best conductor of heat and of electricity. It fuses at a temperature of 960° C. (1760° F.), a little below that required to melt gold and copper, and when liquid it possesses the power of absorbing oxygen from the air, which it gives up on solidification. When silver is quickly cooled after fusion it solidifies on the surface before the oxygen has escaped from the interior; this gas then bursts through the crust, the evolution being attended with the projection of small portions of the metal into a number of protuberances on the surface constituting the phenomenon known as the "spitting" or vegetation of silver. If, however, silver be melted beneath a layer of borax or of charcoal powder, the absorption of oxygen is prevented and the spitting avoided. Silver contracts on solidification, the decrease in volume being about equal to that of zinc; it begins to volatilise at a white heat. When molten silver is poured into water it becomes "granulated," and is usually employed in this condition for the preparation of alloys.

The specific gravity of silver is 10.5, a little lower than that of lead; its specific heat is nearly equal to that of palladium, being .0570; while its expansion per unit of length is $.00193 = \frac{1}{518}$.

Uses for Dental Purposes.—Owing to the soft and flexible nature of pure silver and its affinity for sulphur, it is seldom used in the dental laboratory unless hardened by the addition of other metals. When alloyed with platinum it is employed as a base for artificial dentures; it also forms an important constituent in the alloys used for dental amalgams.

Preparation of Pure Silver.—Scrap or old silver is dissolved in dilute nitric acid, and when dissolved the solution is diluted with hot water. If any gold or platinum is present * it will remain undissolved as a fine black powder; the solution after diluting should, therefore, be allowed to stand until the residue has completely subsided. The clear solution is then carefully poured off, heated nearly to boiling-point, and an excess of a solution of common salt or hydrochloric acid added to precipitate all the silver as chloride. On stirring the hot solution very briskly for a few minutes, the precipitate will readily settle, leaving the supernatant liquor perfectly clear. After

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* If scraps of dental alloy (which consists of silver and platinum) are also present with the material treated, the nitric acid will dissolve out the silver in the alloy, but a part only of the platinum will be dissolved, the remainder being left as a black residue which must be filtered off. After precipitating the silver (with hydrochloric acid) and filtering, the platinum in the solution may be recovered by introducing a clean strip of zinc which precipitates the platinum in the metallic state as a black sponge.

subsidence the acid liquor is poured off, and the chloride well washed with repeated quantities of hot water to free it from copper solution. It is then dried and mixed with four times its own weight of anhydrous sodium carbonate, and the mixture placed in a crucible and heated in a furnace, first at dull redness, and then gradually raised to bright redness. The reduction is complete in about thirty minutes, and when tranquil the contents of the crucible are poured into a suitable mould and allowed to cool, after which the coating of sodium chloride, produced by the reaction, is removed from the button of silver by means of a hammer, and the silver finally cleaned in hot water. As carbonic acid is given off freely during the reduction, care should be taken not to have the crucible more than three parts full, and to avoid a high temperature at the beginning, otherwise the charge may boil over and occasion loss. The silver thus obtained is practically pure.

The silver may also be obtained from the chloride by covering it with water acidulated with a few drops of hydrochloric acid, and then adding two or three pieces of clean sheet-iron, and allowing it to stand for some hours until all the chloride is reduced. The undissolved iron is then removed, and the spongy mass of silver washed with hot hydrochloric acid to dissolve any particles of iron. After standing a few minutes the acid is poured off, and the silver washed several times with hot water by decantation. It is then dried and melted in a crucible, and cast as required. Plates of copper or of zinc may be used instead of iron to reduce the silver chloride, but in this case the spongy silver requires more washing, in order to free it from the copper or zinc solution.

Precipitated Silver.—This is prepared by dissolving pure silver in dilute nitric acid, diluting with hot water, and then placing a strip of copper or of zinc in the solution. Silver is thus precipitated in the metallic state in the form of a spongy mass, which is washed several times with hot water and then dried, when it is ready for use. "Precipitated silver has long been known as forming an excellent filling, though it discolours the teeth greatly."*

Alloys of Silver.—Silver is capable of combining with most of the common metals by direct fusion of the constituents, forming a series of useful alloys. The alloys of silver chiefly used in the dental laboratory are as follows:

Silver and Copper.—These metals combine in all proportions when melted together, the resulting alloys being comparatively homogeneous, though ingots of the alloys are not absolutely identical in composition throughout; many of them undergo a process of "liquation" on cooling, however perfectly the molten alloy may be mixed. In some cases the interior of the ingot is richest in silver, while in other cases the exterior contains most. These alloys are white in colour until the copper amounts to nearly 50 per cent. of the alloy; beyond this limit the tint becomes yellowish, and finally red with the increase in the amount of copper. The density of these alloys is less than the mean of the constituent metals, owing to the expansion which takes place during combination. The effect of copper is to increase the hardness and elasticity, most of the alloys being harder and more elastic than silver, the hardest alloy consisting of about 5 parts of silver and

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* Tomes, "Notes on Amalgams," Odont. Soc. of G. B., 1896.

11 of copper. The ductility is also very considerable, but slightly inferior to that of pure silver. Although silver does not oxidise on the application of heat, silver-copper alloys are subject to change when heated in air, owing to the oxidation of the copper. The coating of oxide formed on the surface of standard silver during annealing may be removed and the silver whitened by heating the metal and plunging it while still hot into dilute sulphuric acid. The most important applications of silver-copper alloys are for the purposes of coinage, plate, jewellery, &c., for which uses pure or fine silver is too soft to withstand the necessary wear; consequently copper is added to obtain the required hardness.

Standard Silver.—British silver coin and plate contain definite proportions of silver and copper regulated by law. The alloy for silver coin contains 11 ozs. 2 dwts. of fine silver per lb. Troy, or 925 parts of silver per 1000, the remaining 18 dwts. or 75 parts being copper. This alloy is designated sterling or standard silver, and has a fineness of ·925. In commerce the purity of silver is referred to this standard, other specimens of different composition being reported in terms of *pennyweights better* or *worse* than the standard. Thus, the French and American coinage, which contain 24 dwts. of copper per lb. Troy (900 parts of silver per 1000), are stated to be *worse* 6 dwts. $(24-18=6)$; while the Indian rupee, containing only 12 dwts. of copper in the Troy lb., is described as *better 6 dwts.* In England all sterling silver goods are stamped, at offices appointed for that purpose, with a special mark known as the "Hall Mark." "Before the introduction of vulcanised rubbers as a base for artificial dentures, standard silver was employed in the United States for temporary dentures, where cheapness was an important consideration."* Standard silver, however, cannot be regarded as a suitable alloy as a base for dental substitutes, on account of the affinity which its constituents possess for sulphur and the readiness with which it is tarnished under the conditions which exist in the mouth. Filings of silver-copper alloys are sometimes employed for dental amalgams.

Silver and Gold.—(See Gold Alloys, p. 103.)

Silver and Platinum.—Alloys of these metals may be obtained by fusion of the constituents, small proportions of platinum rendering silver harder but greyish-white in colour.

As the proportion of platinum increases the alloys become less malleable and ductile, and more difficult to melt. Owing to the very high melting-point of platinum, it may be thought that the preparation of these alloys is a matter of great difficulty. When, however, a small quantity of platinum-foil or "sponge" is added to an excess of the more fusible metal silver in a molten condition, it readily combines with the silver, producing an alloy which melts without difficulty at ordinary furnace temperatures. The alloys of silver and platinum are much more fusible than platinum itself; they are also less readily tarnished than silver or ordinary silver alloys.

In preparing these alloys there is always a tendency for the two metals to separate on cooling according to their densities, the platinum settling to the bottom; it is very essential, therefore, to well stir the molten alloy before pouring. In preparing "dental alloy" it is

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* Essig, "Dental Metallurgy," p. 182, 3rd ed.

necessary to remelt the alloy in order to obtain as uniform a product as possible. An alloy of silver and platinum, containing only 2 per cent. of the latter metal, completely dissolves in nitric acid; but if the platinum much exceeds that proportion, part of it remains undissolved. With sulphuric acid the silver only dissolves.

Dental Alloy.—This name is given to an alloy of silver and platinum used by dentists which contains from 20 to 30 per cent. of platinum according to the quality. Two "qualities" of this alloy are in general use in England, the "first quality" consisting usually of 2 parts of silver and 1 part of platinum, and the "second quality" of 3 parts of silver and 1 part of platinum, but the composition varies slightly with different makers. Dental alloy is much more durable and more rigid than standard silver, and makes a stronger artificial denture, for which purpose it is largely employed. The alloy is hardened by hammering, and requires annealing during swaging. It has much less tendency to blacken than silver-copper alloys when exposed in the mouth, although the presence of platinum does not wholly protect silver from the action of sulphuretted hydrogen and the oral fluids. Dental alloy comes into the market in the form of wire, sheet, and perforated sheet, the last named being used as a base for strengthening vulcanite pieces.

Nitric acid attacks this alloy, and dissolves a considerable quantity of the platinum along with the silver. Concentrated sulphuric dissolves out the silver, leaving the whole of the platinum in the metallic state as a black residue. On heating a plate of dental alloy and dipping it into dilute sulphuric acid, the silver on the surface is dissolved, leaving the platinum. "An alloy of silver and platinum was used by dentists for pivots of artificial teeth before 1835." [*]

The union of two or more pieces of dental alloy is effected by means of gold solders (see p. 110).

Von Eckart's Alloy.—This is an alloy consisting of silver 3.5; platinum 2.4; and copper 11.7; which is used in France as a base for artificial dentures. It is hard, malleable, and very elastic, which latter property it retains after annealing. It is less tarnished by the atmosphere than silver-copper alloys, and is capable of receiving a high polish. Owing to the large proportion of copper it contains, it is gradually blackened in the mouth by the sulphuretted hydrogen present.

Silver and Tin.—These metals combine readily when fused together to form alloys which have about the same colour as pure silver. They are more or less brittle or semi-ductile and in general hard. The addition of a very small quantity of tin renders silver brittle.

Experience has shown that different portions of a mass of any of the solidified alloys of the silver-tin series, except the eutectic alloy, exhibit a want of uniformity in composition. This is no doubt due to the presence of the eutectic alloy (see p. 39). Heycock and Neville [†] have ascertained that the eutectic alloy, which is mechanically homogeneous, consists of 3.53 per cent. of silver and 96.47 per cent. of tin, and solidifies at 220° C.

They have also shown that the initial solidifying-

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[*] Percy, "Metallurgy of Silver," p. 668.

[†] *Proc. Roy. Soc.*, vol. clxxxix. (1897), pp. 25–70.

point of an alloy containing 60 per cent. silver and 40 per cent. tin is about 500° C., and that of an alloy consisting of 40 per cent. silver and 60 per cent. tin about 450° C. It is evident, therefore, that, in the range of temperature between the initial solidifying-points of these alloys and that of the eutectic alloy abundant opportunity is afforded for the mass to arrange itself as previously indicated (p. 40), hence the divergency in composition.

These alloys are very oxidisable. On heating them with bichloride of mercury (corrosive sublimate) the tin is volatilised in the state of chloride, while the silver is left behind in a comparatively pure state. Alloys of these two metals are, as previously stated, largely employed in admixture with mercury for stopping teeth.

The density of the silver-tin alloys is less than the mean result of the densities of the two constituents, thus showing that chemical combination has probably taken place and that expansion has occurred during the union of the metals.

Silver and Mercury.—Silver amalgams are white, soft, granular or crystalline bodies, according to the composition and mode of preparation. They harden slowly, and expansion takes place during combination. The properties of silver amalgams are given under Mercury, p. 136.

Silver Solders.—The alloys used for soldering articles of silver are usually composed of silver, copper, and zinc in variable proportions, with the addition sometimes of tin, the latter metal being added to the silver to increase the fluidity and cause it to run well when fused. Several qualities of silver solders are employed according to the nature of the work upon which they are to be used. The various degrees of fusibility of the silver solders are obtained by using different proportions of the metals which enter into their composition. Alloys of silver and copper form the hardest solders—*i.e.* those most difficult to melt. The addition of zinc gives a medium solder, while the easiest or softest are prepared with the addition of a certain proportion of tin.

The silver solder frequently sold at dental depôts is composed of 3 parts fine silver and 1 part of brass. This represents a percentage composition of :

Fine silver	75·00 per cent.
Copper	16.66 ,,
Zinc	8.33 ,,
	99·99

Richardson * gives the following formulæ for soldering articles made of standard silver :

No. 1.		No. 2.	
Fine silver	66 parts	Fine silver	60 parts
Copper	30 ,,	Copper	20 ,,
Zinc	10 ,,	Brass	10 ,,

Silver solders are usually employed in the form of thin plate; filings, however, are sometimes used. Dental alloy is generally soldered with gold solder, as silver solder would blacken much too readily in the mouth.

The flux used with silver solders is always borax, as it not only prevents oxidation during soldering, but also greatly facilitates the flow of the solder into the required places.

Preparation of Silver Solders.—Silver solders may be

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* Richardson, "Mechanical Dentistry," 1894, p. 111, 6th ed.

prepared by melting the silver and copper together under a layer of charcoal powder in a plumbago crucible heated in a suitable furnace. The zinc, which should be previously heated and in slight excess of that required, is cautiously added after the silver and copper are melted, and the whole well stirred with an iron rod and then poured into a flat ingot mould to obtain a plate of alloy suitable for rolling.

When cool the ingot is removed from the mould and rolled into a sheet of about one-sixtieth of an inch in thickness. Brass is invariably used instead of copper and zinc separately; it should be added after the silver is melted. Silver coins are sometimes used instead of silver and copper separately, in which case the solders are prepared by adding to the coin from one-tenth to one-sixth its weight of zinc.

Assay by Cupellation, or Dry Method of Assay. —The operation of cupellation has for its object the removal of base metals in a gold or silver alloy by oxidation and by the aid of fused litharge (lead oxide). It is based upon a property which characterises the precious metals—viz. that they are not oxidised when exposed in a molten condition to a current of air, while base metals, when similarly treated, are readily oxidised. Lead is always added to the impure gold or silver, as it is readily converted into litharge (lead oxide), which fuses and dissolves the oxides (formed during the operation) of base metals in the alloy. The operation is conducted in a small vessel termed a "cupel" (Fig. 37), made of bone-ash, which, being very porous, absorbs the molten oxides, leaving the unoxidisable metals—gold and silver—on the cupel.

FIG. 37.

The assay of silver alloys by the cupellation method is conducted as follows:

1. A fair sample of the alloy is accurately weighed in a delicate balance.
2. This weighed portion is then wrapped in thin sheet-lead and cupelled, to remove the base metals present.
3. The button of silver remaining on the cupel is weighed.

In conducting the assay 1 gramme (or 10–15 grains) of the alloy is usually taken and carefully wrapped in a weighed quantity of lead-foil. The amount of lead to be added to an alloy of silver and copper varies in accordance with the composition of the alloy, and is greater in proportion as the quantity of copper increases. English standard silver (925 fine) requires about six times its weight of lead for cupellation.

After wrapping the alloy in the required weight of lead-foil it is charged into the cupel, previously heated in a muffle furnace kept at a uniform red heat. If the right temperature is attained the charge quickly melts and cupellation begins, the metallic globule steadily diminishing in size until, after the expiration of about twenty to thirty minutes, the lead and base metals have become completely oxidised and absorbed by the cupel, leaving a bright globule of pure silver. As soon as the cupellation is finished the muffle is allowed to cool down, in order to avoid the spitting of the silver, and the cupel withdrawn when the silver bead is solid.

The bead is then detached, brushed, and weighed. The weight of the silver bead does not, however, give the true proportion of silver in the alloy, as there are always small losses of silver due to volatilisation and absorption by the cupel. These are determined by placing in the muffle with each batch of assays one or more *proof* or *check* assays of the same weight and of similar alloy but of *known* composition. The checks are prepared from pure silver and copper, and when the approximate composition of an alloy is not known a preliminary cupellation must be made to ascertain this before suitable "checks" can be prepared. When these checks are cupelled side by side with the assay piece it is concluded that the loss of silver on each will be the same. In order, therefore, to obtain the true percentage of silver in the alloy submitted to assay, the calculated loss sustained by the check is added as a correction to the weight of the silver bead from the alloy.

When gold or platinum is present in the alloy it remains on the cupel in combination with the silver, and must be subsequently separated (see Gold Assays, p. 99).

Silver alloys, such as those used for dental amalgams, containing tin, or zinc, must be subjected first to "scorification" before cupellation, as these metals produce oxides which are not absorbed by the cupel. Scorification consists in mixing a weighed quantity, usually 5 grammes (or 50 grains), of the alloy with about 10 times its weight of granulated lead in a small saucer-shaped vessel of fire-clay, termed a "scorifier" (Fig. 38), and placing this in a muffle furnace at a bright red heat. By this means the base metals are oxidised and form a fusible "slag" by combining with molten lead oxide, produced by the oxidation of a part of the lead, while the unoxidisable metals remain in combination with the metallic lead present in excess. As the scorifier

FIG. 38.

is not made of absorbing material, the "slag" floats above the excess of lead. When the operation is complete the contents of the scorifier are poured into a suitable mould, the glassy "slag" detached, and the lead "button" cupelled in the ordinary way.

Wet Assay of Silver.—Silver is usually estimated in the wet assay by precipitating it as chloride. A weighed quantity of the alloy is dissolved in dilute nitric acid with the aid of a gentle heat. When dissolved (see note) the solution is diluted with boiling water and an excess of hydrochloric acid added to precipitate the silver as chloride. The solution is well stirred, and when the silver chloride has completely separated, leaving the supernatant liquor clear, it is filtered off and washed well with hot water. It is then carefully dried and weighed and the percentage of silver calculated. One hundred parts of silver chloride contain 75.27 parts of silver.

Note.—Any gold, tin, or platinum present in the alloy treated would be left as an insoluble residue, which must be filtered off before precipitating the silver.

Electro-plating.—This term is applied to the process by means of which a film of metallic silver is deposited on the surface of articles made of German silver, copper, brass, and other base metals, to give them the appearance of silver, and is similar to electro-gilding. The article to be plated is first thoroughly cleaned, as described for gilding on p. 116. It is next dipped into a solution of mercuric nitrate, whereby it receives a thin deposit of mercury, then rinsed in water, and immediately suspended by means of thin copper wire in the plating liquid, which consists of a solution of silver cyanide in potassium cyanide. The article is then connected to the negative pole of a suitable battery, while a strip of pure silver is connected to the positive pole and suspended in the plating liquid. An electric current is thus passed through the solution, causing silver, in a coherent form, to be precipitated upon the article, while the silver plate is gradually dissolved, forming silver cyanide, thus maintaining the strength of the solution. The deposit of silver is usually dull or "frosted," but the addition of a few drops of carbon disulphide to the solution causes the silver deposit to form with a bright surface.

Recovery of Silver from Scraps.—The scraps of dental alloy are treated with nitric acid, and the platinum removed as described on p. 189. Strips of copper or of zinc are then placed in the solution to precipitate the silver. The spongy silver thus obtained is washed, dried, and then melted.

CHAPTER X.

PLATINUM.

SYMBOL, Pt. ATOMIC WEIGHT, 195.

Occurrence.—Platinum is always found in the metallic state, generally as rounded or flattened grains of a light steel-grey colour and metallic lustre, occurring in alluvial deposits, detritus, and gold-bearing sands. It is never pure, but invariably contains iron and a group of rare metals chiefly found in platinum ores—viz. palladium, iridium, rhodium, osmium, and ruthenium, known as the "*platinum group.*" The largest supply of platinum comes from the Ural Mountains, but it is also found in other districts.

Preparation.—The metal is first separated, by careful washing operations, from much of the sandy, earthy, and lighter portions of the ore, the residue consisting of grains of platinum, along with gold, &c. The platinum is extracted by treating the residue with nitric acid, to remove any associated copper, lead, or silver, washing it with water, and treating with hydrochloric acid to dissolve the iron, and then heating with nitro-hydrochloric acid. The solution thus obtained is then mixed with sal-ammoniac (ammonic chloride), whereby a yellow precipitate of the double chloride of platinum and ammonium is obtained. The precipitate is washed, dried, and ignited in a plumbago crucible, when the metal is obtained as a grey spongy mass known as *spongy platinum*, the ammonic chloride and chlorine being expelled. The fine powder is heated to whiteness, and hammered until it is welded into a homogeneous mass, or it is melted in a crucible of lime or gas-coke by means of the oxy-hydrogen flame.

Properties.—Platinum is a white metal with a greyish tinge, and when polished it has a very high metallic lustre. It does not become tarnished by exposure to the atmosphere at any temperature, even in the presence of sulphuretted hydrogen. Platinum resists the action of water and of most chemical agents; it is not attacked by hydrochloric, sulphuric, nitric, or any single acid, except when alloyed with a large proportion of silver, in which case it is soluble in nitric acid. It dissolves slowly in nitro-hydrochloric acid, which is its best solvent. This property of withstanding the action of chemical agents, coupled with its non-oxidisability at all temperatures, makes it a valuable material for dental purposes.

The pure metal is slightly harder than silver and is very malleable and ductile, being only inferior to gold and silver in ductility, while in tenacity it is only surpassed by iron, steel, and nickel. Platinum is hardened by rolling and mechanical treatment, but may be softened by heating to a bright red heat for five to ten minutes and allowing it to cool. It is much inferior to both gold and silver in conductivity for heat and for electricity. It is one of the heaviest substances in nature, its specific gravity being 21.5. It is infusible at the highest temperature attainable in ordinary furnaces, but may be fused by the electric current, or by the oxy-hydrogen blowpipe flame. It becomes soft and workable at a temperature much below its melting-point, and at high temperatures the metal can be welded by pressure or hammering. Like silver, large masses of platinum absorb oxygen when molten but expel it on cooling, causing the mass to "spit." When heated platinum possesses the remarkable property of absorbing considerable quantities of hydrogen and other gases, especially when it is in a fine state of division.

Use in Dental Laboratory.—Platinum is used as a base for continuous gum-work; for pins for attaching teeth; for backing and other minor operations of the dental laboratory. Alloyed with silver, it is largely used as a base for artificial dentures.

Brittle Platinum.—Experience having proved that the platinum pins attached to mineral teeth are frequently brittle and very liable to break, an investigation into the composition of brittle platinum pins was undertaken by Prof. Hartley of Dublin * with a view to ascertain the cause.

For this purpose fragments of brittle pins were submitted to a very careful spectroscopic examination. The results of the experiments showed that the brittle and crystalline character of the platinum was in all probability due to the presence of minute quantities of phosphorus or of carbon, and by remelting in a lime-crucible under the oxy-hydrogen flame its malleability was greatly improved, thus confirming the accuracy of the conclusion arrived at.

Platinum Foil.—Platinum may be rolled or beaten out into thin foil, and can be used in this

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* *Proc. Chem. Soc.*, vol. xviii. (1902), p. 30.

form for filling purposes. In order to make the leaves of platinum adhere when pressed together the surface is covered with a film of pure gold by electro-deposition. The foil must be thoroughly annealed when used in order to make it work easily. The metal is harsh to work compared with gold. Fillings of platinum have the advantage of being almost white when finished.

Platinum Black.—Platinum in an extremely fine state of division forms a black powder known as "platinum black," which resembles lampblack in appearance and soils the fingers in the same way. This finely divided platinum may be obtained in various ways. A common method of preparing it is by precipitation with zinc from a solution of platinic chloride containing an excess of hydrochloric acid, or by adding an excess of a mixture of sodium carbonate and sugar to a solution of platinic chloride and then boiling until the precipitate formed becomes perfectly black and the supernatant liquor colourless. The soft black powder is collected on a filter, washed, and dried at a gentle heat. It is also prepared by fusing platinum with twice its weight of zinc, powdering the alloy thus produced, and dissolving out the zinc with sulphuric acid, when the platinum remains in the form of a black powder.

Platinum black possesses remarkable and powerful chemical properties; it absorbs and condenses gases, especially oxygen, within its pores so rapidly that the mass becomes red hot. When exposed to a red heat the black substance shrinks in volume and assumes the metallic appearance of spongy platinum, and no longer soils the fingers. When prepared from alloys of platinum with zinc and other metals, the black powder when heated in an open vessel to a temperature considerably below redness deflagrates with a hissing noise, sometimes detonating like gunpowder.

Spongy Platinum.—This name is applied to the spongy, slightly coherent form of metallic platinum obtained by heating to bright redness the double chloride of platinum and ammonium. This latter compound is formed as a yellow precipitate when sal-ammoniac (ammonic chloride) is added to a solution of platinic chloride, obtained by dissolving platinum in aqua regia. The yellow precipitate is decomposed on the application of heat and gives off chlorine and sal-ammoniac, leaving a residue of spongy platinum. By the application of pressure to the spongy mass when at a bright red heat its particles may be *welded* together, when it assumes the form and appearance of commercial platinum. Like the other forms of platinum, it is capable of inducing chemical combinations in the mixture of certain combustible gases.

Detection of Platinum in Alloys.—Platinum is usually detected in alloys for amalgams, as described in the qualitative examination of alloys on p. 162. The quantity of platinum in these alloys seldom exceeds 1 per cent., and is usually completely dissolved when the alloy is treated with nitric acid.

The presence of platinum in gold plate may be detected by dissolving a few chippings in aqua regia, removing excess of acid by evaporation, diluting and filtering off any residue of silver chloride, then concentrating by evaporation and adding ammonium chloride and alcohol as before.

In silver alloys (such as dental alloy) the presence of platinum may be detected by treating the alloy with nitric acid, when the platinum is partly dissolved, the remainder being left as a black insoluble residue. The platinum in solution may be detected by adding ammonium chloride and alcohol as before, after precipitating the silver with hydrochloric acid and filtering.

Estimation of Platinum in Alloys.—1. *In Dental Amalgams.*—Owing to the comparatively large proportion of tin present in alloys used for amalgams it is somewhat difficult to accurately estimate the small amount of platinum usually present. The most satisfactory method consists in scorifying (see p. 180) 5 grams, or 50 grains, of the alloy with from 10 to 15 times its weight of granulated lead, whereby the tin is removed and the silver, gold, and platinum retained in the resulting button of lead, which is cupelled. The silver button (containing also gold and platinum) obtained by cupellation is treated with dilute nitric acid to dissolve out the silver and platinum. The residue of gold (if any) is filtered off and the silver precipitated with hydrochloric acid. After filtering off the silver the solution is evaporated to very small bulk, then ammonium chloride and alcohol are added to precipitate the platinum, the precipitate thus obtained being dried, heated to redness to obtain metallic platinum, and weighed.

The small quantity of platinum usually present in amalgam alloys will probably all go into solution with the silver; but when large quantities are present a part of it will remain with the gold; the residue left (if any), after being treated with nitric acid, should therefore be dissolved in aqua regia and the platinum precipitated and weighed as previously directed.

Platinum may also be estimated in amalgam alloys by melting the alloy in a small crucible and gradually adding mercuric chloride, by which means the tin is removed as a volatile chloride. This must be done in a draught cupboard to carry off the fumes produced, as it is dangerous to inhale them. The button of silver left behind contains the platinum (and gold if present). It is treated with nitric acid, as above described.

2. *Platinum in dental alloy* may be conveniently estimated by treating a weighed quantity of the alloy with nitric acid, which dissolves all the silver and part of the platinum. On introducing a sheet of zinc into the solution the silver and platinum are precipitated, and on treating this precipitate with nitric acid the silver only is dissolved. The two quantities of platinum are then put together, washed, heated to redness, and weighed. The platinum precipitate may also be dissolved in aqua regia, the metal precipitated with ammonium chloride and weighed as spongy platinum as previously directed.

The silver may be recovered from the solution in the usual way by precipitation as chloride (see p. 169).

Alloys.—Platinum will alloy with most of the other metals under the influence of heat, producing bodies which are usually considerably more fusible than platinum itself.

Platinum and Gold.—These metals combine with the formation of alloys which are more fusible than platinum, the melting-point being lowered as the quantity of gold increases.

The alloys are elastic and ductile, and their colour approaches more or less to that of gold as the proportion of the latter is increased.

Platinum and Silver.—Silver unites with platinum by fusion, forming alloys which become more malleable, ductile, and fusible as the proportion of silver increases.

Dental Alloy.—This alloy of silver and platinum has been described under Silver Alloys (p. 174).

Platinum and Iridium.—These metals unite in different proportions, but the union is only effected by the use of the intense heat of the oxy-hydrogen flame. The presence of iridium gives increased stiffness, hardness and elasticity to platinum. An alloy consisting of nine parts of platinum and one part of iridium is extremely hard, as elastic as steel, and more difficult to fuse than platinum. It is capable of taking an exceedingly beautiful polish and is unalterable on exposure to air. Alloys with 20 per cent. of iridium are malleable, ductile, and capable of being worked. Platinum containing a small quantity of iridium is stated by Essig* to be of value for strengthening continuous gum-work by forming the backing of it, especially in partial lower sets. It is also of value in combination with vulcanisable rubber for either entire or partial cases. It may be perfectly swaged by the use of a zinc counter-die. Pure gold is used as a solder with these alloys.

Platinum and Copper.—Platinum unites with copper in all proportions by fusion, but a high temperature is required for the production of these alloys. Those containing excess of platinum require the oxy-hydrogen flame to effect combination. The alloys possess considerable malleability, ductility, and tenacity, and are less tarnished by the atmosphere than alloys of copper with base metals.

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* "Dental Metallurgy," p. 201, 1893 edit

Recovery of Platinum from Scraps.—Platinum may be conveniently recovered from scraps of dental alloy by the method described on p. 189 for estimating platinum.

Solder for Platinum.—Pure gold is the only suitable solder for platinum and platinum-iridium alloys. Ordinary gold solders do not make a strong joint, and are not suitable for the purpose. For continuous-gum and porcelain bridge-work "platinum solder," composed of gold 4 parts and platinum 1 part, is supplied * for use with an oxygen blowpipe.

IRIDIUM.

SYMBOL, Ir. ATOMIC WEIGHT, 193.

This metal is found in the form of grains, which consist essentially of an alloy of platinum and iridium, called "platin-iridium," and are usually associated with the grains of platinum ore. Small particles of alloy of osmium and iridium (called "osmiridium") are also found.

Properties.—Iridium is a white, lustrous, steel-like metal slightly heavier than platinum, its density being 22.4. It is not acted upon by air at the ordinary temperature: at a red heat, however, it is superficially oxidised, but regains its metallic lustre on further heating. It is extremely hard and brittle when cold, but it is rendered somewhat malleable at a bright red heat. It is fusible only by the oxy-hydrogen blowpipe flame. It is not acted upon by ordinary acids or aqua regia. When alloyed with much platinum, however, it dissolves in aqua regia.

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* C. Ash & Sons, Ltd., List M.

Alloys.—Iridium alloys with most metals, increasing their hardness, but it cannot be alloyed with gold. With platinum it forms alloys remarkable for their strength and hardness. (See Platinum Alloys.)

Use in Dentistry.—Alloys of platinum and iridium are sometimes used as a base for dental plates, also in the form of wire for pivoting, and occasionally for the manufacture of nerve instruments.

CHAPTER XI.

PALLADIUM.

SYMBOL, Pd. ATOMIC WEIGHT, 106.

Occurrence.—This metal is chiefly found in the metallic state in nature in small quantities associated with platinum and gold.

Preparation.—In order to extract the metal the ore is heated with aqua regia, which dissolves the metals as chlorides. Ammonium chloride is then added to precipitate the platinum present. This is filtered off and the solution neutralised by the addition of sodium carbonate. A solution of mercuric cyanide is then added to precipitate the palladium in the form of palladium cyanide, which separates as a whitish, insoluble substance. This compound, after washing, drying, and heating to redness, yields metallic palladium in a spongy state, which may be welded into a solid mass in the same manner as platinum.

Properties.—Palladium is a white metal, resembling platinum and is capable of being highly polished. It is not acted upon by atmospheric air at the ordinary temperatures, but when heated to dark redness it assumes a violet or blue colour, owing to a superficial film of oxide; at a higher temperature the oxide is reduced and the metal regains its metallic lustre. It also resists the action of sulphuretted hydrogen. Palladium is not attacked by water, but it is more easily acted upon by acids than platinum. It is dissolved by hot nitric acid and is slowly soluble in hydrochloric acid and also in boiling concentrated sulphuric acid. Its best solvent, however, is aqua regia, which readily dissolves the metal.

Palladium is slightly harder than platinum; it is fairly malleable, ductile, and tenacious, and can be hammered into thin plates or drawn into fine wire; it is, however, rather less ductile than platinum. Palladium fuses at a somewhat lower temperature than platinum, viz., 1500° C. (2732° F.), but it cannot be fused in an ordinary furnace. When heated in the oxy-hydrogen flame it volatilises in greenish vapours.

When the metal is melted it absorbs oxygen, which is evolved when the metal solidifies, causing it to "spit" as in the case of silver. Palladium possesses the property of absorbing a large quantity of hydrogen. At a red heat it absorbs, or *occludes*, about 900 times its own volume of hydrogen, while even at ordinary temperatures it is capable of absorbing over 300 times its volume. This absorption of gases forms one of the most characteristic properties of palladium.

Palladium is only one-half as heavy as platinum, its specific gravity being 12.

Although palladium resembles platinum it may be readily distinguished from this metal by placing upon it a drop of tincture of iodine, which upon evaporation by heating produces a black stain with palladium, while platinum is not acted upon by this substance.

Use for Dental Purposes.—Palladium in a finely divided state is used for the preparation of palladium amalgam, but this forms its only use in dentistry. The unalterable nature of palladium in the air, its fine silver-white colour, which it does not lose on exposure to sulphuretted hydrogen, and its lightness make it a very suitable metal for use in prosthetic dentistry, and it is quite probable that it would be used for this purpose if its high price did not exclude it from the dental laboratory.

Palladium Precipitate.—This is the form in which the metal is employed for the preparation of palladium amalgam. It is usually prepared for dental purposes by placing strips of zinc in a solution of palladium chloride, whereby the palladium is precipitated as a fine black powder, which is then carefully washed and dried. The powder appears to lose its affinity for mercury after long exposure to the air.

Palladium and Silver.—These metals unite by fusion in all proportions. An alloy of three parts silver and two parts palladium is white, hard, elastic, and malleable, and it is not blackened by sulphuretted hydrogen. Even when alloyed with as much as three times its weight of silver, palladium retains its colour in the presence of that gas. These alloys are capable of a high polish and retain their brilliant surface. An alloy containing 38 per cent. of palladium and 62 of silver was formerly used by dentists.

Palladium and Gold.—The effect of gold on palladium is to produce alloys that are usually white or grey in colour, hard and ductile.

Palladium and Mercury.—Palladium amalgam may be formed by rubbing the finely divided metal with mercury. The union is accompanied by an evolution of heat. The properties of palladium amalgams have been given on p. 135.

CHAPTER XII.

ZINC.

SYMBOL, Zn. ATOMIC WEIGHT, 65.

Occurrence.—Zinc is stated to have been found in the metallic state in small quantities in Australia, but its chief forms of occurrence are in combination with sulphur as *zinc-blende*, and with carbonic acid as *calamine*, these being by far the most important and abundant ores of zinc. The metal is also found in combination with oxygen.

Preparation.—In extracting zinc from its ores advantage is taken of the volatility of the metal at a bright red heat. The metal is chiefly prepared from the carbonate and sulphide, these minerals being first powdered and roasted to expel the carbonic acid and sulphur, and convert the zinc into oxide. The zinc oxide is then mixed with powdered coal and heated to bright redness in earthenware retorts, when the oxide is reduced with the formation of carbon monoxide, which escapes, while the metallic zinc thus liberated distils over and is collected in clay or iron receivers.

The metal thus obtained is contaminated with a little zinc oxide, from which it is separated by re-melting before it is ready for the market. Zinc ores frequently contain small quantities of cadmium, but as this metal is more readily volatilised than zinc it passes over in the first portions of the distilled product, and can thus be collected. (See p. 224.)

Properties.—This metal, which is known commercially as "spelter," is bluish-white in colour, possessing when polished a bright metallic lustre, and when freshly broken a crystalline surface.

It is not acted upon by exposure to dry air at the ordinary temperature, but at a red heat it rapidly oxidises and burns with a bluish-white flame, with the production of a white flocculent powder of zinc oxide, ZnO. If exposed to a moist atmosphere at the ordinary temperature its surface rapidly becomes coated with a grey layer or film of oxide, which does not, however, increase by exposure, but protects the metal from further oxidation. When carbonic acid is present the coating is formed more rapidly and consists then of zinc carbonate.

Zinc is not attacked by pure cold water, but it is slowly oxidised by hot water and by water containing carbonic acid. Zinc dissolves readily in hydrochloric acid and sulphuric acid ; it is also soluble in nitric acid, and is slowly acted upon by alkaline solutions.

At ordinary temperatures zinc is a brittle metal, but when heated to between 100° and 150° C. (212° and 302° F.) it becomes both ductile and malleable, and may be rolled or hammered, after which treatment it retains its malleability when cold. When the heat is increased to about 205° C. (401° F.) the metal is again brittle, and may be readily pulverised in an iron mortar. Zinc is hardened by rolling and hammering, and requires annealing at a *low* temperature to restore its malleability. It melts at 415° C. (779° F.) and is volatile at a bright red heat. It contracts on solidification, the shrinkage being considerable when compared with that of other metals. It is a harder metal than gold or silver, and has a density of nearly 7.

Zinc has the property of precipitating most of the metals from their solutions.

It is extensively used for making *galvanised iron*, which consists of iron plate coated with zinc by dipping the iron into a bath of the molten metal. Iron thus treated is better able to withstand the action of air and moisture, the zinc preventing its corrosion or rusting.

Use for Dental Purposes.—The chief use of zinc in the dental laboratory is in the formation of dies used in swaging metal plates, for which purpose it is almost the only metal employed, as it possesses the properties required for this purpose to a greater extent than any other metal. Several of the compounds of zinc are also largely employed for the preparation of "cement" fillings.

Zinc Dies.—The use of zinc for dies has been objected to by some on account of the shrinkage which takes place when it solidifies, but this metal is almost universally employed for the formation of dies for swaging plates, as it possesses the properties of hardness, toughness, and malleability, and melts at a comparatively low temperature. Experiments by the late Professor Austen * have demonstrated that an average-sized zinc die measuring two inches transversely contracts $\frac{27}{1000}$th of an inch from the extremities of

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* "Metallic Dies." *American Journ. of Dental Science*, vol. vi.

the alveolar ridge, being equivalent in thickness to about three or four ordinary leaves of a journal.

In a moderately deep arch (about half an inch in depth) the shrinkage between the level of the ridge and the floor of the palate would be nearly $\frac{7}{1000}$th of an inch, or rather thicker than one leaf of a journal. The question of shrinkage is most serious in the deepest arches; in the case of shallow arches it is only about $\frac{1}{1000}$th or $\frac{2}{1000}$th of an inch.

When melting zinc for the preparation of dies it is necessary to remember that zinc castings made at a high temperature are more or less brittle and crystalline, but when cast at a temperature only a little above the melting-point of zinc they are comparatively malleable; care should always be taken therefore to avoid excessive heating. Zinc dies which are cast at a high temperature will require annealing by gentle heating. In some cases the die will be sufficiently annealed during the process of taking the counter-die.

Zinc is also occasionally used for counter-dies, which may be obtained by pouring the metal directly upon the zinc die, provided the necessary precautions are taken. If the metal is only heated sufficiently to render it fluid it may be cast upon the zinc die without fear of adhesion, this being prevented by the thin film of oxide on the surface of the die. Adhesion may also be avoided by rubbing the surface with a little blacklead powder before casting. When cold the die and counter-die will separate as readily as if lead had been used.

Purification of Zinc.—The zinc of commerce is sufficiently pure for ordinary purposes; but in the dental laboratory it becomes deteriorated by constant melting, owing to the fact that a small quantity of zinc oxide is dissolved by the metal. It also becomes contaminated with iron from the ladle. If a small quantity of charcoal is placed on the surface of the metal when melting, oxidation is minimised. The zinc may be purified by placing a few lumps of ammonium chloride (sal-ammoniac) on the surface of the molten metal, then stirring well with a stick of wood and pouring. When melting zinc in an iron ladle care should be taken to avoid excessive heating, as zinc forms an alloy with iron under favourable conditions. A malleable iron ladle should be used, as cast iron is more readily attacked, the zinc in some cases penetrating the ladle and escaping. By coating the inside of the ladle with whiting or a wash of clay and heating carefully, accidents of this kind may be avoided. When zinc has become accidentally contaminated with lead it may be separated from the latter by melting and allowing it to solidify slowly. On account of its density the lead will fall to the bottom and may then be removed by means of a chisel.

Compounds of Zinc.—The following compounds of zinc are those most frequently employed by dentists.

Zinc Oxide (ZnO). Known also as *Zinc White*. This is the only known compound of oxygen and zinc, and is the chief ingredient in the plastic filling-materials known as oxy-chlorides and oxy-phosphates.

It is prepared on a large scale by the combustion of metallic zinc in air, the fumes produced being led into a series of condensing chambers where the oxide is deposited. For pharmaceutical and dental purposes it is usually prepared by adding sodium carbonate to a solution of zinc sulphate. The white precipitate of zinc carbonate thus obtained is washed and dried, and then heated to expel the carbonic acid and water, leaving the zinc oxide as a powder.

Zinc oxide is a pure white, soft substance, which, when heated, becomes yellow, but on cooling again becomes white. It is insoluble in water except when carbonic acid is present, in which case it is dissolved. It is unaffected by dilute alkaline solutions, but acids and strong solutions of alkalies dissolve it readily. The oxide does not fuse even in the oxy-hydrogen flame, and it possesses the advantage of not being blackened by exposure to sulphuretted hydrogen.

Zinc Chloride ($ZnCl_2$).—This compound is usually prepared by dissolving metallic zinc in hydrochloric acid and boiling down the resultant liquid, until on cooling it becomes solid. It is also prepared by the direct combination of zinc with chlorine gas.

Zinc chloride is a soft, greyish-white, easily fusible substance, which resembles wax and may be distilled. It is extremely deliquescent on exposure to moist air, and is very soluble in water and in alcohol, its solution being powerfully caustic. Dry zinc chloride is used in surgery as a caustic, and a dilute solution of the salt in water is employed as an antiseptic.

Zinc Sulphate ($ZnSO_4$) or *White Vitriol*.—Zinc sulphate is formed when zinc is dissolved in sulphuric acid. It is obtained on a large scale by roasting the natural sulphide (blende), whereby the oxygen of the air partially converts it into sulphate, which is then dissolved out with water and allowed to crystallise.

It is extremely soluble in water, with evolution of heat, but only slightly acted upon by alcohol. At a temperature of about 300° C. (572° F.) it loses water and is converted into the anhydrous compound, a white friable substance, which at a white heat is converted into the oxide. Zinc sulphate, in common with all the soluble zinc salts, has an astringent taste and is poisonous.

These three compounds of zinc, viz., the oxide, chloride and sulphate, when mixed together or in combination with other substances, form the basis of the valuable class of materials known as osteoplastic or cement fillings. Three varieties are commonly used, under the names of oxy-chlorides, oxy-phosphates, and oxy-sulphates.

The cement used as a filling for teeth should be capable of being worked easily and should not set too rapidly. It should also possess the following qualities. It should: (1) be dense and harden under water; (2) be unaffected by contact with saliva; (3) be devoid of irritating chemical action; (4) be free from shrinkage or expansion; and (5) adhere firmly to the walls of the cavity.

The materials used for the preparation of the cements consist of a powder and a liquid, which are different for the several varieties made.

Oxy-Chloride.—The powder used for the preparation of this cement is finely powdered zinc oxide, which has been heated almost to whiteness for about two hours, whereby it loses nearly half its original bulk. The liquid is a dilute solution of zinc chloride, to which borax is sometimes added. A paste made by moistening zinc oxide with zinc chloride rapidly sets to a hard mass. Each special preparation of oxy-chloride naturally differs a little in detail of manufacture, but the powder in all consists of zinc oxide with a small admixture of other ingredients, such as finely powdered glass or silica, for the purpose of mechanically conferring greater hardness on the mass when set. A mixture in common use* is prepared by grinding together in a mortar 2 parts of borax, 1 part of fine silex (silica), and 30 parts of zinc oxide. When thoroughly mixed these are placed in a small crucible and heated to bright redness. This is called the "frit," and when cool the semi-coherent mass is again reduced to very fine powder by grinding. It is then mixed with three times its weight of calcined zinc oxide. The liquid usually employed with this powder consists of deliquesced zinc chloride diluted with water in the following proportions—1 ounce of zinc chloride dissolved in 5 or 6 drachms of water.

Oxy-chloride cements as a class are readily acted upon by the alkaline and acid fluids of the mouth, especially at the cervical edges. They are, therefore, valueless as permanent fillings. They usually set slowly, and a notable shrinkage generally takes place.

Oxy-Phosphate.—In this cement the powder is zinc oxide and the liquid is one of the varieties of phosphoric acid. The oxy-phosphate powders are similar mixtures to the oxy-chlorides, and, like them, the various preparations differ only in minor details of manufacture. The liquid used is frequently prepared by dissolving glacial phosphoric acid (ortho-phosphoric acid) in pure water and then evaporating the solution until it attains the syrupy consistency of glycerine, from which a crystalline mass is deposited on standing.

Phosphoric acid is extremely soluble in water; it has a pleasant, purely acid taste, and is perfectly free from

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* Essig, "Dental Metallurgy," 1893, p 241.

smell. When phosphoric acid is mixed with zinc oxide, the latter is dissolved and zinc phosphate formed. Crystals of pyrophosphoric acid are sometimes employed instead of the liquid, and are preferred by some. They are carefully melted in a platinum or porcelain spoon over a spirit-lamp, ebullition being avoided, until the liquid attains the consistency of glycerine.

Oxy-phosphates are soluble in the alkaline secretions of the mouth, the period of duration of these cements varying from two to about seven years. They are antiseptic, though less strongly so than the chlorides. As a class the oxy-phosphates are considered preferable to the oxy-chlorides, as they are more permanent and less irritating.

Oxy-Sulphate.—The powder for this cement consists of a mixture of zinc oxide and calcined zinc sulphate; the liquid consists of a solution of gum arabic. The following proportions are frequently employed:[*] for the powder, 1 part of calcined zinc sulphate with 2 or 3 parts of zinc oxide; for the liquid, 15 grains of gum arabic in ½ oz. of pure water, to which when completely dissolved 1 grain of sulphite of lime is added. The solution is then filtered through absorbent cotton.

In its purest form gum arabic is a yellowish-white substance, which is soluble in cold water, forming a viscid, adhesive, tasteless solution.

These cements usually lack hardness, but they are non-irritating and set rapidly. The oxy-sulphates are all more or less readily acted upon by the alkaline and acid fluids of the mouth.

Alloys of Zinc.—Zinc forms a number of useful alloys, to which when present in certain proportions it

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[*] Flagg, "Plastic Fillings," p. 156.

gives hardness without impairing the malleability of the alloy; while in larger proportions it often induces brittleness. Zinc lowers the melting-point of the metals with which it is alloyed, and for this reason is added to gold solder; it also renders the metals with which it unites less liable to be affected by exposure to the atmosphere.

Zinc and Copper.—These metals unite in all proportions to form the numerous varieties of brass, which are the most important alloys of zinc. (See Copper, p. 222.)

Zinc and Tin.—Alloys of these two metals can be readily prepared by fusion, forming combinations that are generally softer than zinc, harder and less malleable than tin, and more or less crystalline in structure. The alloys contract less than zinc; the amount of shrinkage varies, however, according to the proportions of the constituent metals, those containing excess of zinc contracting most. Zinc-tin alloys are chiefly employed in the arts for casting ornamental objects and patterns; they have also been used as a substitute for zinc in preparing dies for swaging plates. The waste in re-melting is greatest in alloys which contain excess of zinc. (See Alloys for Dies, p. 47.)

Zinc and Lead.—Zinc may be melted with lead in all proportions, but on cooling the mass does not remain homogeneous; the lead on account of its greater density sinks to the bottom, leaving a layer of zinc on top. The lead will, however, retain a small quantity of zinc, which has the effect of hardening the lead without impairing its malleability. (See Lead, p. 212.)

Zinc and Bismuth.—These two metals alloy when molten, but on solidification two layers are formed, the zinc with about 2 per cent. of bismuth rising to the top, while the bismuth on account of its density settles at the bottom, and contains about 8 to 14 per cent. of zinc.

Zinc and Mercury.—(See Zinc Amalgam, p. 138.)

Zinc unites readily with gold, silver, platinum and palladium; the alloys produced are described in the chapters dealing with these metals.

Zinc enters into the composition of the English bronze coinage to the extent of about one per cent. and is also present in varying proportions in the different qualities of German silver. (See p. 252.)

CHAPTER XIII.

LEAD.

SYMBOL, Pb (Plumbum). ATOMIC WEIGHT, 207.

Occurrence.—Lead has been found in nature in small quantities in the metallic state. The chief source of the metal, however, is in combination with sulphur as sulphide, *Galena* PbS, this being the ore from which the metal is chiefly obtained. It is also found in combination with oxygen, carbonic acid and phosphoric acid.

Preparation.—Lead is very readily obtained from galena; the ore is roasted in a reverberatory furnace with free access of air, whereby a portion of the sulphide is oxidised to sulphate, whilst in another portion of the sulphide the whole of the sulphur is burnt off as sulphur dioxide, and lead oxide formed.

The temperature of the furnace is then raised and the air excluded, when the sulphate and oxide of lead react upon the undecomposed sulphide of lead, giving off sulphur dioxide and leaving metallic lead behind.

Galena almost invariably contains a small quantity of silver, which will remain alloyed with the lead after smelting, and is subsequently extracted by the process of cupellation described on p. 167.

Another method of extracting lead from galena consists in heating the ore in contact with metallic iron; the iron combines with the sulphur, and the lead thus liberated sinks to the bottom of the furnace, while the sulphide of iron or *regulus* collects above it.

Properties.—Lead is a bluish-grey metal which may be cut with a knife or scratched by the finger nail, being the softest metal in common use. A freshly cut surface possesses a bright lustre, which, however, becomes rapidly tarnished on exposure to the air.

Lead is both malleable and ductile at the ordinary temperature, possessing the former property to a considerable degree. It can easily be rolled out to thin sheets or foil, in which form it has occasionally been used as a filling for teeth, as it also possesses the property of welding when two clean surfaces are pressed together.

Its tenacity is inferior to that of all the other ductile metals, so that it cannot be drawn into fine wire. It is flexible and non-elastic, and may be bent backwards and forwards repeatedly without fracture. On account of its flexibility and the readiness with which it may be made to "flow," thin sheet lead is frequently employed for obtaining patterns, &c. in the dental laboratory.

It is a very bad conductor of both heat and electricity. Lead fuses at 325° C. (617° F.), and becomes sensibly volatile at a red heat; it also contracts slightly on solidification. When heated to a temperature just below its melting-point it becomes brittle, a property which accounts for the fact that lead counter dies are liable to be broken if they are accidentally dropped immediately after casting. If lead is kept in a state of fusion in contact with the air, rapid oxidation takes place on the surface. When melted repeatedly it becomes hard and brittle owing to the formation of a small quantity of oxide which dissolves in the metal. This oxide may be removed and the lead made soft and malleable again by placing a layer of charcoal powder on the surface of the molten metal or by stirring it with a stick of green wood. Commercial lead is frequently almost pure and extremely soft and malleable; yet small quantities of other metals are sometimes present, the impure lead being usually whiter and less soft than pure lead. Metallic lead, on account of its softness and pliability, its low melting-point, and the fact that it withstands the action of water and many acid liquors better than most of the common metals, is largely employed in the arts for a great variety of purposes in the form of sheets and pipes.

Use for Dental Purposes.—Lead is chiefly employed for the production of counter-dies and in the form of thin sheets for cutting patterns. When alloyed with other metals it is used for several important purposes in the dental laboratory.

Alloys.—Lead may be alloyed with most of the common metals by melting them together. The general effect of the addition of other metals to lead is to harden it and impair its malleability.

Lead and Antimony.—The alloys of lead and antimony are harder and more fusible than either metal alone and also more oxidisible than lead, but if antimony is present beyond a certain proportion the alloys are very crystalline, hard and brittle. Alloys in which the antimony does not exceed 15 per cent. have the important property of expanding on cooling, a property which makes them well adapted for castings.

Type Metal.—This constitutes one of the chief alloys of lead and antimony. For large types it consists of lead with about one-fourth to one-eighth of its weight of antimony, while for small types tin is invariably added, and for special purposes small quantities of other metals such as copper and iron. Type metal is harder than lead, and brittle; it is sometimes used for dies, and also, though much less frequently, for counter-dies. (See also Alloys for Dies, p. 45.)

Lead and Tin.—These metals when fused together readily unite in any proportions, the resulting alloys having a somewhat darker colour and less brilliancy than tin. They are generally harder than tin and contract less on cooling than either of the constituent metals, but they are not so fluid when melted, and castings made with these alloys lack sharpness. The alloy of 4 or 5 parts of lead and 1 part of tin burns like charcoal at a red heat, producing a "cauliflower"-like mass. Lead-tin alloys with the addition of a small proportion of other metals are used for dies instead of zinc. (See Alloys for Dies, p. 49.)

Pewter is an alloy of 4 parts of tin with 1 part of lead, but small quantities of other metals are sometimes added.

Soft Solders.—These are alloys of lead and tin in various proportions, the fusibility of which generally increases with the amount of tin. *Common Solder* consists of equal parts of the two metals; *Fine Solder* is composed of 1 part of lead and 2 of tin; while *Plumbers' Solder* is made by melting together 2 parts of lead and 1 of tin. Alloys of these metals are remarkable for the facility with which they ignite and burn when raised to a red heat.

Lead and Zinc.—These two metals alloy in all proportions when molten, but separate according to their densities on solidification. (See p. 206.)

Lead which has become contaminated with zinc may be "softened" by melting it and exposing the surface of the molten metal to oxidation with occasional stirring. In this way the impurities are oxidised and form a scum on the surface which may be readily removed.

Lead and Mercury. (See Lead Amalgam, p. 135.)

CHAPTER XIV.

TIN.

SYMBOL, Sn (Stannum). ATOMIC WEIGHT, 118.

Occurrence.—All commercial tin is obtained from *tin-stone* or *cassiterite*, oxide of tin, SnO_2, this mineral forming practically the only ore of tin. Tin ore is not very widely distributed, only occurring in large quantities in comparatively few localities.

Preparation.—To obtain the metal the finely crushed ore, after being washed from all earthy matters, is roasted to expel any sulphur or arsenic with which it may be associated. The purified tin oxide is then mixed with powdered anthracite and smelted in a suitable furnace; the carbon of the anthracite combines with the oxygen to form carbon monoxide and thus liberates the tin. The tin so obtained is purified by stirring the molten metal with billets of green wood, which results in the separation of a scum or dross carrying with it the impurities.

The peculiar structure of the commercial metal known as *grain-tin* is produced by heating ingots of the metal to a temperature at which they become brittle and breaking them by dropping from a height.

Properties.—Tin is one of the whitest metals, but possesses a peculiar faint yellow tinge; it rivals silver in lustre and its surface is capable of taking a fine polish. It undergoes little change in dry or moist air at ordinary temperatures, but it tarnishes slowly in the presence of sulphuretted hydrogen owing to the formation of a film of sulphide. If heated in air it rapidly oxidises to stannic oxide (SnO_2), which forms the well-known polishing putty powder, but the pure metal, if melted at a low temperature and poured out, retains its resplendent lustre for a considerable time. Tin has a characteristic odour which becomes evident when the metal is warmed by being held in the hand for a short time. It is a little harder than lead but softer than gold.

Water has no action on the metal, but it is readily soluble in hot hydrochloric acid; boiling concentrated sulphuric acid acts violently on the metal, while the action of the dilute acid is less energetic. Dilute nitric acid acts violently upon it, liberating nitrous fumes, and converting the tin into metastannic acid, which settles at the bottom of the vessel as a white powder. Tin is also soluble in alkaline solutions. A bar of tin when bent emits a peculiar crackling sound, known as the *cry of tin*, caused by the friction of the crystalline particles. Tin is one of the least tenacious of the metals, only lead, antimony and bismuth being inferior to it in this respect; it is, however, very malleable and can be easily rolled out to thin foil of less than $\frac{1}{1000}$th of an inch in thickness. Tin may be welded by the application of pressure, when two clean surfaces are brought into contact. It possesses little ductility, but with care may be drawn into wire. At a temperature of 392° F. (200° C.) it becomes so brittle that it may be readily powdered.

It melts at a temperature of 232° C. (449° F.) and contracts slightly on solidification. Tin is an inferior conductor of heat and of electricity; it has a density of 7.3.

Tin is easily crystallised superficially by treating the surface with a mixture of dilute sulphuric and nitric acids; the ornamental appearance seen on tin boxes, &c., known as "moirée metallique," is obtained in this way. Tin is also obtained in a crystallised state when deposited from its solutions by electrical agency, the metal prepared by this means being in the form of brilliant elongated needles.

Uses in Dental Laboratory.—Tin was formerly used as a base for artificial teeth, and more recently it has been introduced as one of the constituents in the alloys used for the "cheoplastic" process. It is sometimes used for counter-dies and occasionally for dies. "When employed for dies in connection with a lead counter the latter should not be obtained directly from the die, as the comparatively high temperature of molten lead would produce, when poured upon the tin, partial fusion of the latter and consequent adhesion of the two pieces."* As its affinity for sulphur is so slight, tin is largely used in swaging operations, for which purpose it is supplied in thick and thin sheets as "Soft Metal."

Tin as before stated enters into the composition of alloys used for dental amalgams, and for dies.

Clean surfaces of pure tin may be made to cohere by compression, and on this account tin in the

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* Richardson, "Mechanical Dentistry," 1894, p. 125.

form of thin foil is frequently used as a filling for teeth. "Tin-foil is very little employed as a filling by itself, being generally used in combination with gold. The advantages claimed for it are that—(1) it is easy to work; (2) it has a preservative action upon the tooth substance. For the latter reason it is generally used as a lining to cavities and at cervical margins. It has one distinct disadvantage in the fact that it becomes black."[*]

Tin-foil.—Pure tin-foil is made by casting the metal into slabs about one inch thick and reducing these to foils of the desired thinness by passing them repeatedly through a rolling mill. During the rolling soapsuds are allowed to flow on the foil to prevent its sticking to the rolls. Ordinary tin-foil is about $\frac{1}{1000}$th of an inch thick, but for dental purposes foils of varying degrees of thickness are made and are numbered in a manner similar to that employed for gold foils. (See p. 91.)

Tin-plate.—The material known in commerce as tin-plate is composed of thin plates of iron coated with tin by dipping them into a bath of molten tin, the object of the coating being to prevent the formation of rust, which takes place when iron plates are exposed unprotected to the action of air and moisture.

Alloys of Tin.—Tin enters into the composition of a large number of useful alloys, many of which are of considerable importance,

Tin and Silver.—(See p. 175 and also chapter viii.)

Tin and Zinc.—These metals alloy readily when fused together. (See p. 206 and Alloys for Dies, p. 47.)

[*] Smale and Colyer, "Diseases of Teeth," p. 183.

Tin and Copper.—Tin unites readly with copper, the most important alloys being the various bronzes, &c., described under Copper Alloys, p. 222.

Tin and Mercury.—Tin readily combines with mercury. (See Tin Amalgam, p. 138.)

Tin and Antimony.—These metals unite when melted together, the effect of antimony being to harden the tin and generally to impair the malleability and ductility, making it more or less brittle. The brittleness increases with the proportion of antimony. An alloy of 4 parts of tin and 1 part of antimony is sufficiently malleable to be hammered and rolled cold.

Britannia Metal.—This is an alloy of tin and antimony in very variable proportions, to which small quantities of other metals are also frequently added. It is a hard, very malleable and ductile alloy, and can be rolled out and stamped into various shapes. It takes a high polish and is largely employed for the manufacture of impression trays and other articles used by dentists. An inferior kind of Britannia metal known as "Queen's Metal" consists on an average of 75 per cent. of tin, 8.5 per cent. of antimony, with 8.5 per cent. of lead, and 8 per cent. of bismuth.

Meter Metal.—This is composed of tin, antimony, and lead; it is used in the dental laboratory for making matrix and polishing plates. It possesses certain valuable properties that enable it to be worked up in a steam swager, a thin diaphragm of the alloy being made to give accurate copies and adapt itself to the surface of the model with ease. Owing to its fusibility it may be melted over a good Bunsen burner.

Detection of Tin in Alloys.—To detect the presence of tin in an alloy advantage is taken of the fact that the metal is converted into a white insoluble powder (metastannic acid) when acted upon by nitric acid.

A small quantity of the alloy to be tested is heated with dilute nitric acid until the whole of the material is acted upon. The solution is then diluted and the white residue of tin, if present, allowed to settle.

If gold is also present in the alloy, the residue will be purple in colour, owing to the formation of a small quantity of "purple of Cassius."

CHAPTER XV.

COPPER.

SYMBOL, Cu (Cuprum). ATOMIC WEIGHT, 63.

Occurrence.—Copper is found in the metallic state in various parts of the world, notably in the neighbourhood of Lake Superior, where it occurs in enormous masses which are frequently several tons in weight. It is also largely found in combination with sulphur, oxygen and carbonic acid.

Preparation.—From ores containing no sulphur, such as the oxides and carbonates, the metal is obtained by smelting the ore with coal or coke in a blast furnace, whereby the copper is liberated and carbon monoxide formed.

Ores containing sulphur are first subjected to a process of concentration in either blast or reverberatory furnaces to obtain a compound of sulphur and copper known as "regulus." This "regulus" is then roasted, whereby a portion of the copper is oxidised to copper oxide, which, as the temperature rises, reacts upon the undecomposed copper sulphide, giving metallic copper and sulphur dioxide, which last escapes. The copper thus obtained is impure and is subjected to a refining process.

Properties.—Copper possesses a peculiar red colour and a bright metallic lustre. At ordinary temperatures this metal is not altered by exposure to *dry* air, but when heated it oxidises rapidly; while at ordinary temperatures in *moist* air, in the presence of carbonic acid, it becomes coated with a green layer or scale of copper carbonate, commonly known as "verdigris." It is also rapidly tarnished in the presence of sulphuretted hydrogen owing to the formation of a film of copper sulphide. Water and cold hydrochloric acid have no action upon copper, and it is only slowly soluble in strong hydrochloric acid. Strong and dilute sulphuric acid acts on the metal when heated, but its best solvent is nitric acid slightly diluted, in which acid it is readily soluble. Copper is highly malleable, ductile and tenacious, and can be hammered or rolled into thin sheets or drawn into moderately fine wire, but by these operations the metal is hardened and requires frequent annealing or softening during the processes. When wrought it ranks next to iron in tenacity; surpassing platinum and silver in this respect. Copper is one of the best conductors of heat and of electricity, being inferior only to silver. The melting-point of copper is lower than that of gold but a little higher than that of silver, being 1050° C. (1922° F.); it contracts slightly on solidification. When heated to a temperature just below its melting-point copper becomes very brittle and may be readily fractured.

Copper is "granulated" by pouring the molten metal into water, and is frequently sold in this form. The metal is largely used for a great variety of technical and domestic purposes.

Effect of Impurities on Copper.—The physical properties of copper are materially impaired by the presence of even small proportions of impurities. The most common impurities in commercial copper are iron, arsenic, silver, and copper oxide, and occasionally bismuth, tin, antimony, sulphur and lead.

Of these arsenic, sulphur, and antimony are the most injurious, as they harden the metal and impair its malleability and tenacity.

Molten copper has the property of dissolving copper oxide, which makes it more or less brittle. The effect of iron is to render copper harder and paler in colour. Bismuth lessens the toughness of the metal.

Use in Dental Laboratory.—In the uncombined state copper has very little application in the dental laboratory, but when added in small quantities it forms a valuable constituent in alloys of gold and other metals, conferring upon them many useful properties.

Alloys.—Copper unites easily with most other metals, and forms the basis of a large number of important alloys.

Copper and Gold.—When melted together these metals alloy in all proportions, and when the copper does not exceed 10 to 12 per cent. the malleability is little altered—thus 21 carat gold and higher qualities are practically as malleable as pure gold. (See also Gold Alloys, p. 103.)

Copper and Silver.—These metals combine in all proportions, the resulting alloys ranging in colour from the red of copper through yellowish tints to the white colour of silver. These metals form a series of most valuable alloys, having a great variety of applications in the arts. (See also Silver Alloys, p. 171.)

Copper and Zinc.—Copper unites readily with zinc, forming alloys generally known as *brass.*

Alloys of these metals, however, are known in commerce by a variety of names, such as Tombac, Muntz's metal, Mosaic gold, Pinchbeck, Mannheim gold, Prince's metal, &c. Ordinary brass (commonly called composition) consists of 2 parts of copper with 1 of zinc.

Certain varieties of brass are exceedingly malleable and ductile, but these properties vary with the composition and the temperature. Some varieties are only malleable when rolled hot, others can be rolled at any temperature. Brass is harder than copper, and therefore better adapted to resist wear and tear. When melted these alloys alter somewhat in composition owing to the readiness with which zinc is oxidised. The easy fusibility of brass, and its fluidity when melted, render it valuable for casting purposes, as it is capable of receiving very fine impressions from the mould. On this account it was at one time used for dies in the dental laboratory. Cast brass is generally more or less crystalline, this property being very pronounced in the brittle varieties containing excess of zinc.

Copper and Tin.—Copper is extensively alloyed with tin, in combination with which it forms many valuable bodies generally termed "Bronzes."

The effect of tin on copper is to harden it or otherwise modify its properties. The alloys are capable of taking a high polish, and present a beautiful metallic lustre. They melt at a moderate temperature, and are fluid when melted, thus forming excellent alloys for casting. *Bell-metal* is an alloy of copper and tin in variable proportions. With about 2 parts of copper and 1 of tin an alloy is produced known as *Speculum Metal*. This is a very hard, brittle, steel-like alloy, capable of receiving a very high and uniform polish.

Gun Metal.—This is a variety of bronze formerly used to a large extent for ordnance, hence its name. It consists of copper, alloyed with from 8 to 10 per cent. of tin; the term "gun metal," however, is not now exclusively confined to alloys of copper and tin, as small proportions of other metals are very frequently added. Vulcanising flasks for dental purposes are made largely of gun metal, as it is a hard alloy and gives good castings.

Copper and Aluminium.—These metals unite when melted together, forming alloys which are more or less golden-yellow in colour.

With 10 per cent. of aluminium it forms the alloy known as aluminium-bronze. With excess of aluminium the alloys are hard, brittle and crystalline.

Copper and Nickel.—When melted together these metals unite in all proportions. The resulting alloys, with the addition of zinc and sometimes of other metals, are largely used in the arts under the name of German silver, &c.

Copper and Mercury.—In a fine state of division copper readily amalgamates with mercury, the resulting amalgam becoming hard and crystalline after the lapse of a few hours. Copper amalgams have long been used as a material for filling teeth. (See Copper Amalgam, p. 134.)

CHAPTER XVI.

CADMIUM.

SYMBOL, Cd. ATOMIC WEIGHT, 112.

Occurrence.—This metal is never found in the metallic state in nature. It is usually found in combination with sulphur, associated with the ores of zinc, in small quantities not exceeding two or three per cent.

Preparation.—Being more fusible and volatile than zinc, cadmium distils over with the first portions of zinc during the smelting of the ores of that metal. The product thus obtained consists of a mixture of cadmium and zinc, contaminated with oxides of these metals. It is mixed with charcoal and again distilled, when the metal which passes over first contains a larger proportion of cadmium. To obtain pure cadmium the mixture of cadmium and zinc from the last distillation is dissolved in hydrochloric acid and metallic zinc placed in the solution, which precipitates the cadmium in a spongy crystalline form. When melted, this is cast into small cylindrical rods about half an inch thick, in which form it is usually sold.

Properties.—Cadmium resembles tin in colour and appearance and takes a high polish. It is slowly oxidised on the surface by exposure to the atmosphere, and when heated in air it burns with a brown flame to cadmium oxide. In the presence of sulphuretted hydrogen it gradually becomes coated with a yellow film of cadmium sulphide. The metal is not acted upon by water, but is soluble in hydrochloric acid and in sulphuric acid. Its best solvent is nitric acid, in which it is readily dissolved. Acetic acid (vinegar) also acts on the metal, and it is slowly soluble in solutions of the alkalies. These tendencies to corrosion make it unfit for use as a filling material, as it would not withstand the action of the fluids of the mouth.

Cadmium is malleable and ductile and may be rolled into thin sheet or foil or drawn into wire at the ordinary temperature, but at 80° C. (176° F.) it is very brittle and may be readily powdered in a mortar. It melts at the low temperature of 320° C. (608° F.) and may be distilled at a temperature of 770° C. (1418° F.). Cadmium is harder than tin, but may be cut with a knife. It also possesses greater tenacity than tin and is somewhat heavier, its specific gravity being 8.7. Cadmium has no direct use in the arts, but is of value as a constituent of certain alloys, especially those with tin, bismuth and lead.

Use for Dental Purposes.—The only use for cadmium in the dental laboratory is in combination with other metals as "fusible metals" and other alloys. It has also been employed as a constituent in alloys for dental amalgams, but its employment for this purpose has now been abandoned. The advantages and disadvantages of cadmium in amalgams and alloys may be classified as follows :

ADVANTAGES IN AMALGAMS.—Cadmium was at one time employed as a constituent of alloys for dental amalgams, as its presence gives whiteness to the fillings and tends to produce a good plug. On account of its affinity for mercury it also facilitates amalgamation and causes quickness in setting.

In Alloys.—Cadmium, like bismuth, has the valuable property of lowering the melting-point of many alloys, some of which are readily fusible in boiling water. It is therefore a useful constituent in the so-called "fusible metals" described on p. 50 and is occasionally used for dental purposes.

DISADVANTAGES IN AMALGAMS.—Although cadmium confers useful properties on amalgams produced from alloys containing it, it has been generally condemned as a constituent of these alloys. It is readily acted upon by the joint action of sulphuretted hydrogen and the alkaline and acid fluids of the mouth with the formation of an orange-yellow film of cadmium sulphide and the production of soluble salts which stain the tooth substance.

In Alloys.—When present in alloys in large quantities cadmium tends to make them more or less brittle, but many of its combinations are capable of being hammered and rolled. Owing to the affinity of cadmium for oxygen when molten, a considerable loss is liable to take place when alloys containing it are melted, if excessive heating is not avoided and every precaution taken to prevent oxidation. On this account it is extremely difficult to obtain an alloy of definite composition.

CHAPTER XVII.

BISMUTH.

SYMBOL, Bi. ATOMIC WEIGHT, 207.5.

Occurrence.—Bismuth occurs in nature in the metallic state and also in combination with oxygen, sulphur and other elements, but the bismuth of commerce is chiefly obtained from the native metal.

Preparation.—To extract the metal from the matters accompanying it, advantage is taken of its low melting-point, namely, 268° C. (514° F.). The crushed ore is placed in a series of iron tubes or retorts set in an inclined position in a brickwork chamber provided with a fire-grate, by means of which the retorts are heated externally. The upper end of each retort, through which the ore is charged, is closed by an iron door; the lower end is also closed with an iron plate provided with a small aperture. On the application of heat the bismuth melts and the liquid metal soon begins to flow through the small apertures in the lower ends of the tubes and falls into iron bowls, in which it collects and is dipped out with ladles and cast into ingots. As soon as the flow of metal has entirely ceased the residue is raked out and a fresh charge of ore at once introduced into the retorts. The metal thus obtained is refined by various methods to obtain bismuth of good commercial quality.

Properties.—Bismuth is a greyish-white metal, having a decided reddish tinge and a bright metallic lustre. It is not sensibly altered by exposure to the atmosphere at the ordinary temperature, even in the presence of sulphuretted hydrogen, but when heated in air bismuth is readily oxidised and at a high temperature burns with a bluish flame and gives off fumes of a light yellow colour, known as *flowers of bismuth*. Water is without effect on bismuth and hydrochloric acid has but little action on the metal. Sulphuric acid only attacks it when hot and concentrated; while nitric acid forms its best solvent, attacking the metal vigorously. Alkaline solutions have no action on bismuth. This metal is brittle and can be easily pulverised; when broken it presents a highly crystalline surface. Bismuth fuses at a comparatively low temperature, 268° C. (514° F.), and at a high temperature may be volatilised or distilled. It expands very considerably on solidification, the solid metal occupying about $\frac{1}{32}$ more space than the liquid metal, so that bismuth is denser in the liquid than in the solid state; the density of solid bismuth being 9.8. When a large quantity of bismuth is melted, allowed to cool slowly until the surface begins to solidify, the crust broken and the still liquid metal poured out, fine crystals are obtained.

Bismuth is the poorest conductor of heat and of electricity amongst the common metals.

The brittleness of bismuth renders it unfit for use by itself, but in combination with other metals it forms alloys which are frequently employed in the arts. The salts of bismuth are somewhat extensively used in medicine.

Use for Dental Purposes.—The only use for bismuth in the dental laboratory is as a constituent of certain alloys, more especially those known as *fusible metals*.

Alloys of Bismuth.—The effect of bismuth when alloyed with other metals is usually to form bodies which are readily fusible, hard and expand on solidification after fusion.

Bismuth and Antimony.—These metals when united yield alloys which are hard and brittle and expand considerably on cooling.

Bismuth and Tin.—These metals readily combine in all proportions when fused together. A very small proportion of bismuth imparts to tin more hardness, lustre and fusibility. The alloys of bismuth and tin are more fusible than either of the metals taken separately.

Bismuth and Lead.—These metals unite in various proportions by melting them together. If the proportion of bismuth does not exceed that of lead the alloys are ductile, malleable and more tenacious than lead. These properties, however, are diminished with an increase of bismuth.

Fusible Metal.—Bismuth unites readily with tin and lead by fusion, forming a series of alloys known as *fusible metals*, a full description of which will be found on page 50.

An alloy of equal parts of bismuth and lead, alloyed with 2 parts of tin, is used as a solder by pewterers on account of its low melting-point. Bismuth is also an occasional constituent of Britannia metal and Queen's metal.

Bismuth and Mercury.—Bismuth readily amalgamates with mercury at the ordinary temperature, the amalgam retaining a considerable amount of bismuth without losing its fluidity. (See Amalgams, p. 133.) Mercury is frequently adulterated with bismuth, but the presence of this metal may be detected by shaking the mercury with air, when, if bismuth be present, a crystalline black powder separates out. (See Purification of Mercury, p. 126.)

CHAPTER XVIII.

ANTIMONY.

SYMBOL, Sb (Stibium). ATOMIC WEIGHT, 120.

Occurrence.—Antimony is found in the metallic state in nature in various parts of the world, notably in Borneo. It also occurs in combination with sulphur as *stibnite* and with oxygen, the former being the chief source of the metal.

Preparation.—To obtain the metal from the native sulphide the purified ore is broken up and heated in a large crucible along with scrap iron.

As the charge melts the antimony is liberated and settles at the bottom of the crucible, while the sulphur combines with the iron, forming iron sulphide, which remains on the surface of the molten antimony. The antimony is cast into suitable moulds and subsequently refined.

Properties.—Antimony is a comparatively hard bluish-white metal, possessing a highly crystalline surface when fractured, and so brittle that it can be readily powdered. It is not sensibly altered by exposure to the atmosphere at ordinary temperatures, and is only slightly tarnished by sulphuretted hydrogen, but when heated in air it burns with a bluish-white flame, producing thick white fumes of antimonious oxide. Water and dilute sulphuric acid are without action on the metal, but when heated with concentrated sulphuric acid it is converted into antimony sulphate. It is easily dissolved by hot hydrochloric acid as well as by cold aqua regia. It is rapidly oxidised without solution upon treatment with nitric acid, the white oxide formed collecting at the bottom of the vessel. Alkaline solutions have no action on the metal.

It melts at a temperature a little above that required to melt zinc, its melting-point being 632° C. (1170° F.), and volatilises in the air at a bright red heat. It is the next lightest metal to aluminium, its density being 6.8.

Uses for Dental Purposes.—The chief use of antimony in the dental laboratory is as a constituent of alloys for dies and counter-dies.

Alloys.—The effect of antimony is to harden the metals with which it is alloyed and generally to impair the malleability and ductility of the malleable metals, in some cases rendering them brittle.

Antimony and Lead.—The union of these metals is readily effected by melting. With excess of antimony the alloys are hard, brittle, and very crystalline. With less than 15 per cent. of antimony lead alloys have the important property of expanding on cooling. (See p. 210.)

Antimony and Tin.—These metals unite to form alloys which are hard and less malleable than tin, and become brittle as the proportion of antimony increases. These metals when united form the basis of what is termed Britannia metal, many varieties of which consist of tin hardened with antimony. This alloy is used for the manufacture of impression trays, and is described on p. 217.

Antimony and Gold.—Antimony alloys readily with gold, but has a very injurious effect upon it, the presence of 0.5 per cent. of antimony rendering the gold quite brittle.

Antimony and Copper.—Copper and antimony combine well together, producing a crystalline, brittle, violet alloy, known as "Regulus of Venus," which, however, has no practical use in the arts.

CHAPTER XIX.

IRON.

SYMBOL, Fe (Ferrum). ATOMIC WEIGHT, 56.

Occurrence.—Iron is one of the most abundant and widely distributed elements, being found in nature in the metallic state in small quantities as *meteoric-iron* of ultra-terrestrial origin ; also in combination with oxygen forming the minerals magnetite and red *hæmatite*, with oxygen and water the brown hæmatites, and with carbonic acid, the *spathic ore*, these minerals forming the chief sources of the metal.

Iron is also found largely in combination with sulphur and arsenic, but these compounds are not employed for the extraction of the metal, owing to the difficulty of completely separating these substances from the iron, and their deleterious effect on the final product when present. The iron of commerce exists in three distinct forms, namely, cast iron, wrought iron and steel, each of which exhibits different properties.

Cast Iron, or pig iron, is the product obtained by smelting iron ores in the blast furnace, and besides iron usually contains from 2 to 4 per cent. carbon from 0.2 to 3 per cent. silicon and varying proportions of manganese (generally under 2 per cent. in ordinary cast irons), with small proportions of sulphur and of phosphorus. Cast iron varies in composition according to the materials operated upon for its production and this varying composition with differences in the method of treatment (mainly the rate of cooling) causes it to vary considerably also in appearance and mechanical properties, giving rise to three main varieties known as white, mottled and grey, from the appearance of the fractured surfaces. White iron has practically all the carbon in the combined form, and is hard and brittle, while grey iron is comparatively soft, having the carbon mainly present as graphite, scales of which may often be picked off the fractured surface with a penknife, and mottled iron as its name implies is a mixture of grey and white.

In all its varieties, however, it differs from wrought iron and steel by being almost void of ductility; it does not admit of being welded, it is also more brittle, not so tough, and is usually harder than malleable iron. Owing to the presence of carbon, cast iron melts at a lower temperature than wrought iron or steel, but it requires a bright yellow heat to melt it. Grey iron contracts very little on solidification, and on that account has been proposed as a suitable metal for dies, as it is also hard and runs perfectly in open sand in the usual manner of casting dies for dental purposes. The high temperature required to melt it, however, is a considerable drawback to its use for this purpose.

Wrought Iron, or malleable iron, represents the nearest approach to pure iron which can be produced by manufacturing processes upon a large scale, and generally contains from 0.05 to 0.3 per cent. of carbon. Its mechanical properties are totally distinct from those of cast iron; for while the latter is not malleable and has a low tenacity varying from 7 to 15 tons per square inch, wrought iron is comparatively soft, very malleable and ductile with a tenacity in its purest form of 20 tons per square inch. Wrought iron is very difficult of fusion (1600° C.) and before becoming liquid passes through a soft or pasty condition. When in this state clean surfaces if pressed or hammered together cohere and weld into a single mass.

Wrought iron may be magnetised by bringing it into contact with a magnet, but it loses this property on the removal of the magnet. If heated to redness and plunged into cold water, it is not hardened, but retains its original softness, thus differing from tool steels, which become flint hard when similarly treated.

Steel is a malleable alloy of iron (containing from about 0.1 to over 2 per cent. of carbon with small proportions of other elements), which has *either* been cast direct into a malleable mass, *or* becomes flint hard when heated to a bright red heat and cooled rapidly as by quenching in cold water or brine. This definition excludes wrought iron, which will not become flint hard and has been formed in a pasty condition, and also cast iron which has been *cast* but not into a *malleable* mass. It includes all commercial steels, for Shear Steel, like wrought iron, has never been molten as such, but will become flint hard on quenching, while structural or mild steels do not become flint hard on quenching, but have been cast direct into malleable ingots. Carbon is the element which has the greatest effect in modifying the properties of iron. Steels containing only a small amount of carbon, say about 0.1 to 0.5 per cent. are sometimes termed mild steels, and have a tenacity varying from 25 to 50 tons per sq. in., and the better qualities when fractured by a tensile stress, show a fine silky appearance on the edges of the broken surface. These steels generally contain from 0.4 to 1 per cent. manganese and small proportions of silicon, sulphur, and phosphorus, usually less than 0.1 per cent. of each. Tool steels contain from about 0.8 per cent. of carbon, upwards with from 0.05 to 0.4 per cent. of manganese, and generally less than 0.2 per cent. of silicon, and 0.03 per cent. each of sulphur and phosphorus.

Preparation.—Iron is readily reduced from its compounds. The ore, as oxide, together with carbon in the form of charcoal, coal, or coke, and with suitable fluxes to combine with the earthy matters of the ore and render them fusible at the temperatures employed, is charged into a blast furnace, whereby the ore is reduced by the gaseous carbon compounds produced by the action of the blast. The iron thus set free takes up carbon and other elements during its passage down the blast furnace, and thus becoming fusible at the temperature of the furnace, gradually sinks to the hearth, where it accumulates. At intervals it is tapped into suitable moulds, and constitutes what is known as cast or pig iron.

Wrought or Malleable Iron.—This is obtained by melting the cast iron in a reverberatory furnace and gradually removing the impurities by oxidation; the iron "coming to nature" in small pasty particles, which are gathered into a spongy ball of iron particles and cinder, which by hammering and rolling is welded into a solid mass, the great bulk of the cinder being thus expressed. The purest forms, however, always contain some entangled cinder, which may be clearly seen under the microscope, thus forming a convenient distinction between wrought irons and mild steels.

Steel may be produced either from wrought iron by the addition of carbon or from cast iron by removing the carbon. In the former process, known as "cementation," small bars of wrought iron are buried in charcoal and heated for several days to a red heat. Carbon is thus made to pass into the iron, which presents a blistered appearance, and on that account is termed *blister-steel*. When blister-steel is piled, welded, and worked to the required form of bar, it is known as shear steel, which is a favourite hardening steel for some tools. When blister-steel is broken up and melted with suitable additions (of manganese, &c.) in a crucible, cast into an ingot, and hammered or rolled into bars of various sections, the product is known as crucible cast steel, and is mostly used for tools required to harden and keep a cutting edge. The mild steels are generally produced either by the Bessemer or Siemens processes. The Bessemer process consists in oxidising the carbon and some of the other impurities by blowing air through molten pig iron, adding manganese to remove excess of oxygen and carbon according to requirements, by means of suitable alloys of iron rich in carbon and manganese. In the Siemens process the impurities are oxidised by the addition of iron oxide as iron ore to the molten bath of pig iron, and the process finished in a similar manner to the Bessemer process. The metal in each case is generally tapped into a ladle and thence into ingot moulds.

Properties (see also Wrought Iron, p. 235).—Iron is a white metal with a bluish-grey tint. It undergoes no change in perfectly dry air, or in water free from air, but it is rapidly coated with a scale of oxide or *rust* if it is exposed to the action of moist air. When heated to redness it oxidises rapidly with the formation of a scale of oxide. It is soluble in dilute nitric acid (1–1), hydrochloric, and dilute sulphuric acids, but it is not much affected by strong sulphuric acid. Alkalies have no action on the metal.

Effect of Impurities on Iron.—The properties of tenacity, malleability, and ductility in iron are powerfully influenced by the presence of only small quantities of certain impurities.

As the carbon content of iron is increased, the tenacity increases in a general way until a carbon content of 1.2 per cent. is reached, but the malleability and the ductility steadily decrease.

From 0.9 per cent. of carbon and upwards the steel will harden and temper (see next paragraph), but if manganese is also present, the steel will take a cutting edge with less than 0.9 per cent. of carbon.

Very small quantities of sulphur render steel red-short or unworkable at a red heat, while phosphorus in small quantities makes the steel cold-short. Manganese is found to counteract to some extent the evil influence of sulphur, and a certain proportion of phosphorus has more effect in high-carbon than in low-carbon steels.

Until recently arsenic has been considered somewhat similar to phosphorus as to its mechanical effect on iron, but recent research has shown that its influence, even in moderate quantity, is almost negligible. Silicon, when present up to 4 per cent. imparts hardness and brittleness with a gain of tenacity.

Copper in small quantities has little effect.

From these remarks it will be seen that the influence of impurities on iron is a very complicated matter, owing to the considerable influence they exert on one another, and for several other reasons, but the statements above will give a fair general idea of the facts.

Hardening and Tempering.—When steel is heated to redness, and then plunged while red hot into cold water, or is otherwise suddenly cooled, it acquires great hardness and brittleness.

If this hardened steel, which is very hard and brittle, is re-heated to redness and allowed to cool slowly it again becomes soft and malleable, or if it is re-heated below redness and allowed to cool it is also partly softened and made less brittle, the decrease in hardness and in brittleness depending on the temperature employed, the higher the temperature the softer and less brittle the steel is made.

This re-heating to different temperatures to obtain the compromise between hardness and brittleness necessary for the tool being made is called *tempering*. The steel is first hardened in the manner described and then tempered or let down by re-heating it to a definite temperature, varying according to the degree of hardness required, and then cooling it quickly. The temperature necessary is usually judged by the colour of the thin film of oxide which appears on the polished surface of the steel when heated, the tint of the film varying with the temperature, being yellow when the steel is first heated, then passing gradually to brown and purple, and finally to deep blue as the temperature increases.

The temper necessary for various steel articles depends upon their application; thus, most surgical instruments and razors are tempered at 232° C. (450° F.), indicated by a pale straw tint, while the temper given to fine saws, indicated by full blue, corresponds to a temperature of 293° C. (560° F.).

The following table indicates the temperatures and corresponding colours necessary for "tempering" various articles used in dentistry :

Temperature.		Colour.	Temper of various articles.
Fahr.	Cent.		
430°	221°	Very pale yellow	Lancets
450°	232°	Pale straw	Enamel chisels and most surgical instruments
470°	243°	Full yellow	Excavators
490°	254°	Brown	Pluggers
510°	265°	Brown dappled with purple spots	Saws, &c.
550°	288°	Bright blue	Watch-springs

In "tempering" or letting down dental instruments the flame of a spirit lamp may be employed, the instrument after hardening being held in the flame and carefully rotated to ensure uniform heating. The flame should strike the instrument at some distance from the cutting end, and when the end attains the desired colour it should be instantly quenched in cold water and allowed to remain in the water until cold, to prevent "letting down" further.

The same result may also be conveniently effected by heating a small block of iron to dull redness and placing the instrument to be tempered upon it, then removing it as soon as the desired tint appears and plunging into cold water. It is advisable to continually rotate the instrument in order that it may be uniformly heated.

Annealing.—Iron and steel which have become unduly hard or brittle by hammering, rolling, or otherwise working the material, may be softened and made malleable by annealing, *i.e.*, heating the metal to about a cherry-red heat and allowing it to cool very slowly.

This is frequently done by withdrawing it from the source of heat and then immediately covering it with ashes or other bad conducting material such as sand, lime, &c., under which it is allowed to cool down to the ordinary temperature before it is removed. (See also p. 12.)

Burning of Iron and Steel.—When malleable iron or steel is heated to redness and exposed to the air, oxidation proceeds very rapidly with the production of a "scale" or layer of oxide of considerable thickness. By excessively long or intense heating the iron becomes "burnt," is friable, incapable of being welded, and cannot be restored completely to its original state. Steel requires much more precaution in heating than iron, and does not bear the same degree of heat as iron without injury. Steel which has been slightly overheated may be restored to a certain extent by judicious hammering at a lower temperature, but the improvement effected in burnt steel by this treatment is very slight.

CHAPTER XX.

ALUMINIUM.

SYMBOL, Al. ATOMIC WEIGHT, 27.

Occurrence.—Aluminium is one of the most abundant of all the elements, being found in every variety of clay, but it has never been found in the metallic state.

In combination with oxygen it constitutes the minerals *corundum* or *emery* and *bauxite*, from which the metal is mainly extracted on a large scale. Some of its combinations with oxygen are of great beauty and hardness, such as ruby, sapphire, and garnet.

Another mineral from which aluminium sometimes is obtained is *cryolite*, which is found in abundance in Greenland, and consists of aluminium in combination with sodium and fluorine.

Preparation.—Aluminium is almost exclusively obtained by means of the electric furnace, which consists of a large iron box or crucible lined with carbon, forming the negative electrode, while the positive electrode is a bundle of carbon plates. The crucible contains a bath of readily fusible compounds, to which the aluminium oxide (alumina) is added from time to time, and dissolved. When a powerful electric current is passed through the bath the alumina is decomposed and the metallic aluminium thus liberated falls to the bottom, whence it is drawn off at intervals. The oxygen set free combines with the carbon to form carbonic oxide, which escapes and burns in the air forming carbonic acid.

It is only within recent years that aluminium has been prepared in sufficiently large quantities and at a sufficiently low price to enable it to be classed with the other metals in common use.

Properties.—Aluminium is a white metal possessing a colour between that of silver and zinc. It is remarkably light, being only about two and a half times as heavy as water; it is unaffected by air, even in the presence of sulphuretted hydrogen, and consequently preserves its colour in an atmosphere in which silver would rapidly become black. It is extremely malleable and ductile, the pure metal being regularly rolled into sheets one-thousandth of an inch in thickness, and also drawn into very fine wire. Aluminium is most malleable between 100° C. (212° F.) and 150° C. (302° F.) and can be worked some time at that temperature before becoming hard. When rolled and worked cold it needs more frequent annealing. It is highly sonorous, and is a good conductor of heat and of electricity.

The melting-point of aluminium is 625° C. (1157° F.), being a little higher than that of zinc but lower than that of silver; it melts somewhat slowly and is viscous when poured for casting purposes.

The vegetable acids exert no perceptible action on aluminium, consequently it is well adapted for culinary vessels. It is readily dissolved in either dilute or strong hydrochloric acid and also in solutions of caustic potash or soda.

Use for Dental Purposes.—On account of the lightness, strength, and whiteness of aluminium and the facility with which it retains its colour, attempts have been made for several years to employ it as a base for artificial dentures, both by swaging a plate of the metal in the ordinary way and by the cheoplastic process, but these attempts have only been partially successful. Although some of the physical difficulties encountered in the effort to render aluminium available in prosthetic dentistry have been overcome, its great susceptibility to corrosion by the action of alkaline solutions is the chief obstacle to its use fcr this purpose. The difficulty of obtaining a suitable solder by which pieces of the metal may be securely united has also largely prevented its use in the dental laboratory.

Experiments in casting the metal for dental purposes have not been entirely successful on account of the large amount of contraction which takes place on cooling and the somewhat high temperature required to melt the metal. "At the present time the use of aluminium is rarely attempted except as a base in connection with rubber or celluloid, the latter substances being employed as a means of attaching the teeth."* When combined with copper it forms an alloy which has been used to a limited extent in Germany as a base for artificial dentures. (See p. 248.) Impression trays and other dental appliances are now made of aluminium.

Aluminium Plate for Dentures.—When aluminium is used for the construction of an artificial denture the method most frequently adopted is to swage a plate of the metal in the ordinary way.

During the swaging the metal becomes rigid and

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* Richardson's "Mechanical Dentistry," 1894 ed. p. 120.

hard, but it may be softened by heating to dull redness and cooling quickly by dipping into cold water. Thin sheets may be softened by putting into boiling water and letting them cool with the water. After swaging the plate the teeth are attached with rubber or celluloid in a manner similar to that sometimes employed when a gold plate is used. For this purpose the plate is perforated with a number of countersunk holes along the part covering the top of the alveolar ridge. According to Essig,* "sets of teeth made in this way have been known to do good service for eight or nine years, but they showed unmistakable evidence of the action of the oral fluids."

Casting Aluminium for Dentures.—In the application of aluminium to the cheoplastic process several difficulties are met with, as aluminium contracts very much on solidification and requires a high temperature to melt it. For casting in closed moulds the best results have been obtained by the application of a slight artificial pressure to the still liquid metal in the mould immediately after pouring.

The addition of a little copper to aluminium causes a decrease in the contraction and renders it less liable to corrode in the mouth, but the presence of copper increases the hardness of the aluminium.

Essig † states that "aluminium may be cast upon plain teeth with comparative safety, provided the metal is prevented from overlapping the necks of the teeth. But when gum teeth are employed, either singly or in sections, their fracture is almost certain to follow the contraction incident to the cooling of the metal."

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* Essig, "Dental Metallurgy," 3rd ed. p. 253.

† *Ibid.* p. 252.

Solders for Aluminium.—The difficulty of soldering aluminium has prevented a more extensive application of the metal for dental and other purposes. It is difficult to obtain a clean, bright surface owing to the rapid formation of a very thin film of oxide which cannot be removed by the ordinary fluxes used in soldering operations, such as borax, &c., as these are liable to attack the surface of the metal and prevent union taking place. It has also a very high conductivity for heat and thus chills quickly at the joint. A large number of solders for aluminium have been patented within recent years, but comparatively few have given satisfaction.

Two solders containing aluminium are recommended by Schlosser[*] as being specially suitable for use in the dental laboratory on account of their resistance to chemical action.

Platinum-Aluminium Solder.		*Gold Aluminium Solder.*	
Gold	30 parts	Gold	50 parts
Platinum	1 ,,	Copper	10 ,,
Silver	20 ,,	Silver	10 ,,
Aluminium	100 ,,	Aluminium	20 ,,

Another solder consists of zinc 22.5 parts, aluminium 1.5 parts, copper 1 part. With regard to these solders Richardson remarks[†] that "none of them are suitable for attaching artificial teeth."

Two pieces of aluminium may also be united with ordinary solder, with silver chloride as a flux, by means of which a film of metallic silver is deposited on the surface of the aluminium. The finely powdered fused silver chloride is spread along the lines of contact and the soldering completed in the usual way with the blow-

[*] "Das Löthen," p. 103.

[†] "Mechanical Dentistry," 7th ed. 1898, p. 109.

pipe or other device. The union thus obtained is said to be perfectly strong and reliable.*

Aluminium Bronze.—This is an alloy of copper with aluminium, and usually contains 10 per cent. of the latter metal.

PREPARATION.—Aluminium bronze is prepared by simply melting the constituents in a crucible or by first melting the copper and then adding the aluminium. The union is attended by a considerable evolution of heat, which raises the temperature of the whole to a white heat; it is therefore necessary to use crucibles of good quality when preparing the alloy. The alloy is brittle when first prepared, but when re-melted two or three times the brittleness is removed. The melting-point of aluminium bronze is nearly the same as that of silver, being about 950° C. (1742° F.). It shrinks on solidification about twice as much as brass.

PROPERTIES.—It has a fine yellow colour resembling that of gold: it is scarcely tarnished by exposure to air or sulphuretted hydrogen. It resists the action of chemical agents to a large extent and is susceptible of a high polish. The alloy is malleable at the ordinary temperatures, but far more so at a red heat. It becomes very hard and stiff when worked and requires frequent annealing. This is done by heating the alloy at a *bright-red* heat for some time, then cooling to redness and plunging it into cold water to temper it. Aluminium bronze may be swaged as readily as 20-carat gold but it requires frequent annealing during the process. When the alloy is placed in dilute nitric acid the copper is dissolved from the surface, leaving the aluminium, thus changing the colour of the alloy on the surface.

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* *Chemical News*, iv. 81.

Aluminium bronze is used to a limited extent in Germany as a base for artificial dentures, as it is strong, hard, and capable of resisting attrition as well as 18-carat gold. As chemical agents do not readily act on the alloy, it is only slowly discoloured by exposure in the mouth.

Solders for Aluminium Bronze.—Eighteen-carat or fourteen-carat gold solder with the addition of a little copper is sometimes used as a solder for aluminium bronze, the union of the pieces being effected without difficulty. The following alloys are recommended* as effective and convenient solders for 10 per cent. aluminium bronze:

No. I. Hard Solder.
21.5-carat.

Gold	88.88
Silver	4.68
Copper	6.44
	100.00

No. II. Medium Hard Solder.
13-carat.

Gold	54.40
Silver	27.00
Copper	18.60
	100.00

No. III. Soft Solder.

Copper	70 per cent.	Bronze	14.30
Tin	30 " "		
		Gold	14.30
		Silver	57.10
		Copper	14.30
			100.00

Alloys of Aluminium.—Dr. Carroll has used the following aluminium alloys for casting artificial dentures:

Aluminium	90 to 93 parts
Silver	5 " 9 "
Copper	0 " 1 "

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* Richards, "Aluminium," 3rd ed. p. 569.

These alloys when cast under slight pressure give good castings, are very white, and easy to work. The addition of the copper is said to decrease to a minimum the shrinkage of the alloys and also to give a closer grain.

CHAPTER XXI.

NICKEL.

SYMBOL, Ni. ATOMIC WEIGHT, 59.

Occurrence.—Nickel occurs chiefly in combination with arsenic and sulphur, and its ores almost invariably contain small quantities of cobalt.

Preparation.—Nickel is extracted from its ores by first concentrating the metal in combination with arsenic or sulphur in blast furnaces. The product obtained is then roasted to expel the arsenic or sulphur, and the nickel oxide thus formed reduced to the metallic state with carbon at a high temperature.

Properties.—Nickel is a lustrous metal, approaching almost to a silver whiteness in colour, but possessing a slight yellow tinge. It is very hard and takes a fine polish. It does not readily tarnish by exposure to the atmosphere at ordinary temperatures, but when heated in air it is slowly oxidised. The metal is not tarnished to any appreciable extent in the presence of sulphuretted hydrogen. Water is without action on the metal, and it is only slowly soluble in hydrochloric acid or dilute sulphuric acid or even in concentrated sulphuric acid. On the other hand, it dissolves readily in dilute nitric acid or in aqua regia. The metal is not attacked by alkaline solutions or vegetable acids.

It is very malleable and ductile, and may be easily rolled out into thin plate or drawn into wire; it is also very tenacious, in which quality it is only exceeded by steel. It is magnetic like iron, but possesses this quality to a much smaller degree, and loses its magnetism by heating to 250° C. (481° F.), recovering the quality again, however, upon cooling. It requires a very high temperature to fuse it, the melting-point of nickel being 1600° C. (2912° F.), and it may be welded at a red heat.

Use in the Dental Laboratory.—Cast and sheet nickel muffles are now extensively employed for dental furnace work; the metal appears to have been first introduced for this purpose in 1886.

Alloys of Nickel.—The chief alloys of nickel are those in combination with copper and zinc in varying proportions, producing a series of alloys of much value, and to denote which different manufacturers employ fanciful names.

German Silver, or nickel silver, consists of nickel, copper, and zinc in proportions varying with the uses to which it is applied, the best qualities containing a larger proportion of nickel than the inferior qualities. German silver, as made by good makers, consists usually of one part of nickel, one part of zinc, with two or three parts of copper.

PREPARATION.—Various methods are pursued for the manufacture of German silver, but that generally adopted at the present time consists in first alloying the zinc with one-half of the copper, the brass so formed being cast into thin plates, so that it can be easily broken up, while the nickel is melted with the remaining portion of the copper in another crucible, to which, after thorough mixing, the brass is added in small pieces until the necessary composition has been obtained. Owing to the high temperature required for the fusion of the nickel and the low melting-point and oxidisable nature of zinc, the preparation of this alloy is attended with a considerable loss of zinc; special care is accordingly required in its production. When re-melting the alloy it is necessary to add a portion of zinc to compensate for the loss, and it is advisable to add this zinc after the fusion of the alloy has been effected. On account of this oxidation the relative amounts of the constituents are altered: it is therefore difficult to obtain an alloy of definite composition. In all cases a layer of charcoal should be placed on the surface to prevent oxidation as far as possible.

PROPERTIES.—German silver is greyer in colour and harder than silver, and is capable of receiving a high polish. It is also tough, tenacious, malleable, and ductile, and works well under the hammer or between the rolls.

It is crystalline after casting and requires careful annealing before rolling or hammering, but after the crystalline character has been thus overcome the alloy may be rolled and hammered into a variety of shapes. Sound castings are secured by the use of borax, glass, or other good flux. When exposed to the atmosphere German silver acquires a yellow tint due to the presence of sulphuretted hydrogen, and in acid solutions, such as vinegar, with access of air, it becomes gradually coated with a layer of green verdigris. It is superficially oxidised when heated in air, and at a bright red heat the alloy fuses, a proportion of the zinc burning away. The alloy is readily soluble in nitric acid. Impression trays, matrices, and a number of other dental appliances are made of German silver.

Nickel and Iron.—These metals unite when melted together to form a series of alloys which are very hard and tenacious and little affected by the atmosphere. The alloys are more fluid than ordinary steel when melted, set more rapidly, and can be readily hammered and rolled. Nickel steels are extensively used for armour-plates.

Nickel Plating.—This is the process by which articles of iron, copper, and other metals are coated with metallic nickel by means of an electric current in a manner similar to gold and silver plating.

The solution usually employed is the double sulphate of nickel and ammonia.

It is of great importance that the articles to be coated should be absolutely clean and that any existing film of nickel should be entirely removed, the cleaning of the article being even more important in nickeling than in silvering or gilding. Small articles are frequently cleaned by rubbing with fine emery cloth, but a chemical method is more often employed, which consists in dipping the articles for a brief period into an acid bath. On account of its extreme hardness the nickel deposit cannot be burnished like deposits of gold and silver: it is essential, therefore, that the articles be well polished before immersing in the plating solution. After polishing every trace of grease is removed by dipping in a solution of potash; then, after a thorough rinsing in water, the article is transferred to the plating bath and connected with the negative pole of a suitable battery, a plate of pure nickel being connected with the positive pole. Generally speaking, from half an hour to four hours will suffice for the deposition.

When the thickness of coating is sufficient the article is removed from the solution and thoroughly washed in water, dried in hot sawdust or a small stove and then finally polished. Articles of cast iron are usually covered with a film of copper before being suspended in the plating solution.

Nickel-plating is now largely employed for coating articles of all kinds on account of the brilliant polish the metal is capable of taking and its non-liability to tarnish under ordinary atmospheric conditions.

A thin coating will also resist the wear and tear of hard use owing to the hardness of deposited nickel.

PART II.

EXPERIMENTS RELATING TO THE PHYSICAL AND CHEMICAL PROPERTIES OF METALS AND ALLOYS.

In order that the student may acquire a more practical knowledge of the properties of the various metals given in Part I., the following simple experiments have been arranged, all of which may be readily conducted in a moderately well equipped dental laboratory. In addition to the following experiments, it would be well for students to perform also the various experiments mentioned in the text of Part I. The quantities of metal necessary for the various experiments are given in grammes, as the metric system is now universally employed for all experimental work; but as the weights usually sold with scales for dental purposes are Troy, the quantities are also given in grains for convenience. In most cases larger quantities of material may be taken with advantage, but with due care satisfactory results can be obtained with the quantities given.

The experiments relating to malleability may be performed with a hammer and bright steel anvil when a rolling-mill is not available.

GOLD.

Material Required.—About 5 grams. (or 75 grains) of 22-carat or other carat gold.

Experiment 1.—Dissolve the gold alloy in aqua regia; evaporate nearly to dryness to expel excess of acid; dilute with about a pint of water; add a solution of iron sulphate and gently heat, when the gold will be precipitated as a fine brown powder.* Filter through a filter paper, wash the precipitated gold repeatedly with water, and warm till perfectly dry. Carefully rub a little of the brown powder with some hard smooth surface, such as a steel or agate burnisher, and note that the characteristic yellow colour and metallic lustre of gold appear. Reserve about .5 gram. (or 5 grains) of the powder for Experiment 14. Transfer the remainder to a suitable support and melt into a globule by means of the blowpipe, heating gently at first to avoid loss. Note that it requires a bright red heat to fuse it.

Experiment 2.—Determine the density of the gold by suspending it from the arm of a balance by means of fine silk, and accurately weighing it in air. Then place a small vessel of water in such a position that the gold is completely immersed while still suspended, carefully remove air bubbles by means of a camel's-hair brush, and then note the weight in water.

The gold will appear lighter than before, the loss in weight being exactly equal to the weight of an equal volume of the water.

Calculate the specific gravity of the gold as follows:—

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* Any of the reagents mentioned on page 96 may be used for precipitating the gold.

$$\frac{\text{Weight in air}}{\text{Difference between weight in air and weight in water}} = \text{Density}$$

Experiment 3.—Strongly heat the globule of "fine" gold before the blowpipe for a few minutes and observe that no oxidation takes place, the surface remaining perfectly bright; allow to cool in air, and notice that there is no alteration of the surface due to the liberation of oxygen, as in the case of silver when similarly treated. (See p. 168.)

Experiment 4.—Cut the gold with a knife to ascertain its softness. Roll or hammer it out into a strip, and prove its great malleability, the edges remaining perfectly smooth. Note that mechanical treatment tends to make it hard and "springy." Heat the strip to redness, allow it to cool, and observe that it is soft and pliant after thus "annealing."

Experiment 5.—Cut off two small pieces of gold, place one on top of the other on an anvil, strike with a hammer and notice that the two pieces weld. They may also be welded by passing between the rolls.

Experiment 6.—Place the strip of gold in dilute sulphuretted hydrogen water and observe that no discoloration takes place, proving that gold has no affinity for sulphur under these conditions.

Experiment 7.—Melt 1 gram. (or 10 grains) of gold in a small crucible with the addition of .005 gram. ($\frac{1}{20}$th of a grain) of lead, and roll or hammer out as before. Notice that the edges now crack, showing that this small amount of lead has rendered the gold brittle; it has also altered the colour.

Experiment 8.—Melt 1 gram. (or 10 grains) of gold as before, with the addition of antimony instead of lead, and in the same proportion. Observe that the same effect is produced as with lead.

Experiment 9.—Re-melt the gold from Experiments 7 and 8 in a small crucible, and when fusion has taken place cautiously add a few crystals of nitre (potassium nitrate). Pour the gold into a suitable mould, or let it solidify, and then break the crucible. Roll or hammer out and note that it is now malleable after being refined.

Experiment 10.—Dissolve .5 gram. (or 5 grains) of pure gold in aqua regia as before and dilute to about a pint. Reserve a small portion of the solution for Experiment 11.

Heat the solution slightly, then add a solution of oxalic acid to precipitate the gold and observe the "*spongy*" nature of the mass which settles at the bottom. Filter off the gold, wash with water, then dry and examine with a lens. Notice that the spongy mass is made up of minute crystals.

Beautiful spangles of metallic gold are obtained by using a more dilute solution of gold. The precipitate may not appear until the solution has been standing for a short time.

Experiment 11.—Take a small quantity of the solution prepared for Experiment 10 and further dilute with water to obtain a *very* dilute solution of gold. Add a solution of stannous chloride, mixed with a little stannic chloride, shake well and notice the purple precipitate (purple of Cassius). This forms a very delicate test for gold.

Experiment 12.—Melt .5 gram. (or ·5 grains) of gold in a crucible or before the blowpipe, with the addition of two and a half times its weight of silver. Roll out the resulting alloy into a thin strip, place it in dilute nitric acid, and heat. Observe that the silver is dissolved, leaving the gold behind as a brown residue. Pour off the silver solution, wash and dry the gold thus "parted," and then heat to redness. The gold assumes its characteristic yellow colour and also contracts in volume.

Note.—The silver may be recovered as directed in Experiment 16.

Experiment 13.—Melt 1 gram. (or 10 grains) of gold in a crucible with the addition of .2 gram. (or 2 grains) of copper, using a thin layer of charcoal powder and also a cover to prevent oxidation. Allow the resulting alloy to solidify in the crucible and turn out when cold. Clean the alloy with sand and water and notice that the colour of the gold is deepened. Roll out into a strip, and prove its malleability and hardness as compared with pure gold. Anneal it at a red heat and notice the discoloration which takes place owing to the oxidation of the copper present. Plunge the strip while still hot into dilute nitric or sulphuric acid, and observe the "colouring" which takes place owing to the dissolving of the copper on the surface.

Experiment 14.—Place about .5 gram. (or 5 grains) of finely divided gold (Experiment 1) in a clean glass test-tube, add a few drops of mercury, warm gently and shake for a few seconds, closing the top of the tube with the finger. Notice that amalgamation takes place readily. Squeeze the resulting amalgam in chamois leather with a pair of pliers and observe the nature of the amalgam left. Allow it to rest for some days and note the "hardness."

Experiment 15.—Heat the amalgam in a small porcelain crucible until all the mercury is expelled. Note the character of the residue and weigh.

This experiment should be performed in connection with a suitable flue for carrying off the mercury fumes, as these are poisonous if inhaled.

SILVER.

Material Required.—About 10 grams. (or 200 grains) of standard silver or silver scrap.

Experiment 16.—Dissolve the silver in dilute nitric acid in a glass beaker of about one pint capacity, then add distilled water until three parts full; heat nearly to boiling and carefully add a strong solution of common salt to precipitate the silver as chloride. Stir briskly with a glass rod for a few minutes, allow the precipitate to settle, then carefully pour off the clear supernatant liquid; add hot water to the precipitate, stir, allow to settle; again decant the clear liquid, and repeat this operation three or four times in order to remove all the copper solution. Wash the precipitate into a basin, dry, add twice the bulk of sodium carbonate, well mix, transfer to an earthenware crucible, and fuse at a good red heat for about twenty minutes; then pour into an ingot mould, cool, and detach the slag, the last portions of which may be removed by dissolving in hot water. The heat should not be raised too suddenly, otherwise the charge may boil over owing to the rapid escape of carbonic acid.

Experiment 17.—Melt the silver on a cupel or suitable support by means of the blowpipe flame, and keep in the molten condition for a few minutes. Observe that it requires less heat to fuse it than gold, and that the metal does not tarnish in contact with the air. Allow the silver to cool quickly in contact with air, when the oxygen, which has been mechanically absorbed by the molten metal, is disengaged on the metal solidifying, causing a number of small excrescences on the surface. This action is called "spitting."

Experiment 18.—Re-melt 2 grams. (or 20 grains) of the silver with the addition of one-fifth of its weight of copper, cool in air as before, and notice that the presence of copper prevents "spitting."

Experiment 19.—Melt the remainder of the silver with sufficient common salt to cover the metal, so that the metal cools under a layer of salt, to prevent absorption of oxygen, and notice the smooth surface.

Experiment 20.—Determine the density of the silver, as directed for gold in Experiment 2, after carefully removing the salt adhering to the metal.

Experiment 21.—Roll the silver into a thin strip, noting its malleability and elasticity; heat to redness, allow to cool, and note that it is now pliant and "soft"; cut with a knife to ascertain its "hardness."

Experiment 22.—Place the strip of silver in dilute sulphuretted hydrogen water, and observe that it readily blackens owing to the formation of a film of silver sulphide.

Experiment 23.—Melt the silver in a crucible under a layer of charcoal powder, and when molten add one-fifth of its weight of platinum in the form of foil. When thoroughly melted, pour out and roll the alloy into a strip; observe its hardness and toughness compared with pure silver; anneal at a red heat and note the effect by bending.

Experiment 24.—Place the strip in a glass beaker and cover with dilute nitric acid. Observe that platinum is left undissolved as a black residue, while the silver (with a small quantity of platinum) is dissolved. Pour off the solution, wash the residue with hot water, dry and heat to redness; when cold rub with a burnisher and notice the bright metallic surface of platinum.

Experiment 25.—Roll the button from Experiment 18, observing that it is malleable, tough, and harder than pure silver. Heat the strip to redness and notice that discoloration takes place owing to the presence of copper. Re-heat the strip and plunge while hot into dilute sulphuric acid. Notice the "frosted" appearance produced by thus "pickling" in acid, and also observe that the bright metallic lustre is restored by burnishing.

Experiment 26.—Dissolve 1 gram. (or 15 to 20 grains) of pure silver in dilute nitric acid, dilute to about one-third of a pint with hot distilled water, place a strip of copper in the solution and observe the grey crystalline precipitate of silver produced. Allow the precipitation to go on for about half an hour, remove the copper, carefully wash off all silver adhering to it, allow the precipitate to settle, pour off the copper solution, and then wash the precipitate two or three times with hot water. Remove a small portion of the precipitate, dry, and examine with a lens. Notice its crystallised character.

Experiment 27.—Place the precipitated silver in a mortar, add mercury, and rub until amalgamation takes place. Remove excess of mercury by pressing the product in a piece of chamois leather; observe the character of the soft amalgam left behind. Reserve a portion for Experiment 28, and allow the remainder to harden, then break and examine with a lens, noting its crystalline state and brittleness.

Experiment 28.—Carefully pack a small quantity of the amalgam into a small glass tube until full, level the surface, and allow to rest until hard. Ascertain whether expansion or contraction has taken place by examining carefully with a lens. (See p. 149.)

Experiment 29.—Heat a small portion of the amalgam in a porcelain crucible (in a suitable draught) and expel the mercury. Examine the product left behind and note its character.

Experiment 30.—Dissolve .5 gram. (or 5 grains) of silver in dilute nitric acid, remove excess of acid by heating, dilute with hot water; then pour a small quantity of mercury into the vessel containing the silver solution, and allow it to stand undisturbed for several hours. Observe the crystallised amalgam or "silver tree" which is formed.

MERCURY.

Material Required.—20 grams. (or 300 grains) of pure mercury.

Experiment 31.—Take a small quantity of mercury: observe that it has a silvery-white colour and bright lustre; that it is tasteless; and that it is liquid at ordinary temperatures. Pour a few globules of mercury on to a clean sheet of glass, notice that the globules are spherical and leave no "tail," and that the surface of the glass is not "wetted," as with ordinary liquids. Heat a very small quantity of mercury, preferably in a muffle, and observe that it is completely volatilised. No oxidation takes place at the ordinary temperature, or on gently heating, but at the boiling-point of mercury (350° C.) the metal begins to oxidise.

Experiment 32.—Pour a little mercury into dilute sulphuretted hydrogen water, and observe that no discoloration takes place.

Experiment 33.—Place about 4 grams. (or 50 grains) of mercury in a mortar, add a little lead and either tin or zinc, but not sufficient to destroy the liquidity of the mercury, and rub until amalgamation takes place. Then cause the globule of impure mercury thus obtained to roll down a slightly inclined surface. Observe that the mercury does not maintain the spherical shape, as in the case of pure mercury, but that the globule elongates, carrying a tail with it. Place the globule in a small glass tube, shake well, and observe the thin film of oxide which forms on the surface, impairing the lustre of the mercury.

Experiment 34.—Introduce a small quantity of mercury into a long glass tube closed at one end. Heat until the metal has volatilised, and observe that the mercury is condensed at the cold end of the tube in the form of very minute globules, which adhere to the surface of the glass, thus proving that mercury may be readily distilled.

Experiment 35.—Pour a little mercury into a mortar, add flower of sulphur and well mix, when black mercury sulphide will be formed. Transfer this to a small porcelain crucible, cover with a close-fitting lid, heat gently for some time; allow to cool, and observe the small red crystals of vermilion.

Place a little of the sulphide in a glass tube and heat, when the vermilion will be completely volatilised without leaving any residue. To another portion of the vermilion add a little red lead or oxide of iron, heat in a tube as before, and notice that the impurity is left as a residue.

PLATINUM.

Material Required.—About 5 grams. (or 100 grains) of platinum plate or wire.

Experiment 36.—Determine the density of the metal, as directed in Experiment 2. Observe that it is heavier than any of the other metals in common use.

Experiment 37.—Roll a piece of platinum to ascertain its malleability and "stiffness." Heat it strongly in the blowpipe flame for five to ten minutes; allow to cool and observe that annealing has made it soft and flexible.

Experiment 38.—Heat a strip of platinum at a bright red heat for some minutes, then cool in the air. Notice that the surface remains bright, no oxidation taking place.

Experiment 39.—Place a clean strip of platinum in sulphuretted hydrogen water. The metal remains untarnished, as it has practically no affinity for sulphur.

Experiment 40.—Place a small piece of platinum on a suitable support and heat for some time to the highest possible temperature attainable with the blowpipe. Observe that the metal does not melt or even show signs of fusion at the sharp edges.

Experiment 41.—Take two small pieces of platinum with clean surfaces: place one on the top of the other, and heat to a white heat for five minutes, then squeeze quickly and hard with a pair of pliers. Notice that the pieces have welded and cannot be readily separated.

Experiment 42.—Heat a piece of clean platinum to a white heat, and while at this temperature place a small piece of pure gold upon it. Observe that the union of the metals takes place at once.

Experiment 43.—Repeat Experiment 42, using lead instead of gold. A similar result is obtained. When cold place the strip of platinum thus treated in the vice and strike with a hammer. Notice that the presence of very little lead makes platinum brittle.

Experiment 44.—Dissolve 1 gram. (or 15 grains) of platinum in aqua regia; cautiously evaporate nearly to dryness; re-dissolve the residue in a small quantity of water; divide the solution into two portions; reserve one portion for Experiment 45; to the other add excess of a solution of ammonium chloride (sal-ammoniac), then about an equal bulk of alcohol; allow to stand in a warm place for a few hours until all the platinum is precipitated. Filter; wash the yellow precipitate with alcohol; dry and ignite. A grey spongy mass of metallic platinum is left behind (see p. 187). Heat the sponge to a white heat for five minutes, quickly place on a bright anvil and hammer into a compact mass, which will have the appearance and metallic lustre of platinum.

Experiment 45.—Further dilute the solution of platinum chloride reserved from Experiment 44 with a small quantity of hot water, add a few drops of hydrochloric acid, place a clean strip of zinc in the solution, and allow the action to go on until the liquid is colourless. Remove the zinc, wash off any adhering precipitate of metallic platinum, allow the black spongy precipitate to settle, pour off the clear liquid, and then wash the residual platinum first with a little hydrochloric acid, and then with hot water. Place the platinum in a heated mortar, and add a little mercury and rub well for some time. Amalgamation is readily effected by continual mixing, producing a more or less unctuous mass. The amalgam may also be obtained by using finely divided platinum, such as that produced by heating the precipitate of double chloride of ammonia and platinum, as described in Experiment 44. After removing excess of mercury by squeezing in chamois leather, allow the amalgam to stand for some days, and note that it hardens very imperfectly.

TIN.

Material Required.—150 grams. (or 2500 grains) of pure tin.

Experiment 46.—Melt 50 grams. (or 1000 grains) of tin in a small crucible or ladle, and notice that it melts at a very low temperature, the melting-point of tin being lower than that of any of the other metals in common use. Allow the tin to cool and cast into a flat open mould at as low a temperature as possible (*i.e.*, just before solidification takes place). To prevent any dross from getting into the mould a stick should be placed across the lip of the crucible when pouring. Allow the tin to cool without disturbance, and observe the clear, white, and bright surface of the metal when cold. If the tin is too hot when cast the surface will be discoloured owing to oxidation.

Commercial tin often contains small portions of other metals, and when impurities are present they impart to the tin a more or less dull and frosted appearance. Hold the ingot close to the ear and bend it, when a peculiar crackling sound, known as the "cry" of tin, will be heard.

Experiment 47.—Ascertain the density of the metal by weighing in air and in water as directed in Experiment 2. Notice that the specific gravity of tin is slightly higher than that of zinc.

Experiment 48.—Cut the metal with a knife, noting its softness. Test the malleability of pure tin by rolling. Cut a strip of sheet tin about one-eighth of an inch wide, fix one end firmly in a vice, hold the other end securely in the pliers, and observe that little force is required to produce rupture, the tenacity of tin being very low.

Experiment 49.—Melt 50 grams. (or 1000 grains) of tin, cast into an ingot mould ; cool and then fracture by placing in a vice and bending backwards and forwards with a hammer. Notice the toughness of the metal. Re-melt, cast into a warm mould, then remove quickly when solidified and break. Notice that the metal is more or less brittle and fractures readily.

Experiment 50.—Melt 50 grams. (or 1000 grains) of tin, and raise to a red heat; the surface of the metal will be speedily covered with a layer of oxide. Allow the metal to cool somewhat, then cast into a warm iron mortar and pound with the pestle as soon as solidification takes place. Observe that the metal is readily powdered, tin being brittle at a temperature near its melting-point.

Experiment 51.—Take two perfectly clean strips of sheet tin, place one on top of the other, and pass through the rolls or strike several blows with a hammer. Observe that the two pieces become welded. The strips should be scraped with a knife to clean them, as any dirt or film of oxide on the surface tends to prevent union taking place.

Experiment 52.—Place a clean strip of tin in sulphuretted hydrogen water, and notice that no black film is formed, as in the case of silver when thus treated.

Experiment 53.—Put about .5 gram. (or 10 grains) of tin in a glass beaker, add a little dilute nitric acid, and warm. The tin is acted upon with the formation of a white residue (metastannic acid).

Experiment 54.—Melt 2 grams. (or 20 grains) of tin with a little charcoal powder to prevent oxidation, add 2 grams. (or 20 grains) of lead, then 4 grams. (or 40 grains) of bismuth; stir and then cast the resulting alloy into a mould, and note its brittleness. Place the alloy in boiling water, observing that it melts readily. Determine the melting-point of the alloy as directed on p. 52, Part I.

Experiment 55.—Melt 6 grams. (or 60 grains) of silver, add 4 grams. (or 40 grains) of tin, using a layer of charcoal to prevent oxidation. Clean the surface of the resulting alloy with emery, then heat it and observe that it is easily oxidised. Cut with a knife or file it to determine the hardness; place in a vice and fracture, noting its brittleness. Repeat the experiment, using 6 grams. (or 60 grains) of tin and 4 grams. (or 40 grains) of silver. Note the characteristics of the alloy as before.

Experiment 56.—Test the affinity of tin for mercury by placing tin foil in a mortar and adding mercury. Observe that amalgamation is speedily effected. Mix well with the pestle, place in chamois leather, and remove excess of mercury by squeezing. Reserve a portion of the plastic amalgam for Experiment 57, and allow the remainder to stand for a few days until it hardens. Note its white colour, fracture with a hammer, and observe its brittleness.

Experiment 57.—Pack the plastic amalgam into a glass tube, as directed in Experiment 28, and note whether expansion or contraction takes place.

Experiment 58.—Take filings of each of the alloys prepared in Experiment 55; add a little mercury to each, and observe that amalgamation takes place with less facility in the case of the alloy containing excess of silver.

ZINC.

Material Required.—100 grams. (or 1500 grains) of zinc.

Experiment 59.—Melt 50 grams. (or 1000 grains) of zinc, cast into an ingot mould (similar to that described on p. 76, Part I.) to obtain a flat ingot. Observe that zinc requires a slightly higher temperature to melt it than lead. Place the ingot in a vice and strike with a hammer, when the metal will break off short, thus showing its brittleness at the ordinary temperature, and its crystalline structure. Cut the metal with a knife, and ascertain its hardness. Take one-half of the ingot, heat to about 150° C., place it on the anvil and hammer, observing that it is now malleable. Heat again if necessary, and roll into a thin sheet. The ingot may require annealing once or twice during the operation by heating to about 150° C. Heat the other half of the ingot to a temperature of 200° to 300° C., and prove the brittleness of zinc at this temperature by hammering or powdering in an iron mortar.

Experiment 60.—Melt 10 grams. (or 200 grains) of zinc in an open crucible with free access of air; observe that the surface of the metal is readily covered with a film of oxide. Raise the temperature to a bright red heat; notice that the zinc is volatile and burns with a brilliant bluish-white flame, forming a very light white powder, which is zinc oxide.

Experiment 61.—Place the strip of sheet zinc from Experiment 59 into dilute sulphuretted hydrogen water; observe that no discoloration takes place.

Experiment 62.—Take equal parts (about 30 grams. or 500 grains) of zinc and lead, melt well together, and pour into an upright ingot mould. When cold remove from the mould and carefully inspect the surface of the ingot; a line will be observed where the two metals have separated on cooling. Place the ingot in the vice, as near as possible at the line of junction of the two metals, and strike with a hammer, when it will break off short. Hammer each half separately on the anvil; notice that the upper half consists of zinc, which is hard, crystalline, and brittle; while the lower half is lead, being very malleable and soft.

Experiment 63.—Place a little mercury in a mortar, add zinc filings, and rub with the pestle until amalgamation takes place. Observe the character of the amalgam produced; also that union is not readily effected. Amalgamation is facilitated by the addition of water slightly acidulated with a few drops of acid.

LEAD.

Material Required.—100 grams. (or 1500 grains) of lead.

Experiment 64.—Melt 50 grams. (or 1000 grains) of lead in a crucible or ladle. Observe that it melts at a comparatively low temperature and that oxidation takes place when the metal is molten. Pour into an upright ingot mould, remove when cold, place one end in the vice, bend it backwards and forwards with a hammer until it breaks, thus proving the toughness of the metal. Cut with a knife and notice that it is very soft; roll into a thin sheet and prove its malleability. Take two pieces of the sheet lead, clean the surfaces by scraping, place one piece on top of the other and pass through the rolls or hammer on an anvil. Notice that the pieces have welded.

Experiment 65.—Prepare an ingot of lead as in Experiment 64, remove at once from the mould when set, place the ingot across two iron supports about 1½ inches apart; heat the centre by means of a Bunsen flame, held in the hand. When the lead shows signs of melting, remove the burner at once and strike the centre of the ingot one sharp blow with a hammer, when the metal will break, showing the brittleness of lead at this temperature. Examine the transverse columnar structure of the broken surface and compare it with that obtained by fracturing lead when cold.

Experiment 66.—Melt 50 grams. (or 1000 grains) of lead, add 1 gram. (or 20 grains) of antimony, stir well and cast into an ingot mould. When cold remove, place in a vice and fracture. Notice that the presence of antimony has made the lead brittle; cut with a knife and observe that the alloy is much harder than pure lead.

Experiment 67.—Determine the density of lead as described in Experiment 2, observing that it should be classed with the heavy metals.

Experiment 68.—Place a clean strip of sheet lead in dilute sulphuretted hydrogen water and notice that the metal is tarnished.

Experiment 69.—Clean a piece of sheet lead, place it in a vessel with a little vinegar, and allow it to stand. Observe that the metal is acted upon somewhat readily.

COPPER.

Material Required.—50 grams. (or 750 grains) of sheet copper or thick copper wire.

Experiment 70.—Cut a piece of copper with a knife and notice its hardness; test the malleability of the metal by rolling or hammering; observe that mechanical treatment renders it hard. Heat the slip of copper to redness, observe that the metal is readily tarnished in contact with the air. Plunge the metal while still hot into cold water; notice that the metal is soft and pliant after annealing. Re-heat and plunge into dilute sulphuric acid; observe that the coating of oxide is removed from the surface by the action of the acid.

Experiment 71.—Take a small coil of copper wire and determine the density of the metal as directed in Experiment 2.

Experiment 72.—Place a clean strip of copper in dilute sulphuretted hydrogen water. Notice that discoloration of the copper rapidly takes place owing to the formation of a film of sulphide.

Clean a piece of copper, place it in a vessel with a few drops of vinegar, and allow it to remain for a day or two. Observe that the copper is acted upon, with the formation of a green coating of "verdigris."

Experiment 73.—Hold a piece of copper in contact with the tongue and notice that it possesses a peculiar faint, nauseous, metallic taste.

Experiment 74.—Melt 5 grams. (or 50 grains) of copper on a cupel or charcoal support by means of the blowpipe. Notice that the temperature required to fuse it is a little below that required to melt gold. Keep in the molten condition for some minutes, allow to solidify, then roll or hammer. Observe that the metal is more or less brittle owing to the presence of dissolved copper oxide. The copper is more readily melted in a small crucible in a suitable furnace.

Experiment 75.—Melt 30 grams. (or 500 grains) of copper in a crucible with the addition of a little charcoal powder and add 1 gram. (or 20 grains) of metallic arsenic. When mixed pour into a suitable mould. Roll or hammer the resulting alloy and observe that the presence of the impurity causes brittleness.

[*Note.*—About half the quantity of arsenic will probably be lost by volatilisation when conducting the experiment.]

Experiment 76.—Melt 30 grams. (or 500 grains) of copper and add .5 grams. (or 10 grains) of antimony. Roll or hammer as before, and notice that the effect of antimony is very similar to that of arsenic.

[*Note*—Some of the antimony will be lost owing to oxidation.]

Experiment 77.—Place a strip of bright metallic copper in a solution of mercuric chloride (*corrosive sublimate*). A silvery white deposit of metallic mercury is obtained, which, when gently rubbed, shows a bright metallic lustre.

Experiment 78.—Dissolve 1 gram. (or 20 grains) of copper in a small quantity of dilute nitric acid; when all fumes are expelled dilute with water and place a strip of iron plate into the solution. Allow it to stand for some time until the copper is precipitated. Remove the iron, pour off the solution, wash the spongy copper precipitate well with repeated quantities of cold water, then transfer to a mortar, add a little mercury and rub well with the pestle until amalgamation is complete. The union may be facilitated by the addition of a little hot water and a few drops of sulphuric acid, or by adding a solution of mercuric nitrate to the precipitate before the introduction of the mercury. Remove the excess of mercury, if necessary, by squeezing through chamois leather, and allow the resulting plastic amalgam to stand for about twenty-four hours. Notice that it becomes quite hard. Hammer and observe its malleability, then pound or knead in a mortar until it acquires its original softness. Allow to stand for a few hours, and notice that it recovers its hard crystalline character.

Experiment 79.—Prepare a small quantity of copper precipitate as directed in Experiment 78, allow it to stand exposed to the air for a short time; observe that it becomes rapidly coated with a film of oxide and is unfit for amalgamation.

CADMIUM.

Material Required.—40 grams. (or 500 grains) of cadmium.

Experiment 80.—Melt the cadmium in a small crucible; observe its low melting-point and that it is readily oxidised; heat to bright redness, when the metal burns with a brown flame. Cast the metal into a suitable mould. Test its toughness, softness, malleability and welding properties as described for lead in Experiment 64.

Experiment 81.—Place a clean strip of cadmium in sulphuretted hydrogen water. Notice that the metal is soon covered with a yellow film of cadmium sulphide.

Experiment 82.—Mix together in a mortar mercury and cadmium ; observe that combination readily takes place, producing a soft tin-white mass. Allow it to stand for some time, when it hardens and forms a brittle mass which softens when moderately heated and can be kneaded like wax.

BISMUTH.

Experiment 83.—Prove the brittleness of bismuth by crushing in a mortar. Heat the metal in a crucible ; observe its low melting-point and that it burns with a blue flame when heated to a high temperature. Cast the metal into a mould, and notice that it expands in the act of solidifying.

Experiment 84.—Prepare an amalgam of bismuth by shaking powdered bismuth with mercury in a tube. Notice the liquid character of the amalgam obtained.

ANTIMONY.

Experiment 85.—Crush a little antimony in a mortar to prove its extreme brittleness. Melt the metal, noting its melting-point, raise it to a red heat ; notice that it burns with a white flame, forming the white oxide.

Experiment 86.—Place a little powdered antimony and mercury in a glass tube, shake well and observe that union does not take place readily even when heated.

IRON AND STEEL.

Experiment 87.—Take a piece of *soft iron* wire ; notice that it bends readily without breaking ; heat it to redness and plunge while hot into cold water; observe that it still retains its softness and bends readily.

Experiment 88.—Take a piece of steel wire (pianoforte wire); observe that it is "stiff" and hard, but can be bent; heat to redness and plunge into cold water; notice that the wire is now very hard and brittle and breaks readily,

Heat another piece of the wire to redness, plunge into water to harden it, clean the surface carefully with emery, heat gently over a Bunsen flame until it acquires a blue tint, then plunge at once into cold water. Observe that the wire has lost its brittleness and can now be bent after thus tempering.

Experiment 89.—Heat a piece of soft iron wire at the highest temperature attainable with the blowpipe; observe that it does not melt. Continue heating for 5 or 10 minutes; notice that the metal is oxidised and "burnt" and becomes more or less brittle.

Experiment 90.—Cut some hoop iron into small pieces, place about 50 grams. (or 500 grains) in a crucible, raise to a red heat and add small pieces of sulphur at intervals. When the whole is melted pour into a mould, and when cool fracture the iron sulphide and notice that it is hard, more or less brittle, and has a bronze-like colour. (See Spence's "Metal," p. 47.)

ALUMINIUM.

Experiment 91.—Take a sheet of aluminium and determine its density as described in Experiment 2. Observe that it is the lightest of the common metals. Melt a small piece of the metal before the blowpipe; observe that it requires a bright red heat to melt it and that it is somewhat "pasty" when molten. Roll the metal to prove its malleability and toughness, heat to redness and drop into cold water, thus proving that it is softened by annealing. (See p. 246, Part I.)

Experiment 92.—Place a strip of the metal in sulphuretted hydrogen water; notice that no discoloration takes place.

Experiment 93.—Prepare a solution of sodium carbonate, put a strip of aluminium into it, and observe that the metal is acted upon.

Experiment 94.—Remove the aluminium from the solution in the preceding experiment and rub a little mercury on the surface; the plate will soon become covered with a white film of oxide, which swells up on the surface and may be detached in flakes.

NICKEL.

Experiment 95.—Take a piece of nickel wire or plate, clean with emery, observe that it is white, malleable when hammered or rolled, very tenacious, hard, tough, and difficult to break. Heat it at the highest temperature obtainable with the blowpipe, and notice that it does not melt, and that it is oxidised on the surface.

Experiment 96.—Place a clean strip of metal in sulphuretted hydrogen water; observe that no discoloration takes place.

THE BLOWPIPE FLAME.

Experiment 97.—Make a small cavity in a piece of charcoal, place in it a piece of lead foil and heat before the *oxidising* flame of the blowpipe (see p. 57, Part I.). Notice that the lead is gradually converted into oxide.

Experiment 98.—Clean a piece of copper and heat it before the oxidising flame, observing that it is quickly "blackened" or oxidised.

Experiment 99.—Place a little lead oxide (red lead) in a cavity in charcoal and heat with the *reducing* flame of the blowpipe (see p. 57, Part I.). The lead oxide is "reduced" to the metallic state in the form of little globules.

Experiment 100.—Heat a clean sheet of copper before the reducing flame, and notice that the metal is less readily tarnished than in the oxidising flame.

APPENDIX

List of the Common Elements, with their Symbols and Atomic Weights.

[*Note.*—The words in brackets are the Latin names of the elements from which the symbols have been derived.]

Name.	Symbol.	Atomic Weights.	
		Approximate Values.	More Exact Values.
Aluminium	Al	27	27.04
Antimony (*Stibium*) . .	Sb	120	119.6
Arsenic	As	75	74.9
Bismuth	Bi	207.5	—
Bromine	Br	80	79.76
Cadmium	Cd	112	111.7
Carbon	C	12	11.97
Chlorine	Cl	35.5	35.37
Copper (*Cuprum*) . . .	Cu	63	63.18
Fluorine	F	19	19.06
Gold (*Aurum*)	Au	197	196.8
Hydrogen	H	1	—
Iodine	I	127	126.54
Iridium	Ir	192.5	—
Iron (*Ferrum*)	Fe	56	55.88
Lead (*Plumbum*) . . .	Pb	207	206.39
Mercury (*Hydrargyrum*) . .	Hg	200	199.8
Nickel	Ni	59	58.6
Nitrogen	N	14	14.01
Oxygen	O	16	15.96
Palladium	Pd	106	106.2
Phosphorus	P	31	30.96
Platinum	Pt	195	194.3
Potassium (*Kalium*). . .	K	39	39.03
Silver (*Argentum*) . . .	Ag	108	107.66
Sodium (*Natrium*) . . .	Na	23	22.99
Sulphur	S	32	31.98
Tin (*Stannum*)	Sn	118	117.35
Zinc	Zn	90.4	—

CONVERSION OF CENTIGRADE AND FAHRENHEIT DEGREES.

The thermometric scales in use in this country are the Centigrade and Fahrenheit; the former of these is rapidly becoming universal for scientific purposes. The two scales are mutually convertible by the following rules:

1° C. = 1.8° F. or $\frac{9}{5}$° F.

To Convert Centigrade into Fahrenheit.—Multiply by 9, divide by 5, and add 32.

To Convert Fahrenheit into Centigrade.—Subtract 32, multiply by 5, and divide by 9.

ENGLISH WEIGHTS.

APOTHECARIES' WEIGHT.

Pound.		*Ounces.*		*Drachms.*		*Scruples.*		*Grains.*
℔ 1	=	12	=	96	=	288	=	5760
		℥ 1	=	8	=	24	=	480
				ʒ 1	=	3	=	60
						℈ 1	=	Gr. 20

AVOIRDUPOIS WEIGHT.

Pound.		*Ounces.*		*Drachms.*		*Troy Grains.*
℔ 1	=	16	=	256	=	7000
		oz. 1	=	16	=	437·5
				dr. 1	=	27·344

RELATIVE VALUE OF TROY AND AVOIRDUPOIS WEIGHTS.

Pound.		*Pounds.*		*Pound.*	*Ounces.*	*Grains.*
1 Troy	=	0.822857 Avoir.	=	0	13	72·5
1 Avoirdupois	=	1.215277 Troy	=	1	2	280

IMPERIAL MEASURE.

Gallon.		*Pints.*		*Fluid Ounces.*		*Fluid Drachms*
1	=	8	=	160	=	1280
		1	=	20	=	160
				1	=	8

1 gallon . . . . = 70,000 grains of water
1 fluid ounce ($\frac{1}{20}$ pint) = 437.5 ,, ,,
1 gallon = 277.280 cubic inches
1 fluid ounce = 1.733 ,, ,,

METRIC SYSTEM OF WEIGHTS AND MEASURES.

In the French or decimal system the smaller denominations are obtained by taking a tenth, hundredth, thousandth, &c., of the unit chosen, and are designated by the Latin prefixes *deci-*, *centi-*, *milli-*, &c., whilst the higher denominations are 10 times, 100 times, 1000, &c. times the unit, and are named by the Greek prefixes *deca-*, *hecto-*, *kilo-*, &c. ; examples of this will be found in the tables given below.

The *unit of weight* is the GRAMME, which is the weight of 1 cubic centimetre of water, and is equal to 15.432 grains.

The *unit of length* is the METRE, and is one ten-millionth of the distance on the earth's surface from the equator to the pole. It is 39.37 inches.

The *unit of measure of capacity* is the LITRE, which is 1 cubic decimetre, and is equal to 1.761 pints. The chief convenience arising from the use of the metric system is that the different denominations can be written as one, since they are either multiples by 10 or are decimal fractions of the unit. Thus 6 decagrammes, 2 grammes, 5 decigrammes, 3 milligrammes would be written 62.503 grammes.

METRICAL MEASURES OF WEIGHT.

1 gram. = the weight of 1 cubic centimetre (c.c.) of water at 4° C.

—	Grams.	Grains.	Avoirdupois.		
			lbs.	oz.	drms.
Milligram.	.001	0.01543			
Centigram.	.01	0.15432			
Decigram.	.1	1.54323			
Gram.	1.0	15.43235			
Decagram.	10.0	154.32349	0	0	5.65
Hectogram.	100.0	1543.23488	0	3	8.5
Kilogram.	1000.0	15432.34880	2	3	5
Myriogram.	10000.0	154323 48800	22	1	2

1 grain . . . . = 0.0649 gram.
1 gram. = 15.43235 grains = 0.032151 oz. Troy = 0.0352736 oz. Avoir.
1 oz. Troy = 31.104 grams. = 480 grains = 1.0971 oz. Avoir.
1 oz. Avoir. = 28.3675 grams. = 437.5 grains = 0.9114 oz. Troy.
1 lb. Avoir. = 16 ozs. Avoir. . . = 7000 grains.
1 lb. Troy = 12 ozs. Troy . . . . = 5760 grains.
1 oz. Troy . . . . = 31.1035 grams.
1 lb. Avoirdupois . . . . . = 453.593 grams.
1 cwt. . . . . . . = 50.8024 kilograms. (kilos).
1 ton . . . . = 1016 kilos.

The following approximate relations may be found useful :

Grammes.	Grains.
1	15½
5	77½
10	155
20	310
28½	1 oz.
100	3½ oz.
142	5 oz.
284	10 oz.

METRIC MEASURES OF LENGTH. ENGLISH.

	Metre.	Ins.	Mile.	F'l'g.	Yds.	Ft.	Ins.
Millimetre (mm.)	= 0.001 =	.03937 =	—	—	—	—	.03937
Centimetre	= 0.01 =	.39371 =	—	—	—	—	.39371
Decimetre	= 0.1 =	3.93708 =	—	—	—	—	3.9371
Metre	= 1.0 =	39.37079 =	—	—	—	3	3.371
Decametre	= 10.0 =	393.70790 =	—	—	10	2	9.7
Hectometre	= 100.0 =	3937.07900 =	—	—	109	1	1
Kilometre	= 1000.0 =	39370.79000 =	—	4	213	4	10.2
Myriometre	= 10000.0 =	393707.90000 =	6	1	156	0	6

1 inch = .0254 metre = 2.5425 centimètres.
1 foot = .3048 " = 3.048 decimètres.
1 yard = .9144 " = 9.144 "
1 mile = 1.609 kilometre.

METRIC MEASURES OF CAPACITY.

1 litre = 1 cubic decimetre.

	Litre.	Cubic Inches.	Pints.
Millilitre or Cubic centimetre (c.c.)	= .001	= .06103	= 0.00176
Centilitre	= .01	= .61027	= 0.01761
Decilitre	= .1	= 6.1027	= 0.17608
Litre	= 1.0	= 61.027	= 1.76077
Decalitre	= 10.0	= 610.27	= 17.60773
Hectolitre	= 100.0	= 6102.7	= 176.07734
Kilolitre	= 1000.0	= 61027.0	= 1760.77341
Myriolitre	= 10000.0	= 610270.0	= 17607.73414

1 cubic inch = .01639 litre = 16.39 c.c.
1 cubic foot = 28.31531 litres.
1 gallon = 4.54336 "
1 litre = 1000 cubic c.m. = 61.02705 cubic inches = 1.76 pint.
1 pint = 34.66 cubic inches.

List of Substances which are known by Common or Popular Names, with their Chemical Names and Formulæ.

Common Name.	Chemical Name.	Formula.
Alum	Double sulphate of aluminium and potassium	$Al_2(SO_4)_3,K_2SO_4$ $24H_2O$
Aqua fortis	Nitric acid	HNO_3
Aqua regia	Mixture of nitric and hydrochloric acids	$3HCl + HNO_3$
Bleaching powder or chloride of lime	Compound of calcium chloride and calcium hypochlorite	$Ca(OCl)Cl$
Bone ash	Nearly pure calcium phosphate	$Ca_3(PO_4)_2$
Calomel	Mercurous chloride	Hg_2Cl_2
Caustic potash	Potassium hydrate	KHO
Caustic soda	Sodium hydrate	$NaHO$
Chalk, marble or limestone	Calcium carbonate	$CaCO_3$
Common salt	Sodium chloride	$NaCl$
Corrosive sublimate	Mercuric chloride	$HgCl_2$
Epsom salts	Magnesium sulphate	$MgSO_4,7H_2O$
Glauber's salt	Sodium sulphate	Na_2SO_4
Litharge	Lead oxide	PbO
Lunar caustic	Silver nitrate	$AgNO_3$
Muriatic acid or spirits of salt	Hydrochloric acid	HCl
Plaster of Paris or gypsum	Calcium sulphate	$CaSO_4$
Prussic acid	Hydrocyanic acid	HCy
Putty powder	Tin oxide	SnO_2
Quicksilver	Mercury	Hg
Rouge or colcothar	Oxide of iron	Fe_2O_3
Sal ammoniac	Ammonium chloride	$AmCl$
Salts of lemon	Citric acid and potassium oxalate	
Saltpetre or nitre	Potassium nitrate	KNO_3
Spirits of wine	Alcohol	C_2H_6O
Tartar emetic	Potassium antimony tartrate	$4(SbO)K(C_4H_4O_6)$
Vermilion or cinnabar	Mercury sulphide	HgS
Vitriol (oil of)	Sulphuric acid	H_2SO_4
,, blue	Copper sulphate	$CuSO_4$
,, green	Iron sulphate	$FeSO_4$
,, white	Zinc sulphate	$ZnSO_4$
Washing soda	Sodium carbonate (crystallised)	$Na_2CO_3 10H_2O$
White lead	Lead carbonate	$PbCO_3$

INDEX.

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140