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CERAMICS

A MANUAL FOR

CHEMISTS, ENGINEERS AND MANUFACTURERS

Including a Collection of Tables and Problems
for Laboratory and Plant Use

WITH A DICTIONARY OF USEFUL MINERALS

BY

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THIS LITTLE BOOK
IS RESPECTFULLY DEDICATED
TO
THOSE WHO ARE SEEKING SUCCESS
IN THE SOLUTION OF NATURE'S LAW
AND
WHO WISH TO UNFOLD AND COMMAND
ITS DEEPEST SECRET.

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PREFACE

CERAMICS includes all industries manufacturing silicate ware, and all kinds of clay products, glasses, enamels, cements, mortars, etc.

The ceramic industry is one of the oldest in the world, its beginning might almost be said to have been coincident with the birth of humanity, since it was the first industry in which our early ancestors engaged. To-day it ranks third in importance.

The author has attempted to write a condensed book on the silicate industries, including the methods of qualitative and quantitative analysis of silicates and chemical and ceramic calculations in use in every day practice in the silicate industry. As success in the manufacture of clay products depends largely upon the accuracy of the calculations, it is hoped that this book will be found valuable by chemists and ceramic engineers as an aid for the solution of the various mathematical problems that arise.

Beginners preparing for a career in ceramic engineering will find this book of service not only for its mathematics, but for its presentation of the fundamentals of ceramic laboratory procedure as combined with the elementary laws of chemistry.

The author has made free use of original formulas and tables from the following works: Keramische Rundschau, Sprechsaal Kalendar, Grunwald; Enamel Industry Trans. American Ceramic Society. H. Ries; Clays, their Occurrence, Properties and Use. E. Bourry; A Treatise on Ceramic Industry. Havard; Refractory and Furnace. J. W. Mellor; Treatise on the Ceramic Industries.

He wishes to express here his thanks to Mr. J. E. Boynton, Mechanical Engineer, for furnishing valuable formulas for calculations, and also to Professor M. J. Campbell for valuable assistance.

ANDREW MALINOVZSKY.

BELLVILLE, ILL.,
April, 1921.

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CERAMIC INDUSTRIES

CLAYS

CLAY is a term familiar to everyone. It designates a tenacious earthy substance, composed chiefly of a mixture of silica and alumina in various proportions and in a variety of colors. Clay when wet is plastic and can be molded by hand or machine into any desired shape and it will preserve that form until dry enough to be handled and made permanently hard by fire. It is this property of plasticity that makes clay so valuable to man.

Clays have been formed by the disintegration of rocks (especially aluminous rocks) by the forces of nature, such as rain, snow, freezing, and thawing. Some clays have been carried in suspension in water for considerable distances from the mother rocks from which they were formed. These clays are known as transported clay. Then again, clay has been carried far from the mother rock by the action of glaciers. This clay is known as *boulder* or *till*. Where the clay has not been transported so far but that it can be traced to its mother rock, it is known as *residual* clay.

Owing to the difference in composition of the mother rocks and because of the rocky debris and other foreign material with which they become mixed in *transportation* clays differ very much in their chemical and physical properties. They generally contain various impurities such as iron, lime, magnesia, potassium, sodium, titanium, etc., and also organic matter.

Pure clay, known technically as kaolin, is a hydrated silica of aluminum having the formula

$$Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O.$$

This is the basis of all the clays which are designated by the following names: ball, pottery, pipe, stoneware, fire, flint, slip, and brick clays, loam, marl, shale, etc. All of these clays range through all stages of impurity down to a point where the material contains but little or none of the clay base, and therefore cannot be technically classed as a clay.

Weathering.—Clays brought from the mine or bank and worked up at once usually crack in cubes very badly. So it is customary for the clay to be exposed to the weather some time before being manufactured into clay wares. The clay is exposed to rain, snow, freezing, thawing, etc., for a certain length of time, according to the purpose for which it is to be used. This is known as the weathering process.

The rain and snow are known as acid carriers. The snow acts the more energetically, as it often lies for months on the clay and as it melts in the spring, the melted snow percolates more uniformly through the clay and dissolves more of the impurities such as the alkaline earths and compounds of iron, sulphur, etc. At the same time vegetable substances and other organic compounds are decomposed. By this process the clay is rendered purer, the proportion of the colloid substance is increased, and therefore the clay becomes more plastic.

Soaking.—Another method of preparing clay is the so-called *soaking* process. The clay is placed in a pit and allowed to remain covered with water from twenty-four to seventy-two hours. To get the best results by this process the clay should be finely ground before being placed in the pit and enough water added so that no more water will be necessary when the wet clay is transferred to the pug mill.

Many manufacturers soak the clay only one night and then transfer it to the wet pan. This is the practice especially with shales, some of which are very hard and unless finely ground absorb the water slowly.

If the clay contains gravel or other rock fragments, this coarse material must be removed or else ground fine before the clay is used for manufacturing purposes. This is especially true of limestone.

The weathering, soaking, and tempering of the clay should never be neglected but should always be carefully carried out in the preparation of any clay or clay mixtures. Neglect in this particular spells failure.

As an example, the author had an experience with some washed clay which had been shipped into the factory. It was mixed and pressed. When examined the next day everything was found cracked. The whole was placed in a wet pan, then in the pug mill. After the clay rested for a week, it was reduced, sieved and pressed again. The articles then proved satisfactory.

The thoroughness of this process may be tested by pressing or molding some of the clay into brick shapes by hand and letting them dry. If the bricks crack in cube shapes, it is an indication that the clay has not been tempered and weathered sufficiently or that it is too plastic or too fine. This is true of any mixture of clays.

Weathering or soaking is necessary even in the dry or semi-dry process.

In preparing clays or body mixtures, cleanliness and exactness must be practiced in every stage of the process throughout the whole plant. This is especially true in the manufacture of porcelain or stoneware or refractory. *No ceramic engineer can hope to be successful unless every step of the process is put under his control and he sees to it that everything is done according to his instructions.*

Molding and Drying.—When the weathering or soaking process is completed and the clay or body mixture is carefully prepared to a workable condition, the clay or mixture is then shaped by hand or machine and allowed to dry.

All clays or mixed bodies that are molded wet will contract on drying. This is called *air shrinkage or dry shrinkage.* Some bodies will shrink more on drying than others—the shrinkage depending on the amount of water that was used in working up the clay and the amount that was evaporated in drying.

All clays contain two kinds of water; namely, hydroscopic water and chemically combined water.

After the molded articles are dried they still contain moisture, although they feel bone dry. This moisture is driven off in the kiln. Some clays dry faster than others. As a rule the finer and more plastic clay gives off moisture more slowly and therefore has to be dried very carefully. The addition of " grog " or sand will open the clay so that the water can pass through the capillary channels to the surface more freely and thus dry more rapidly.

The clay or mixture should always be carefully tested out as to how quickly it may be dried.

In the dry or semi-dry process the brick or other articles are placed in the kiln immediately after being molded. But this does not preclude the necessity of care in drying. The only difference is that the articles made by the *plastic* method have to be placed in a specially designed dryer; while in the dry or semi-dry methods the articles are dried in the kiln.

The best results by the *press* method are obtained with the semi-dry process. The clay or body mixture should be wet just enough for the particles to stick together when pressed by hand. Successful operation is secured by leaving the clay after it is mixed with water to rest for twenty-four to forty-eight hours before pressing. This will give a uniformly moistened mass and entirely eliminate lamination troubles.

The difference between the articles made by the "plastic" method and those made by the "semi-dry" method is that all articles made by the plastic method have a *cohesive* structure, whereas those made by the semi-dry process have an *adhesive* structure. The explanation follows:

In the plastic process, the great amount of water added to bring the clay to its working consistency dissolves some of the fine mineral particles of the clay and forms a slurry-like mass which surrounds the coarser particles. When the article is burnt in the kiln, this slurry-like mass fuses and forms a magmatic solution which binds all the coarser grains in a hard dense body.

In the semi-dry process, not enough water has been added to form this slurry-like mass, but the grains have been forced together with the powerful pressure of the press and are held together principally by the interlocking of the grains and by the little colloid material present in the clay.

In the dry process where no water is added at all, the fine particles of dust are forced between the coarser grains and are held together by their interlocking only.

Lamination troubles must be guarded against in all of these methods. In the dry process the inlocked air is more difficult to overcome than in either the plastic or the semi-dry method. When the semi-dry method is carefully conducted, it gives no trouble and a first-class product may be obtained. Very plastic clay is not suited to the dry or the semi-dry process. Material that is not very plastic is not suited to the plastic method, but will give better results with the dry or semi-dry process. Ceramic engineers should make numerous tests before deciding on the process to be used with the material at hand.

Burning.—After the articles have been dried sufficiently, they are placed in the kiln for burning. In setting saggers, bricks, etc., in the kiln sufficient space must be left for the free passage of the smoke and flames among the articles. Only practical experience can teach one how to set and support the articles in the kiln so that there may be a good draught and an even distribution of heat to all parts of the kiln. As a rule, half an inch or the thickness of a finger is ample space to leave between the articles.

Special care sould be taken in placing wet articles, especially brick, in a kiln, as not all brick can be set flat for flashing purposes. Brick made from a short or very fine plastic clay will crack, especially when pressed.

After the burning and the articles are being removed, those who set the articles in the kiln should note carefully the results of the burning and thus be able to place the articles in the next kiln so as to get a greater number of perfect articles out of it. Articles that were not sufficiently burned should be set more openly; and more closely if burned too much.

When the kiln is all charged and ready for firing, everything should be carefully inspected before starting the fire. Be sure that all flues, grate bars, and dampers are as they should be and that there is no leakage. The kiln should be provided with draught gage, pyrometer cones, and trial pieces.

The burning is generally divided into three stages known as dehydration, oxidation, and vitrification. During the first stage the heat must be raised very slowly. This is the stage when the moisture is driven out of articles and the temperature should not be raised much above 100° C. (212° F.) until all this moisture is driven off. Otherwise the surface pores will be closed and when the articles are heated still more, the inlocked moisture will turn to steam and burst the articles. This stage, sometimes known as "water smoking," may require from forty-eight to ninety-six hours. The heat should not be raised above 125° C. until the burner in charge is sure that no more moisture is present in the kiln. This may be determined in two ways. Firstly, by the appearance of the smoke issuing from the smoke stalk; and secondly, by placing a dry iron rod in the kiln and leaving it there for a short time. The rod remaining dry is an indication that there is no moisture in the kiln. This ends the first stage or the dehydration. The heat may now be raised but slowly so as to avoid cracking the goods. The thicker the articles, the more slowly should the heat be increased. After the temperature reaches 400° C. the heat may be increased more rapidly provided the material is free from sulphur, especially pyrites.

When pyrites is present, and a temperature of 500° C. has been reached, the temperature should not be increased until the pyrites has been broken up. The equation for the reaction is as follows: $FeS_2 = FeS + S$. FeS is known as black iron sulphide and will not give up the rest of the sulphur until a temperature of 800° C. to 1000° C. is reached, and then only in a good oxidizing atmosphere. When this atom of sulphur is not driven off it will melt with the iron to form a black slag.

After the iron pyrites has been reduced to black iron sulphide, the temperature of the kiln should be raised to 800° C. and held at this temperature until oxidation (the second stage of the burning) is completed. At this point the carbonates are converted into oxides as shown by the following equations:

$$CaCO_3 \text{ (heated)} = CaO + CO_2;$$

$$MgCo_3 \text{ (heated)} = MgO + CO_2, \text{ etc.}$$

The lower oxides are oxidized to high oxides:

$$4FeO + O_2 = 2Fe_2O_3.$$

Also, all the carbon from the carbonaceous compounds is driven off as CO_2. Therefore an abundance of air should be admitted to the kiln during this stage of the burning so as to supply the oxygen necessary for the oxidation of these substances. It is during this and the following period that the clay mixtures undergo most of their chemical and physical changes.

Before the heat is raised further, a trial piece should be taken from the kiln and carefully examined to see if all the carbon has been driven off. If the trial piece is found to have a black core when broken the oxidation is not complete. The heating should be continued at a temperature of 800° C. to 850° C., until a trial piece when broken has no black coloration but is uniform in color all the way through.

When this is accomplished, the heat can be raised to 900° C. to 950° C. so as to drive off the second atom of sulphur. This is shown by watching the blue color of the smoke from the smokestack, which is an evidence that sulphur is still present. The burner must be sure that oxidation is complete before increasing the heat any further. Should the next stage be attempted before oxidation is complete, the ware will be blown, cracked and worthless. This may result either from heating too short a time at the oxidizing temperature or from an insufficient supply of oxygen furnished to the wares.

The last stage is known as vitrification. The word vitrification means the act of changing by heat or fusion into glass or a glassy substance. This is done by raising the temperature to a point which has been determined by experiment with the materials used.

The fine mineral particles and the silicates which have the lowest fusing point naturally will fuse first, and the other materials in the order of their fusing points until the required result is obtained.

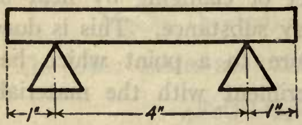
This vitrification process should be well understood. It is very interesting to consider the action which takes place between the alkaline earth and the metals and the oxides of silica, aluminium, and iron during the vitrification period.

In the manufacture of vitrified ware, it is very essential that the limit of the burning of the clay or mixture be known definitely. It is necessary to determine at what point the clay or body mix will collapse. The degree of heat or the number of the cone of the fusing point and the deformation point must be determined by experiment.

The best method of testing for the range between sound vitrification and deformation is to make from the mixture under investigation bars 12 mm. (½ inch) square and 15 cm. (6 inches) long. The material before being made into bars should be tested with the sieve to determine the proportions of fine and coarse grains. Bars should be made of different proportions so that the best proportion may be determined by the test.

These bars should be placed on two wedge-shaped blocks made from good refractory clay 4 cm. high as shown in the following diagram.

Set different cones near the bar and watch carefully for the temperature or cone at which the bar begins to sag, thus indicating that the mineral particles of the clay have commenced to soften.



If the bar should sag only 1 cm. in an interval of 4 to 5 cones from the cone where the sagging commenced, the clay can be burned to sound vitrification without any danger. Should the bar break, it is an indication of a short or sandy clay, although coarse-grained clay may sometimes break.

If the bar sags not more than 1 cm. in an interval of six or seven cones from the cone where the sagging started, the clay will stand vitrification. When the bar bends about 3 cm. in an interval of one or two cones, the clay will not stand vitrification.

If the bar stood the above test satisfactorily, a few balls about 4 cm. in diameter should be made and burned hard, dense, and then well annealed. After the ball has become cold, it should be dropped a number of times from a height of 75 cm. to a hard floor. If the ball bounces back without breaking, the articles will not be brittle when burned to vitrification.

All tests should be recorded so that no mistakes may result from faulty memory of what were the proportions used to get the best results.

It is well known to ceramists that the greater the proportion of undissolved material present in the clay or the mixture, the longer will the material resist deformation. Therefore, it is essential to learn how to correlate the material in such molecular proportions as to preserve the form of the molded articles when under the high heat in the kiln, and to keep the temperatures far apart between sound vitrification and deformation.

Many minerals present in the clay mixture contain occult gases which are given off only at a high temperature. When the heat is raised to complete vitrification, the articles are dense and hard; but if the temperature is further raised and the coarse grains begin to soften, then the clay warps, sags, blisters, becomes honeycombed and worthless.

The foregoing tests should be applied to the dry and semi-dry processes. The articles made by these processes have to be burned to a higher temperature and then obtain only a sintering between the mineral particles without a glassy bond. For this reason articles made by either the dry or semi-dry process are seldom vitrified.

After the vitrification has been completed and the firing has ceased, the cooling process begins. It is very essential that the cooling be under as good control as the firing. This is especially true in the manufacture of porcelain, terra cotta, stoneware bricks, glass, etc. The ceramist must know at what stage the cooling may be rapid, at what stage it must be slow and how slow. Too slow cooling will cause too great a crystallization of the magma or molten material. Therefore, the cooling can proceed very rapidly until the temperature has fallen to red heat, at which temperature the fusing temperature of the eutectic has been reached. From that stage, the cooling must proceed slowly especially when the body is high in silica. Most clays or body mixtures can be cooled rapidly from 800° C. to 600° C. From then on precautions should be taken to avoid too rapid cooling or the ware will be brittle and liable to crack.

This slow cooling or *annealing* process permits the silicates in the molten glass and vitrified bodies to settle and arrange themselves in an orderly manner, and thus avoid molecular strain. This annealing is of the highest importance, although it is not well understood and too little attention is paid to it by many manufacturers.

The importance of this annealing process is exemplified in the case of glass tiles on sidewalks. Many of these have become broken or even disintegrated into powder. The reason for this arises from the method of manufacture. The glass in the molten state was poured into steel molds and pressed. In this way the glass cooled quickly and the molecules of the outside solidified instantly which prevented the orderly arrangement and uniting of the molecules of the interior of the glass, thus producing internal stress. The glass is in a state of continual strain and is prevented from breaking only by the intense rigidity of the external walls. If this hard surface of the glass is damaged, the tile breaks into pieces and the interior crumbles to powder.

Vitrified ware does not crumble to powder but invisible cracks will occur which can be determined only by knocking or hitting with an iron. Careful cooling gives a sound product. Every precaution should be taken to secure a perfect ware.

GLAZES

Glazes are compounds of silicates consisting of a mixture of silica, bases, and metallic oxides. Silica is the acid part, which is mixed with the basic materials that will fuse to a glass when heated.

In mixing glazes it is very important to know how to compound one that will have the same coefficient of expansion and contraction as that of the body to be glazed. Otherwise the result will be a defective product.

It is more difficult to mix a glaze for a porous body than for a vitrified body or for iron. A porous body will expand more when heated and contract more when cooled than a vitrified body. If the glaze does not contract as much on cooling as the body, the glaze will scale or "*shiver*." If it contracts more than the body it will crack or *craze* as it is called. Both result in an unsatisfactory product.

To adjust the glaze to the body to be glazed, repeated tests must be made. New tests must be made every time a change is made in the formula for the body or the glaze. With every change in composition there is a change in the coefficient of expansion and contraction.

The following facts will help in adjusting the glaze to the new product. The addition of silica, silicious clay, or grog to the *body* material will increase the coefficient of expansion. The coefficient of expansion of the *glaze* should be increased by the addition of silica or boric acid.

The addition of lime or alkali to the body material can be offset or remedied by the addition of lime, lead, or alkali to the glaze. The addition of boric acid, silica, and lime also increase the fusibility of the glaze.

Crazing can also be prevented by grinding the silica finer. *Scaling* can be prevented by grinding coarser. The addition of certain metallic oxides for coloring the glaze sometimes cause crazing.

To adjust a glaze to a given body mixture, a systematic study should be made by firing to different cone temperatures. If the pieces are fired insufficiently, the glaze will scale; if heated too high it will scale. Between the two may be found good specimens on which the glaze is thoroughly vitrified and the agreement between the body and the glaze is satisfactory. These specimens give the information desired as to the temperature necessary for good results.*

From the above it will be seen that it is impossible to give a receipt for a universally satisfactory glaze.

* See E. Bourry, " A Treatise on Ceramic Industries."

Each manufacturer must work out his own mixture according to the foregoing principles.

Engobe is a fusible mixture, not as fusible as glass or enamel. It consists of clay, feldspar, and silica and is usually opaque.

Enamel is a more fusible mixture then engobe. It is a fused glass of calx, feldspar, silica, together with basic materials as lime, etc., and metallic oxides. It also contains tin, zinc, alumina, calcium phosphates, etc., to destroy the transparency and make the mixture opaque.

(N.B.—Bodies, engobes, glazes and enamels should be mixed in quantities sufficiently large to last one or more weeks.)

Transparent glazes are mixtures of clay, feldspar, silica, calcium, lead, boric acid, etc., and must be ground very fine. The addition of lead and boric acid increases the brilliancy of the glass.

The purpose of glazing may be for decoration, or as a preventive of disintegration, or for the purpose of rendering porous bodies impervious to liquids or acids.

The glaze is applied as a very thin coat on the surface of the ware by spraying or dipping, and must possess the property of flowing evenly when fused.

Some manufacturers burn the body and glass in one operation—that is, the glass is applied on the ware when still green. But others burn the body first, then apply the engobe and glaze, and burn again.

FRITTING

Oftentimes there is a general advantage in *fritting* the glaze. The silica and bases fuse so that the base is not volatilized in the furnace, and at the same time rendering the soluble material insoluble.

The raw materials are ground very fine, thoroughly mixed, placed in a crucible, and the crucible and contents placed in a specially designed fritting oven. The heat is raised until the contents of the crucible fuse and runs through a hole in the bottom of the crucible into a pan of water.

The water shatters the vitreous material and makes it more easily ground. This "fritted" glaze may be applied alone or it may be mixed with raw glass and then applied.

CRYSTALS

Crystals in the glaze are usually produced by cooling very slowly so that the silicates separate from the soluble glass. They may also be produced when the glaze has been applied in a very thick layer.

Crystallization is also promoted by the addition of oxide of zinc or of titanium (rutile). Crystallization seldom occurs if the glaze has been applied in a very thin coat.*

* See "Crystalline Glazes," by R. C. Purdy, and J. F. Kochbiel, University of Illinois, Bulletin 12, Trans. Amercan Ceramic Society, Vols. 6 and 8.

CLAY PRODUCTS

REFRACTORY WARES

REFRACTORY wares are those that possess the property of withstanding a high temperature combined with load and pressure.

The most highly refractory ware is manufactured from fire clay. For high grade refractories the fire clay is mixed with flint clay or bauxite. Silica wares are made from quartz, or quarzite or ganister. Chrome, magnesia, dolomite, carbon, carborundum, corundum, alundum, and zirconium are also used.

Crucibles of refractory ware must not only be able to withstand a high temperature, but they must be able to stand the pressure of their own weight and that of their contents. Fire brick should have been brought to their greatest degree of hardness and must have contracted to their full extent before they are suitable for use in a furnace.

Refractories are divided into 3 classes: acidic, basic. and neutral. Acidic refractories are composed chiefly of silica combined with 1 to 2 per cent of lime, or 5 to 10 per cent of good plastic clay. If clay is used, it must be selected with great care. The writer at one time tested a mixture of 15 per cent of plastic fire clay with 85 per cent quartz. The colloid of the clay had contracted too much for the expansion of the quartz which resulted in a brick of loose and open structure. On reheating, the silica expanded further while the clay contracted, making the brick absolutely worthless.

This difference in behavior of the clay and quartz in ceramic bodies is responsible for many of the troubles in the industry.

The best acidic refractories (silica brick) are made by mixing silica and lime. To be successful this must be done carefully. The silica grains should be angular and mixed with milk of lime. In this way every grain will be covered with a thin coating of the lime. When this is heated, the lime and the fine silica will combine, forming a net-like bond which cements together the coarser grains. This bond is readily seen with a microscope. The best silica brick are made by heating to cone No. 20, as at this temperature the greater part of the silica has been transformed to tridymite and crystoballite.*

The author made some experiments with sand-lime bricks to determine their refractory qualities. In all sixteen tests were made from four different sand mixtures containing 6, 8, 10, and 12 per cent of lime. In some mixtures the sand, calcined lime, and water were mixed and left to stand overnight; in the other mixtures, the lime was first slaked with the water then mixed with sand and water, and afterwards pressed and steam cured. To these mixtures feldspar or finely ground granite was added. The feldspar and granite were mixed with lime and water before being added to the sand-lime mixture. These mixtures were next made into brick by the power press and then exposed to steam of 100, 125, and 150 pounds for eight, ten, and twelve hours.

The brick were burned in a little test kiln holding

* See "Study of the Silica Refractory," by J. Spotts McDowell, American Institute of Mining Engineers, November, 1916.

about 400 bricks. The brick were burned for seventy-two hours and allowed to cool for seventy-two hours. Trial pieces were drawn at 200, 300, 400, 500, 700, 800, 900, 1000 and 1200° C., and when cone No. 11 was fused down flat.

The first trial piece, drawn at 200° C., showed the beginning of disintegration of the bond. At 400 and 500° the bond was practically destroyed. All the trial pieces drawn up to 1000° C. were very soft and crumbled on exposure to the air. At 1200°, the trial piece showed some surface fusion; and at cone No. 11 the brick were seriously deformed. This test showed that the lime was affected and its binding power destroyed by the early firing.

After the kiln had been allowed to cool down to the temperature of the room and opened, all the brick were found cracked and worthless. Some were only slightly imperfect, but many were soft and crumbled. The brick had been badly affected by the moisture, gases and acids.

While all the brick were worthless in the end, there was quite a difference in the behavior in those containing feldspar and the ones containing granite. Those containing 10 to 25 per cent of feldspar softened during the steam curing, but behaved better in the burning. The trouble was that the fusion and deformation temperatures were so near together that it was impossible to control the result.

The brick in which granite was used instead of feldspar behaved better in both the curing and the burning but still the brick were a failure.

Mixtures which contained from 10 to 16 per cent of alumina (Al_2O_3) were soft when they came out of the steam curing cylinder, but behaved very well in the burning. Some of these brick were glazed, placed in sagger and burned to cone No. 11. They came out in good shape, the glaze covered the brick evenly and smoothly, had not been absorbed by the body at all, had a nice gloss free from all defects, and the shape was well preserved.

Brick made from a clean sand which was 97 per cent silica (SiO_2) mixed with 10 per cent of lime rang like steel when struck with iron after being cured for twelve hours under a pressure of 125 pounds of steam. But on heating, the cementing power of the lime was destroyed and the brick cracked as in the other samples.

A few brick were also made with pure sand, lime, and asbestos (serpentine). In this mixture the quality and hardness were an improvement over that in which feldspar, granite, or alumina were used.

All acid refractory ware has the power of combining at a high heat with basic oxides. Nearly all fire clay is acidic. So it is necessary in the manufacture of silica refractories to try out the silica grains as to their structure, their purity, and their behavior when heated. All materials and mixtures must be thoroughly tested.

NEUTRAL REFRACTORIES

Neutral refractories are those that resist the action of basic and acidic substances. *Chrome* brick are used to form a neutral line between magnesite and fire clay bricks in the basic open-hearth steel furnace and in other furnaces. The chrome brick is the most economical brick to use for this purpose, although a mixture of fire clay and bauxite brick or a silica brick may be used.

Chrome brick is valuable in metallurgy especially for repairing furnaces at a working heat as it is not affected by sudden changes in temperature. Like magnesite, it stands a high temperature but will not withstand a heavy load.

But in the industries, fire clay brick are most commonly used. As the fire clay is expected to stand a high temperature, it is important that it should be free from impurities that are easily fused. It should be kept in mind that clay is a mixture of complex silicates, each one of which has a different chemical and physical behavior when heated. Some may have a tendency to promote a certain physical or chemical change while others to hinder the change. Some clays that have almost the same chemical composition, set very different when heated. When fire clay is heated some of the flux may begin to melt at 1000° C. and will attack some of the refractory particles. Some of this fluxing action is necessary to bind the brick together; but if too much flux is present, it will lower the refractory properties of the brick and cause it to deteriorate more rapidly under the influence of the flue ash, vapors, slags, etc., of the furnace.

Only one experienced with refractory ware should be employed to make the necessary tests for the manufacturer Too many add grog or quartz to the clay without testing the properties of the grog or quartz. If the grog is not fired higher than the bond clay of the refractory, the strength or load carrying capacity is not improved at all. Nor will the refractory quality of the ware be improved by the addition of grog of the same clay as is used for binder. The grog will serve only to promote the drying, at the same time opening, the body and thus controlling the shrinkage during drying and burning, but not increasing the refractory qualities. If highly calcined flint clay, bauxite, or high fire clay are used as grog the fire and slag resistance qualities are greatly increased. If the grains are properly bound with a highly plastic fire clay and burned hard at a high temperature, the body will have a very small contraction.

The author has used old silica brick free from injurious material as a grog with good results. Practically all the silica was converted into tridymite and crystoballite. Care must be taken in using old silica bricks as a grog, that they do not contain fluxes which will lower the fusing point of the refractory.

Refractories containing coarse grains will resist sudden changes of temperature, but are more rapidly disintegrated by the action of fumes, gases, ashes, vapors, flue dust, cinders, etc. Finer grained bodies will the better resist abrasion, slags, fumes, gases, etc., of the furnace.

Chemical analysis will give better guidance in the selection of the raw materials by the ceramic engineer than any other method. The methods of calculation as for instance the calculation of the "refractory quotient," etc., are for the most part misleading. Also, what is known as the "rational analysis" is seriously in error and should not be used at all. This "rational analysis" is a laborious process and the results are not dependable. We frequently notice in the report of an analysis by this method where sulphuric acid is used, the term *free silica* is mentioned. When the sulphuric acid is applied, mica, feldspar, hornblende, augite, and other rock or mineral debris present in the clay are also attacked, and the same is just as much combined as the silica in the kaolin.

Ceramic engineers should not overlook the kind of mortar that is o be used in the laying of the fire brick. The material of this mortar is just as important as the material of the brick. The mortar for laying silica bricks should be high in silica and very low in alumina and other impurities such as iron and alkalies. Fire bricks should be laid with the same material as that of which the bricks are made; or a mixture of the brick finely ground (1 : 1) may be added to the mortar so as to balance the contraction between the brick and the mortar.

In the building of furnaces the ceramic engineer must select the materials suitable to the kind of furnace to be installed. An unsuitable mortar will give way and leave crevices where the destructive agents will find lodging and, acting as a flux, will fuse cavities in the brick which will weaken the whole structure. The mortar for silica bricks should not contain more than 10 per cent of alumina or it will act as a flux and slag the brick.

The analysis of the clay as suggested in this book will be of assistance to the ceramic engineer in giving him an idea of the proportions of the materials such as feldspar in the clay. But this, as has already been said, is not the only guide to be used. Chemical and microscopic analyses will give many important points. But the physical and mechanical test is the only reliable one. The chemical test is the forerunner in the investigation of the raw material and will tell the purity of the material. The microscope will tell of the mineral constituents, and the shape of the grains. Then the material is prepared and burned at different temperatures; holes are drilled in the samples before and after burning, filled with finely powdered slags of different kinds and burned against a high temperature so as to fuse the slag; after which the samples are allowed to cool and then examined to determine how far the slag penetrated into the body of the refractory samples. These tests give the reliable data as to the uses that may be made of the material tested.

In order for the ceramic engineer to give satisfactory information, he must know the kind of furnace in which the refractory is to be used and also in what part of the furnace. For some refractory ware will stand up in one furnace under one set of conditions and fail in another under other conditions.

Refractory wares are also made from the oxides of the rare metals zirconium, thorium, yttrium and beryllium. Among these zirconium has been most developed. It has a very high melting point and resists all acid and basic slags. It is recorded that the lining of a hearth of a Siemens-Martin furnace in a steel works at Renscheid, Germany, after four months of continuous service at a high temperature was apparently in a condition good enough to last another four months. Its heat conductivity is low, it has a small coefficient of expansion, and for these reasons makes a superior lining for an electric furnace of the arc type.*

Zirconium is widely distributed but usually in small quantities chiefly in the form of zirconium silicate $ZrSiO_4$. Zirconia, the oxide of zirconium is commonly used. It is obtained mostly from baddeleyite, which

* This is the same metal that is used in the filaments of Nernst, Sanders and Ternig electric lamps.

was discovered in Southern Brazil in 1892 by Hussak and is composed of from 80 to 94 per cent of zirconia.

In Germany several patents have been taken out for the use of zirconia in refractory ware and for other purposes. It is mixed with clay, alumina, thoria, yttria, and beryllium. The raw zirconia when fired to 1800° to 1850° C. gives a dense mass, and the silica which was present as a binding material is volatilized. Zirconium is also used in glass and glazes. Siloxide is a zircon product resembling opaque quartz glass.

It is very interesting to note the changes which take place in refractory bricks when re-heated several times. The writer read a paper in 1917 at the Exposition of National Chemical Industry at New York on refractories and showed the following analyses of refractories on heating and the action of slag.

The following test was made of fire brick shipped to the Malinite Co. Analyses were made of the raw clay from which the brick was made and also of the brick. The analyses were made of the same kind of brick after being heated ten times and one analysis was made of the brick after two years of use in the fire box of our own kiln. On inspection it showed that the raw clay and brick contained flint clay. The results of the four analyses are given on the following page.

The analyses show that when fire bricks are subjected to prolonged heating at high temperatures they lose some of the alkalies by volatilization, which indicates a source of weakening the structure. On the other hand when bricks are subjected to slag, as for instance in furnaces, they will gradually melt away, especially when porous and when the content of free silica is high.

The fourth analysis shows how the brick increased in iron and alkalies. The brick weighed 6 pounds when placed in the fire box, after two years it weighed 4.9 pounds, a loss of nearly 25 per cent.

	Raw Clay.	Brick.	Brick after being H ated Ten Times.	Brick after Two Years' Use.
SiO_2	48.26	54.94	55.36	51.38
Al_2O_3	33.59	38.37	38.75	31.69
Fe_2O_3	2.22	2.48	2.42	6.74
CaO	.54	.59	.52	3.01
MgO	.57	.63	.59	3.18
Alk.	.92	.97	.54	1.74
TiO_2	1.92	2.00	1.82	1.75
SO_3	.19	.04	....	.81
H_2O	11.76			
	100.00	100.00	100.00	100.00

ANALYSES OF COAL ASH

	Lincoln, Ill., Coal Ash. Per Cent.	Franklin Co., Ill., Coal Ash. Per Cent.
SiO_2	41.40	54.30
Al_2O_3	13.82	21.40
Fe_2O_3	14.78	3.25
CaO	13.70	5.20
MgO	2.14	1.96
Alkalies	2.40	3.16
TiO_2	0.60	3.15
SO_3	0.87	0.00
CO_2	5.34	2.67
Moisture	4.80	4.80
Loss on ignition	0.15	0.11

The preceding two samples of coal ash analysis, made by the author, will show why some cinders or slag attack the refractory material more than others.

BASIC REFRACTORIES

Basic refractories resist the action of metallic oxides; but are attacked by silica at a high temperature. The materials for basic refractories are magnesite, dolomite, and limestone. Magnesite is most commonly used both for electric furnaces and all others where a basic refractory is required. For research work magnesite bricks are very valuable owing to their great resistance to high temperatures. But their use in the industries is limited because of their tendency to spall or chip when subjected to sudden changes of temperature, and their liability to fail suddenly at a high temperature when under pressure.

Magnesite bricks are manufactured by calcining the raw material at a white heat, crushing this when cool and then adding magnesite calcined at a low temperature to serve as a binder, and then water. This material is then mixed and molded into bricks by hand or machine. Usually the bricks are molded under high pressure, dried, and burned at a very high heat to convert the greatest part to periclase.

The calcined magnesite may also be mixed with surface clay, or magnesium chloride, or sodium silicate, and with iron solution or iron scale or iron powder. The surface clay when used should be of the right proportions of silica, iron, etc.

Furnace bot'oms are usually made of calcined magnesite mixed with iron ore, basic steel slag, and hot boiled tar.

Dolomite is also used in making basic refractories. First the dolomite is calcined (dead burned) at a high heat, mixed with tar, and again burned at a high temperature. The calcium combines more or less with the magnesia which prevents the slaking or carbonizing of the lime. Limestone itself has great refractory properties and does not fuse or soften except in an electric furnace.

GRAPHITE REFRACTORIES

Graphite refractories are usually in the form of crucibles. Native graphite contains from 1 to 48 per cent of alumina. As graphite is unctuous (like grease or oil), it has no binding properties and must be mixed with a very plastic fire clay which has a high drying and heat shrinkage.

The clay used to mix with the graphite formerly came from Klingenberg, Germany. From 25 to 75 per cent of clay is mixed dry with the graphite. To this mixture, quartz (free from dust), grog, or asbestos with short fibers (serpentine) is added in different proportions according to the purpose for which the crucible is to be used. The materials are then wet and pressed, or shaped on the jolley.

ANALYSES OF VARIOUS CRUCIBLES *

SiO_2	51.40	45.10	50.00
Al_2O_3	22.00	16.65	20.00
Fe_2O_3	3.50	0.95	1.50
Graphite	20.00	34.00	25.50
CaO	0.20		
Water	1.80	2.50	3.00
	98.90	99.20	100.00

* Handbuch der gesammten Thonwarenindustrie," E. Cramer, Bruno Kerl and Dr. H. Hecht.

In the United States much artificial graphite is made from anthracite coal by means of the electric furnace. The use of none but imported clay was not necessary. By actual experiment the author got good results by the use of a mixture of Kentucky ball clay and Georgia kaolin. There are many good clays which can be synthesized to produce the same results as those obtained with the Klingenberg clay.

RECENTLY MADE ANALYSES

	Grossalmeroder (Hesse).		Reinischer.	Düsseldorfer.
SiO_2	25.91	27.22	33.44	34.03
Al_2O_3	11.26	7.03	....	
Fe_2O_3	0.48	0.51	15.70	12.95
CaO and MgO	and Tr	Tr		
Graphite	58.24	62.54	48.15	50.18
Water	2.77	2.42	0.77	1.63
	97.66	99.72	98.06	98.79

	German Crucible Used 18 Times.	Londoner (Morgan).	English.	American.
SiO_2	32.67	37.09	31.40	31.31
Al_2O_3	11.52	....	19.57	
Fe_2O_3	2.79	14.58	1.78	17.30
CaO and MgO	....	....	0.30CaO 0.80 MgO	
Graphite	48.68	44.40	42.08	47.40
Water	1.50	2.92	1.20	3.42
	97.16	98.99	97.13	99.43

CHEMICAL STONEWARE

The manufacture of chemical stoneware is an industry of considerable proportions and importance. Skilled workmen are required to make the many shapes, some of which are quite difficult. Then there must be the ceramic engineer to select the raw materials so as to produce a satisfactory ware. When finished the ware must resist the action of all acids and bases whether hot or cold—except hydrofluoric acid. It must not break under sudden changes of temperature. It must not absorb moisture.

It is usually the practice in making chemical stoneware to mix different clays so as to produce a body mixture similar in character to porcelain. So stoneware clays which contain enough flux to produce a very close structure at a high temperature are commonly used.

If stoneware clay is not at hand, a low grade of fire clay can be substituted. The fire clay is burned to a temperature of from 1400 to 1500° C., at which temperature the iron content of the clay will act as a flux. Or the fire clay can be mixed with an impure clay of low fusing point, in which case the fire clay acts as a skeleton to preserve the shape of the body, while the impure clay serves as the flux which at a high temperature binds the particles of the fire clay into an impervious body. Lime or furnace slags or other cheap fluxes can be used where the color is of no importance.

In the manufacture of chemical stoneware it is essential to produce a uniform body. The best results are obtained by plunging all the material and then screening so as to remove all the coarse particles. The surplus water is then removed by the filter press. Sometimes only the fusible clay is plunged, but it is better to plunge all the material.

It is especially necessary to remove all the coarse particles if tightly fitting taps are required. The spigots and faucets are usually made from the same materials as the body. Sometimes the materials are ground finer for the spigot and faucet than for the body. The spigot and faucet are ground with sand or emery and water, so as to make them tight fitting.

The body mixture should be high in silica and yet plastic enough to permit the shaping of large pipes and vessels such as stills, condensers, acid containers, etc. The interval between vitrification and deformation should be between 200 and 300° C.

SEWER PIPES

Sewer pipes are manufactured from stoneware clay, shale, or a mixture of fire clay and surface clay in such proportions as experiment has determined to be best. Sometimes, sand or grog is added to hasten drying and to control the shrinkage.

The clay is ground and thoroughly mixed, after which water is added and the clay tempered. Then the clay is pressed into the molds which give it its shape. The material must be plastic enough to retain its shape when released from the mold and strong enough to withstand rough handling.

After the pipes leave the press they may be trimmed and joined together so as to form elbows or junctions. When dry the pipes are placed in the kiln for burning. They are placed upright with the smaller pipes inside the larger to a height of 12 to 16 feet, and so arranged that the hot gases can circulate freely around and inside the pipes to insure an even distribution of the heat

Great care must be exercised at the beginning of firing. Air spaces are often produced in the material when fed into the pipe molds in balls as large as a man's fist or larger, which prevent all of the air from escaping as the pressure is applied. The walls of the pipe will then contain "air pockets" even after it is dried. When the heat in the kiln rises, the entrapped air expands and at a temperature of 600° C. or higher may force large pieces from the pipe, causing noises like small explosions.

To prevent "slabbing" it is essential that great care be used in the preparation of the raw material from the pit or mine to the factory. It is important that the mixture should be as uniform and homogenic as possible. Weathered clay should be used if possible. Imperfect mixing or unevenly watered and tempered clay will cause slabbing and cracking. Some of the clay being too wet or too dry will cause slabbing or longitudinal cracks in drying and as the pipe comes from the kiln. Slabbing may be caused by the presence of organic matter or sulphides in the material, but the above causes are the usual ones.

Pipes that are broken before being burned should never be returned to the mixer or press before being pugged or retempered.

When the pipes are drying and being placed in the kiln, they should be watched for signs of "air pockets" in the walls. When noticed, the blisters or air pockets should be punctured with a needle so that the entrapped air may escape. Pressing down the spots with a wet sponge after puncturing the blister will also help.

Salt glazing is usually applied just a few hours before it is time to close the kiln. Before throwing in the salt, the fire boxes should be cleaned out so as to have a clean hot fire. Then about three shovelfuls of common salt ($NaCl$) is thrown into each fire box. The chlorine is liberated by the intense heat and the sodium combines with the silica, forming on the surface of the pipes a sodium silicate glaze. Trial pieces should be drawn out to see if the glaze is uniform and sufficient.

CASTING

By *casting* is meant the molding of articles by filling a dry plaster mold with a liquid body, known as *slip*, and allowing it to stand until a coating of the required thickness is deposited on the inside of the plaster mold. The time required to obtain a cast of the required thickness must be determined by trial, and depends on the desired thickness of the wall of the cast and the absorbing qualities of the walls of the mold. The mold should be dried as frequently as found necessary.

The best results are obtained by placing the mold in a hermetically sealed box to which a vacuum can be applied. This hastens the absorption by the plaster mold and is especially valuable when a thick cast is desired. The surplus body slip can be removed, after the required thickness has been obtained, through the opening by which it was poured in or through a lower opening which had up to this time been kept closed.

The " cast " is then left in the mold until it becomes hard enough to be handled. By this method, when all others would be unsuitable, it is possible to make the most difficult pieces with thin or thick walls as desired.

The body slip has to be "lean." No plastic body can be used, as it would form an impermeable coating which would stick to the walls of the mold and prevent absorption. The cast would not shrink away from the mold and therefore crack on removal.

Body slip should contain as little water (never exceeding 30 per cent) as is absolutely necessary to bring the material to a working consistency. In order to produce the proper liquefaction without the addition of too much water, carbonates or hydroxides of sodium, potassium, or lithium together with sod um silicate (water glass) is used. The present practice is to use sodium hydroxide or sodium carbonate with the sodium silicate.

Frank H. Riddle has shown that a body mixture of 22.6 parts of water and 77.4 parts of dry body to which .266 per cent of mixture of equal parts of sodium carbonate and sodium silicate were added will give satisfactory results.*

Simons (Sprechsaal, 1905, No. 31) recommends the following method for the determination of the liquefaction of the body slip with the addition of soda:

In each of six 300 c.c. flasks, 50 gm. of the dry body should be placed. In flask No. 1, 50 c.c. of water is added; in flask No. 2, 49 c.c. of water and 1 c.c. of the sodium solution (5 gms. calcined soda in 1000 c.c. of water) in flask No. 3, 45 c.c. of water and 5 c.c. of the soda solution. The solutions should be shaken vigorously and the results of the liquefaction noticed

* Bureau of Standards, Technologic Paper No. 51.

carefully. The result in No. 3 should be about right. But little variation from this proportion will be found necessary, and can usually be determined by one or two more trials. Generally the 5 gms. of calcined soda in 1000 c.c. of water give good results.

The specific gravity method of determining the proper solution to be added to the dry body is considered the best. The slip should weigh 36 ounces to the pint.

When casting refractory bodies or other bodies containing grog or other coarse material, the slip must be adjusted to hold the coarse particles in suspension. Otherwise the coarse particles will settle to the bottom and spoil the cast.

SOME DEFECTS AND THEIR REMEDIES

Absorption or Blinding of the Glaze. This is usually caused by the body of the ware being too porous, or the glass too dilute or not enough of it is applied. The trouble may also be caused by heating the goods too long. The cause of the trouble and the remedy can be easily determined by the systematic use of trial pieces. The body and the glaze should be mixed so as to mature at the same time.

Blisters or Blebs. These result from many causes. The body mixture may not be properly prepared as by insufficient pugging, careless mixing, some parts of the body being too wet while others are too dry. They may be caused by the evolution of gas from the organic matter or the sulphates or the sulphides contained in the clay when the goods are placed in the kiln without being sufficiently dry. Again they may be caused by improper firing as when reduction takes place at 800° C. A very plastic clay is more liable to this fault than a lean or short clay. Short clay does not cause this trouble, but will crack and crumble to pieces if overfired.

In the manufacture of pipes, the faulty design of the mold may cause this trouble; or the clay may not have been fed into the mold uniformly and the lack of sufficient clay may result in the particles not being pressed together tightly enough to drive out all the air. Then when heated in the kiln the air will expand and force out pieces from the sides as explained under the heading of "sewer pipe." Goods that are placed in the kiln too wet may blister, crack, or fall to pieces when heat is applied. These defects can usually be remedied by careful water-smoking, oxidizing, and adding grog to the body mixture.

The author had an experience in the manufacture of sanitary ware in which the grog had been added dry to the bodies. The trouble was not eliminated by pugging and wetting. Good results were obtained only by grinding and wetting the grog on the day before it was to be mixed with body.

Blisters in the glaze may be caused by applying the glaze to a green body from which gas is liberated from the organic matter contained in the body. Or they may be caused by metallic compounds not suitable at the temperature at which the glaze matures, or by overheating or too rapid heating.

Bricks blister as a result of improper heating, especially vitrified brick. (See under heading of *Brick.*)

Brittleness is caused in vitrified ware high in silica by too rapid cooling as a result of which the goods are not properly annealed. Fire bricks become brittle by repeated alternations of heating and cooling or on cooling too slowly through the critical temperature. A dense clay when heated and cooled rapidly becomes brittle.

Cracks are known by names such as dunt cracks, S cracks, etc. Cracks in the ware may be caused by a poorly designed mold box, by the cutting wire, by a high silica content, by dense clays, careless handling or setting in the kiln, improper drying or burning, from pebbles and limestone in the body mixture. Whatever the cause, the trouble can be cured but may add to the expense of production.

The most difficult cracks to cure are those caused by small stones in the clay which are very hard and in some cases impossible to separate. The only cure is to grind the clay very fine, which adds considerably to the cost.

If limestone is present in the clay it must be ground very fine. Limestone also makes the burning of the ware especially difficult if it is to be vitrified, as it brings the fusion point and the deformation points near together. Lime is known as an active flux for the reason that at a high temperature it acts very suddenly on the silica compounds contained in the clay.

Another cause of trouble is the lack of uniformity in the mixture when sand is added to plastic clay. This mixing may be done in the dry pan or other machines, but in any case the results are not altogether satisfactory. The only means of getting a homogenic body is by plunging, but this makes the cost of production too high to be profitable commercially. Too fine clay is also apt to crack in drying and burning.

" S " cracks in wire-cut or stiff-mud bricks are usually caused by a defective mouth piece or by the axle being too close to the mouth piece. In the latter case, the placing of a piece of metal between the mouth piece and the barrel of the auger will usually remedy the difficulty.

Searle states* that if the cracks are open at the edge, too rapid firing at the beginning of the burning may be suspected. If a dunt is produced in cooling, it will show no opening at the edge of the cracks; and when broken, the edge of the crack will be smooth. If the

* The Clay Worker's Hand Book.

crack was in existence before the firing commenced, the fracture will be much rougher.

The author had an experience with some ware that was high in silica. The goods were stored after being burned and three months later on assorting the goods he heard some cracking sounds, but could discover no cracks in any of the ware. But on striking the goods with a piece of metal some of the pieces gave a " dead " sound, showing that there were hidden cracks.

S cracks in bricks made by the dry press method, are due to the high silica content especially when the silica is too fine, or a cold draft is allowed to strike the brick when they have been cooled down to red heat. The bricks will have cracks in the form of the letter " S " extending all the way through them. This trouble is the result of the high silica content and can be remedied by adding more of the plastic material so as to have a larger proportion of clay.

Crazing. The crazing of the glazes on glazed pottery is caused chiefly by a difference in the expansion and contraction of the glaze and the body. Seger, who studied these defects very carefully, has recommended the following remedies:

(*a*) Less of the plastic material in the body of which the goods are made and a large proportion of non-plastic material.

(*b*) Grind the body material finer, especially the silica, or use a coarser glaze.

(*c*) In non-vitrifying bodies increase the proportion of flux; but in vitrified ware such as porcelain use less flux, especially less feldspar.

(*d*) Prolong the heating in the kiln near the finishing point, so as to increase the mobility of the glaze.

(*e*) Increase the proportion of flint in the glass.

(*f*) Replace all or a part of the silica in the glaze by boric acid. (But even if this ware comes out of the kiln without any defects, it is liable to craze sometime later. The author made some ware with a boron glaze which appeared to be all right for six years after it was burned when it suddenly crazed.)

(*g*) Replace some of the alkali of the glaze by a similar substance with a lower molecular weight. Thus, zinc oxide may replace litharge or white lead, or baryta to a small amount; but more than 5 per cent of zinc oxide should never be used for a clear glaze.

Peeling or Scaling. The following remedies for peeling or scaling are suggested:

(*a*) Reduce the proportion of silica in the body, or increase the proportion of plastic clay.

(*b*) Substitute leaner clay for the more plastic one in the body.

(*c*) Increase the proportion of the flux, especially feldspar, in the body.

(*d*) Use coarser materials.

(*e*) Finish the burning at a lower temperature.

(*f*) Increase the fluxes in the glaze or reduce the silica.

(*g*) Replace part of the alkali by lead or baryta, or replace whiting by baryta.

(*h*) Avoid polishing the surface of the green goods too highly.

(*i*) Avoid loose dust or grease on the surface of the goods.

(*j*) See that the clay is of even composition and that it does not contain stones or roots or other material that can shrink unduly in the kiln.

(*k*) If the glaze contains gelatine it must be applied as a solid. If applied in the liquid form, the glaze will peel.

Pinholes. Pinholes are usually due to dust on the surface of the goods on which the glaze is applied or they may be due to a hard glaze.

Scum. After careful investigation by many persons interested in the clay industry both in this country and abroad, the following are given as the causes of scum or efflorescence:

(*a*) Soluble salts in the clay.

(*b*) Condensation on the goods when set in the dryer or the kiln.

(*c*) Storing the goods after burning on ground saturated with salts, as near to an ash or cinder pile.

(*d*) The use of improper water in mixing.

(*e*) The use of improper mortar when building the bricks into the wall.

The following remedies are considered best. First try to remedy by burning. If pyrites (FeS_2) is present in the clay, stop at 600° C. for about ten hours. Variation of time may be determined by experiment. Then raise the heat to the oxidation stage (800° C.), first cleaning out the fire boxes. Supply the fire with sufficient air so that on the inspection of trial pieces no black core is found. Oxidize and reduce alternately three or four times if necessary for sixteen or thirty hours until the oxidation is completed. Then raise the heat to the finishing temperature.

If burning as above does not remedy the trouble, then the addition of barium chloride or barium carbonate to the mixture should be tried. These form insoluble salts with the sulphates or sulphides. But they must be added in the right proportions or they will increase the trouble instead of remedying it.

The correct proportions may be found as follows:

If barium chloride is to be used, take 10 graduated bottles and place in each bottle 100 c.c. of the water to be used in making the ware. As barium chloride is soluble in water, it may be added directly to the water. Put ½ gram of the barium chloride into the first bottle, and 1 gram into the second, 1½ in the third, and so on placing ½ gram more in each successive bottle. The last bottle will therefore receive 5 gm. Weigh out 10 piles of 100 gm. each of the clay mixture. Then in order wet the first pile with the water from the first bottle, the second pile with the water from the second bottle and so on till all is used. Press each pile into brick shape dry and burn. Careful inspection after burning will indicate the right proportions.

If barium carbonate is used, it should be added to the clay in the same proportions as given above for the barium chloride. Then the water should be added, the clay pressed, dried and burned.

If the above tests should indicate that not enough barium chloride or barium carbonate had been used, further tests with larger quantities should be made.

Warped or Crooked ware may be caused by the body mixture being too fine or too plastic; or it may be caused by careless placing in the dryer or the kiln; or by faulty workmanship. The cause is usually evident and the trouble can be easily prevented.

QUALITATIVE ANALYSIS

In order to make determinations of the different constituents present, the specimen of clay, rock, glasses or pottery bodies under examination must first be reduced to a liquid state.

Suppose it is desired to find the ingredients of a glass. The sample is reduced to a fine powder and mixed as follows:

Mix 1 gm. of the finely pulverized sample with 5 gms. of sodium carbonate (Na_2CO_3) and 5 gms. of potassium carbonate (K_2CO_3). Fuse this mixture in a platinum crucible for about ten minutes at a low temperature and then for about twenty minutes at a high temperature until no bubbles occur in the crucible.

After the fused mass in the crucible is cool remove it into a beaker, cover it with distilled water and boil until the fused mass is broken up and crumbles. Add hydrochloric acid (HCl) drop by drop until effervescence. Transfer the liquid to an evaporating dish and evaporate to dryness on a water bath. If dry add about 60 c.c. conc. HCl, and evaporate again. When dry add 100 c.c. 10 per cent HCl then heat on water bath for twenty minutes, filter and wash the precipitate (SiO_2) with hot water until free from chlorine; collect in a small test tube of the washing acidified with HNO_3. It shows a form of cloudiness only when $AgNO_3$ is added and no precipitate is obtained by shaking. Set filtrate aside to be treated for the next group and marked for " Group II."

I. Hydrochloric Acid Group

Place a clean beaker under the funnel, punch a hole in the apex of the filter and with about 50 c.c. hot water wash the precipitate into the beaker. Place on the gauze and heat to boiling while stirring with a glass rod. Filter and wash two or three times with hot water and add to the filtrate H_2SO_4. A white precipitate indicates the presence of Pb. The silicon has to be freed from the lead by washing with hot water, and tested again with H_2SO_4.

After the silica is freed from the lead, about 30 c.c. of NH_4OH is added. If silver is present on the filter it will dissolve and go through the filter.

After NH_4OH is added to the silica on the filter it has to be washed again with about 50 c.c. water and then transferred to the platinum crucible and ignited, heated strongly, moisten with a few drops of dilute H_2SO_4 and about 15 c.c. HF is cautiously added. Evaporate on sand bath to dryness then ignite. The silica is volatilized and a residue of Al_2O_3, Fe_2O_3, and TiO_2 will remain in the crucible if present in the sample.

Silver. If silver is present in the solution it will give the following reactions with the following reagents:

1. Hydrochloric acid (HCl) when added to the solution will give a white precipitate of silver chloride (AgCl), insoluble in hot water or in HNO_3, but readily soluble in NH_4OH.

2. Hydrogen sulphide (H_2S) or ammonium sulphide $(NH_4)_2S$, a black precipitate of silver sulphide (Ag_2S) soluble in HNO_3 with the separation of sulphur. The precipitate will not dissolve easily in cold dilute acids.

3. Sodium hydroxide (NaOH), a light brown precipitate of silver oxide (Ag_2O), insoluble in NH_4OH.

4. Ammonium carbonate $(NH_4)_2CO_3$, a wh te precipitate of silver carbonate ($AgCO_3$) soluble in an excess of the reagent.

5. Potassium chromate (K_2CrO_4), a dark red precipitate of silver chromate (Ag_2CrO_4) soluble in hot HNO_3 and on cooling, needle-shaped crystals like sillimanite are crystallized out of the solution.

Lead. Lead, if in a solution, will give the following precipitates with the following reagents:

1. Hydrochloric acid (HCl), a white precipitate of lead chloride ($PbCl_2$) soluble in hot water.

2. Sulphuric acid (H_2SO_4), a white heavy precipitate of lead sulphate ($PbSO_4$) almost insoluble in dilute acids, soluble in NaOH. If the $PbSO_4$ is dissolved in boiling HCl and water is added to the dissolved precipitate and boiled again, needle-shaped crystals of $PbCl_2$ will be deposited when the solution cools.

3. Hydrogen sulphide (H_2S) or ammonium sulphide $(NH_4)_2S$, a black precipitate of lead sulphide (PbS) insoluble in cold dilute acids or alkalies, soluble in boiling dilute HNO_3.

4. Potassium chromate (K_2CrO_4), a bright yellow precipitate of lead chromate ($PbCrO_4$) readily soluble in NaOH, and re-precipitates if HNO_3 is added.

II. Hydrogen Sulphide Group

A little of the filtrate from the beaker which was set aside and marked for Group II is first placed in a test tube and treated with H_2S. If a precipitate is obtained it indicates the presence of lead, copper, bismuth, cadmium, arsenic, tin, or antimonium. (These are usually found in colored glasses.) If no precipitate is obtained the liquid in the test tube is thrown away and the filtrate in the beaker should be examined for the next Group III.

If a precipitate is obtained it will be better to treat the filtrate with the H_2S gas, as this will give a better and more certain result than a solution of H_2S. When the precipitation is completed allow the precipitate to settle. Decant off the clear liquid, wash the precipitate with hot water two or three times, and set the beaker with the filtrate aside for the "Group III."

The precipitate must be examined carefully to determine what metals are present and to what groups they belong. Therefore, place a little of the precipitate formed by the H_2S into a small porcelain crucible and dissolve the precipitate with 1 c.c. NH_4OH and 1 c.c. yellow $(NH_4)_2S_2$. Heat and stir continuously with a glass rod. If all the precipitate is dissolved only the following metals of division two are present: arsenic (As), antimony (Sb), and tin (Sn).

If a residue is left, then the metals of division one are present. These are lead (Pb), copper (Cu), bismuth (Bi), and cadmium (Cd). Filter and wash the precipitate with hot water. Collect a little of the filtrate into a test tube and add a few drops of HCl. If a kind of cloudiness appears, the metals of division one only are present. If a yellow precipitate is obtained, the presence of the metals of division two is indicated.

After this test, remove the precipitate from the filter paper to a porcelain evaporating dish. Dissolve with $(NH_4)_2S$ and NH_4OH, 1 : 1. Place the dish on gauze and asbestos and heat to boiling while stirring constantly. Filter and wash two or three times with hot water. Set the filtrate aside. Mark the beaker containing the filtrate "division 2." Remove the precipitate to the evaporating dish again and dissolve with a mixture of HNO_3 and water, 1 : 1. Heat to boiling until all is dissolved. The sulphur is usually thrown out and should be filtered off.

To the filtrate add 6 c.c. of conc. H_2SO_4 and evaporate it on gauze (placing asbestos on gauze) until white fumes are given off. Let it cool, add about 25 to 50 c.c. water and let stand for about three hours. A white precipitate indicates the presence of lead. Filter and wash. Dissolve the precipitate with acetic acid ($C_2H_4O_2$) and add K_2CrO_4. A yellow precipitate confirms the presence of lead.

Add HN_4OH to the filtrate. A white precipitate indicates that Bi is present. If the solution turns blue on adding NH_4OH, the presence of Cu is established. Filter and wash the precipitate of Bi. If the precipitate is left in the solution and boiled, the precipitate will turn yellow as Bi_2O_3.

Add to the filtrate KCN solution until the blue color disappears. Then add H_2S. If Cd is present, it will form a yellow precipitate, soluble in HNO_3 insoluble in $(NH_4)_2S$, KCN and KHS, also in hot H_2SO_4.

Bismuth. If bismuth is present in a solution the following precipitates are obtained with the following reagents:

1. Hydrogen sulphide (H_2S) and ammonium sulphide ($(NH_4)_2S$), a black precipitate of bismuth sulphide (Bi_2S_3), insoluble in cold dilute acids, KHS and KOH, but soluble in boiling HNO_3.

2. Ammonium hydroxide (NH_4OH), and sodium

hydroxide (NaOH), and potassium hydroxide (KOH), a white precipitate insoluble in an excess of any of the reagents.

3. Potassium chromate (K_2CrO_4) a yellow precipitate of basic bismuth chromate ($Bi_2O(CrO_4)_2$) soluble in HNO_3 but insoluble in NaOH.

Copper. Copper, if in a solution, will give the following reactions with the following reagents:

1. Hydrogen sulphide (H_2S) or ammonium sulphide ($(NH_4)_2S$), a black precipitate of a black copper sulphide (CuS) soluble in HNO_3, KCN and slightly in $(NH_4)_2S_3$ but insoluble in KHS and H_2SO_4.

2. The addition of a small quantity of NH_4OH will precipitate a greenish blue basic salt, soluble in an excess of the reagent giving the solution a dark blue color.

3. Sodium hydroxide (NaOH), a light blue precipitate of copper hydroxide ($Cu(OH)_2$) insoluble in an excess, but soluble in NH_4OH and in acids.

4. Potassium hydroxide (KOH) precipitates a pale blue copper hydroxide ($Cu(OH)_2$) insoluble in an excess of the reagent. On boiling, the precipitate becomes black.

5. Potassium cyanide (KCN) a pale greenish precipitate of copper cyanide ($Cu(CN)_2$) soluble in excess. But if KCN is present in a solution (as above where the KCN is added to destroy the color of the solution) and then H_2S is added to precipitate the cadmium as CdS, copper is not precipitated by the addition of KCN.

6. Potassium ferrocyanide ($K_4Fe(CN)_6$), a brownish red precipitate of copper ferrocyanide ($Cu_2Fe(CN)_6$).

7. If very clean iron such as a penknife is placed in

a solution containing a copper salt, iron will replace some of the copper and the iron will become coated with copper. ($CuSO_4 + Fe = FeSO_4 + Cu$.) If the solution is strong, especially in the presence of a little free acid, the reaction is very rapid.

Cadmium. Cadmium, if in a solution, will give the following reactions with the following reagents:

1. Hydrogen sulphide (H_2S), or ammonium sulphide ($(NH_4)_2S$), a yellow precipitate of cadmium sulphide (CdS), insoluble in an excess of either reagent, KHS, KCN, and in cold dilute acids, but soluble in HNO_3 and hot H_2SO_4.

2. Sodium or potassium hydroxide, a white precipitate of cadmium hydroxide ($Cd(OH)_2$) insoluble in an excess of both reagents.

3. Ammonium hydroxide (NH_4OH), a white precipitate of cadmium hydroxide ($Cd(OH)_2$, soluble in an excess of the reagent.

To the filtrate marked "division 2," add HCl drop by drop. This throws out sulphur which should be filtered off. More HCl is added to the filtrate until the metals are all precipitated. Filter and wash two or three times with hot water. Place the precipitate on an evaporating dish, cover with HCl, place on gauze and heat to boiling. Sn and Sb are dissolved and AsS remains undissolved. Filter and wash two or three times with hot water. Remove the precipitate and the filter paper to an evaporating dish and cover with conc. HNO_3. Heat until all of the precipitate is dissolved and the acid driven off. Add about 15 c.c. water and mark "Filtrate from As." Place some of the filtrate in a test tube and add a few drops of magnesium sulphate solution. (Prepare the solution by dissolving magnesium sulphate in water then adding NH_4OH as long as a precipitate is obtained, and dissolving the precipitate with NH_4Cl solution.) Add this solution to the filtrate in the test tube.

The solution must remain alkaline. Shake vigorously for a few moments. The presence of As is indicated when a white crystalline precipitate is obtained.

To the filtrate in the beaker marked, "Filtrate from As," place a few pieces of Zn. When chemical action commences, hold the cover from the platinum crucible in contact with the zinc for a few seconds. If a black stain is formed on the platinum cover, it indicates the presence of antimony (Sb). Remove the platinum cover. Cover the beaker with a glass funnel and let it rest until the chemical action ceases. Remove all the zinc on which the antimony is deposited as a black powder and the tin as a spongy mass or a gray powder. Then wash every piece of the zinc carefully back into the beaker, being sure to remove all the adhering metals by washing with the wash bottle. When the metals are all settled, decant the clear liquid. Pour hot water in the metals and decant again. Then add conc. HCl and place on gauze, heat to boiling. If tin is present it will be dissolved forming stannous chloride ($SnCl_2$) and the antimony will remain undissolved.

Dilute the contents of the beaker with water and filter. Wash the precipitate two or three times with hot water. Dissolve the precipitate with three parts of conc. HCl and two parts conc. HNO_3 in a porcelain evaporating dish. Heat to drive off nearly all of the acid. Then dilute with water and add H_2S. A white precipitate confirms the presence of antimony.

Add mercuric chloride ($HgCl_2$) to the filtrate left from the antimony. A white precipitate indicates the presence of tin (Sn).

Arsenic, Tin, and Antimony. If a solution contains arsenic, tin, and antimony the following reactions will take place if the following reagents are added to the solution:

Arsenic. 1. Hydrogen sulphide (H_2S), or ammonium sulphide ($(NH_4)_2S$), does not produce a precipitate in a neutral solution. In an acid solution, a yellow precipitate of arsenious sulphide (As_2S_3) soluble in an excess of $(NH_4)_2S$, in KOH and in HNO_3 but insoluble in HCl;

2. Silver nitrate ($AgNO_3$) in neutral or alkaline solutions, a pale yellow precipitate of silver arsenite (Ag_3AsO_3);

3. Copper sulphate ($CuSO_4$) a green precipitate of copper arsenite ($CuHAsO_3$) (known as the Scheele's green) soluble in NH_4OH and acids.

Tin. 1. Hydrogen sulphide (H_2S), or ammonium sulphide ($(NH_4)_2S$), a brown precipitate of stannous sulphide (SnS). Both soluble in yellow $(NH_4)_2S_4$, and re-precipitated by HCl as yellow stannic sulphide (SnS_2). If the SnS precipitate is dissolved in KOH, the addition of HCl will produce a brown precipitate of stannous sulphide (SnS);

2. Ammonium hydroxide, sodium hydroxide, or potassium hydroxide will produce a white precipitate of stannous hydroxide ($Sn(OH)_2$). The precipitate with NH_4OH is insoluble in an excess of the reagent but the precipitate with NaOH and KOH is soluble in an excess of the reagent.

Antimony. 1. Hydrogen sulphide (H_2S) or ammonium sulphide ($(NH_4)_2S$), an orange-red precipitate of antimonium sulphide (Sb_2S_3), insoluble in an excess of H_2S but soluble in an excess of $(NH_4)_2S$. By adding HCl to the ammonium sulphide solution, Sb_2S_3 is again precipitated;

2. Zinc placed in a solution in the presence of HCl and Pt precipitates the antimony as a black powder which adheres to the platinum (as mentioned above when the cover of the platinum crucible was placed in the solution containing Sb). The precipitate is insoluble in HCl but is readily soluble in hot HNO_3;

3. Ammonium, sodium or potassium hydroxide, a white precipitate of antimony oxide (Sb_2O_3). The precipitate produced by NH_4OH is not soluble in an excess of the reagent, but the precipitates obtained by the NaOH and KOH are soluble in excesses of the reagents.

III. Ammonium Hydroxide Group

The filter marked " Group III " is now boiled until all the H_2S is driven off. A filter paper saturated with lead or silver chloride, when held in the vapor, will color as long as H_2S is present. If sulphur collects on the surface of the liquid, it should be filtered off.

After all the H_2S is driven off, add to the filtrate NH_4OH drop by drop stirring continuously until the solution turns red litmus paper blue.

Place the beaker on the gauze and gently heat to near the boiling point. Let the precipitate settle and filter as long as warm. Wash the precipitate with hot water until a little filtrate, collected in a test tube, shows no precipitation on adding HNO_3 and $AgNO_3$.

After shaking, place the filtrate aside and mark "Group IV."

The precipitate should be tested for Mn. To do this a small portion of the precipitate is placed on the platinum lid and fused with Na_2CO_3 and KNO_3. A bluish green mass indicates the presence of Mn.

To be certain that Mn is not being mistaken for Cr place a clean beaker under the funnel and dissolve the precipitate by adding about 15 to 20 c.c. HCl to the filter. It will run through the filter paper. Add to the filtrate about 10 c.c. NH_4Cl solution, boil, add NH_4OH, place the beaker with the contents on gauze and again heat to boiling. Filter and wash again with hot water until the precipitate is free from chloride as before. Add this filtrate to the one previously obtained. The precipitate is now free from Mn.

Half of the precipitate is removed into a beaker. The other half is removed with the paper into the same platinum crucible where the residue from the HF volatilization of SiO_2 was left after it had been ignited, allow to cool. Fuse the residue with $KHSO_4$ and when cool, remove into a beaker. Add sufficient hot water to cover. Add a few drops of H_2SO_4, boil, and when cool, add hydrogen peroxide (H_2O_2). A yellow color indicates the presence of Ti.

Dissolve the other half of the precipitate which was placed in the beaker with as little diluted HCl as possible. Heat to boiling. Transfer a small portion of the solution into a test tube and add $K_4Fe(CN)_6+3H_2O$. A blue precipitate indicates the presence of iron. Add NaOH in excess to the solution of the beaker and heat to boiling. All the alumina will dissolve. Fe and Cr when present will be precipitated. Filter and wash two or three times with hot water. Transfer the precipitate to the platinum crucible and fuse with Na_2CO_3 and KNO_3. Dissolve the fused mass in water and filter. The residue is Fe. Divide the filtrate into two parts. To one part add $AgNO_3$. A yellow filtrate with a red precipitate indicates the presence of Cr. Acidify the other part with HCl, add NH_4OH. A white precipitate indicates Al.

Solutions containing aluminum, iron and chromium will give the following reactions with the following reagents:

Aluminum. 1. Ammonium, sodium or potassium hydroxide, a white precipitate of aluminum hydroxide ($Al(OH)_3$). The precipitate obtained with NH_4OH is not soluble even in excess of the reagent if NH_4Cl is present. The precipitate obtained with NaOH or KOH is soluble in an excess of the reagents and also in acids, even in hot $C_2H_4O_2$;

2. Sodium or ammonium carbonate, a white precipitate of aluminum hydroxide ($Al(OH)_3$. The precipitate obtained with NaOH is soluble in an excess of the reagent, whereas the precipitate obtained with $(NH_4)_2CO_3$ is insoluble in an excess of the reagent but dissolved in acids;

3. Sodium phosphate (Na_2HPO_4) precipitates white aluminum phosphate ($Al_2P_2O_8$), insoluble in NH_4OH and in hot $C_2H_4O_2$, $Al(HO)_3$ dissolves in hot $C_2H_4O_2$. The precipitate obtained with Na_2HPO_4 dissolves readily in NaOH or KOH and in acids.

Iron. 1. Ammonium sulphide ($(NH_4)_2S$), a black precipitate of ferrous sulphide (FeS), soluble in NaOH, KOH, HCl, and H_2SO_4. H_2S gives no precipitate of Fe, Mn, Cr, Zn, Co or Ni, in acid solution;

2. Sodium or potassium hydroxide, a white precipitate of ferrous hydroxide ($Fe(OH)_2$) which readily changes to greenish yellow and then reddish brown, owing to the absorption of oxygen which converts the precipitate into ferric hydroxide ($Fe(OH)_3$). The precipitate is insoluble in an excess of the reagent.

3. Potassium ferrocyanide ($K_4Fe(CN)_6$), a white precipitate of potassium ferrous ferrocyanide ($K_2Fe_2(CN)_6$, which turns blue rapidly by oxidation to $Fe_5(CN)_{12}$ (known as the Prussian blue). Insoluble in acids but dissolves in alkalies;

4. Potassium ferric cyanide ($K_3Fe(CN)_6$), precipitates blue ferric cyanide ($Fe_5(CN)_{12}$) insoluble in acids, dissolves in alkalies.

Chromium. 1. Ammonium, sodium, or potassium hydroxide, a bluish green precipitate of chromium hydroxide ($Cr(OH)_3$). The precipitate obtained with NH_4OH is slightly soluble in an excess of the reagent which gives a pink color to the solution, but on heating a complete precipitation of $Cr(OH)_3$ is obtained. The precipitate obtained with NaOH or KOH is soluble in an excess of the reagent, but on boiling or an addition of NH_4Cl and heating the solution, a complete precipitation of $Cr(OH)_3$ is obtained;

2. Ammonium sulphide ($(NH_4)_2S$) a greenish blue precipitate of chromium hydroxide ($Cr(OH)_3$) insoluble in an excess of the reagent;

3. Ammonium or sodium carbonate a greenish blue precipitate of a basic carbonate, which is not completely precipitated until allowed to stand for a time.

IV. Ammonium Sulphide Group

Add $(NH_4)_2S$ to the filtrate marked "Group IV." Before adding $(NH_4)_2S$ to the whole filtrate it is advisable to take a little of it in a test tube and to add a few drops of $(NH_4)_2S$. If a precipitate is obtained it indicates the presence of this group of metals.

Add $(NH_4)_2S$ to the filtrate in the beaker until the metals are completely precipitated. Boil the solution and let the precipitate settle completely. Decant the clear liquid through the filter paper.

Then filter the whole, wash two or three times with hot water, adding always one drop $(NH_4)_2S$ to avoid the precipitate oxidizing to soluble sulphate. The filtrate is set aside and marked for "Group V."

If the precipitate is light in color only Mn and Zn are present. If the color of the precipitate is dark Ni or Co or perhaps all of the group metals are present.

Dissolve the precipitate with cold dilute 1 : 8 HCl, stirring it for one or two minutes. Filter and wash with dilute HCl. The residue contains Co and Ni, and the filtrate Mn and Zn.

Transfer the precipitate to a porcelain evaporating dish. Dissolve the precipitate in aqua regia (three parts of conc. HCl, to two parts of conc. HNO_3). Evaporate to dryness. Add a little water. Filter and wash. Make filtrate alkaline then add acetic acid, and a few pieces as large as peas of potassium nitrate KNO_2. Let rest for a few hours. A yellow precipitate indicates the presence of Co as double nitrate of potassium and cobalt. Filter, wash, and add NaOH solution to the filtrate. A green precipitate indicates the presence of Ni.

Boil the filtrate from Co and Ni until all $(NH_4)_2S$ is expelled. Add NaOH solution in excess. Filter and wash. A brown precipitate indicates the presence of Mn. Add H_2S to the filtrate. A white precipitate indicates the presence of Zn.

Solutions containing cobalt, nickel, manganese, and zinc will give the following reactions with the following reagents:

Cobalt. 1. Ammonium, sodium or potassium hydroxide precipitates a blue basic salts, insoluble in excesses of the reagents. The precipitate from NaOH or KOH turns green if exposed to air by oxidation; and on heating changes to red cobaltous hydroxide ($Co(OH)_2$) which soon changes again to brown cobaltic oxide (Co_2O_3). The precipitate obtained from NH_4OH is easily soluble in an excess of the reagent, giving a reddish brown solution. Adding to this solution KOH or NaOH will produce a precipitate of ($Co(OH)_2$);

2. Ammonium or sodium carbonate, a reddish precipitate of basic cobalt carbonate. The precipitate from $(NH_4)_2CO_3$ is soluble in an excess of the reagent, producing a reddish violet solution, but the precipitate from Na_2CO_3 is insoluble in an excess of the reagent;

3. Ammonium sulphide ($(NH_4)_2S$), a black precipitate of cobalt sulphide (CoS), insoluble in an excess of the reagent and slightly soluble in HCl, but dissolves in hot HNO_3 and in aqua regia. Dissolve the precipitate of CoS in aqua regia, evaporate to dryness, driving off almost all of the acid. Add a little water and NaOH to make the solution strongly basic. Then add sufficient tartaric acid ($H_2C_4H_4O_6$) to make the

solution acid. Heat gently and pass H_2S into the solution. A black precipitate of CoS is obtained.

Nickel. 1. Ammonium, sodium, or potassium hydroxide, a green precipitate of nickel hydroxide ($Ni(OH)_2$). The precipitate produced by NH_4OH is readily soluble in an excess of the reagent yielding a dark blue solution. If to this solution is added NaOH or KOH the Ni is precipitated. The precipitate formed by NaOH or KOH is insoluble in an excess of either reagent and will not change color when exposed to the air;

2. Ammonium or sodium carbonate, precipitates a light green basic nickel carbonate. The precipitate from $(NH_4)_2CO_3$ is soluble in an excess of the reagent while that from Na_2CO_3 is insoluble;

3. Potassium cyanide (KCN), a green precipitate of $Ni(CN)_2$ soluble in an excess of the reagent which renders the solution brownish yellow ($2KCN+Ni(CN)_2$). From this solution the nickel is precipitated by adding dilute HCl or H_2SO_4. If boiled with strong solution of NaClO, a black precipitate of nickel hydroxide is obtained $Ni(OH)_3$.

Manganese. 1. Ammonium, sodium, or potassium hydroxide, a white precipitate of manganese hydroxide ($Mn(OH)_2$) insoluble in all three reagents. These precipitates turn brown rapidly upon exposure to air by absorbing oxygen. NH_4OH gives no precipitate in a solution containing an excess of free acid or NH_4Cl as this retards precipitation; but if the solution is allowed to stand for a while, a dark brown precipitate is formed, which separates out slowly from the solution;

2. Ammonium sulphide ($(NH_4)_2S$), a flesh-colored precipitate of manganese sulphide (MnS), soluble in acids even in acetic acid;

3. Ammonium or sodium carbonate, a white precipitate of manganese carbonate ($MnCO_3$) insoluble in an excess of either reagents. The absorption of oxygen causes both precipitates to change color to brown.

Zinc. 1. Ammonium, sodium, or potassium hydroxide, a white precipitate of zinc hydroxide ($Zn(OH)_2$) soluble in an excess of any of the reagents. NH_4OH gives no precipitate in the presence of free acid or NH_4Cl;

2. Ammonium or sodium carbonate, a white precipitate of basic carbonates. The precipitate obtained by $(NH_4)_2CO_3$ is soluble in an excess of the reagent; but the precipitate by Na_2CO_3 is not;

3. Ammonium sulphide ($(NH_4)_2S$), a white precipitate of zinc sulphide (ZnS), insoluble in an excess of the reagent but dissolves in KOH, HCl, HNO_3 and H_2SO_4.

V. Ammonium Carbonate Group

The filtrate marked "Group V" is boiled until the $(NH_4)_2S$ is completely driven off. If sulphur is thrown out, it must be filtered off. To the filtrate add NH_4OH and boil. Add $(NH_4)_2CO_3$, and heat. As soon as it boils, filter and wash two or three times with hot water. Precipitates may contain Ba, Sr, and Ca. Mark filtrate for "Group VI."

Dissolve the precipitate with dilute acetic acid, which will run through the filter paper into a clean beaker placed under the funnel. Add to the filtrate K_2CrO_4 solution. A yellow precipitate indicates the presence of Ba.

Filter and divide into two portions. Add $CaSO_4$ solution to one portion. Boil a few minutes and allow to stand for a moment. Filter and wash. A white precipitate shows the presence of Sr.

Add $(NH_4)_2C_2O_4$ to the other portion. A white crystalline precipitate indicates the presence of Ca. All these metals should be dissolved and tested in a flame.

Solutions containing barium, strontium or calcium will give the following reactions with the following reagents:

Barium. 1. Ammonium, sodium or potassium carbonates, a white precipitate of barium carbonate ($BaCO_3$), insoluble in an excess of the reagents. The precipitate of $(NH_4)_2CO_3$ is only slightly soluble in NH_4Cl, but is soluble in acids, that of Na_2CO_3 or K_2CO_3 is also soluble in acids with effervescence;

2. Sulphuric acid (H_2SO_4), a heavy white precipitate of barium sulphate ($BaSO_4$) which is immediately formed and is insoluble in acids and in NH_4Cl. Any soluble sulphates will produce the same reaction as H_2SO_4;

3. Ammonium oxalate ($(NH_4)_2C_2O_4$), a white precipitate of barium oxalate (C_2BaO_4) soluble in HNO_3, HCl and $H_4C_2O_2$, in a concentrated solution, but no precipitate is formed in a dilute solution;

4. Potassium chromate (K_2CrO_4) produces a yellow precipitate of barium chromate ($BaCrO_4$) insoluble in alkalies and $H_4C_2O_2$, but soluble in HCl and HNO_3;

5. Barium in solution or in the solid form if taken on a platinum wire loop and held in the Bunsen flame a green coloration is obtained. If dipped in HCl and heated again a characteristic yellowish green color is produced due to the formation of the volatile salt of $BaCl_2$.

Strontium. 1. Ammonium, sodium, or potassium carbonate, a white precipitate of strontium carbonate ($SrCO_3$), insoluble in an excess of the reagent, and only slightly soluble in NH_4Cl, but soluble in HNO_3, HCl and $C_2H_4O_2$;

2. Sulphuric acid (H_2SO_4), a white precipitate of strontium sulphate ($SrSO_4$). In a concentrated solution, the precipitate is formed immediately, but in a dilute solution only after standing for some time. Heating favors precipitation. Calcium sulphate solution also produces a white precipitate of $SrSO_4$ after standing for some time;

3. Potassium chromate (K_2CrO_4) produces only in a concentrated solution a yellow precipitate of strontium chromate ($SrCrO_4$) which is easily soluble in HNO_3, HCl, and $C_2H_4O_2$;

4. Ammonium oxalate ($(NH_4)_2C_2O_4$), a white precipitate of strontium oxalate (SrC_2O_4) soluble in HNO_3, HCl and slightly in NH_4Cl, and $C_2H_4O_2$.

Strontium in solution or in a solid state gives a crimson color if held in a flame of a Bunsen burner on a platinum wire loop. If the Sr is dipped in dil. HCl a volatile salt of $SrCl_2$ is produced.

Calcium. 1. Ammonium, sodium or potassium carbonate, a white precipitate of calcium carbonate ($CaCO_3$). Heating favors the precipitation which becomes crystalline. All the precipitates are dissolved in acids with effervescence;

2. Ammonium oxalate ($(NH_4)_2C_2O_4$) produces even in a dilute solution a white precipitate of calcium oxalate (CaC_2O_4), insoluble in $C_2H_4O_2$, but readily soluble in HCl or HNO_3;

3. Sulphuric acid (H_2SO_4), a white precipitate of

calcium sulphate $CaSO_4$ from a concentrated solution very slowly. As this precipitate dissolves in excess of water, and in all acids, therefore, no precipitate is obtained from a diluted solution;

4. Sodium phosphate (Na_2HPO_4), a white precipitate of dicalcium phosphate ($CaHPO_4$) in slightly acid or neutral solutions. The precipitate obtained from an alkaline solution is tricalcium phosphate ($Ca_3(PO_4)_2$). Both precipitates are soluble in dilute acids and can be re-precipitated by NH_4OH. All volatile calcium salts give a brick-red coloration to the flame if held on a platinum wire loop in a flame of a Bunsen burner.

Magnesium. Add to the filtrate marked for "Group VI," NH_4OH and ammonium sodium phosphate ($NaH \cdot NH_4 \cdot PO_4$) (microcosmic salt). Stir well and let stand for a while to cool. A white precipitate indicates the presence of Mg.

Magnesium in a solution will give the following reactions with the following reagents:

1. Sodium ammonium phosphate ($NaH \cdot NH_4 \cdot PO_4$) a white precipitate of magnesium ammonium phosphate ($MgNH_4PO_4$), soluble in HCl, HNO_3 and $C_2H_4O_2$ but insoluble in NH_4Cl. The precipitate is very slowly formed in dilute solutions, but by stirring well with a glass rod the precipitation is hastened.

2. Sodium phosphate (Na_2HPO_4), a white crystalline precipitate of magnesium ammonium phosphate ($MgNH_4PO_4$) in an alkaline solution containing NH_4OH and NH_4Cl, but no precipitate is obtained in a solution containing free acids. The precipitate is soluble in HNO_3, HCl, H_2SO_4, and $C_2H_4O_2$;

2. Ammonium or sodium hydroxide, a white precipi-

tate of magnesium hydroxide ($Mg(OH)_2$) from neutral solutions or solutions free from acids or NH_4Cl.

SOLUTIONS (WET REAGENTS) REQUIRED

The strength of every solution after it is adjusted and accurately determined should be indicated on the label of the bottle containing it.

Hydrochloric acid (HCl), M.w. = 36.5, equ. = 36.5, conc. sp. gr. = 1.20 13/N (normal). Dilute with 8 volumes of water (1 : 8), makes 5/N.

Sulphuric acid (H_2SO_4), M.w. = 98, equ. = 49, conc. sp. gr. = 1.84, its strength is 36 normal (36/N). Diluted with 6 volumes of water (1 : 6) = 5/N.

Nitric acid (NHO_3), M.w. = 63, equ. = 63, conc. sp. gr. = 1.40 (handle with great care, as it is very caustic and corrosive, more so than HCl or H_2SO_4). Diluted with two volumes of water (1 : 2) = 5/N.

Acetic acid ($C_2H_4O_2$), M.w. = 60, conc. sp. gr. = 1.0 (handle carefully), equ. = 60. Diluted with 2.5 volumes of water = 5/N.

Ammonium carbonate $(NH_4)_2CO_3$, M.w. = 96, equ. = 48. Dissolve 200 gms. of solid in 500 c.c. of water and 200 c.c. of conc. ammonium hydroxide $(NH_4)OH$, then dilute with water to 1000 c.c.

Ammonium chloride $(NH_4)Cl$, M.w. = 53.5, equ. = 53.5. Dissolve 107 gms. of the dry pure salt in 700 c.c. of water, then add enough water to make 1000 c.c. = 2/N. Or $53.5 \times 5 = 267.5$ gms. in 1000 c.c. water = 5/N.

Ammonium hydroxide $(NH_4)OH$, M.w. = 35. conc. sp. gr. = 0.90, add 400 c.c. to 600 c.c. water = 6/N.

Ammonium sulphide $(NH_4)_2S$, M.w. = 68, equ. = 34, lead sulphurated hydrogen (H_2S) into a bottle containing 70 c.c. 6/N $(NH_4)OH$, until it is saturated (which is indicated by the bubbles rising through the liquid undiminished in size). Then fill the bottle to 1000 c.c. mark 6/N $(NH_4)_2S$.

Yellow ammonium sulphide $(NH_4)_2S_2$, is made by adding a small quantity of flowers of sulphur to ammonium sulphide, and shaking until dissolved. The solution when properly prepared should have an amber color. Or let the $(NH_4)_2S$ stand, it is slowly decomposed by the atmospheric oxygen, and ammonium yellow sulphide $(NH_4)_2S_2$, is evolved.

Ammonium nitrate $(NH_4)NO_3$, M.w. = 80, dissolve 40 gms. in 1000 c.c. water = N/2. Or neutralize 20 c.c. of the conc. HNO_3 with conc. $(NH_4)OH$. (The solution must show alkaline with litmus.) Dilute to 1000 c.c. with water.

Ammonium oxalate $(NH_4)_2C_2O_4$, M.w. = 142. 35.5 gms. of the salt dissolved in 1000 c.c. water will make an N/2 solution. Place it in a warm place for ten hours occasionally shaking it and when dissolved filter the solution.

Silver nitrate ($AgNO_3$), M.w. = 170, dissolving 17.0 gms. of the salt in 500 c.c. of water will make an N/5 solution.

Barium chloride ($BaCl_2 \cdot 2H_2O$), M.w. = 244. Dissolve 122 gms. of the salt in 1000 c.c. water 1/N solution.

Potassium permanganate solution ($KMnO_4$), M.w. = 158, $2KMnO_4 = 316$ ($2KMnO_4 + 3H_2SO_4 = K_2SO_4 + 2MnSO_4 + 3H_2O + O_5$). Dissolve 0.398 gm. of $KMnO_4$ in 1000 c.c. of pure water, and against pure ferrous ammonium sulphate (Mohr salt)$FeSO_4(NH_4)_2SO_46H_2O$

as described in the analysis of clay for iron by the volumetric method.

Standard titanium solution is prepared exactly as described under the determination at TiO_2 in clay (see p. 73).

Potassium ferrocyanide, $K_4Fe(CN)_6 \cdot 3H_2O$, M.w. = 422. Dissolve 105 gms. in 1000 c.c. water = 1/N.

QUANTITATIVE ANALYSIS

Moisture. One gram of sample is carefully weighed heated in a weighed platinum crucible at 110° C. until constant weight is obtained, cooled in desiccator, then weighed.

The loss is recorded as hydroscopic moisture.

Ignition Loss. Heat the residue to redness (900 to 1000° C.). The loss of weight is recorded as chemically combined moisture plus loss due to organic matter, is present. Some of the loss in weight may also be due to carbon dioxide from carbonates or sulphur dioxide from sulphates.

SiO_2. Mix the residue in the crucible with 5 gms. Na_2CO_3 and 5 gms. K_2CO_3; cover the crucible. Fuse over a very small flame for at least five minutes, then over a blast flame until complete fusion is obtained and no bubbles are present. Cool the fused mass by rotating the crucible so as to spread the mass up the side walls of the crucible until it solidifies. (Note the color, a bluish gun-metal color reveals the presence of manganese and brownish indicates iron.) After cooling remove the melted mass into an evaporating dish, add water, place on gauze and heat gently to boiling until all of the material is dissolved. (If some undissolved residue remains, it is better at this stage to filter it off and fuse the residue over again with Na_2CO_3 and K_2CO_3 dissolve and add it to the filtrate previously obtained.) After cooling, to the filtrate in the evaporating dish add conc. HCl drop by drop from a dropping bottle until no more CO_2 is given off and effervescence ceases. Keep the dish covered with a watch glass. (If iron is present the solution will turn to a yellowish straw color.)

Evaporate the contents in the evaporating dish to dryness on a water bath, add 60 c.c. of conc. HCl and evaporate to dryness and until all the fumes of HCl are driven off.

Add 100 c.c. dilute HCl (1 : 10) and heat on water bath for ten minutes, filter and wash with hot distilled water until the filtrate collected in a test tube gives no precipitate (AgCl) when shaken with a few drops of HNO_3 and $AgNO_3$, an indication that the precipitate is washed free of chlorides.

Transfer the precipitate with paper into a weighed platinum crucible and ignite until only a white residue of SiO_2 is left. Place in desiccator, allow to cool and weigh. Repeat heating and blasting for five minutes weigh again, and repeat until constant weight is obtained.

Moisten the residue with dilute H_2SO_4. Then 15 to 20 c.c. HF is added cautiously. Evaporate in fume hood on sand bath to dryness and then ignite at high heat. Repeat the heating until a constant weight is obtained.

After cooling weigh and subtract from the former weight. This difference is the weight of the SiO_2. The residue in the crucible may contain Al_2O_3, Fe_2O_3, TiO, etc.

Al_2O_3. Evaporate the filtrate from SiO_2 by boiling from about 500 to 300 c.c. add about 10 c.c. NH_4Cl solution and heat to boiling. Place a piece of red litmus paper in the liquid, add conc. NH_4OH drop by drop while stirring until the paper turns blue. Heat nearly to boiling, let the precipitate settle and filter while warm. Wash three or four times by decantation with hot solution of ammonium nitrate until free from chlorides, as for SiO_2.

If Mn is present (when the Na_2CO_3 and K_2CO_2 fused cake shows a bluish-green color in the platinum crucible) place a clean beaker under the funnel and dissolve the precipitate with 50 c.c. dilute HCl. Wash the precipitate from the filter paper into the beaker, being careful that all of it is dissolved and passes into the beaker. If some of the precipitate still adheres to the paper add more HCl.

Place a red litmus paper into the filtrate and as before add NH_4OH until the paper turns blue. Warm the solution and filter (into the same beaker containing the filtrate previously obtained), exactly as before. Wash the precipitate with warm ammonium nitrate solution until free from chlorides, indicated by no precipitate forming when HNO_3 and $AgNO_3$ are added.

Evaporate the filtrate almost to dryness, add a little NH_4OH and continue the evaporation—being sure to keep the solution alkaline. If iron and aluminum are present it will coagulate as iron and aluminum hydroxides. Filter and wash thoroughly free from chlorides as before. Place both precipitate and filter papers on a watch glass in a drying oven until dry. Then place in platinum crucible which contains the residue from ignition of SiO_2. Ignite, cool in desiccator, then weigh as Al_2O_3. Blast for about five minutes and weigh, repeat blasting and weighing until a constant weight is obtained.

Moisten the residue with dilute H_2SO_4, add about 15 c.c. HF. Carefully evaporate, ignite, and weigh, repeating the blasting and weighing to constant weight. Subtract this weight from the previous weight. The difference in weight is SiO_2. This weight must be added to the weight of SiO_2 previously obtained.

Multiply the weight in grams of residue in the platinum crucible by 12. Add this number of grams of $KHSO_4$. Cover the crucible, heat gently at a very low temperature for about thirty minutes (avoid sputtering). Then raise to dark red heat for one hour or more until all is dissolved. Let it cool, then digest the mass in warm water, add about 5 c.c. conc. H_2SO_4, evaporate to a small volume, then gently heat to a higher temperature until white fumes of SO_3 begin to come off. (Be sure that sufficient H_2SO_4 is present to form a pasty mass when cooled.) Place the crucible and contents also the cover into a clean beaker. Cover with hot water and heat gently to boiling. Remove the crucible and cover having washed off all adhering particles into the beaker. Transfer the solution from the beaker into a 400 c.c. Erlenmeyer flask. Dilute the solution to 200 c.c. add 15 c.c. dilute H_2SO_4 and boil until the liquid commences to clear.

If a residue is left the liquid should be filtered and the residue fused with $KHSO_4$, treated exactly as before. The quantity of $KHSO_4$ must be added to the former weight. If a residue is still left it should be filtered again and washed thoroughly. Then placed in a weighed platinum crucible, ignited, cooled and weighed. This weight represents SiO_2. Volatilize with HF as before, ignite and weigh repeat ignition and weighing to constant weight. Subtract this weight from the former weight. The difference is SiO_2. (This weight of SiO_2 should be also subtracted from the final weight of Al_2O_3) and should be added to the weights previously obtained as the weight of SiO_2. Place a rubber stopper on the flask provided with a Bunsen valve and stand aside.

(The residue left from the $KHSO_4$ fusion should be examined carefully; the writer has found that the residue contains zirconium, vanadium, cobalt and also manganese.)

Mn. The two combined filtrates from Al_2O_3 are heated to boiling until the NH_4OH is driven off. Be sure no NH_4OH is present. When all is driven off add a few drops of 10 per cent hydrogen peroxide drop by drop while stirring. After gently heating to boiling, NH_4OH is added. As soon as the solution becomes strongly alkaline the Mn will instantly precipitate as a dark brown hydroxide MnO(OH). Filter, wash, ignite in porcelain crucible and weigh as Mn_3O_4. To convert the Mn_3O_4 to MnO multiply the weight of Mn_3O_4 obtained by the factor .9301.

$$\frac{3MnO}{Mn_3O_4}=\frac{213}{229}=.9301.$$

CaO. The filtrate from Al_2O_3 and Fe_2O_3 should be evaporated to 200 c.c. about 5 c.c. acetic acid ($H_2C_2O_4$) is added to the solution and heated to boiling. Add NH_4OH and $(NH_4)_2C_2O_4$ while continuously stirring. Heat to boiling and place in warm place for about ten hours or overnight. As the precipitate is contaminated with Na, K and Mg salts, the precipitate should be dissolved in 50 c.c. warm dilute HNO_3 (1 : 5). Pour the 50 c.c. dilute warm HNO_3 into the same beaker in which the calcium was precipitated. Fill the beaker so that the acid wets the sides all around in order to dissolve any adhering precipitate. Remove the beaker containing the filtrate and cover with a watch glass and mark "Filtrate from CaO."

Place a clean beaker rinsed out with distilled water under the funnel containing the Ca precipitate. Pour the contents of the beaker carefully on the filter to dissolve all the calcium precipitate on the filter paper. If some of the precipitate still adheres to the paper add more of the warm dilute nitric acid. Add a slight excess of NH_4OH and about 15 c.c. of $(NH_4)_2C_2O_4$ solution. Boil about a minute and allow it to stand in a warm place overnight.

Filter and wash. Pour this filtrate into the beaker containing the filtrate previously obtained. Wash the filter with dilute NH_4OH (1 : 10) until free from chlorine, place the precipitate with the paper in a weighed platinum crucible. Ignite until all the oxalates are driven off. Cool in desiccator and weigh as CaO. Repeat the ignition and weighing until the weight is constant.

MgO. Evaporate the filtrate from CaO to 200 c.c. add NH_4OH and about 10 to 20 c.c. sodium ammonium phosphate solution ($Na(NH_4)HPO_4 \cdot 4H_2O$). Stir the solution vigorously for about twenty minutes, being careful not to touch the sides of the beaker with the stirring glass rod as the Mg will crystallize on the sides of the beaker. Stand aside in a cool place for ten hours or overnight.

Filter and dissolve the precipitate in 50 c.c. warm dilute HNO_3 and proceed exactly as with the precipitate of calcium. Add sodium ammonium phosphate solution and NH_4OH. Stir vigorously for twenty minutes. Stand aside for ten hours.

Filter, wash the precipitate with dilute NH_4OH (1 : 10) dry and ignite in a weighed porcelain or aluminum crucible until constant weight is obtained.

Weigh as $Mg_2P_2O_7$. From this calculate MgO by using the factor .3606.

$$\frac{2MgO}{Mg_2P_2O_7} = \frac{80}{222} = 0.3606.$$

Fe_2O_3. To the solution in the Erlenmeyer flask 10 gms. of c.p. mossy zinc is added. Let it stand until all chemical action has ceased. A blank solution is prepared by fusing the same weight of $KHSO_4$ as before and treated as the former. To this is also added 10 gms. of zinc and placed aside and marked blank solution. When chemical action has ceased in both flasks the solution is filtered and washed as quickly as possible, then titrated with a $KMnO_4$ V. S.

The $KMnO_4$ solution is prepared as follows:

Dissolve 1 gm. of $KMnO_4$ in 1000 c.c. distilled water, let it stand for two or three days in a dark amber-colored bottle, then dissolve 3.924 gms. $FeSO_4(NH_4)_2SO_46H_2O$ in 1000 c.c. distilled water; both bottles should have glass stoppers to be air tight. Let this solution also stand two or three days.

One c.c. of the $FeSO_4(NH_4)_2SO_46H_2O$ equal to .0008 gm. Fe_2O_3. Fill into one clean burette the $FeSO_4(NH_4)_2SO_46H_2O$ solution and into another the $KMnO_4$ solution.

Let 20 c.c. of the $FeSO_4(NH_4)_2SO_46H_2O$ solution into a clean beaker, dilute with 20 c.c. distilled water and add 15 c.c. dilute 1 : 10 H_2SO_4, then titrate with the $KMnO_4$ solution. Note carefully how many cubic centimeters are required to produce the pink color.

Three of five such tests must require the same amount of $KMnO_4$ solution.

Twenty c.c. of $FeSO_4(NH_4)_2SO_46H_2O \times .0008 = .016$ gm. Fe_2O_3. If the solution required 10 c.c. $KMnO_4$ solution, then $.016 : 10 = .0016$ gm. Fe_2O_3. This factor .0016 should be marked on the label of the bottle.

Assuming that to the solution which was transferred from the flask into the beaker, 12 c.c. of $KMnO_4$ was required and the blank 2.3 c.c. of $KMnO_4$ solution was required 2.3 c.c. has to be subtracted from the 12 c.c.

Then $(12 - 2.3 \times .0016) \times 100 = 1.55$ per cent Fe_2O_3 present in the sample.

TiO_2. This is determined colorimetrically as follows: Transfer the solution in which the Fe_2O_3 was determined into a 500 c.c. graduated flask, dilute it with water make exactly 490 c.c., and add 10 c.c. 3 per cent hydrogen peroxide, shake well and let it stand for a few minutes.

This solution is then compared with the St·S of TiO_2. The St·S is prepared by dissolving 1 gm. $Ti(SO_4)_2$ in 1000 c.c. distilled water (the solution should be kept in dark-colored glass-stoppered amber bottle). Pipette 5 c.c. from this solution into a clean 100 c.c. glass-stoppered bottle. Add 5 c.c. peroxide and fill exactly to the 100 mark with distilled water. Each cubic centimeter is then equivalent to 0.0001 gm. of TiO_2.

Place the St·S in the right cylinder of the Kennicott colorimeter and 100 c.c. of the test solution in the left cylinder. Note the number of cubic centimeters of the St·S required to match the color, multiply the result first by .0001 by 5 and then by 100, which gives the percentage of TiO_2 present in sample. The St·S can be poured back in the 100 c.c. bottle again and used for the next operation.

The amount of $TiO_2+Fe_2O_3$ is added and subtracted from the amount of Al_2O_3 found gives the exact percentage of Al_2O_3 present in the sample.

S. The filtrate from Mg is heated to boiling. If the solution is 300 c.c. add 15 c.c. HCl and heat again, add $BaCl_2$ in sufficient excess to precipitate all the S present as $BaSO_4$. Filter, wash and ignite in a weighed porcelain crucible. Multiplying the result by .13756 gives S or by .3433 gives SO_3.

Alkalies. .5 gm. of the sample taken mixed with .5 gm. of NH_4Cl+4 gms. $CaCO_3$. Place in a covered platinum crucible and heat at a low temperature then increase to dull red for one hour. After this treat the contents with hot water in a beaker, boiling until the mass is completely disintegrated. Filter off the insoluble and wash with hot water until a small quantity of the washing collected in a test tube forms no precipitate on adding HNO_3+AgNO_3. Evaporate to 100 c.c., remove from the flame, add $NH_4OH+(NH_4)_2CO_3$ as long as precipitate is formed, heat to boiling, let precipitate settle, filter and wash with hot water. Evaporate to a small bulk transfer to platinum crucible, evaporate to dryness on water bath, then heat gently to faint red to drive off all ammonium compound.

When cool dissolve residue in 5 c.c. water, add 1 or 2 drops $NH_4OH+(NH_4)_2CO_3$ and heat on water bath for ten minutes. Filter and wash in a weighed platinum crucible, add 1 drop HCl. Evaporate to dryness, drive off all ammonium salt, finally heating to faint red. Cool in desiccator and weigh as the combined chloride of Na+K. Dissolve residue in 5 c.c. water, add $PtCl_6$ in a sufficient quantity to convert the chlorides into double chlorides of platinum (1 c.c. should be sufficient). Place crucible on water bath and evaporate the contents to a pasty substance, add 35 c.c. 80 per cent alcohol and stand the crucible in a warm place for twc hours, stirring the contents occasionally. Filter on a weighed filter paper, wash thoroughly with 80 per cent alcohol, dry in air bath at 130° C., weigh as K_2PtCl_6, multiply by .19376, which gives K_2O, or by .30674 to give KCl.

Subtract the latter weight from the weight of the mixed chlorides to give NaCl, which multiplied by .53028 gives Na_2O.

Determination of FeO. Mix .5 gm. of sample with 2 gms. of Na_2CO_3, place the mixture into the platinum crucible, cover the mixture with more Na_2CO_3, cover the crucible and heat gently until the contents in the crucible are all fused.

When cool dissolve the melted mass in a beaker with dilute H_2SO_4. Transfer the solution into a flask and boil until the liquid is clear. Add 10 gms. of zinc, cork with a rubber stopper fitted with a Bunsen valve, and leave in a warm place for about four hours, until all chemical action has ceased.

Titrate with $KMnO_4$ exactly as for Fe_2O_3.

Determination of SO_3. Heat 1 gm. of the sample to 150° C. Allow to cool in desiccator, then quickly place the sample in a flask, add about 10 c.c. NH_4CO_3 to cover the specimen, cork with a rubber stopper and let it stand for twenty-four hours, shaking it occasionally.

Filter and wash with warm water. If the solution is 200 c.c. add 10 c.c. HCl, boil, then add $BaCl_2$ solution, filter and wash. Let precipitate dry, place in a porcelain crucible, ignite, let cool and weigh. The weight of the residue, $BaSO_4$, multiplied by .3334 and then by 100 gives the percentage of SO_3 present in the sample.

CHROMITE ANALYSIS

Frequently a ceramic chemist is called upon to make an analysis of chrome ore. The following very convenient method gives accurate results:

Place 1 gm. of the dry pulverized sample in a previously weighed platinum crucible and weigh the crucible with the contents again. Moisten the contents of the crucible with a few drops of water and add 10 to 15 drops concentrated sulphuric acid and stir well with a platinum wire. Now add 6 c.c. of hydrofluoric acid very cautiously and stir very carefully with the platinum wire.

The crucible with the contents is carefully placed on a sand bath and very gently heated at a very low temperature, until the contents in the crucible are dry. (In this way all the silica is volatilized and the acids almost driven off.) Remove the crucible and ignite and blast for about fifteen minutes. Place the crucible with contents in desiccator, allow it to cool, then weigh. The difference between this and the former weight is silica and it is reported as such.

The residue from the platinum crucible is now very carefully washed into a very clean 30 c.c. nickel crucible.

(Do not use a platinum crucible, only nickel, silver or copper will do.) Be sure that every particle from the platinum crucible is washed into the nickel crucible. Place the nickel crucible with its contents on the hot plate until the contents is thoroughly dry.

Mix the dry residue in the crucible with 6 gms. of powdered sodium peroxide (Na_2O_2) and stir thoroughly with a platinum wire from which all adhering particles should be carefully brushed back into the crucible. (Be sure also that the Na_2O_2 is pure and fresh as it decomposes very rapidly forming Na_2CO_3.)

Heat the crucible with its contents with a very low flame, which should be regulated so as to complete the fusion in from ten to fifteen minutes and keep the contents in a fused state for ten minutes to insure complete fusion of every thing. Allow it to cool, place contents in a porcelain dish, add about 150 c.c. water, stir with a glass rod until the contents are all dissolved. Then place the crucible on a gauze and heat to boiling. It should be kept so for about twenty or twenty-five minutes until the Na_2O_2 is all decomposed. Filter and wash the filtrate four or five times with hot water. (It is advisable to fuse the residue on the filter paper again with 3 gms. of Na_2O_2 to make sure that all the Cr is separated and treated in the same manner as before.)

The filtrate will contain the chromium in solution and the residue on the filter paper will contain Fe, Al, Mn, etc. The greater part of the Al went through the filter paper as well as the silica if it was not all volatilized by the hydrofluoric acid treatment.

The filtrate is now acidified with acetic acid and allowed to stand on the hot plate for about fifteen minutes; then filtered and washed with hot water. This precipitate is added to the one previously obtained.

The chromium, almost pure, is now in the solution, and can be precipitated with barium chloride ($BaCl_2$) or with lead acetate ($Pb(C_2H_3O_2)_2 3H_2O$). If $BaCl_2$ is used then the precipitate is barium chromate ($BaCrO_4$) and if lead acetate is used then the precipitate formed is lead chromate ($PbCrO_4$). The precipitate is dried and placed in a weighed porcelain crucible ignited and allowed to cool in desiccator, then weighed. Subtract the weight of the crucible and multiply the result with the factor .45784 if barium chloride were used as a reagent. If lead acetate were used as a reagent then factor 1.56011 is used as the multiplier to convert the lead chromate to CrO_4.

The precipitate of Fe, Al, Mn, etc., is now placed in a weighed platinum crucible and ignited. When cool it is weighed and placed in desiccator. Add a few drops of water and concentrated sulphuric acid as at the beginning and then cautiously add hydrofluoric acid to volatilize all the silica. When the contents of the crucible are dry ignite and blast. Place the crucible with contents into the desiccator. When cool weigh and subtract the loss from the former weight. This is silica and should be added to the former weight of silica obtained.

If Mn should be present and it is desired to separate it from the precipitate use the method described in the clay analysis, but before the ignition and volatization of the second silica, the Fe and Al must be precipitated first from the solution by NH_4OH, and the NH_4OH driven off after the Fe and Al has been precipitated, and H_2O_2 added to precipitate the Mn.

The precipitate is now again placed into the weighed platinum crucible ignited and weighed.

In either case when the Mn is all separated from the Fe and Al precipitate, add eight times the weight of the residue of potassium bisulphate and proceed exactly in the same way as for the determination of Fe by the volumetric method for clay.

If it is desired to determine the chromium by the volumetric method consult any standard work.*

ANALYSIS OF LIMESTONE, CEMENT, AND MAGNESITE

Place 1 gm. of the dry finely ground sample in a porcelain evaporating dish, add 5 c.c. water and 20 c.c. conc. HCl. Stir well with a glass rod. Before removing the rod from the dish after the stirring is completed wash the rod carefully back into the dish and cover with a watch glass. Place the dish on water bath until effervescence has ceased.

Remove the watch glass carefully wash it into the dish, leaving the dish on the water bath until the contents are dry. Remove the dish from the water bath, place on gauze, and heat gently until almost all the fumes are driven off. (Avoid excessive ignition.)

When cool dilute the residue with about 30 c.c. water and a few drops of HCl. Heat to boiling, filter, and wash till the wash comes through free from chlorides. Place the precipitate with paper in a weighed platinum crucible, dry, ignite, and weigh.

* A Treatise on Quantitative Inorganic Analysis, by J. W. Mellor or Standard Methods of Chemical Analysis, by W. W. Scott.

Add a few drops of water and H_2SO_4 to the residue. Then add about 5 c.c. hydrofluoric acid. Volatilize the silica, ignite and weigh. Subtract the loss from the former weight and report as SiO_2.

Now proceed for determining Al, Fe, Ca, Mg, and alkalies as described under "clay analysis."

If the samples are high in silica it is better to conduct the analysis as we did with the clay making, the sample to fuse in Na_2CO_3 and K_2CO_3.

(For a thorough test and physical analysis on cement consult "Standard Methods of Chemical Analysis," W. W. Scott, D. Van Nostrand Company.)

ZIRCONIUM

Zirconium occurs as a silicate, $ZrSiO_4 = SiO_2$ 32.8, $Zr = 67.2$, containing also Al_2O_3, Fe_2O_3, TiO_2, and other rare metals. The mineral is decomposed by mixing 1 gm. of the finely powdered mineral with 5 gms. Na_2CO_3 and 1 gm. K_2CO_3. This mixture is placed in a platinum crucible and heated gradually until fused. The fused cake, when cold, is removed into an evaporating dish in which it is disintegrated in water and hydrochloric acid is added, and if manganese is present a few drops of hydrogen peroxide is added in order to reduce the manganate to a manganous salt. Filter and wash the residue with a solution of sodium hydroxide (NaOH). Silica and zirconium with other impurities as Al_2O_3, Fe_2O_3, TiO_2 and Ba will be on the filter paper. Wash the residue with about 50 c.c. dilute H_2SO_4, being careful to wash every part of the paper. Place a blue litmus paper in the beaker and see that the solution is acidic.

Dry the residue with the paper then ignite in a platinum crucible previously weighed. Allow to cool and weigh. Add a few drops of dilute H_2SO_4, and then about 6 c.c. of hydrofluoric acid. Carefully drive off the silica, ignite and weigh. The loss in weight from the previous weight is the silica, and the residue in the crucible is zirconium with other impurities.

To separate the zirconium from the impurities the reader is referred to the following works: "A Treatise on Quantitative Inorganic Analysis," by J. W. Mellor, and "Standard Methods of Chemical Analysis," by Scott.

The following reagents will produce precipitation as follows:

Ammonium sulphide $(NH_4)_2S$ gives a white precipitate of zirconium hydrate insoluble in excess. KOH, NaCH, and $(NH_4)OH$ give the same precipitate inso'uble in excess.

Hydrogen peroxide gives a bulky white precipitate as hydrate. Sodium and potassium carbonates precipitate zirconium as a flocculent powder soluble in an excess of the reagents. Ammonium carbonate $((NH_4)_2CO_3)$ gives a white precipitate of a basic carbonate which is soluble in an excess of the reagent. From this last solution the zirconium is precipitated as a hydrate on boiling.

NOTES ON CALCULATIONS OF THE RESULTS OF ANALYSIS

X+R of SiO_2....................	21.404 gms.
X..............................	20.955
	.449 gm. SiO_2
X+R left after HF. volt..........	21.404 gms.
	20.968
	.436 gm. SiO_2
X+R of Al_2O_3, etc................	21.342 gms.
X+R left after HF. volt..........	21.329
	.013 gm. SiO_2

$(.436+.13)\times 100=44.90\%$ total SiO_2

1 c.c. of $KMnO_4$ V.S. represents .00258 gm. of Fe_2O_3

The reduction was completed after 10 gms. of Zn had been dissolved in the solution. The solution required 6 c.c. of $KMnO_4$ V.S. Also 10 gms. of Zn was dissolved in the blank solution and to both solutions 15 c.c. dilute 1 : 10 H_2SO was added. The blank solution required 1.8 c.c.

$$\therefore \quad (6-1.8\times .00258)\times 100=1.08\%\ Fe_2O_3)$$

7 c.c. of TiO_2 was required to match the color. 1 c.c. St·S represents .0001 gm. per cubic centimeter. The test solution was made up to 490 c.c. to which 10 c.c. of 3 per cent peroxide was added. From this 100 c.c. were taken.

$$\therefore \quad (7\times .0001\times 5)\times 100=.35\%\ TiO_2$$

$37.40\ Al_2O_3-(1.08\ Fe_2O_3+0.35\ TiO_2)=35.97\%\ Al_2O_3$.

X+R of CaO..................	20.965 gms.
X............................	20.953
	$.012 \times 100 = 1.2\%$

X+R of $Mg_2P_2O_7$	11.151 gms.
X..............	11.117

$(.034 \times .3627) \times 100 = 1.23\%$ MgO

X+R of mixed Cl........................	20.967 gms.
X..................................	20.947 gms.
	.020 gm.
Paper w.+R of K_2PtCl_6................	.641 gm.
Paper w..............................	.592 gm.
	.049 gm.

$.049 \times .3065 = .0150185 \times .6320 = .00949168200 \div 500$

$0.0189 \times 100 = 1.89\%$ K_2O

$.020 - .0150185 = .0049815 \div 500 = 0.0099 \times 100 = 0.99\%$ Na_2O

X+sample............................	21.952 gms.
X+sample after being heated to redness.	21.8285
	.1235 gm.

$.1235 \times 100 = 12.35\%$ moisture.

SiO_2........................	44.90
Al_2O_3........................	35.97
Fe_2O_3........................	1.08
CaO........................	1.20
MgO........................	1.23
K_2O........................	1.89
Na_2O........................	0.99
TiO_2........................	0.35
Moisture........................	12.35
	99.96

CALCULATING THE RATIONAL ANALYSIS FROM AN ULTIMATE ANALYSIS

SiO_2	49.26
Al_2O_3	36.64
Fe_2O_3	.46
CaO	.06
MgO	.04
Alk	1.52
H_2O	12.02
	100.00

$$x=\frac{556\times 1.52}{94}=8.99 \text{ feldspar substance;}$$

This contains:

$$x=\frac{8.99\times 102}{556}=1.65\ Al_2O_3$$

and

$$x=\frac{8.99\times 360}{556}=5.82\ SiO_2.$$

Subtracting 1.65 Al_2O_3 from the Al_2O_3 in ultimate analysis $36.64-1.65=34.79\ Al_2O_3$.

$$X=\frac{34.99\times 258}{102}=88.50 \text{ clay substance.}$$

Containing:

$$x=\frac{88.50\times 120}{258}=41.16 \text{ quartz;}$$

and

$$x=\frac{88.50\times 36}{258}=12.35 \text{ water.}$$

Add the quartz found in the feldspar and clay substance, then subtract from the sum in the ultimate analysis:

$$49.26-(41.16+5.82)=2.28 \text{ free quartz.}$$

Summing up all the data the report is as follows:

Clay substance................	88.50
Feldspar sub....................	8.99
Quartz..........................	2.28
	99.77

Adding the $Fe_2O_3+CaO+MgO$,

$$99.77+.56+.06+.04=100.33.$$

The ultimate analysis shows only 12.02 per cent H_2O. The calculation shows 12.33 per cent H_2O. $12.35-12.02=.33$ per cent too much H_2O or .33 per cent less in the clay. If we subtract this from 100.33 we have exactly 100 per cent. $100.33-.33=100$, which is right.

Cone No. 20 has the following formula:

$$\left.\begin{matrix}0.3\ K_2O\\0.7\ CaO\end{matrix}\right\}3.9Al_2O_339SiO_2.$$

What is the percentage of the mass?

$$(94\times.3)+(56\times.7)+(102\times3.9)+(60\times39)=2805.2$$

$$X=\frac{2340\times100}{2805.2}=\ 83.44\%\ SiO_2;$$

$$X=\frac{397.8\times100}{2805.2}=\ 14.18\%\ Al_2O_3;$$

$$X=\frac{39.2\times100}{2805.2}=\ 1.38\%\ CaO;$$

$$X=\frac{28.2\times100}{2805.2}=\ 1.00\%\ K_2O;$$

$$100.00\%$$

What is the rational analysis of Cone No. 20?

$$x=\frac{556\times 1}{94}=5.91\%\ \text{F.s.}$$

This contains:

$$x=\frac{5.91\times 102}{556}=1.09\%\ Al_2O_3;$$

$$x=\frac{5.91\times 360}{556}=3.83\%\ SiO_2;$$

$$1\ K_2O+1.08\ Al_2O_3+3.82\ SiO_2=5.91.$$

Subtracting from the total:

$$14.18\ Al_2O_3-1.08\ Al_2O_3=13.10.$$

This is calculated for clay substance as follows:

$$x=\frac{13.10\times 258}{102}=33.13\%\ \text{C.s.}$$

This contains:

$$X=\frac{33.13\times 120}{258}=15.41\%\ SiO_2;$$

$$x=\frac{33.13\times 36}{258}=4.62\%\ H_2O;$$

$$15/41\ SiO_2+13.10\ Al_2O_3+4.62\ H_2O=33.13\ \text{C.s.}$$

From 83.44 we subtract the amount of SiO_2 calculated for feldspar and clay substance and the result is the free SiO_2:

$$83.44-(3.83+15.41)=64.20\%\ \text{quarts.}$$

Summing up the whole results:

Clay substance..............	33.13%
Feldspar substance..........	7.29
Quartz....................	64.20
	104.62%

The 4.62 per cent H_2O calculated in clay substance has to be subtracted because the percentage calculation does not show any H_2O.

$$104.62-4.62=100\%\text{—which is correct.}$$

In order to figure out the amounts of the different substances required for ceramic bodies, glazes, enamels, etc., some knowledge of the meanings of chemical formulas and chemical equations is necessary. The chemical equation shows not only what substances enter into the combination and the resulting substances, but also gives the means for determining the relative weights of each substance. These relative weights may be in ounces, pounds, tons, grams, or kilograms as the case may be.

Every element is designated by a definite symbol as: O for oxygen, C for carbon, Fe (ferrum) for iron, K (kalium) for potassium, etc. In the usually accepted sense, these symbols stand for a definite amount of each substance. For example O stands for 16 parts by weight (any unit—ounces, pounds, grams, kilograms, tons, etc.), of oxygen; C stands for 12 parts by weight of carbon; Fe for 56 parts of iron, etc. These numbers are variously designated as atomic weights, reacting weights, combining weights, and equivalent weights. These numbers are given in the table of elements.

In writing formulas small figures are frequently written to the right and below the symbols. For example, we write O_2 or O_3. This small number is used as a multiplier of the reacting weight as given in the table. O_2 stands for 2×16 parts or 32 parts by weight of oxygen. O_3 stands for 3×16 or 48 parts of oxygen. Sometimes a large figure is written to the left of a symbol or formula. This number is to be used as a multiplier of the reacting weights of all the elements found in the formula that follow the figure. $2O$ means 2×16 or 32 parts by weight of oxygen. $2O_2$ means $2\times16\times2$ or 64 parts by weight of oxygen. $3CO_2$ means 3×12 parts of carbon$+3\times16\times2$ parts of oxygen or $36+98=132$ parts by weight of carbon dioxide, the symbol of which is CO_2.

A further study of the following examples of symbols, formulas and equations will serve to make these principles clear:

Symbols.	Equivalent Weights.
$Si=Si$ $28=28$	$=28$ units of silicon;
$2O=O_2$ $2\times16=16\times2$	$=32$ units of oxygen.
$Al=Al$ $27=27$	$=27$ units of aluminum;
$2Al = Al_2$ $2\times27=27\times2$	$=54$ units of aluminum;
$Al_2 + O_3=Al_2O_3$ $27\times2+16_3= 102$	$=102$ units of aluminum oxide;
$H=H$ $1= 1$	$=1$ unit of hydrogen;
$2H +O =H_2O$ $2\times1+16= 18$	$=18$ units of water;
$Ca=Ca$ $40 =40$	$=40$ units of calcium;
$Ca+O =CaO$ $40+16= 56$	$=56$ units of calcium oxide, and so on;
$Pb + O = PbO$ atom+atom = molecule	$=1$ molecule of lead oxide;

Symbols		Equivalent Weights.
$Mg + O = MgO$		$= 1$ molecule of magnesium oxide;
atom + atom = molecule		
$MgO + CO_2 = MgCO_3$		$= 1$ molecule of magnesium carbonate.
molecule + molecule = molecule		

In the above, MgO stands for one molecule of magnesium oxide whose molecular weight is 40, consisting of 24 units of magnesium and 16 units of oxygen. The molecular weight of $MgCO_3$ is 84, consisting of 24 units of magnesium, 12 of carbon and 48 (3×16) of oxygen.

Kaolin or the clay base is expressed as $Al_2O_3 + 2H_2O + 2SiO_2$ and consists of the following units by weight:

2×27	units of	Al =	54	units,	or grams,	kilos	or tons
3×16	"	O =	48	"	"	"	"
2×28	"	Si =	56	"	"	"	"
4×16	"	O =	64	"	"	"	"
4×1	"	H =	4	"	"	"	"
2×16	"	O =	32	"	"	"	"
			258 the molecular weight.				

$Al_2O_3 + K_2O + 6SiO_2$, molecular weight 556 (orthoclase, sometimes called potash feldspar).

2×27	units of	Al =	54	units,	or grams,	kilos	or tons.
3×16	"	O =	48	"	"	"	"
2×39	"	K =	78	"	"	"	"
1×16	"	O =	16	"	"	"	"
6×28	"	Si =	168	"	"	"	"
12×16	"	O =	192	"	"	"	"
			556 the molecular weight				

Examples. We wish to increase 4 per cent of K_2O

(potash) into a body mix. How much pure orthoclase feldspar is necessary to give the required amount?

$$K_2O : \text{feldspar} = \text{required weight} : x$$
$$94 : 556 = 4 : x$$

$$x = \frac{556 \times 4}{94} = 23.67. \quad \text{Ans.}$$

Suppose we wish to know how many grams of sulphuric acid (H_2SO_4), and ferrous sulphide (FeS) are necessary to produce 50 grams of hydrogen sulphide (H_2S).

$$FeS + H_2SO_4 = FeSO_4 + H_2S$$
$$88 + 98 = 152 + 34$$

$34 : 50 = 88 : x$, 129.47 gms. of FeS,

and

$34 : 50 = 98 : x$, 144.12 " H_2SO_4

Or, we wish to find out how much sulphuric acid will be required to dissolve 50 gms. of zinc, how much hydrogen and how much zinc sulphate will be obtained:

$$Zn + H_2SO_4 = ZnSO_4 + 2H$$
$$65 + 98 = 161 + 2$$

$65 : 98 = 50 : x$, $x = 75.38$ gms. of H_2SO_4
$65 : 2 = 50 : x$, $x = 15.38$ " H
$65 : 161 = 50 : x$, $x = 123.85$ " $ZnSO_4$

CALCULATING CERAMIC BODIES

We wish to mix a body containing the following:

SiO_2	68.5
Al_2O_3	23.5
Fe_2O_3	.5
CaO	.7
Mg	....
K_2O	6.8
	100.0

The materials on hand from which the mixture is to be prepared are as follows:

	Kaolin.	Feldspar.	Quartz.
SiO_2	45.78	71.65	98.65
Al_2O_3	36.46	16.10	1.09
Fe_2O_3	1.36	.10	.12
CaO	.50	.20	
MgO	.14	.00	
K_2O	.31	8.59	.09
Na_2O	....	2.98	
TiO_2	....	.03	
Loss on ignition	15.45	.35	.06
	100.00	100.00	100.00

First we reduce the Fe_2O_3 to the equivalent amount of Al_2O_3 and all of the monoxides to K_2O as follows:

Fe_2O_3

Kaolin $= 160 : 102 = 1.36 : x, \; x = .87$

$36.46 + .87 = 37.33$

Feldspar $= 160 : 102 = .10 : x, x = .06$
$16.10 + .06 = 16.16$

Quartz $= 160 : 102 = 12 : x, x = .08$
$1.09 + .08 = 1.17$

Body $= 160 : 102 = .5 : x, x = .32$
$23.5 + .32 = 23.82$

CaO

Kaolin $= 56.94 = .64 : x, x = 1.07$
$1.07 + .64 = 1.71$

Feldspar $= 56.94 = .23 : x, x = 0.39$
$8.59 + .39 = 8.98$

Body $= 56 : 94 = .7 : x, x = 1.18$
$6.8 + 1.18 - = 7.98$

Na_2O

Feldspar $= 62 : 94 = 2.98 : x, x = 4.52$
$8.98 + 4.52 = 13.50$

MgO

Kaolin $= 40 : 94 = .14 : x, x = .33$
$1.71 + .33 = 2.04$

By the above calculations we have obtained the following sums:

	Body.	Kaolin.	Feldspar.	Quartz.
SiO_2...........	68.50	45.78	71.65	98.64
Al_2O_3.........	23.82	37.33	16.16	1.17
K_2O...........	7.98	2.04	13.50	0.09
Loss on ignition.	....	15.45	.35	.06

$X \times SiO_2$ x in kaolin $+y$ in feldspar $+z$ in quartz.

$X \times Al_2O_3$ x in kaolin $+y$ in feldspar $+z$ in quartz.

$X \times K_2O$ x in kaolin $+y$ in feldspar $+z$ in quartz.

Then

$$x45.78+y71.65+z98.64=68.50$$

$$x37.33+y16.16+z\ 1.17=23.82$$

$$x\ 2.04+y13.50+z\ .09=\ 7.98$$

$$45.78x+71.65y+98.64z=68.50\ldots\ (1)$$
$$37.33x+16.16y+\ 1.17z=23.82\ldots\ (2)$$
$$2.04x+13.50y+\ 0.09z=\ 7.98\ldots\ (3)$$

$\times 1.2263595$ [(2) → (4)]; $\times 18.290196$ [(3) → (6)]

$$45.78x+71.65000y+98.64000z=68.50000 \quad (1)$$
$$45.78x+19.81796y+\ 1.43484z=\ 29.21188 \quad (4)$$
$$51.83204y+97.20516z=\ 39.28812 \quad (5)$$

$\times 4.5432516$ [(5) → (8)]

$$37.33x+247.03676y+1.64691z=146.0261764 \quad (6)$$
$$37.33x+\ 16\ 16\ \ y+1.17\ \ z=\ 23.82 \quad (2)$$
$$230.87676y+\ .47691z=122.2061764 \quad (7)$$

$$230.87676y+432.98338z=175.0020614 \quad (8)$$
$$230.87676y+\ \ .47691z=122.2061764\ \ldots\ (7)$$
$$432.50647z=\ 52.7958850\ \ldots\ (9)$$
$$z=.1220693\ \ldots\ (10)$$

$$\left.\begin{array}{l}230.87676y+(.47691x\ .1220693)=122.2061764\\ 230.87676y+.05821606=122.2061764\end{array}\right\}\quad(7)$$

$$y=\ .5290613\ \ldots\ldots\ (11)$$

$$\left.\begin{array}{l}2.04x+(13.50\times.5290613)+(.09\times.1220693)=7.98\\ 2.04x+7.14232755+.01098623=7.98\end{array}\right\}\quad(3)$$

$$2.04x=.82668622\ \ldots\ldots\ (12)$$

$$x=.405238\ \ldots\ldots\ (13)$$

$$x=.41+y=.53+z=.122=1.062\ \ldots\ldots\ (14)$$

$$230.87676y = .5290613 \quad . \quad . \quad . \quad . \quad (12)$$

$$2.04x + 7.14232755 + .01098623 = 7.98 \quad . \quad . \quad . \quad . \quad (3)$$

$$2.04x = .826687 \quad . \quad . \quad . \quad . \quad . \quad . \quad (13)$$

$$x = .405238 \quad . \quad . \quad . \quad . \quad . \quad . \quad (14)$$

$$x = .41 + y = .53 + z = .122 = 1.062$$

$$x = \frac{100 \times .41}{1.062} = 38.60\% \text{ kaolin}$$

$$y = \frac{100 \times .53}{1.062} = 49.90\% \text{ feldspar}$$

$$z = \frac{100 \times .122}{1.062} = 11.49\% \text{ flint}$$

$$99.99\%$$

Example. We wish to build up a body as follows: clay substance (C.s.) 50 per cent; feldspar substance (F.s.) 25 per cent; quartz (SiO_2) 25 per cent.

A and B raw material on hand:

	A		B	
C.s. =	94.12	+	24.94	= 50
F.s. =	.30	+	42.64	= 25
SiO_2 =	5.58	+	32.42	= 25

(1 part of A and x part of B)

$$.9412 + x(2494) = 2(.003) + x(.4264)$$

$$.9412 + .2494x = .006 \quad + 8528x$$

$$.8528 - .2494x = .9412 \quad - .006$$

$$.6034x = .9352$$

$$x = 1.55$$

Clay substance from A	.9412
Clay substance from B = (.2494 × 1.55)	.3870
	1.3282 C.s.
Feldspar substance from A	.0030
Feldspar substance from B	.6600
	.6630 F.s.
SiO_2 from A	.0558
SiO_2 from B = (.3242 × 1.55)	.5040
	.5598 SiO_2

.6630 = feldspar substance
.5598 = SiO_2 in A and B

.1032 = SiO_2 to be added

Result = 1 part of A
1.55 parts of B
.1032 part of SiO_2

2.6532

$$\frac{1 \times 100}{2.65} = 37.75\% \text{ of A}$$

$$\frac{1.55 \times 100}{2.65} = 58.49\% \text{ of B}$$

$$\frac{.1032 \times 100}{2.65} = 3.76\% \ SiO_2 \text{ to be added}$$

100.00%

Example. We wish to build up a body which shall contain 70 per cent clay substance, 18 per cent feldspar substance and 12 per cent quartz.

The raw materials on hand are as follows:

	x	y	z
Clay substance.......	61.50+	72.80+	70.30
Feldspar substance....	20.85+	14.29+	12.46
Quartz..............	2.65+	8.26+	2.27

$$\text{C.s.} = 61.50x + 72.80y + 70.30z = 70$$

$$\text{F.s.} = 20.85x + 14.29y + 12.46z = 18$$

$$SiO_2 = 2.65 + 8.26 + 2.27z = 12$$

$$61.50x + 72.80y + 70.30z = 70.000$$

$$106.218x + 72.80y + 64.393z = 91.699$$

$$-44.718x \quad 5.907z = 21.699$$

$$20.85x + 14.29y + 12.64z = 18.00$$

$$4.584x + 14.29y + 3.80z = 10.76$$

$$16.266x \quad 8.84z = 7.24$$

$$44.718x + 5.907z = 21.699$$

$$44.718x + 24.336z = 18.932$$

$$30.243z = 2.767$$

$$z = .0915$$

$$-44.718x + .5405 = 21.699$$

$$-44.718x = 22.2395$$

$$x = .5$$

$$1.325 + 8.26y + .208 = 12$$

$$8.26y = 10.467$$

$$y = 1.267$$

$x = .5$

$y = 1.267$

$z = .0915$

$x = \frac{100 \times .5}{1.8585} = \quad 26.90\%$

$y = \frac{100 \times 1.267}{1.8585} = \quad 68.18\%$

$z = \frac{100 \times .0915}{1.8585} = \quad 4.92\%$

100.00%

We have the following raw materials on hand, A and B, which contain:

	A	B
Clay substance...........	60.45	78.36
Feldspar substance.......	3.10	12.35
Lime as ($CaCO_3$).........	13.25	
Quartz....................	23.00	9.29
	100.00	100.00

We wish to prepare a stoneware body from the above to have the following composition:

Clay substance......................	60.00
Feldspar substance..................	15.00
Lime as (CaO).......................	4.00
Quartz..............................	21.00

It is necessary first to calculate the quantity of CaO, but A contains the CaO as $CaCO_3$ so we must determine first how much $CaCO_3$ is needed to introduce 4 per cent CaO.

$$CaCO_3 + \text{heat} = CaO + CO_2$$
$$56 + 44$$

$$\underset{CaO}{56} : \underset{CaCO_3}{100} = 4 : x, \quad x = \frac{100 \times 4}{56} = 7.14.$$

This contains

$$x = \frac{7.14 \times 44}{100} = 3.14\%\ CO_2, \quad x = \frac{7.14 \times 56}{100} = 3.99\%\ CaO$$

Now to obtain 7.14 pounds of $CaCO_3$ from A.

$$x = \frac{7.14 \times 100}{13.25} = 53.88$$

It will require 53.88 pounds of A to yield 4 per cent of CaO.

These 53.88 pounds will introduce into the mixture as follows:

$$x = \frac{53.88 \times 60.45}{100} = 32.57\%\ \text{clay substance}$$

$$x = \frac{53.88 \times 3.10}{100} = 1.67\%\ \text{feldspar substance}$$

$$x = \frac{53.88 \times 13.25}{100} = 7.14\%\ \text{lime as } (CaCO_3)$$

$$x = \frac{53.88 \times 23.20}{100} = 12.50\%\ \text{quartz}$$

$$53.88\%$$

Subtracting from the required 60 per cent clay substance $-32.57=27.43$ which clay substance has to be furnished from B.

$$x=\frac{27.43\times 100}{78.36}=35 \text{ pounds from B}$$

This will introduce the following ingredients:

$$X=\frac{35\times 12.35}{100}=4.32\% \text{ feldspar substance}$$

$$x=\frac{35\times 9.29}{100}=3.25\% \text{ quartz}$$

$$x=\frac{35\times 78.36}{100}=27.43\% \text{ clay substance}$$

35.00%

Adding up all the results:

$27.43+32.57=60\%$ clay substance required

$15-(4.32+1.67)=9.01$ feldspar to be added

$21-(12.50+3.25)=5.25\%$ SiO_2 to be added

53.88 pounds from A
35.00 pounds from B
9.01 pounds feldspar to be added
5.25 pounds SiO_2

103.14

Subtracting the 3.14 of CO_2, $103.14-3.14=100.00$, which makes the mixture exactly 100 per cent.

Example. We wish to mix a stoneware body with the following substance: Clay substance, 48 per cent; feldspar substance, 15 per cent; quartz substance, 37 per cent.

We have the following two raw clays on hand:

	x	y
Clay substance	80	45
Feldspar substance	15	42
Quartz	37	13
	100	100

Taking 32 per cent clay substance from x:

$$y=\frac{32\times 100}{80}=40 \text{ pounds.}$$

This will introduce

$$x=\frac{40\times 15}{100}=6 \text{ pounds } SiO_2$$

and

$$x=\frac{40\times 5}{100}=2 \text{ pounds feldspar substance.}$$

We now take 16 per cent clay substance from y.

$$y=\frac{16\times 100}{45}=36 \text{ pounds.}$$

This will introduce into the mixture,

$$y=\frac{36\times 42}{100}=15.12 \text{ pounds } SiO_2$$

and

$$y=\frac{36\times 13}{100}=4.68 \text{ pounds feldspar substance.}$$

Adding all of this together we have $15-(4.68+2)=8.32$ pounds of feldspar substance to add and $37-(15.12+6)=15.88$ pounds SiO_2.

Clay substance................	48.00
Feldspar substance............	6.68
Feldspar substance to add.....	8.32
Quartz....................	21.12
Quartz to add..............	15.88
	100.00

Example. We wish to obtain 100 pounds from the above raw material A and B for a body which should contain 50 per cent clay substance regardless of feldspar quartz, etc.

$$1 \text{ part } A + xB = (1+x) \text{ pounds}$$

$$.9412 + .2494x = 5(1+x)$$

$$.9412 + .2494x = 5 + .5x$$

$$.2506x = .4412$$

$$x = 1.7605$$

1.000 pound of A+1.7605 pounds of B=2.7605 pounds

$$x = \frac{100 \times 1}{2.7605} = \quad 36.22 \text{ pounds of A}$$

$$x = \frac{100 \times 1.7605}{2.7605} = \quad 63.78 \text{ pounds of B}$$

$$100.00$$

Or rounding up the figures to 36+64=pounds.

Example. We have on hand two different clays, one containing 60 per cent and the other 80 per cent clay substance. We wish to make a body mixture of 100 pounds containing 65 per cent clay substance.

$$x = 100(65-60)(80-60)$$

$$x = \frac{100 \times 5}{20} = 25 \text{ pounds from } 80\%$$

$$100 - 25 = 75 \text{ pounds from } 60\%$$

Proof:

$$\frac{25\times 80}{100}=20\%\text{ clay substance}$$

$$\frac{75\times 60}{100}=45\%\quad\text{"}\quad\text{"}$$

$$65\%$$

Example. *We wish to synthetise a glaze from the following formula:*

.15 K_2O		2.85 SiO_2
.15 Na_2O		.30 B_2O_3
.25 CaO	.38 Al_2O_3	
.45 PbO		
.11 ZnO		

An examination of this formula indicates that this glaze cannot well be used without fritting. Glazes containing Na_2O and K_2O in proportion as above, cannot be found in any feldspar, therefore the Na_2O must be introduced with (Na_2CO_3) or borax ($Na_2B_4O_7 \cdot 10H_2O$).

Assume the following raw materials to be on hand for compounding the above formula:

Boric oxide (B_2O_3) mol. w. 70, feldspar (K_2O, Al_2O_3, $6SiO_2$) mol. w. 556, whiting (CaO, CO_2) mol. w. 100, sodium carbonate (Na_2O, CO_2) mol. w. 106, kaolin (Al_2O_3, $2SiO_2$, $2H_2O$) mol. w. 258, red lead (Pb_3O_4) mol. w. 658, zinc oxide (ZnO) mol. w. 81, flint (SiO_2) mol. w. 60.

All of the bases of RO will be taken to fritt as follows:

Construct a chart of squares by drawing as many vertical lines as there are ingredients of the raw material to be mixed, and also the same number of horizontal lines.

FRITT

Fritt Formula.	K_2O .15	Na_2O .15	CaO .15	ZnO .11	Al_2O_3 .38	SiO_2 2.85	B_2O_3 .30
$\frac{.30\ B_2O_3 \times 70}{1} = 21.00$							
$\frac{.15\ K_2O \times 556}{1} = 83.40$	.15	....	....	....	.15	.90	
$\frac{.15\ Na_2O \times 106}{1} = 15.90$	.15						
$\frac{.15\ CaO \times 100}{1} = 15.00$			.15				
$\frac{.11\ ZnO \times 81}{1} = 8.91$	....	....	....	.11			
144.21 weight of fritt					−.23	−1.95	

.15 Al_2O_3 and .90 SiO_2 were introduced in the feldspar which must be subtracted from the original formula:

$$\frac{102 \times .15}{102} = .15\ Al_2O_3, \quad \frac{360 \times .15}{60} = .90\ SiO_2$$

.38−.15=.23 Al_2O_3 has to be added in the kaolin.

2.85−.90=1.95 has to be added as at first.

.15 of CaO was mixed in the fritt, leaving .10 of CaO still to be added to the glaze mixture.

We proceed with the calculation of the glaze exactly as above:

GLAZE

Glaze Formula.	CaO .10	PbO .45	Al_2O_3 .23	SiO_2 1.95
$\frac{.10\ CaO \times 100}{1} = 10$	.10			
$\frac{.45\ PbO \times 685}{3} = 102.75$	......	.45		
$\frac{.230\ Al_2O_3 \times 258}{1} = 59.34$	......	......	.23	.46
$\frac{1.49\ SiO_2 \times 60}{1} = 89.40$	......	......	......	1.49
Total............	......	......	......	1.95

261.49 weight of the glaze.

Assembling all results:

SiO_2...... .46+1.49+.90..... 2.85
Al_2O_3..... .23+ .15.........., .38
CaO...... .15+ .10.......... .25
K_2O...... .15................ .15
Na_2O..... .15................ .15
PbO...... .45................ .45
ZnO...... .11................ .11
B_2O_3..... .30................ .30

Mixing a fritt from the following formula representing Cone No. .014:

.5 Na_2O	.5 Al_2O_3	3.0 SiO_2
.5 PbO		1.0 B_2O_3

Name, Molecular Weight and Required Weight.	Na_2O .5	PbO .5	Al_2O_3 .5	SiO_2 3.00	B_2O_3 1.00
$\frac{.5\ PbO \times 222\ M.v.}{1} = 191$		.5			
$\frac{1\ Na_2B_4O_7\ 10H_2O \times 382\ M.v.}{1} = 191$	.5	.....	.....	.....	1.00
$\frac{.5\ Al_2O_3 \times 258\ M.v.}{1} = 129$	.....	.....	.5	1.00	
$\frac{3\ SiO_2 \times 60\ M.v.}{1} = 180$	.....	....	...	2.00	
Batch weight.............611.0	.5	.5	.5	3.00	1.00

Example. A mixture of window glass is to be compounded from the following raw material on hand and with the following proportions in weight:

Sand	= 1000 pounds
Limestone	= 400
Sodium sulphate	= 400
Coal	= 25
	1825 pounds

What will be the glass composition in percentage and the chemical formula after it is fused?

The coal will be completely volatilized and the SO_3 driven off from the sodium sulphate and the CO_2 from the limestone. The whole 1000 pounds of silica will enter into the glass, if the silica sand is pure.

400 pounds of limestone will give:

$$\begin{matrix} (CaCO_3 = & CaO - & CO_2) \\ 100 = & 56 - & 44 \end{matrix} \quad \frac{400 \times 56}{100} = 224 \text{ pounds } CaO$$

and 400 pounds of sodium sulphate:

$$\begin{matrix} (Na_2SO_4 = & Na_2O - & SO_3) \\ 142 = & 62 - & 80 \end{matrix} \quad \frac{62 \times 100}{142} = 43.7\% \ Na_2O$$

therefore it will require:

$$\frac{400 \times 43.7}{100} = 175 \text{ pounds } Na_2O$$

This sums up	1000 pounds	SiO_2
	224	CaO
	175	Na_2O
	1399 pounds	

To calculate the percentage of the glass composition:

$$1000 \ SiO = \frac{1000}{1399} = 71.48\% \ SiO_2$$

$$224 \ CaO = \frac{224}{1399} = 16.00\% \ CaO$$

$$175 \ NaO = \frac{175}{1399} = 12.52\% \ Na_2O$$

and the chemical formula is then as follows:

$71.48 : 60 = 1.1913 \ SiO_2$

$16.00 : 56 = 0.2857 \ CaO \qquad \left.\begin{matrix} 0.2857 \ CaO \\ 0.2020 \ Na_2O \end{matrix}\right\} 1.1913 \ SiO_2$

$12.52 : 62 = 0.020 \ Na_2O$

The loss of raw material is as follows:

$$\frac{1399 \times 100}{1825} = 76.7 \text{ pounds}$$

or

$$76.7 \div 1825 = 4.2\%$$

LIMITED VALUE FOR COMPOUNDING GLAZES

Hollow green or bottle glaze:

(Na_2O or K_2O) from 0.1 to 0.3 (CaO, MgO, MnO, Fe_2O_3, Al_2O_3) 1.00	SiO from 2.2 to 2.6

Hollow white glaze:

(Na_2O or K_2O) from 0.8 to 1.5 or 2.0 (CaO) 1.0 (Fe_2O_3 Al_2O_3) 1.0	SiO_2 from 4.95 to 9.7 or 15.00

Plate glaze:

(Na_2O or K_2O) from 0.6 to 1.0 (CaO)1.0 (Al_2O_3 Fe_2O_3) 1.0	SiO_2 from 4.1 to 6.00

Lead glaze crystals:

(Na_2O or K_2O) from 0.3 to 1.0 (PbO) 1.0	SiO_2 from 3.3 to 6.0

Flint glaze:

(K_2O) from 0.245 to 3.36 (PbO) 1.00	SiO_2 from 1.45 to 15.15 B_2O_3

Window glass: Na_2O, CaO, 6 SiO_2, 75.0 SiO_2, 12.9 Na_2O, 11.6 CaO.

Potassium lead glass: K_2O, PbO, 6 SiO, 53.2 SiO_2, 13.9 K_2O, 32.9 PbO.

Potassium glass: K_2O, CaO, 6 SiO, 70.6 SiO_2, 18.4 K_2O, 11.0 CaO.

Green bottle glass: 66.0 SiO_2, 2.8 K_2O, 2.8 Na_2O, 22.9 CaO, 2.7 Al_2O_3, Fe_2O_3 2.8.

Jenear glass: 67.3 SiO_2, 2.0 B_2O_3, Na_2O 14.0, CaO 7.0 O 7.0, Al_2O_3 2.5, Mn_2O_3 0.3.

This glass mixture will melt at Cone No. 022 to 020.

0.10 NaO 0.15 KO 0.75 PbO	0.15 AlO	2.5 SiO 0.4 BO
0.30 NaO 0.20 KO 0.50 PbO	0.15 AlO	2.55 SiO 0.45 BO
0.20 NaO 0.30 KO 0.50 PbO	0.15 AlO	2.55 SiO 0.45 BO

This mixture will melt at cone 020 to 018.

0.15 NaO 0.15 KO 0.60 PbO 0.10 BaO	0.15 AlO	2.45 SiO 0.45 BO
0.15 NaO 0.15 KO 0.60 PbO 0.10	0.15 AlO	2.45 SiO 0.50 BO
0.10 NaO 0.15 KO 0.65 PbO 0.10 BaO	0.15 AlO	2.50 SiO 0.40 BO

This mixture will melt at cone 015.

0.8 PbO 0.2 BaO	0.15 AlO	2.50 SiO 0.40 BO
0.9 PbO 0.1 BaO	0.15 AlO	2.50 SiO 0.40 BO

(Berdel, Sprechsaal, 1905, No. 8–11.)

Enamel is vitreous, easily fusible, translucent, or opaque glass, applied on metals, or as a glaze on pottery bodies.

When employed as a coating on the surface of iron or tin, to protect it from rust and corrosion against acids or other chemical agencies, specially cooking utensils, the base of the enamel is usually a transparent glaze in which metallic oxides or salts are in suspension, which render the enamel opaque or semi-opaque and of various colors.

The white or milky enamel is usually produced by the addition of tin oxide, antimony oxide, bone ash, cryolite, etc.

Wondracek * gives the following limited value for ground enamels for cast iron.

$$\left.\begin{array}{l} 0.7-0.5\ Na_2O \\ 0.15-0.3\ K_2O \\ 0.15-0.2\ CaO \end{array}\right\}\ 0.25-0.5\ Al_2O_3$$

$$\left.\begin{array}{l} 0.5-0.8\ B_2O_3 \\ 5.0-9.1\ SiO_2 \end{array}\right\}\ 0.1\ Ca_3(PO_4)_2$$

ENAMEL FOR CAST IRON

$$\left.\begin{array}{l} 0.3-1.0\ Na_2O \\ 0.7-0.0\ CaO \end{array}\right\}\ \begin{array}{l} 0.0-2.0\ B_2O_3 \\ 2.6-6.3\ SiO_2 \end{array}$$

WHITE ENAMEL FOR CAST IRON

$$\left.\begin{array}{l} 0.5-0.7\ Na_2O \\ 0.2-0.3\ K_2O \\ 0.3-0.0\ CaO \end{array}\right\}\ 0.15-0.35\ Al_2O_3 \left\{\begin{array}{l} 0.5-1.1\ B_2O_3 \\ 2.0-3.1\ SiO_2 \\ 0.0-0.03\ F_2 \end{array}\right.$$

* Sprechsaal Kalender 1911, pp. 38–39.

White Enamel for Tin

$$\left.\begin{array}{l} 0.45\text{–}0.7\ Na_2O \\ 0.15\text{–}0.3\ K_2O \\ 0.4\text{–}0.0\ MgO \end{array}\right\}\ 0.0\text{–}0.55\ Al_2O_3\ \left\{\begin{array}{l} 0.15\text{–}0.7\ B_2O_3 \\ 2.0\text{–}4.3\ SiO_2 \\ 0.0\text{–}0.8\ F_2 \\ 0.3\ \text{–}\ \ SnO_2 \end{array}\right.$$

White Enamel for Iron Tiles

$$\left.\begin{array}{l} 0.6\ PbO \\ 0.3\ Na_2O \\ 0.1\ K_2O \end{array}\right\}\ 0.1\ Al_2O_3\ \left\{\begin{array}{l} 0.6\ B_2O_3 \\ 0.5\ SiO_2 \end{array}\right.$$

White Enamel for Jewelry

$$\left.\begin{array}{l} 0.0\text{–}0.8\ Na_2O \\ 0.0\text{–}0.2\ CaO \\ 1.0\text{–}0.0\ PbO \end{array}\right\}\ \begin{array}{l} 0.0\text{–}1.0\ B_2O_3 \\ 1.0\text{–}7.0\ SiO_2 \\ 0.0\text{–}3.5\ SnO_2 \end{array}$$

White Enamel for Copper

$$\left.\begin{array}{l} 0.4\text{–}0.9\ K_2O \\ 0.6\text{–}0.1\ PbO \end{array}\right\}\ \begin{array}{l} 0.0\text{–}0.2\ SnO_2 \\ 1.0\text{–}1.2\ SiO_2 \end{array}$$

Shaw gives the following limits for ground enamel:*

$$\left.\begin{array}{l} 0.15\text{–}0.75\ K_2O \\ 0.00\text{–}0.60\ Na_2O \\ 0.14\text{–}0.64\ CaO \\ 0.00\text{–}0.06\ CoO \\ 0.00\text{–}0.00\ MnO_2 \end{array}\right\}\ 0.1\text{–}0.5\ Al_2O_3\ \left\{\begin{array}{l} 1.1\text{–}1.7\ SiO_2 \\ 0.2\text{–}0.5\ B_2O_3 \end{array}\right.$$

Shaw gives the following formula for a cover enamel:

$$\left.\begin{array}{l} 0.15\ K_2O \\ 0.50\ Na_2O \\ 0.35\ CaO \end{array}\right\}\ 0.10\ Al_2O_3\ \left\{\begin{array}{l} 1.60\ SiO_2 \\ 0.30\ B_2O_3 \end{array}\right.$$

* Trans. American Ceramic Society, 1909, Vol. 9.

$$\left.\begin{array}{l}0.0\text{–}0.60\ K_2O\\ 0.0\text{–}0.65\ Na_2O\\ 0.2\text{–}0.60\ CaO\end{array}\right\}\ 0.0\text{–}0.5\ Al_2O_3\ \left\{\begin{array}{l}1.0\text{–}1.8\ SiO_2\\ \\ 0.2\text{–}0.5\ B_2O_3\end{array}\right.$$

Grunwald * gives the following white cover for enameled kitchen utensils:

$$\left.\begin{array}{l}0.195\ K_2O\\ 0.683\ Na_2O\\ 0.122\ CaO\end{array}\right\}\ 0.34\ Al_2O_3\ \left\{\begin{array}{l}0.571\ B_2O_3\\ 2.315\ SiO_2\\ 1.390\ F_2\\ 0.235\ SnO_2\end{array}\right.$$

Cover White Enamel on Cast Iron

$$\left.\begin{array}{l}0.19\ K_2O\\ 0.80\ Na_2O\\ 0.01\ MgO\end{array}\right\}\ 0.36\ Al_2O_3\ \left\{\begin{array}{l}0.42\ B_2O_3\\ 0.516\ SiO_2\\ 0.16\ SnO_2\\ 0.99\ F_2\end{array}\right.$$

* Enamel Industry, p. 207.

COLORS

Color effects are applied by incorporating the colors directly with the body, or by applying them on the surface of the body before glazing—by spraying or with brush, or by mixing the colors with the glaze or enamel, then spraying or dipping the articles.

The following colors are most commonly used in ceramics:

Iron. Red, brown, at moderate oxidizing atmosphere. Violet, bluish, greenish, and blackish in reducing atmosphere at high temperature.

Manganese. Brownish, violet, deep black mixed with cobalt or iron.

Cobalt. Blue, black, gray, mixed with zinc gives ultramarine blue, with manganese deep black, also purple.*

Chromium. Green, bright green with calcium or borax glaze, bluish green in glazes containing alkalies, yellow in reducing atmosphere. If applied on other bodies as white produces a muddy effect. The slightest quantity of iron darkens the color. The colors are very much affected by the influence of the atmospheric conditions inside the kiln at firing.

Uranium. Yellow in oxidizing atmosphere, orange yellow, green and black in reducing atmosphere; very bright yellow when mixed with plumbiferrous glazes in oxidizing atmosphere.

Copper. Black, green, intense green in boric or plumbiferrous glazes in reducing firing. Bluish green

* Trans. A. C. S., Vol. 14, 1912.

in alkaline glazes in oxidizing firing, the only blue is given by the cupric silicates, purple in reducing atmosphere, also red. Copper is usually used in glazes vitrified at a moderate temperature.

Antimony. Yellow, when mixed with lead or with iron, gives different tints. Alone imparts no color to the glazes and is used for opacifying.

Titanium. Yellow in different tints with varying amount of iron.

Lead. Yellow when lead chromate is used.

Nickel. Yellowish, greenish, also blue or purple.*

Silver Chloride. Yellowish, it is seldom used alone, except in addition to purple of cassius.

Gold. Applied in different ways, as dull or brilliant gold, in different tints of violet, purple as (Cassius purple) rose.

Platinum. Silver, gray or black, it resists great heat as does gold.

Iridium. Gray to black.

Zinc. Imparts no color to glass and is used mostly as an opacifying agent the same as antimony.

It should be borne in mind that all the colors in bodies or glazes are confined within certain limits of temperature and are affected by atmospheric conditions inside of the kiln. Faulty fires may make the colors vary or possibly destroy them.

The properties of the different metallic oxides must be understood thoroughly in order to know the temperatures at which they fuse or volatilize. The low fusing colors will run together with the refractory colors at high heat.

* A. C. S., Vol. 14, 1912.

Metallic combinations produce the following colors:

Oxide of chromium, green.
Oxide of iron, red, brown, violet, black, gray, yellow tints.
Oxide of uranium, orange, yellow, black.
Oxide of manganese, violet, brown, black.
Oxide of cobalt, blue, gray, black.
Oxide of antimony, yellow, different tints.
Oxide of titanium, yellow.
Oxide of copper, green suboxide of copper, red.
Sesquioxide of iridium, beautiful black.
Protochromate of iron, brown.
Chromate of lead (and chromate of baryta), yellow.
Chloride of silver, as an addition to carmine and purple.
Purple of Cassius, purple.

ANALYSIS OF KNOWN REFRACTORY CLAYS

REFRACTORY CLAYS

	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	TiO_2
Olive Hill, Ky., plastic clay	44.52	40.81	1.03	0.62	0.55	0.00	0.00	0.00
Olive Hill, Ky., flint	43.38	40.35	0.85	0.88	0.23			
Strasburgh, O.	55.87	41.39	1.60	0.40	0.30	0.29	0.20	0.45
Woodbridge, N. J.	56.80	21.83	1.57	0.28	0.24	0.24	....	1.15
Woodbridge, N. J.	47.75	35.83	1.85	0.22	0.18	0.67	0.98	
Carter Co., Ky.	68.01	24.09	1.01	3.01	....	....	....	
Clarion Co., Pa.	44.61	38.01	1.25	0.08	0.41	1.74	....	1.02
St. Louis, Mo.	46.27	27.06	4.45	1.00	1.05	1.89	....	3.85
St. Louis, Mo.	45.45	38.98	1.42	0.20	0.32	0.83	....	0.49
Stourbridge, Eng.	73.82	15.88	2.95	....	....	0.90	....	
Glenboig, Scotland	65.41	30.55	1.70	....	....	....	....	1.33
Coblentz, Germany	55.40	31.74	0.59	0.19	0.14	2.94	0.68	
La Bauchade, France	53.40	26.40	4.20	0.69	0.64	0.55		
Jacksonville, Ala.	38.92	44.62	0.36	0.14	1.04	0.08		
Fire clay for open hearth furnace	44.50	42.50	0.50	1.00	0.50			
For zinc retorts	49.50	34.50	1.50	0.50	0.50			

The chemical composition of different porcelain bodies after firing, shown by the following table of analysis:

	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O
Vienna	61.5	31.6	0.8	1.8	1.4	2.2
Berlin	66.6	28.0	0.7	0.3	0.6	3.4
Meisen	57.7	34.2	0.8	0.3	Tr.	5.2
Vienna	59.6	34.2	0.8	1.7	1.4	2.0
Nymphenburg	72.8	18.4	2.5	3.3	0.3	0.6
China vase	70.5	20.7	0.08	0.05	0 1	6 0
Paris	58.0	34.5	....	4.5	....	3.0
Sevres	59.6	32.6	0.6	4.5	....	2.0
Seger	77.2	17.2	....	0.3	0.2	3.8
English	39.9	21.5	....	10.6	....	2.1
English	40.6	24.1	....	14.2	0.4	5.3
Limoges	66.7	21.6	0.5	0.6	0.4	2.9
Japan	74.5	16.9	1.0	0.1	0.3	4.4
American electrical insulation	63.7	29.5	0.2	0.3	0.2	5.3

	Na_2O	TiO_2	Loos.	Bone.	Analyst.
Vienna	0.0	0.0	0.0	....	Laurent
Berlin	....	....	....	....	"
Meisen	....	....	....	....	"
Vienna	....	....	....	....	Seger
Nymphenburg	1.8	....	....	....	"
China vase	....	....	....	....	Laurent and Malaguti
Paris	....	....	....	....	"
Sevres	0.7	....	....	....	Seger
Seger	0.8	....	....	....	"
English	....	....	....	26.44	Cowper
English	....	....	....	15.32	"
Limoges	1.6	....	5.54	....	Seger
Japan	1.8	....	2.83	....	"
American electrical insulation	0.5	0.1	....	....	Author

THE RELATION OF FORMULA QUANTITIES TO PERCENTAGE COMPOSITION

Analysis of a sample of .500 gm. of feldspar gives .1165 mgm. of mixed chlorides of KCl and NaCl and then .2649 gm. of K_2PtCl_6. What is the percentage of K_2O and Na_2O in feldspar?

The factor for converting K_2PtCl_6 to KCl is .3065. Multiplying this factor by the weight of the precipitate we have $.2649 \times .3065 = .08119185$ mgm. of KCl. Subtracting this weight of KCl from the total weight of the mixed chloride we have $.1165 - .0812 = .0353$ mgm. for weight of the NaCl.

The factor for converting KCl to K_2O is .6320. Multiplying the result by the weight of KCl obtained above we have: $.0812 \times .6320 = .05131840$ mgm. of K_2O. Dividing the weight of the sample taken (.500 mgm.) and multiplying by 100 we have:

$$.0513184 \div 500 = 0.1026 \times 100 = 10.26\% \ K_2O$$

Calculating for the Na_2O we use the factor .5308 and we have: $.0353 \times .5308 = .01873724$ mgm.

Dividing by the weight of the sample taken and multiplying by 100 we have

$$.01873724 \div .500 = 0.0375 \times 100 = 3.75\% \ Na_2O.$$

Example. A sample of clay analyses gave .220 mgm. $BaSO_4$, how much S is present in 1 gm. of the sample?

Converting $BaSO_4$ to S we have to multiply by the factor .13756, then multiply the result by 100, and this gives $.220 \times .13756 = .03026320 \times 100 = 3.03\%$ S.

Example. One gram of clay analyzed 3 per cent of SO_3. How much of $BaCO_3$ must be taken to convert the SO_3 into $BaSO_4$ and how much $BaSO_4$ is produced?

$$BaCO_3+SO_3=BaSO_4+CO_2$$

$$197 \quad +80 \quad =233 \quad +44$$

80 : 3 = 233 : x, x = 8.74% of $BaSO_4$ is produced and requires:

$$233 : 159 = 8.74 : x, \; x = 5.96 \text{ of } BaCO_3.$$

When $BaCl_2$ is used:

$$BaCl_2+SO_3+O=BaSO_4+Cl_2$$

$$244 \; +80 \; +16=233 \quad +73$$

80 : 3 = 244 : x, x = 9.105 per cent of $BaSO_4$ is produced and requires 244 : 137 = 9.105 : x, x = 5.112 per cent of $BaCl_2$ to convert the SO_3 into $BaSO_4$.

Example. One gram of limestone yielded on analysis .5505 mgm. of CaO. Calculate the purity of the sample.

$$x=\frac{.5505\times 100}{1}=55.01\% \text{ CaO}$$

Theoretically:

$$CaCO_3=CaO+CO_2$$

$$100= \; 56 \; - \; 44$$

$$56 : 56 = 100 : x, \quad x = 56\%$$

Example. One gram of limestone when analyzed yielded .5234 mgm. of CaO. What percentage of CaO and $CaCO_3$ is present in the sample and what is the percentage of CO_2?

$$x=\frac{.5234\times 100}{1}=52.34\% \text{ CaO}$$

$$x=\frac{52.34\times 100}{56}=93.46 \; CaCO_3$$

$$x=\frac{93.46\times 44}{100}=41.12 \; CO_2$$

Calculating the molecular formula of the following feldspar from its analysis:

SiO_2 =	65.53	$65.33 \div 60 = 1.0922 \div .1738 = 6$
Al_2O_3 =	18.12	$18.12 \div 102 = .1776 \div .1738 = 1$
K_2O =	16.35	$16.35 \div 94 = .1738 \div .1738 = 1$
	100.00	$K_2O \quad Al_2O_3 \quad 6SiO_2$

Calculating the formula of a glaze which has the following analysis:

Silica	60.00
Alumina	6.50
Boracic acid	6.50
Lead oxide	10.25
Lime	7.25
Potash	5.25
Soda	4.25
	100.00

$SiO_2 = 60.00 \div 60 = 1.0000$

$Al_2O_3 = 6.50 \div 102 = .0637$

$B_2O_3 = 6.50 \div 70 = .0929$

$PbO = 10.25 \div 222 = .0461$

$CaO = 7.25 \div 56 = .0129$

$K_2O = 5.25 \div 94 = .0559$

$Na_2O = 4.25 \div 62 = .0685$

$PbO = .0461$
$CaO = .0129$
$K_2O = .0559$
$Na_2O = .0685$

.1834

$$1.0000 \div .1834 = 5.453 = SiO_2$$
$$.0637 \div .1834 = .347 = Al_2O_3$$
$$.0929 \div .1834 = .507 = B_2O_3$$
$$.0461 \div .1834 = .251 = PbO$$
$$.0129 \div .1834 = .070 = CaO$$
$$.0559 \div .1834 = .305 = K_2O$$
$$.0685 \div .1834 = .374 = Na_2O$$

$$\left.\begin{array}{l} .251\ PbO \\ .070\ CaO \\ .305\ K_2O \\ .374\ Na_2O \end{array}\right\} .347\ Al_2O_3 \left\{\begin{array}{l} 5.453\ SiO_2 \\ .507\ B_2O_3 \end{array}\right.$$

CALCULATION OF PERCENTAGE COMPOSITION OF A COMPOUND

Finding the percentage composition of cone number 4.

$$\left.\begin{array}{l} 0.3\ K_2O \\ 0.7\ CaO \end{array}\right\} 0.5\ Al_2O_3,\ 4\ SiO_2$$

$$(94 \times .3 = 28.2\ K_2O) + (56 \times .7 = 39.2\ CaO)$$
$$+ (102 \times .5 = 51.0,\ Al_2O_3) + (60 \times 4 = 240\ SiO_2) = 358.4$$

$$K_2O = \frac{28.2 \times 100}{358.4} = 7.87\%$$

$$CaO = \frac{39.2 \times 100}{358.4} = 10.94\%$$

$$Al_2O_3 = \frac{51.0 \times 100}{358.4} = 14.23\%$$

$$SiO_2 = \frac{240 \times 100}{358.4} = 66.96\%$$

$$100.00$$

Example. A feldspar has the following formula, K_2O, Al_2O_3, $6SiO_2$. *What is the percentage composition?*

$$K_2O = \frac{94 \times 100}{556} = 16.91\%$$

$$Al_2O_3 = \frac{102 \times 100}{556} = 18.34\%$$

$$SiO_2 = \frac{360 = 100}{556} = 64.75\%$$

$$100.00$$

Calculating the percentage of potash alum from the following formula:

$$K_2SO \cdot Al_2(SO_4) + 24H_2O = \text{m.w. } 948$$

$$x = \frac{78 \times 100}{948} = 8.23\% \text{ K}$$

$$x = \frac{128 \times 100}{948} = 13.50\% \text{ S}$$

$$x = \frac{54 \times 100}{948} = 5.70\% \text{ Al}$$

$$x = \frac{640 \times 100}{948} = 67.51\% \text{ O}$$

$$x = \frac{48 \times 100}{948} = 5.06\% \text{ H}$$

$$100.00$$

Example. In order to compound 45 pounds of lead chromate, how much of pure lead oxide (litharge) (PbO), and potassium bichromate (K_2CrO_7) should be used?

$$K_2Cr_2O + 2PbO = (PbCrO_4)_2 + K_2O$$

$$295 + \frac{2 \times 222}{444} = \frac{2 \times 323}{646} + 94$$

$$646 : 45 = 295 : x, \; x = 20.55 \; K_2Cr_2O_7$$

$$646 : 45 = 444 : x, \; x = 30.93 \; PbO$$

Example. Fifteen grams of ferrous sulphide (FeS) treated with sulphuric acid (H_2SO_4) will yield how many grams of ferrous sulphate ($FeSO_4$), and of hydrogen sulphide (H_2S). How many grams of sulphuric acid will be required?

$$FeS + H_2SO_4 = FeSO_4 + H_2S$$

$$88 + 98 = 152 + 34$$

$$88 : 152 = 15 : x, \quad x = 24.77 \text{ gms. of } FeSO_4$$

$$88.34 = 15 : x, \quad x = 5.8 \text{ gms. of } H_2S$$

$$88 : 98 = 15 : x, \quad x = 16.70 \text{ gms. of } H_2SO_4$$

CONTRACTION

Example. A dry-press brick when it left the mold measured

$8\frac{1}{2} \times 4\frac{5}{16}''$ } after it was burned { $8\frac{1}{82} \times 4\frac{1}{16}''$
8.500×4.3125 } it measured { 8.125×4.0625

What percentage did it shrink?

$8.500 - 8.125 = .375$, $8.500 : 100 = .375 : x$, $x = 4.41$ per cent shrinkage.

Example. We wish to make a porcelain tube for electric insulation. It should measure 2 inches in diameter. The body is known to shrink 8 per cent. What should be the size of the mold to make a 2-inch tube?

$$100 - 8 = 92, \quad 92 : 100 = 2 : x, \quad x = 2.173 \text{ inches}$$

Example. A brick weighing 5 pounds and 4 ounces when molded, after it was dried weighed 4 pounds 8 ounces, and after it was burned weighed only 4 pounds. What is the percentage loss in weight drying and in burning? What was the total loss?

Convert pounds into ounces.

$$x = \frac{(84 - 72) \times 100}{84} = 14.28\%$$

$$x=\frac{(72-64)\times 100}{72}=11.11\%$$

$$x=\frac{(84-64)\times 100}{84}=23.81\%$$

Example. It is desired to make a slab of the following dimensions, length 18 inches, width 16 inches, thickness 4 inches.

Our body has a shrinkage of 12 per cent. What size must the mold be built to have the above dimensions after the slab is burned?

$1.00-.12=\ .88$

Then

$18.00\div .88=20.4540$ inches in length

$16.00\div .88=18.1818$ inches in width

$4.00\div .88=\ 4.545$ inches in thickness

Proof:

$20.4540\times .12=2.4540 \quad 20.4540-2.4540=18$

$18.1818\times .12=2.1818, \quad 18.1818-2.1818=16$

$4.545\times .12=\ .545, \quad 4.545-.545=4$

CALCULATING THE VALUE OF RAW MATERIAL

Example. Two kinds of feldspar are received from the mill both ground wet. One contained 5 per cent moisture, the other 8 per cent moisture.

The feldspar containing 5 per cent cost $15.00 per ton. What is the other feldspar containing 8 per cent moisture worth?

$$100-5=95, \quad 100-8=92.$$

$$\frac{92\times 15}{95}=\$14.52$$

CALCULATING THE PER CENT AND COST OF THE RAW MATERIAL

A piece of terra cotta was made from the following formula: Clay substance 50 per cent, feldspar 20 per cent, calcium oxide (CaO) 5 per cent, and quartz 25 per cent, and weighed 700 pounds.

The raw material on hand from which the above formula should be mixed is as follows:

	Clay, Per Cent.	Feldspar, Per Cent.	Flint. Per Cent.	Chalk. Per Cent.
Clay substance	94	6		
Feldspar	....	83		
Chalk	....	....	....	100 as ($CaCO_3$)
Quartz	6	11	99.98	
	100	100	99.98	100

Then

$$x=\frac{20\times 100}{83}=24.1 \text{ pounds feldspar}$$

This will introduce the following:

$$x=\frac{24.1\times 6}{100}=1.45\% \text{ clay substance}$$

$$x=\frac{24.1\times 11}{100}=2.65\% \text{ quartz.}$$

Subtracting: $50-1.45=48.55$ per cent of clay substance has to be taken from the clay.

$$x=\frac{48.55\times 100}{94}=51.65 \text{ pounds of clay.}$$

This will bring into the mixture:

$$x=\frac{51.65\times 6}{100}=3.1\% \text{ of } SiO_2$$

$2.65 - 3.1 = 5.75$ SiO_2 which has to be subtracted from the amount of the 25 per cent SiO_2 required in the formula.

$25 - 5.75 = 19.25$ pounds of SiO_2 has to be added to the mixture as flint and 9 pounds of chalk.

$$x = \frac{5 \times 100}{56} = 9 \text{ pounds.}$$

This will introduce,

$$x = \frac{44 \times 9}{100} = 3.96\% \ CO_2 \text{ or } 4\%$$

$$x = \frac{56 \times 9}{100} = 5.04\% \ CaO \text{ or } 5\%$$

How much will the body mixture cost for the above terra cotta piece, when the clay costs \$8.00 per ton, feldspar \$12.00, and chalk \$9.00, and flint \$14.00

We used for the body mixture 24.1 pounds of feldspar, 48.55 pounds of clay, and 9 pounds of whiting, and 19.25 pounds of flint. Cost per 100 pounds terra cotta=

$$\frac{24.1 \times 12}{2000} + \frac{51.65 \times 8}{2000} + \frac{19.25 \times 14}{2000} + \frac{9 \times 9}{2000} = 53 \text{ cents}$$

or

$$\frac{(24.1 \times 12) + 51.65 \times 8) + (19.25 \times 14) + (9 \times 9)}{2000} = 53 \text{ cents}$$

per 100 pounds

As the piece weighs 700 pounds it has to be multiplied by 7.

$\therefore$ $7 \times .53 = 3.71$, the raw material entered in the piece will cost \$3.71. Had the piece only weighed 7 pounds, it would have cost $.07 \times .53 = \$0.0371$.

CALCULATIONS OF SLIP

A slip is known to contain the following quantities:

Ball clay	24 ounces per pint
Kaolin	26 "
Feldspar...........	32 "
Flint...............	32 "

To convert the ounces per pint to grams per liter multiply the number of ounces per pint by 5 (1 pint = 5.5 deciliter, as 2 pints make 1.10 liters we discard the .5 and multiply only by 5) as follows:

Ball clay...	24 ounces per pint $\times 5 = 1200$ gms. per liter
Kaolin.....	26 ounces per pint $\times 5 = 1300$ "
Feldspar....	32 ounces per pint $\times 5 = 1600$ "
Flint.......	32 ounces per pint $\times 5 = 1600$ "

If we wish to know the depth of the slip in the slip tank. Assuming that the above proportions are mixed in dry state as follows:

Ball clay = 2 parts

Kaolin = 1 part

Feldspar = 1 "

Flint = 1 "

Then the wet inches may be found as follows:

$$\text{Ball clay} = \frac{2}{(24-20)} = \frac{1}{2} \text{ wet inch}$$

$$\text{Kaolin} = \frac{1}{(26-20)} = \tfrac{1}{6} \text{ wet inch}$$

$$\text{Feldspar} = \frac{1}{(32-20)} = \tfrac{1}{12} \quad \text{"}$$

$$\text{Flint} = \frac{1}{(32-20)} = \tfrac{1}{12} \quad \text{"}$$

To convert the above fractions into round numbers multiply all by twelve, then:

Ball clay = 6

Kaolin = 2

Feldspar = 1

Flint = 1

To convert wet inches to dry parts by weight:

$(24-20)\times 6 = 24$ parts by weight of ball clay			
$(26-20)\times 2 = 12$	"	"	kaolin
$(32-20)\times 1 = 12$	"	"	feldspar
$(32-20)\times 1 = 12$	"	"	flint

Example. To mix 5000 liters of slip for sanitary ware, what will be its weight when the following receipt is used?

Kaolin = 40%	which as a slip weighs		1.300 kgs.	to liter
Ball clay = 16%	"	"	1.200	"
Feldspar = 20%	"	"	1.600	"
Flint = 24%	"	"	1.600	"

$$\frac{(1.300 \times 40) \times 5000}{100} = 2600 \text{ kilograms}$$

$$\frac{(1.200 \times 16) \times 5000}{100} = 960 \text{ ``}$$

$$\frac{(1.600 \times 20) \times 5000}{100} = 1600 \text{ ``}$$

$$\frac{(1.600 \times 24) \times 5000}{100} = 1920 \text{ ``}$$

Total . . . . . . 7080 kilograms

To determine the dry contents of the above slip apply the following methods:

Stir up the slip well and transfer 100 c.c. of it into a graduated glass cylinder, which must be filled with slip exactly to the 100 c.c. mark.

Then transfer the slip from the cylinder into a weighed porcelain evaporating dish. (Be careful to wash all mineral particles from the cylinder into the dish.)

Place the dish in drying oven and heat gently to 105° C. until all the water is driven off. Allow to cool and weigh. Subtract the weight of the dish. The remainder is the weight of the dry slip.

For instance 100 c.c. of slip was transferred into a dish, which weighed 65 gms. After the moisture was all driven off the dish and contents weighed 125 gms. Subtracting the weight of the dish from 125−65=60 gms. which is the weight of the dry materials present in the slip and the water weighed 40 gms.

We will now be able to find the proportion of the kaolin, ball clay, feldspar and flint, as follows:

$$x=\frac{40\times 60}{100}=24.0\% \text{ kaolin}$$

$$x=\frac{16\times 60}{100}=9.6\% \text{ ball clay}$$

$$x=\frac{20\times 60}{100}=12.0\% \text{ feldspar}$$

$$x=\frac{24\times 60}{100}=14.4\% \text{ flint}$$

60.0
40.0% water

100.0

CALCULATING 1HE REFRACTORY VALUE OF FRE CLAY

Bischoff's formula $Qu=\frac{a^2}{bc}$ for determining the refractory value of a fire clay.

Professor Bischoff derived the refractory coefficient by the relation of Al_2O_3 to the fluxes and the relation of SiO_2 to the Al_2O_3 and by dividing the latter into the former he obtained the refractory quotient.

$$Qu=\frac{\text{O in } Al_2O_3}{\text{O in RO}}\div\frac{\text{O in } SiO_2}{\text{O in } Al_2O_3}$$

In this formula the O in RO must be multiplied by 3.

$$\therefore\quad Qu=\frac{\text{O in } Al_2O_3}{3\times\text{O in FeO}}\div\frac{\text{O in } SiO_2}{\text{O in } Al_2O_3}$$

$$=\frac{(\text{O in } Al_2O_3)}{(3\times\text{O in FeO})\times(\text{O in } SiO_2)}.$$

As an example, assuming a clay containing 48.5 per cent SiO_2, 38 per cent Al_2O_3, and 1.5 per cent Fe_2O_3.

The first step in the calculation is to convert the Fe_2O_3 into its equivalent in FeO by multiplying by .9 which will give $1.5 \times .9 = 1.35$ per cent FeO. Now the oxygen in the SiO_2 is 25.87 per cent $(48.5 \times .5333)$.

The oxygen in FeO is .3 per cent $(1.5 \times .222)$.

The oxygen in Al_2O_3 is 17.88 per cent $(38 \times .4706)$.

The oxygen in Al_2O_3 is 17.28 per cent $(38 \times .4706)$.

Then

$$Qu = \frac{(17.28)^2}{(.9 \times 25.87)} = \frac{298.59}{23.28} = 12.82$$

12.82 is the refractory quotient which, after Bischoff, is very good.

Bischoff classified the clay after its refractory quotient as follows:

A clay with a refractory quotient from 2 to 4 is placed as a third-class ware, a coefficient from 4 to 6 second-class, and from 6 to 14 as a first-class. This, however, is not exact, as it does not take into consideration the physical characters of the clay as the size of grains, or density or porosity. But it is fairly good for a quick knowledge of the ware for many commercial purposes.

The following analysis of fire clay is shown to exemplify the above.*

SiO_2	= 59.92
Al_2O_3	= 27.56
Fe_2O_3	= 1.03
CaO	= Tr.
MgO	= Tr.

* Ries, "Clays, Their Occurrence and Properties."

K_2O = .67

Na_2O = Tr.

H_2O = 9.70

Moisture = 1.12

To find the refractory quotient of the above clay proceed as follows:

$59.92 \times .5333 = 31.96\%$ O in SiO_2

$27.56 \times .4706 = 12.97\%$ O in Al_2O_3

the square of $(12.97)^2 = 168.5009$

$(1.03\ Fe_2O_3 \times .222) = .228866\%$ O in FeO

$(0.67\ K_2O \times .1702) = .114034\%$ O in K_2O

$(.23\ FeO + .11\ K_2O) = .34\%$ in $RO \times 3 = 1.02$

$(31.96 \times 1.02) = 32.59$

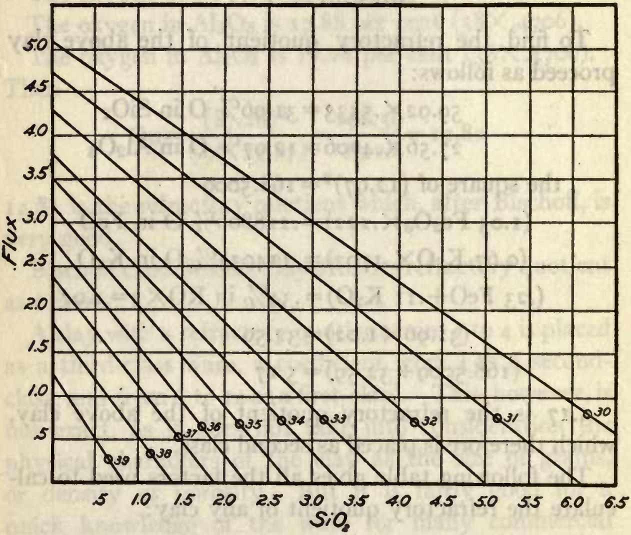
$(168.5009 \div 32.59) = 5.17$

5.17 is the refractory quotient of the above clay, which therefore is placed as second class.

The following table gives all the factors used to calculate the refractory quotient of any clay:

O in SiO_2	$= \times .5333 = \frac{32}{60}$	$= .5333$	factors
O in Al_2O_3	$= \times .4706 = \frac{48}{102}$	$= .4706$	"
O in FeO–Fe_2O_3	$= \times .2222 = \frac{160}{72}$	$= .2222$	"
O in CaO	$= \times .2857 = \frac{16}{56}$	$= .2857$	"
O in MgO	$= \times .4000 = \frac{16}{40}$	$= .4000$	"
O in MnO	$= \times .2254 = \frac{16}{70}$	$= .2254$	"
O in K_2O	$= \times .1702 = \frac{16}{94}$	$= .1702$	"
O in Na_2O	$= \times .2580 = \frac{16}{62}$	$= .2580$	"
O in TiO_2	$= \times .4000 = \frac{32}{80}$	$= *.4000$	"

The originator of the following chart was the German scientist, Ludwig, who based the refractory value of clay more according to modern chemical theories as follows.



Ludwig's isotectic lines of refractory clays.

The following analysis, made by the author, is of a clay from St. Louis, Mo.:

SiO_2	= 46.47
Al_2O_3	= 27.06
Fe_2O_3	= 4.45
CaO	= 1.00
MgO	= 1.05
Alk.	= 1.89

$$\left\{\begin{array}{ll} TiO_2 & = 3.85 \\ SO_3 & = .51 \end{array}\right.$$

Moisture = 13.72

The following gives the method for the calculations:

$$Al_2O_3 = \frac{27.06}{102} = .2653, \quad \frac{.2653}{.2653} = 1$$

$$SiO_2 = \frac{46.47}{60} = .7745, \quad \frac{.7745}{.2653} = 2.92$$

$$Fe_2O_3 = \frac{4.45}{80} = .0556, \quad \frac{.0556}{.2653} = .0209$$

$$CaO = \frac{1.00}{56} = .0178, \quad \frac{.0178}{.2653} = .0671$$

$$MgO = \frac{1.05}{40} = .0262, \quad \frac{.0262}{.2653} = .0987$$

$$K_2O = \frac{1.89}{94} = .0201, \quad \frac{.0201}{.2653} = .0757$$

$$TiO_2 = \frac{3.85}{80} = .0481, \quad \frac{.0481}{.2653} = .0181$$

The following calculation shows the equivalent of the basic to the acidic which is really very useful to clay workers:

$$\left.\begin{array}{l} 2.9200\ SiO_2 = \times 2 = 5.8400 \\ 0.0181\ TiO_2 = \times 2 = 0.0362 \end{array}\right\} \text{acid equivalent}$$

$$5.8762$$

$$\left.\begin{array}{lll} 0.2415\ RO & = \times 2 = & 0.4830 \\ 1.0000\ Al_2O_3 & = \times 6 = & 6.0000 \\ 0.0209\ Fe_2O_3n & = \times 6 = & 0.1254 \end{array}\right\}\text{basic}$$

$$\overline{6.6084}$$

$$\frac{5.8762}{6.6084} = 0.8892$$

This shows that 6.6084 of basic are contained 0.8892 times in the 5.8762 acidic equivalents and also gives us an idea of the proportion of RO, R_2O_3 to SiO_2.

CEMENT

The essential ingredients of Portland cement are silica, alumina, calcium. Usually other ingredients in small quantities are present, as iron oxide, magnesia, sulphur anhydride, and alkalies.

Bleininger gives the following proportions for Portland cement:

$$SiO_2 = 18 \text{ to } 26\%$$

$$Al_2O_3 = 4 \text{ to } 5\%$$

$$Fe_2O_3 = 2 \text{ to } 5\%$$

$$CaO = 58 \text{ to } 67\%$$

$$MgO = 0 \text{ to } 5\%$$

$$Alk. = 0 \text{ to } 3\%$$

$$SO_3 = 0 \text{ to } 2.5\%$$

The product of Portland cement is obtained from a mixture of argillaceous and calcareous substances ground fine and thoroughly mixed then burned to incipient vitrification. The clinker so obtained is then ground to an impalpable powder.* W. B. Newberry shows that the Portland cement consists of tricalcium silicate, and dicalcium aluminate, the composition being expressed by the following formula:

$$3\ CaO \cdot SiO_2 + 2\ CaO \cdot Al_2O_3$$

* Eckel, "Cements and Limes and Plaster."

To synthetize a mixture of Portland cement the following method for calculation is convenient:

$$\underset{(3\times 56)+60}{3CaO \cdot SiO_2} = \frac{56\times 3}{60} = 2.8$$

This shows that to every pound of SiO_2 2.8 pounds of CaO must be present to form tricalcium silicate.

$$2.8 \text{ pounds } CaO = \frac{2.8\times 100}{56} = 5 \text{ pounds of } CaCO_3$$

Therefore 5 pounds of $CaCO_3$ must be present to every pound of SiO_2 if the lime is calculated as $CaCO_3$.

$$\underset{(2\times 56)+102}{2CaO \cdot Al_2O_3} = \frac{56\times 2}{102} = 1.1 \text{ pounds to every pound of}$$
Al_2O_3

1.1 pound of CaO must be present to form decalcium aluminate.

$$1.1 \text{ pounds } CaO = \frac{1.1\times 100}{56} = 1.96 \text{ pounds of } CaCO_3.$$

It is more convenient to calculate all the way through by using the equivalent of $CaCO_3$.

As for example: The raw materials on hand from which the Portland cement should be compounded are the following:

	Cement Rock. Per Cent.	Limestone. Per Cent.
SiO_2	18.84	1.98
Al_2O_3	6.04	.85
Fe_2O_3	1.50	.35
$CaCO_3$	71.12	96.42
$MgCO_3$	2.50	.60

LIMESTONE

$CaCO_3$ needed for 1.98 pounds SiO_2 in limestone
= 1.98×5 = 9.90 $CaCO_3$
$CaCO_2$ needed for .65 pound Al_2O_3 in
limestone = .65×1.96 = 1.27

11.17 $CaCO_3$

$CaCO_3$ present in limestone.................... 96.42
$CaCO_3$ needed for $SiO_2+Al_2O_3$ present in limestone.................................. 11.17

$CaCO_3$ available.................. 85.25

CEMENT ROCK

$CaCO_3$ needed for 18.84 pounds SiO_2 present in rock
= 18.84×5 = 94.20 $CaCO_3$
$CaCO_3$ needed for 6.04 pounds Al_2O_3
present in rock = 6.04×1.96 = 11.84

106.04 $CaCO_3$

106.04 pounds of $CaCO_3$ needed for the present of SiO_2 $-Al_2O_3$ in the cement rock.................. 106.04
$CaCO_3$ present in the cement rock........... 71.12

$CaCO_3$ required to every 100 pounds of rock... 34.92

To every 100 pounds of cement rock 40.96 pounds of lime has to be added.

Therefore $\frac{34.92\times 100}{85.25} = 40.96$ lbs.
available $CaCO_3$ from limestone
of limestone will contain as follows:

100 : 1.98 = 40.90 : x, $x-00.81$ SiO_2

100 : 0.65 = 40.96 : x, $x-00.27$ Al_2O_3

100 : 0.35 = 40.96 : x, $x-00.14$ Fe_2O_3

100 : 96.42 = 40.96 : x, $x-39.49$ $CaCO_3$

100 : 0.60 = 40.96 : x, $x-00.25$ $MgCO_3$

40.96 pounds

The raw mixture will analyze as follows:

39.49 pounds $CaCO_3$ from limestone + 71.12 pounds $CaCO_3$ present in the cement rock = 110.61 pounds CaCO.

100 pounds of cement rock + 40.96 of limestone = 140.96 pounds of mixture. Therefore

140.96 : 110.68 = 100 : x, $x = 78.47\%$ $CaCO_3$

This mixture after being burned should give an analysis, theoretically, as follows:

SiO_2 from limestone 0.81 +
18.84 from cement rock = 19.65 pounds SiO_2

Al_2O_3 from limestone 0.27 +
6.04 from cement rock = 6.31 pounds Al_2O_3

Fe_2O_3 from limestone 0.14 +
1.50 from cement rock = 1.64 pounds Fe_2O_3

$CaCO_3$ from limestone 71.12 +
39.49 from cement rock = 110.61 pounds $CaCO_3$

$MgCO_3$ from limestone 2.50 +
0.60 from cement rock = 3.10 pounds MgCO

141.31 pounds

110.61 pounds of $CaCO_3$ give 61.94 pounds of CaO, and 46.67 pounds of CO_2 which is driven off by heat.

$100 : 110.61 = 44 : x, \quad x = 48.67$ pounds of CO_2.
$100 : 110.61 = 56 : x, \quad x = 61.94$ pounds of CaO

110.61 pounds

3.10 pounds of $MgCO_3$ give 1.48 pounds MgO and 1.62 pounds of CO_2.

$84 : 3.10 = 40 : x, \quad x = 1.48$ pounds of MgO
$84 : 3.10 = 44 : x, \quad x = 1.62$ pounds of CO_2

3.10 pounds

As the CO_2 is driven off from $CaCO_3$ and $MgCO_3$ then, theoretically, the analysis will be as follows:

$SiO_2 = 19.65 : 91.02 = x : 100, \quad x = 21.58\%$ SiO_2

$Al_2O_3 = 6.31 : 91.02 = x : 100, \quad x = 6.94\%$ Al_2O_3

$Fe_2O_3 = 1.64 : 91.02 = x : 100, \quad x = 1.81\%$ Fe_2O_3

$CaO = 61.94 : 91.02 = x : 100, \quad x = 68.04\%$ CaO

$MgO = 1.48 : 91.02 = x : 100, \quad x = 1.63\%$ MgO

91.02 100.00%

By the above calculation the highest amount of lime is given under the best possible working conditions, by grinding, mixing and burning and therefore the limestone should be reduced about 10 per cent. (See Eckel, Cement and Plaster, page 393.)

COST OF MANUFACTURE OF CERAMIC BODIES

Example. A piece of porcelain body was made for electric insulation, the raw material used for compounding the body was as follows:—

32	pounds of	China clay
15	"	ball clay
23	"	flint
30	"	feldspar
100	pounds	

The piece after it was drawn from the kiln weighed 50 pounds.

The China clay lost 25 per cent during firing and cost \$12.00 per ton.

The ball clay lost 28 per cent during firing and cost \$10.00 per ton.

The flint lost 5 per cent during firing and cost \$15.00 per ton.

The feldspar lost 12 per cent during firing and cost \$14.00 per ton.

It is desired to determine the cost of manufacture and the proportions of the raw materials that entered into the piece weighing 50 pounds, and what the cost of the raw material was.

$100 - 25\%$ lost $= 75\%$ China clay

$100 - 28\%$ " $= 72\%$ ball clay

$100 - 5\%$ " $= 95\%$ flint

$100 - 12\%$ " $= 88\%$ feldspar

$\frac{75 \times 32}{100} = 24.00$ pounds China clay

$\frac{72 \times 15}{100} = 10.80$ " ball clay

$\frac{95 \times 23}{100} = 21.85$ " flint

$\frac{88 \times 30}{100} = 26.40$ " feldspar

83.05 pounds

$\frac{25 \times 32}{100} = 8.00$ " lost in kiln of China clay

$\frac{28 \times 15}{100} = 4.20$ " " ball clay

$\frac{23 \times 5}{100} = 1.15$ " " flint

$\frac{12 \times 30}{100} = 3.60$ " " feldspar

100.00 pounds

Fifty pounds has therefore required the following number of pounds of the raw materials:

$\frac{24.00 \times 50}{83.05} = 14.45$ pounds China clay

$\frac{10.80 \times 50}{83.05} = 6.51$ " ball clay

$\frac{21.85 \times 50}{83.05} = 13.15$ " flint

$\frac{26.40 \times 50}{83.05} = \frac{15.89}{50.00}$ " feldspar

The cost of the raw material should be calculated as it arrives at the plant.

Therefore:

$$\frac{24.00 \text{ bbls.} \times \$12.00 \text{ per ton}}{1 \text{ ton } 2000 \text{ bbls.}} = \$0.144$$

Cost of China clay which entered into the 50 bbls.

$$\frac{10.80 \text{ bbls.} \times \$10.00 \text{ per ton}}{1 \text{ ton } 2000 \text{ bbls.}} = 0.054$$

Cost of ball clay which entered into the 50 bbls.

$$\frac{21.85 \text{ bbls.} \times \$15.00 \text{ per ton}}{1 \text{ ton } 2000 \text{ bbls.}} = 0.154$$

Cost of flint stone which entered into the 50 bbls.

$$\frac{26.40 \text{ bbls.} \times \$14.00 \text{ per ton}}{1 \text{ ton } 2000 \text{ bbls.}} = 0.185$$

$$\$0.537$$

Cost of feldspar which entered into the 50 bbls.

Say 0.54 cent is the cost of the raw material required to produce the insulating piece weighing 50 pounds.

The above prices on all the raw material are figured as at mill, and therefore the freight has to be added as incoming and outgoing freight.

Incoming freight of

China clay,	$0.08	per 100 lbs.	= $1.60	per ton	(2000 lbs.)
Ball clay,	0.08	"	= 1.60	"	"
Flint stone,	0.09	"	= 1.80	"	"
Feldspar,	0.09	"	= 1.80	"	"

Incoming freight:

24.00 bbls.	China clay	× $.08	per 100 lb.	=	.0192
10.80 "	ball clay	× .08	"	=	.0080
21.85 "	flint stone	× .09	"	=	.0197
26.40 "	feldspar	× .09	"	=	.0238
					.0707

Outgoing freight on finished product: 0.17 per 100 pounds,

$$\frac{.17 \times 50}{100} = .08\tfrac{1}{2}$$

The whole sums up $3.19 \times .50\% = 1.60$. $\$3.19 + \$1.60 = \$4.79$.

The charge of 50 per cent for overhead would seem to be high but on pieces that are very difficult to make and pack for transportation the overhead is sometimes figured at as high as 100 or 125 per cent. The loss in handling and burning should be calculated, therefore in charging the overhead expenses at 50 per cent it is not high.

The raw material for the 50 pounds cost......	$0.54
The incoming freight for the 50 pounds cost...	0.07
Outgoing freight for the 50 pounds cost......	0.08½
Cost of production for the 50 pounds is......	2.50
Overhead charges including lost 50 per cent...	1.60
Total cost..........................	$4.795

The finished insulator will weigh 50 pounds and cost four dollars and eighty cents ($4.80).

CALCULATION OF B.t.u. OF COAL FROM PROXIMATE AND ELEMENTARY ANALYSIS

The only reliable and accurate method of ascertaining the calorific power of coal is by direct determination by burning in compressed oxygen in a bomb calorimeter. When this is impossible an approximation to the calorific power may be calculated from the chemical analysis so that clay workers may know how much they pay for their coal.

Comparison of many experiments has resulted in several methods of estimating the calorific value of coals from the proximate analysis. Three well known formulas and methods are known as the Dulong, Mahler, and Goutal formulas.

To prove the accuracy of these formulas the author made two different analyses from the Latham Coal Mine at Lincoln, Illinois. The analysis was performed from 1000 pounds of nut coal, which, as is usually done, was powdered and quartered. 1.5 gms. of the powdered coal was placed in a 26 c.c. platinum crucible then put in a drying oven and heated for twenty-five minutes at 105° C., then cooled in a desiccator. The following weights were recorded:

Crucible, cover and coal...............	26.257 gms.
Crucible and cover....................	24.757 "
	1.500 gms.

Crucible, cover and coal before drying . .	26.257 gms.
Crucible, cover and coal after drying . . .	26.032 "
Moisture	0.225 gm.

Per cent of moisture $\frac{.225 \times 100}{1.5} = 15\%$

The crucible with the dry coal contents was heated over a Bunsen burner for four minutes, then over the blast lamp for three minutes then cooled in the desiccator.

Crucible, cover and coal before heating . .	26.032 gms.
Crucible, cover and coal after heating. . . .	25.492
Volatile and combustible matter, one-half sulphur	0.540 gm.

Per cent of volatile and combustible matter and one-half sulphur

$$\frac{0.540 \times 100}{1.5} = 36\%$$

Crucible, cover and coal before complete combustion	25.492 gms.
Crucible, cover and coal after complete combustion	24.932 "
Fixed carbon and one-half sulphur . . .	0.560 gm.

Per cent of fixed carbon and one-half sulphur

$$\frac{0.560 \times 100}{1.5} = 37.3\%$$

Crucible, cover and coal after complete

combustion (ash)	24.932 gms.
Crucible and cover	24.757 "
Ash	0.175 gm.

Per cent of ash $\frac{0.175\times 100}{1.5}=11.67\%$

The sulphur was determined by taking 1 gm. of the finely powdered coal mixed with 10 gms. of sodium carbonate and 5 gms. of potassium nitrate and placed in a platinum crucible in small portion, heated to red heat for ten minutes, cooled and the contents with the crucible placed into a beaker containing 100 c.c. of water then warmed until the mass dissolved. The crucible was then removed from the beaker and washed with hot water, the washing allowed to run into the beaker. The solution was then filtered and acidified with hydrochloric acid, boiled and then barium chloride solution was added in slight excess; this was allowed to stand twelve hours; filtered, washed, dried, ignited and weighed as barium sulphate and calculated for sulphur.

Crucible, cover and residue of $BaSO_4$....	25.211 gms.
Crucible, cover and residue of $BaSO_4$....	24.757 "
	.454 gm.

Multiplied by the factor 0.1373 for sulphur

Per cent of sulphur $.1372\times .454\times 100=6.24\%$ S.

Volatile and combustible matter and one-half sulphur	36.00
Less one-half sulphur	3.12
Per cent of volatile matter	32.88

Fixed carbon and one-half sulphur..........	37.30
Less one-half sulphur........................	3.12
Per cent of fixed carbon...............	34.18

Hence the analysis is:

Moisture..................................	15.00%
Volatile and combustible matter............	32.88
Fixed carbon..............................	34.18
Sulphur..................................	6.24
Ash......................................	11.67
	99.97%

An elementary analysis of the same coal was made in the usual way in a combustion furnace.

Amount of coal taken..................	0.500	gm.
Calcium chloride tube and H_2O.........	42.184	"
Calcium chloride+tube.................	42.1584	"
H_2O............................	.0256	gm.

$$\frac{.0256\times 2}{18}=\frac{.0283\text{H}\times 100}{.500}=5.66\%\text{ H}$$

The potassium bulbs+CO_2.............	38.2954
The potassium bulbs..................	37.2370
CO_2............................	1.0584

$$\frac{1.0584\times 12}{44}=\frac{.2832\text{ C}\times 100}{.500}=56.64\%\text{ C}$$

Porcelain tube—residue (ash)..........	10.0473
Porcelain tube.......................	9.4638
Ash..........................	.5835

$$\frac{.5835\times 100}{.500}=11.67\%\text{ ash}$$

Coal taken (dried) .... .500 gm.
H_2SO_4 solution taken .... 30.000 c.c.
Normal soda solution required to neutralize
free acid .... 29.536 c.c.

H_2SO_4 .... .464 c.c.

Solution neutralized by the ammonia:

If 1 c.c. H_2SO_4 solution = 0.049 gm. H_2SO_4 then 0.464 c.c. $\times$ .049 = .0227 gm. H_2SO_4.

$$1.3466 \times .0227 = 0.0306$$

$$\frac{0.0306 \times 34}{132} = .00788 \text{ } NH_3$$

$$0.8235 \times .00788 = 0.00649 \text{ N}$$

$$\frac{.00649 \times 100}{.500} = 1.29\% \text{ N}$$

The constituents in the dried coal are:

C	= 56.64%
H	= 5.66
N	= 1.29
S	= 6.21
Ash	= 11.67
	81.47%

The oxygen is estimated by subtracting the sum of the other constituents from 100 as follows: 100 − 81.47 = 18.53.

$$
\begin{aligned}
C &= 56.64\% \\
H &= 5.66 \\
N &= 1.29 \\
S &= 6.21 \\
Ash &= 11.67 \\
O &= 18.53 \\
\hline
& \quad 100.00\%
\end{aligned}
$$

Thus far all but the moisture which is hygroscopic of the constituents in the dried sample have been accounted for.

This moisture in the coal since it absorbs heat is a direct loss in the calorific power.

Coal taken..........................	1.500 gms.
Watch glass and coal before drying for fifteen minutes at 105° C...........	16.356 "
Loss (moisture)................	.209 gm.

$$\frac{.209 \times 100}{1.5} = 13.93\% \text{ moisture}$$

The analysis including moisture is then as follows:

$100 : 56.64 = 13.93 : x.$	$x = 48.76\%$ C
$100 : 5.68 = 13.93 : x.$	$x = 4.88\%$ H
$100 : 1.29 = 13.93 : x.$	$x = 1.12\%$ N
$100 : 6.21 = 13.93 : x.$	$x = 5.34\%$ S
$100 : 11.67 = 13.93 : x.$	$x = 10.04\%$ Ash
$100 : 18.51 = 13.93 : x.$	$x = 15.93\%$ O
	13.93% H_2O
100.00	100.00

From the complete analysis of the coal, the heating value was calculated as follows, by Dulong's formula:

C = the percentage of carbon in the coal
H = " " hydrogen "
O = " " oxygen "
S = " " sulphur "
W = " " moisture "

Then

$$81\,C+290\left(H-\frac{O}{8}\right)+25\,S-6\,W$$

$48.76\times81=3949.56$

$15.93 : 8=1.99.\quad 4.88-1.99$
$=2.89.\quad 2.89\times290=738.10$

$5.34\times25=133.50$

$3949.56+738.10+133.50=4821.16$
$13.93\times6=\quad 83.58$
$=4737.58$ calories

$$\frac{4737.58\times9}{5}=8529.8 \text{ B.T.U.}$$

The heating value of the same sample after Mahlet's formula, whose proximate analysis is as above, fixed carbon 34.18 per cent, volatile matter 32.88 per cent, ash 11.67 per cent, moisture 15 per cent. The combustible portion amounts to $32.88+34.18=67.06$.

$$34.18\div.6706=51$$

Fixed Carbon in Coal, Dry and Free of Ash. Per Cent.	Heating Value per Pound of Combustible. B.T.U.
100	14,600
97	14,940
94	15,210
90	15,480
87	15,660
80	15,840
72	15,660
68	15,480
63	15,120
60	14,580
57	14,040
55	13,320
53	12,600
51	12,240

From the above table we find the nearest value for the combustible portion of this coal to have a heat value of 8208.14 B.T.U. Hence the heating value of the coal per pound is $12.240 \times .6706 = 8208.14$ B.T.U. with 321.66 B.T.U. less than in the former calculation.

Goutal gives the carbon a fixed value and considers the heat value of the volatile matter a function of its percentage referred to combustible, and evolves the following formula:

$$\text{B.T.U.} = 14{,}760\,C + AV$$

in which C = percentage of fixed carbon.

in coal A = variable depending on ratio;

R of volatile matter to combustible;

V = percentage of volatile matter in coal.

The value A corresponding to R for several values of V and C are given in the following table:

$R=\frac{V}{V+C}$	A
.05	26,1.0
.10	23,400
.15	21,060
.20	19,620
.25	18,540
.30	17,640
.35	16,920
.38	15,300
.40	14,400
.49	9,150

As the table is calculated only to .40 it was necessary to calculate the value of R to A at .49 by the following method:

$$\text{B.T.U.} = 14{,}760C + AV$$

$$8208.14 = 14{,}760 \times .3418 + A\ .3288$$

$$8208.14 = 5030 + .3288\,A$$

$$.3288\,A = 8208.14 - 5030$$

$$.3288\,A = 3178.14$$

$$A = 9.150$$

Now if this calculation is correct, then we have:

$$C = 34.18 \quad V - 32.88$$

Therefore

$$R = \frac{.3288}{.3418 = .3288} = .49$$

$$14{,}760 \times 34.18 - 9150 \times .3288 = 8053.99 \text{ B.T.U.}$$

Or

$$A = 8053.99 \text{ B.T.U.}$$

With 154.15 B.T.U. less than in the following calculations made after Mahler's formula, and with 475.81 B.T.U. less than the calculation made after Dulong's formula.

It can be clearly seen from the above that the calculations are very close and reliable and that the coal should be bought for its calorific value.

It is simpler to calculate the heat value of coal and the flame temperature by the following method:

The coal from Franklin County, Ill., has the following analysis:

Moisture	7.30%
Volatile matter	28.67
Fixed carbon	54.59
Ash	7.74
Sulphur	0.48
Nitrogen	1.22
	100.00%

Table of heating value given by J. J. Koch * are as follows:

			Heat Units per lb., in B.T.U.
C	burning to	CO_2	14,500
CO	"	CO_2	4,500
C	"	CO	4,000
H	"	water (vapor)	52,000
H	"	water (liquid)	62,032
S	"	SO_2	4,100

* The Clay Worker, 1913.

From the following chemical equation $C+O_2=CO_2$ it can be seen that 12 units by weight (grams, kilos, or ounces, pounds, or tons) require for complete combustion 32 units by weight of oxygen to produce CO_2.

The equivalent weights are as follows: $\frac{32}{12}$ or 2.667 pounds of oxygen+1 pound of C=3.667 pounds of CO_2.

The equivalent weight of C to CO is 12 pounds or C to 16 pounds of O=28 pounds of CO, $\frac{16}{12}$ or 1.333 pounds of oxygen+1 pound of C=2.333 pounds of CO.

And the equivalent of CO to CO_2 requires $\frac{16}{28}$ or 0.571 pounds of O+1 pound of CO=1.571 pounds of CO_2.

From the above table of heating values can be seen (as Koch states) that when burning 1 pound of C to CO 4000 B.T.U. is generated (8100 gram calories per gram of carbon) and weighs 2.333 pounds, if CO is burned to CO_2 4500 B.T.U. is given up thus producing $4500\times 2.333=10{,}498.500$ B.T.U. or 10,500 B.T.U. which when added to the 4000 B.T.U. produced by primary burning gives 14,500 B.T.U. just as C burns to CO_2.

Air Needed for Combustion

In air containing 23 per cent of oxygen and 77 per cent of nitrogen (Molinari) the equivalent of nitrogen to oxygen is $\frac{77}{23}$ or 3.335+1 pound O=4.335 pounds of air.

If the oxygen requirement should be figured only for CO to form CO_2, then 0.571 is multiplied by 4.335=2.475 pounds of air necessary.

When hydrogen is burned to water for every 2 pounds of hydrogen, 16 pounds of oxygen will be required or every pound of hydrogen will require 8 pounds of oxygen, $4.335 \times 8 = 34.68$ pounds of air.

To calculate the heating value of the above coal proceed as follows:

The volatile matter is usually calculated as marsh gas, CH_4, showing that 4 units by weight of H, to 12 units by weight of C, or $\frac{12}{4} = 3$, 3 of C to 1 of H. This will then change the 28.67 per cent of volatile matter into $28.67 : 4 = 7.14$ of H, and $28.67 - 7.17 = 21.50$ of C, and the analysis will be as follows:

Moisture	7.30%
Carbon (21.50+54.59)	76.09
Hydrogen	7.17
Ash	7.14
Sulphur	0.48
Nitrogen	1.22
	100.00%

Considering only hydrogen and carbon to be involved in generating heat by the combustion of 1 pound of fuel, the theoretical calculations will then give the following results:

$76.09 : 100 = 0.7609$ C burning to CO_2
$\times 14{,}500 = 11{,}033$ B.T.U.

$7.17 : 100 = 0.0717$ H burning to H_2O
$\times 52{,}000 = 3{,}728$ B.T.U.

14,761 B.T.U.

TABLE OF SPECIFIC HEAT *

Water	1.0000
Air	0.2375
Carbon (graphite)	0.160
Carbon at 977° C.	0.467
Carbon monoxide	0.2425
Carbon dioxide	0.2025
Hydrogen	3.4090
Nitrogen	0.2438
Sulphur dioxide	0.1544
Oxygen	0.2175
Coke, Ashes, Fire brick	0.2000
Superheated steam	0.4825

THEORETICAL TEMPERATURE

The following method after Koch will calculate the temperature with sufficient accuracy for commercial purposes: Divide the heat units developed by the combustion of 1 pound of the fuel by the number obtained by multiplying the weight of the product in pounds by its specific heat. For example:

Analysis of Coal.	Air Required for Combustion.	Weight of Prod. of Com.	Sp. Ht. of Gases.	Furnace Gases Times Sp. Ht.
H_2O = .0730	+	= 0.0730 H_2O	× .480	= 0.03504
H = .0717	+ 0.5738 oxygen	= 0.6453 H_2O	× .480	= 0.30974
C = .7609	+ 2.0293 oxygen	= 2.0293 CO_2	× .2025	= 0.41093
		8.6807 N	× .2438	= 2.11635
	Air required	11.2836		2.87206

* Hand-book of Chemistry and Physics.

Dividing the product of 14,761 B.T.U. obtained above by the product of 2.87206 = 5140° F.

But as it is the practice in commercial kiln firing to direct twice the amount of air that is necessary, then 11.2836 pounds of air × .2375 = 2.6799, adding this product to the product of 2.87206 = 5.55196.

Dividing again 14,761 by the product of 5.55196 = 2658° F. which is approximately the temperature of the products of combustion.

Heat Units

Converting Fahrenheit into Centigrade:

$$F = \tfrac{9}{5} = C + 32$$

and Centigrade into Fahrenheit:

$$C = \tfrac{5}{9}(F - 32)$$

Example. What temperature on the Centigrade scale is equal to 350° F.

$$\frac{(350-32)\times 5}{9} = 176.7\ \text{C.}$$

or

$$(350-32) \div 1.8 = 176.7\ \text{C.}$$

What temperature on Fahrenheit scale is equal to 100° C. (boiling point of water in centigrade)?

$\left(\frac{100\times 9}{5}\right) + 32 = 212$ (boiling point of water in Fahrenheit of $(100 \times 1.8) + 32 = 212$.

The *British thermal unit* (B.T.U.) is the quantity of heat required to raise the temperature of 1 pound of water 1° F. For instance we wish to raise 75 pounds of water from 60° F. to 150° F. we have to raise only 90° F. then and will require 75×90 = 6750 B.T.U.

The small *calorie* (denoted by cal.) represents the quantity of heat necessary to raise 1 gm. of water one degree Centigrade.

The *kilogram calorie* or large calorie (which is always abbreviated Cal. and is 1000 times larger than the small calorie) represents the quantity of heat necessary to raise the temperature of 1 kilogram of water one degree Centigrade.

To convert cal. into B.T.U. multiply the amount of cal. by 3.968 or by 2.2 and then by $\frac{9}{5}$. One kilogram = 2.2 pounds and $1° C. = \frac{9}{5} \times 1° F.$ Therefore 1 cal. $= 2.2 \times \frac{9}{5} = 3.968$ B.T.U.

Example: How many B.T.U. is 75 cal.

$$75 \times 3.968 = 297.6 \text{ B.T.U.}$$

or

$$\frac{(75 \times 2.2) \times 9}{5} = 297 \text{ B.T.U.}$$

reverse,

$$(297 \text{ B.T.U.} \times \tfrac{5}{9}) \div 2.2 = 75 \text{ cal.}$$

The *specific heat* of a substance is the number of small calories required to raise one gram of the substance one degree Centigrade; or the number of large calories (Cal.) to raise 1 Kgr. of the substance 1 degree Centigrade.

Example. The specific heat of a fire brick which weighs 3 kilograms is .2000. How many Cal. will it require to raise the heat to 800° C.?

Since it takes .2000 Cal. to raise one kilogram of the fire brick 1° C. then it will take $.2000 \times 3 \times 800$ to raise the fire brick to 800° C. $(.2000 \times 3) \times 800 = 480$

Cal. What will it be required in B.T.U.? $3 \times 2.2 = 6.6$ pounds brick weight, and $800°$ C. $= 1472°$ F.

$$\therefore \quad (.200 \times 6.6) \times 1472 = 1943.04 \text{ B.T.U.}$$

Example. A piece of terra cotta weighs 500 pounds and we wish to know how many heat units it will require to burn the piece from room temperature (60° F.) to 2100° F.—assuming that after the piece was dried it still contained 6 per cent moisture.

Knowing the analysis of the different ingredients in the mixture the specific heats of the elements and the temperature range, the number of heat units required may be readily calculated as follows:

Analysis.		Average Specific Heat.	Pounds.	
SiO_2..........	66	.2030	330	66.9900
Al_2O_3.........	18	.2143	90	19.2870
Fe_2O_3.........	3	.1138	15	1.7070
CaO..........	5	.1743	25	4.3575
MgO..........	1	.2440	05	1.2200
K_2O–Na_2O.....	4	.1650	20	3.3100
Imp..........	3	.1700	15	2.5500
			Total..	99.4215

To raise the temperature

$$2040° \text{ F.} \times 99.4215 = 202819.8600 \text{ B.T.U.}$$

To evaporate 30 pounds of water $= 1117.7 = 33531.0$ B.T.U.

To burn the above terra cotta piece will require $33531.0 + 202819.8600 = 236350.8600$ B.T.U.

Found *A*.	Sought *B*.	Factor Converting *A* into *B*.	Log.	Factor Converting *B* into *A*.	Log.
AgCl.....	Ag......	0.75216	87656	1.32870	12343
Al_2O_3....	Al......	0.53033	72455	1.88560	27545
Al_2O_3....	AlC.....	0.70646	84909	1.41550	15091
$AlPO_4$....	Al......	0.22193	34621	0.45060	65379
$BaSO_4$...	Ba.......	0.58851	76975	1.70100	23025
$BaSO_4$...	BaO....	0.65705	81756	1.52190	18240
$BaSO_4$....	$BaCO_3$...	0.84555	92714	1.18270	07286
BiOCl....	Bi......	0.80166	90399	1.24740	09601
$CaSO_4$....	CaO.....	0.41186	61475	2.42800	38525
$CaCO_3$...	CaO.....	0.56039	74843	1.78470	25157
Cl.......	AgCl....	0.24738	39337	4.03950	60633
Fe_2O_3....	Fe......	0.69940	84473	1.42977	15527
KCl.....	K_2I.....	0.63169	80051	1.58300	19949
K_2PtCl_6..	K_2O.....	0.19376	28727	5.16100	71273
K_2PtCl_6..	KCl.....	0.30674	48676	3.26015	51324
$Mg_2P_2O_7$.	MgO....	0.36207	55879	2.76189	44121
NaCl....	Na_2O....	0.53028	72451	1.88580	27549
NiO.....	Ni......	0.78576	89529	1.27260	10471
$Mg_2P_2O_7$..	P.......	0.27873	44511	3.58766	55481
$Mg_2P_2O_7$..	P_2O_5....	0.63852	80517	1.56615	19483
$PbSO_4$...	Pb......	0.68311	83449	1.46390	16551
$PbCO_3$...	PbO....	0.83528	92183	1.19720	07817
$BaSO_4$....	S.......	0.13738	13793	7.27900	86207
$BaSO_4$....	SO_3.....	0.34300	53530	2.91540	46470
SiO_2.....	Si.......	0.46933	67147	2.13070	32853
SnO.....	Sn......	0.88149	94522	1.13440	05478
$SrSO_4$....	Sr......	0.47703	67855	2.09629	32145
$SrSO_4$....	SrO.....	0.56415	75140	1.77257	24860
TiO_2.....	Ti......	0.60051	77852	1.66520	22148
$BaSO_4$...	ZnS.....	0.41742	62057	2.39570	37943
ZnS......	Zn......	0.67087	82664	1.49060	17336
ZnS	ZnO.....	0.83507	92172	1.19750	07820
ZrO_2.....	Zr......	0.73899	86864	1.35320	13136

To use the factors from the above table, multiply the weight found by the factor from the table and then by 100.

For example: One gram clay was taken for analysis and it yielded .028 gm. of $Mg_2P_2O_7$. It is necessary to convert the $Mg_2P_2O_7$ to MgO. To do it we will simplify our work and save time by looking in the table for the right factor which we will find to be 0.36207. Then we proceed as follows:

$$(.028 \times .36207) \times 100 = 1.01\% \text{ MgO}$$

CHEMICAL FORMULA, ATOMIC OR MOLECULAR WEIGHT AND LOGARITHMS OF VARIOUS SUBSTANCES

Substances.	Formula.	Molecular or Atomic Weight.	Log.
Acetic acid	$HC_2H_3O_2$	60.00	77815
Aluminum	Al	27.00	43297
" chlorides	Al_2Cl_6	267.00	42651
" chlorides	$Al_2Cl_6 12H_2O$	483.00	68395
" hydroxide	$Al_2(OH)_6$	78.00	89209
" oxide	Al_2O_3	102.00	00945
" mono silica	Al_2SiO_5	162.00	20952
" sulphate	$Al_2(SO_4)_3$	342.00	53403
" sulphate	$Al_2(SO_4)_3 18H_2O$	667.00	82393
" sulphide	Al_2S_3	150.00	17609
Ammonia	NH_3	17.00	23045
" alum	$Al_2(SO_4)_3(NH_4)_3 SO_4 24H_2O$	904.00	95617
" ammonium	NH_4	18.00	25527
" bichromate	$(NH_4)_2Cr_2O_7$	253.00	40312
" chloride	NH_4Cl	53.00	72835
" hydroxide	NH_4OH	35.00	54407
" nitrate	NH_4NO_3	80.00	90309
" sulphate	$(NH_4)_2SO_4$	132.00	12057
Antimony	Sb	120.00	07918
" oxide	Sb_2O_3	287.00	45788
Arsenic	As	75.00	87506
" oxide	As_2O_5	230.00	36173
Arsenious oxide	As_2O_3	198.00	29667
Barium	Ba	137.00	13672
" carbonate	$BaCO_3$	197.00	29447
" chloride	$BaCl_2$	208.00	31806
" chromate	$BaCrO_4$	253.00	40312
" chloride	$BaCl_2 2 \cdot HO$	244.00	38739
" oxide	BaO	153.00	18469
" peroxide	BaO_2	169.00	22789
" sulphate	$BaSO_4$	233.00	36736
Bismuth	Bi	207.50	31597

Substances.	Formula.	Molecular or Atomic Weight.	Log.
Bismuth oxide.......	Bi_2O_3..............	468.00	67025
Borax...............	$Na_2B_4O_7 10H_2O$......	382.00	58206
" oxide.........	B_2O_3..............	70.00	84510
" acid..........	H_3BO_3..............	62.00	79239
Boron...............	B..................	11.00	04139
Cadmium carbonate..	$CdCO_3$............	172.00	23553
" chloride....	$CdCl_2$..............	183.00	26245
" chloride....	$CdCl_2 2H_2O$..........	219.00	34044
" sulphide....	CdS................	144.00	15836
Calcium............	Ca.................	40.00	60206
" carbonate...	$CaCO_3$............	100.00	00000
" chloride (fused).....	$CaCl_2$..............	111.00	04532
" chloride.....	$CaCl_2 6H_2O$..........	219.00	34044
" fluoride.....	CaF_2..............	78.00	89209
" oxide (lime)..	CaO..............	56.00	74819
" hydroxide...	$Ca(OH)_2$...........	74.00	86923
" phosphate...	$Ca_3(PO_4)_2$..........	310.00	49136
" sulphate.....	$CaSO_4$.............	136.00	13354
" sulphate " (gypsum)..	$CaSO_4 2H_2O$..... ...	172.00	23353
Carbon............	C..................	12.00	07918
" dioxide.......	CO_2...............	44.00	64345
" monoxide.....	CO...............	28.00	44716
Carborundum........	SiC..............	40.00	60206
Chlorine............	Cl...............	35.50	54407
Chrome oxide........	Cr_2O_3.............	153.00	18469
Chromium..........	Cr...............	52.00	71600
" sulphate...	$Cr(SO_4)_3 18H_2O$......	717.50	85582
" trioxide...	CrO_3..............	100.00	00000
Citric acid..........	$H_3C_6H_5O_7$..........	192.00	28330
Cobalt..............	Co...............	58.50	76716
" carbonate.....	$CoCO_3$............	118.50	07372

Substances.	Formula.	Molecular or Atomic Weight.	Log.
Cobalt chloride.......	Co_2Cl_6............	329.00	51720
" chloride.......	$CoCl_26H_2O$.........	237.00	37475
" nitrate........	$Co(NO_3)_26H_2O$......	290.00	46240
" oxide (black)..	Co_2O_3.............	165.00	21748
" oxide (prep.)..	CoO...............	74.50	87216
" sulphate......	$CoSO_47H_2O$.........	280.00	44716
Copper.............	Cu................	63.00	79934
" chloride......	$CuCl_22H_2O$.........	170.50	23172
" chloride......	Cu_2Cl_2............	198.00	29667
" oxide.........	CuO...............	79.50	90037
" oxide........	Cu_2O..............	143.00	15534
" sulphate (blue vitriol)	$CuSO_45H_2O$.........	249.00	39707
" sulphate......	$CuSO_4$.............	159.50	20276
" sulphide......	CuS...............	95.50	98000
Cyanogen...........	CN................	26.00	41497
Ferric oxide.........	Fe_2O_3.............	160.00	20412
Ferrous oxide........	FeO...............	72.00	85733
" ferric oxide...	Fe_3O_4.............	232.00	36549
" carbonate....	$FeCO_3$.............	116.00	06446
" sulphate.....	$FeSO_4$.............	152.00	18184
" sulphate.....	$FeSO_47H_2O$.........	278.00	44404
" sulphide.....	FeS...............	88.00	94448
Ammonium sulphate..	$FeSO_4(NH_4)_2SO_46H_2O$	392.00	59329
Gold...............	Au................	169.50	29336
" chloride.........	$AuCl_32H_2O$.........	339.00	53020
Hydrobromic acid....	HBr...............	81.00	90849
Hydrochloric acid....	HCl...............	36.50	56229
Hydrocyanic acid.....	HCN...............	27.00	43136
Hydrofluoric acid.....	HF................	20.00	30103
Hydroiodic acid......	HI................	127.00	10380
Hydrogen peroxide...	H_2O_3..............	34.00	53148
" sulphide...	H_2S...............	34.00	53148

Substances.	Formula.	Molecular or Atomic Weight.	Log.
Iodine	I	126.00	10037
Iridium	Ir	192.50	28443
Iron	Fe	56.00	74819
Lead	Pb	207.00	31597
" carbonate	$PbCO_3$	267.00	42651
" (Basic white lead) carbonate	$Pb(OH)_2 2PbCO_3$	773.00	88818
" chloride	$PbCl_2$	277.00	44248
" chromate	$PbCrO_4$	323.00	50920
" oxide (litharge)	PbO	222.00	34635
" red (meninge)	Pb_3O_4	685.00	83569
" peroxide	PbO_2	239.00	37840
" sulphate	$PbSO_4$	302.00	48001
" sulphide (galena)	PbS	239.00	37840
Magnesium	Mg	24.00	38021
" carbonate	$MgCO_3$	84.00	92428
" chloride	$MgCl_2$	95.00	97772
" chloride	$MgCl_2 6H_2O$	203.00	30750
" oxide	MgO	40.00	60206
" sulphate	$MgSO_4$	120.00	07918
" sulphate	$MgSO_4 7H_2O$	246.50	53970
Malic acid	$H_2C_4H_4O_5$	134.00	12710
Manganese	Mn	55.00	74036
" carbonate	$MnCO_3$	115.00	06070
" chloride	$MnCl_2$	126.00	10037
" oxide (braunite)	Mn_2O_3	158.00	19866
" peroxide	MnO_2	87.00	93952
" sulphate	$MnSO_4$	151.00	17898
Trimanganic tetraoxide	Mn_3O_4	229.00	35984
Mercury	Hg	200.00	30103
Mercuric chloride	$HgCl_2$	271.50	43377

Substances.	Formula.	Molecular or Atomic Weight.	Log.
Mercurous chloride...	Hg_2Cl_2	471.00	67302
Nickel..............	Ni................	59.00	77085
" oxide.........	NiO...............	75.00	97506
" sulphate......	$NiSO_46H_2O$.........	263.00	41996
" sulphate......	$NiSO_47H_2O$.........	281.00	44871
Nitric acid..........	HNO_3..............	63.00	79934
Nitrogen trioxide.....	N_2O_3..............	76.00	88081
" pentoxide...	N_2O_5..............	108.00	03342
Nitrous acid.........	HNO_2..............	47.00	67210
Nitrogen...........	N.................	14.00	14613
Oxygen............	O.................	16.00	20412
Oxalic acid.	$N_2C_2O_4$............	90.00	95424
Oxalic acid..........	$N_2C_2O_42H_2O$........	126.00	10037
Phosphoric acid.....	H_2PO_4.............	98.00	99123
Phosphorus..........	P.................	31.00	49136
Platinum...........	Pt................	194.00	28780
" chloride....	$PtCl_45H_2O$.........	426.50	62992
Potassium..........	K.................	39.00	59106
" oxide......	K_2O..............	94.00	97313
" hydroxide..	KOH...............	56.00	74819
" carbonate...	K_2CO_3.............	138.00	13988
" sulphate....	K_2SO_4.............	174.00	24055
" chloride....	KCl...............	74.50	86953
" chlorate....	$KHSO_4$............	136.00	13354
" antimoniate.	$KSbO_3$............	206.00	31387
" alum.......	$K_2SO_4Al_2(SO_4)24H_2O$	948.00	97681
" bicarbonate.	K_2CO_3.............	100.00	00000
" bicarbonate.	$K_2Cr_2O_7$..........	295.00	46982
" chromate...	K_2CrO_4............	194.00	28892
" chrome alum	$K_2SO_4Cr_2(SO_4)24H_2O$	999.00	99957
" chlorate....	$KClO_3$.............	122.50	08814
" perchlorate .	$KClO_4$.............	138.50	14146

Substances.	Formula.	Molecular or Atomic Weight.	Log.
Potassium cyanide....	KCN..............	65.00	81291
" ferricyanide	$K_3Fe(CN)_6$..........	329.00	51720
" ferrocyanide	$K_4Fe(CN)_6$..........	366.00	56348
" ironsulphate	$K_2SO_4Fe_2(SO_4)24H_2O$	1006.50	002814
" nitrate.....	KNO_3.............	101.00	00432
" nitrite.....	KNO_2.............	85.00	92942
" permanganate.....	$KMnO_4$............	158.00	19866
" platinum chloride..	K_2PtCl_6...........	485.00	68574
" sulphide....	K_2S..............	110.00	04139
" sulphocyanide.....	(KCNS)KSCN......	97.00	98677
Silver...............	Ag..................	108.00	03342
" nitrate........	$AgNO_3$............	170.00	23045
Silica...............	SiO_2..............	60.00	77815
Silicilic acid.........	H_2SiO_3, etc.........	Varies	
Silicon..............	Si..................	28.00	44716
" tetrafluoride...	SiF_4...............	104.00	01703
Sodium.............	Na..................	23.00	36173
" biborate (borax)	$Na_2B_4O_710H_2O$......	392.00	58206
" bicarbonate....	$NaHCO_3$...........	84.00	92428
" bichromate....	$Na_2Cr_2O_72H_2O$.......	299.00	47567
" carbonate (ash)	Na_2CO_3............	106.00	02531
" carbonate (crystals)........	$Na_2CO_310H_2O$.......	286.00	45637
" chloride.......	NaCl...............	58.50	76716
" chromate......	$NaCrO_410H_2O$.......	342.50	53466
" hydroxide.....	NaOH..............	40.00	60206
" nitrate........	$NaNO_3$............	85.00	92942
" nitrate........	$NaNO_2$............	69.00	83885
" oxalate........	$Na_2C_2O_4$...........	134.00	12710
" oxide.........	Na_2O..............	62.00	79239

Substances.	Formula.	Molecular or Atomic Weight.	Log.
Sodium ammonium phosphate	$NH_4NaHPO_44H_2O$	210.00	32222
" silicate (water glass)	$Na_2Si_4O_9$	301.00	47857
" sulphide	Na_2S	78.00	89209
" sulphate	Na_2SO_4	142.00	15229
" acid sulphate	$NaHSO_4$	120.00	07918
" thiosulphate	$Na_2S_2O_35H_2O$	248.00	39445
" sulphate	$Na_2SO_410H_2O$	322.00	50786
Stannous chloride	$SnCl_2$	189.50	27761
" chloride	$SnCl_22H_2O$	225.50	27761
" oxide	SnO	135.00	13033
Sulphur	S	32.00	50515
" dioxide	SO_2	64.00	80618
" acid (ic)	H_2SO_4	98.00	99123
" trioxide	SO_3	80.00	90309
" acid (ous)	H_2SO_3	82.00	91381
Hydrogen sulphide	H_2S	34.00	53148
Tartaric acid	$H_2C_4H_4O_6$	150.00	17609
Tin	Sn	119.00	07555
" oxide	SnO_2	150.00	17609
Titanium oxide	TiO_2	80.00	90309
Uranium	U	240.00	38021
" oxide	UO_2	272.00	43457
Zinc	Zn	65.00	81291
" carbonate	$ZnCO_3$	125.00	09691
" chloride	$ZnCl_2$	136.00	13354
" oxide	ZnO	81.00	90849
" sulphate	$ZnSO_4$	161.00	20412
" sulphate	$ZnSO_47H_2O$	287.50	45864

PHYSICAL PROPERTIES

MODULUS OF RUPTURE

The modulus of rupture is calculated from the following formula:

$$R=\frac{3WD}{2bt^2}$$

in which R=modulus of rupture; W=the required pressure to break the brick, D=distance between the supporting knife edges, b=breadth of the brick, t=thickness of the brick.

The above formula explains that the modulus of rupture is three times the pressure in pounds multiplied by the distance between the supports divided by twice the breadth of the brick multiplied by the square of the thickness.

For example it was necessary to apply a pressure of 2450 pounds to break a brick. The distance between the supports was 6 inches. The width of the brick was 4.25 inches and the thickness was 2.25 inches. The modulus of rupture (R) is calculated as follows:

$$R=\frac{3\times 2450\times 6}{2.25\times 4.25\times 2^2}=\frac{44100}{38.2500}=1152.94$$

POROSITY

The porosity of fired and unfired bodies is determined by two methods. The following formula is for burned clay or bodies:

$$\text{Porosity}=\frac{(\text{Wt. saturated in water}-\text{Wt. dry})\times 100}{\text{Wt. dry}}.$$

For example a piece of a burned body weighing 40 gms., after being saturated in water for forty-eight hours weighs 54.56 gms. $54.56-50=4.56$, $50:4.56=100:x$.

$$\therefore \frac{4.56\times 100}{50}=9.12\%$$

The porosity of an unfired clay or body can be determined at any stage of dryness by the following formula:

$$\text{Porosity}=\frac{(\text{Wt. saturated}-\text{Wt. dry})\times 100}{(\text{Wt. Dry}-\text{Wt. suspended})}.$$

For example a piece of dry clay or body weighs 66 gms. After being saturated in paraffin it weighs 72 gms. and when suspended weighs 47 gms.

$$\text{Porosity}=\frac{(72-66)=6\times 100}{(72-47)=25}=24\%$$

SPECIFIC GRAVITY

By the specific gravity of a body we understand the ratio between its weight and the weight of a like volume of pure water at 4° C. Or in other words the weight in air divided by the volume of water displaced by the body.

Example. Assuming that a piece of burned brick weighed in air 4.556 gms. After having been immersed in water for twenty-four or forty-eight hours it were placed in a glass of water by holding it by a very fine wire or thread from a balance beam it weighed 2.733 gms.

The specific gravity of the brick is then calculated by the following rule: W = weight of body in air. W' = weight of body in water.

$$\text{Sp. gr.}=\frac{W}{W'-W}=\frac{4.556}{4.556-2.733}=\frac{4.556}{1.822}=2.5.$$

To find the specific gravity of a substance in powder form. First weigh the dry substance in air, then weigh a flask filled with water. Then weigh the flask containing the substance previously weighed and filled full of water.

Example. Assuming that we wish to find the specific gravity of a sample of sand, the weights are as follows: dry sand weighs 6.666 gms. Bottle filled with water 100 gms. Weight of bottle containing sand and water 103.029 gms.

The specific gravity is then found by the following rule: Ws = weight of substance in air. Ww = weight of flask and water. W = weight of flask containing water and substance.

$$\frac{Ws}{Ws-(W-Ww)}=\frac{6.666}{6.666-(103.029-100)}=2.27 \text{ sp. gr.}$$

To find the cubic weight in pounds of a substance, use the following formula:

Specific gravity $\times$ 62.4 = weight in pounds of a cubic foot of the substance.

Example. The specific gravity of zircon is 4.7, and a cubic foot of water weighs 62.4 pounds.

$\therefore$ $62.4\times4.7=293.28$ pounds. Therefore a cubic foot of zircon will weigh 293.28 pounds.

The specific gravity of a substance when the weight of a cubic foot is known is found from the following formula:

$$\frac{\text{Wt. in pounds of a cubic foot}}{62.4}=\text{Sp. gr.}$$

Example. One cubic foot of quartz weighs 165 pounds, what is the specific gravity?

$$165 \div 62.4 = 2.64$$

Example. We wish to know the weight in pounds of a ceramic block which after it is burned measures 4565 cubic inches, the specific gravity of the block is 2.15. One cubic foot of water weighs 62.4 pounds and 1 cubic foot contains 1728 cubic inches.

$$\therefore \quad \frac{4565 \times 62.4}{1728} = \frac{284856.0}{1728} = 164.85$$

$164.85 \div 2.15 = 837.067$ pounds, weight of the block.

SEGER CONES AND THEIR FUSING-POINTS

Cone No.	Molecular Composition.						Fusing-point in C.
	Na_2O	PbO	Al_2O_3	Fe_2O_3	B_2O_3	SiO_2	
022	0.5	0.5	....	....	1.0	2.0	590
021	0.5	0.5	0.1	....	1.0	2.2	620
020	0.5	0.5	0.2	....	1.0	2.4	650
019	0.5	0.5	0.3	....	1.0	2.6	680
018	0.5	0.5	0.4	....	1.0	2.8	710
017	0.5	0.5	0.5	....	1.0	3.0	740
016	0.5	0.5	0.55	....	1.0	3.1	770
015	0.5	0.5	0.6	....	1.0	3.2	800
014	0.5	0.5	0.65	....	1.0	3.3	830
013	0.5	0.5	0.7	....	1.0	3.4	860
012	0.5	0.5	0.75	....	1.0	3.5	890
011	0.5	0.5	0.8	....	1.0	3.6	920
	K_2O	CaO					
010	0.3	0.7	0.3	0.2	0.50	3.50	950
09	0.3	0.7	0.3	0.2	0.45	3.55	970
08	0.3	0.7	0.3	0.2	0.40	3.60	990
07	0.3	0.7	0.3	0.2	0.35	3.65	1010
06	0.3	0.7	0.3	0.2	0.30	3.70	1030
05	0.3	0.7	0.3	0.2	0.25	3.75	1050
04	0.3	0.7	0.3	0.2	0.20	3.80	1070
03	0.3	0.7	0.3	0.2	0.15	3.85	1090
02	0.3	0.7	0.3	0.2	0.10	3.90	1110
01	0.3	0.7	0.3	0.2	0.5	3.95	1130
1	0.3	0.7	0.3	0.2	....	4	1150
2	0.3	0.7	0.4	0.1	....	4	1170
3	0.3	0.7	0.45	0.05	....	4	1190
4	0.3	0.7	0.50	....	....	4	1210
5	0.3	0.7	0.55	....	....	5	1230
6	0.3	0.7	0.60	....	....	6	1250
7	0.3	0.7	0.70	....	....	7	1270
8	0.3	0.7	0.80	....	....	8	1290
9	0.3	0.7	0.90	....	....	9	1310
10	0.3	0.7	1.00	....	....	10	1330

Cone No.	K_2O	CaO	Al_2O_3	SiO_2	Fusing-point in C.
11	0.3	0.7	1.2	12.0	1350
12	0.3	0.7	1.4	14.0	1370
13	0.3	0.7	1.6	16.0	1390
14	0.3	0.7	1.8	18.0	1410
15	0.3	0.7	2.1	21.0	1430
16	0.3	0.7	2.4	24.0	1450
17	0.3	0.7	2.7	27.0	1470
18	0.3	0.7	3.1	31.0	1490
19	0.3	0.7	3.5	35.0	1510
20	0.3	0.7	3.9	39.0	1530
21	0.3	0.7	4.4	44.0	1550
22	0.3	0.7	4.9	49.0	1570
23	0.3	0.7	5.4	54.0	1590
24	0.3	0.7	6.0	60.0	1610
25	0.3	0.7	6.6	66.0	1630
26	0.3	0.7	7.2	72.0	1650
27	0.3	0.7	20.0	200.0	1670
28	......	......	1.0	10.0	1690
29	......	......	1.0	8.0	1710
30	......	......	1.0	6.0	1730
31	......	......	1.0	5.0	1750
32	......	......	1.0	4.0	1770
33	......	......	1.0	3.0	1790
34	......	......	1.0	2.5	1810
35	......	......	1.0	2.0	1830
36	......	......	1.0	1.5	1850
37	......	......	1.0	1.33	1870
38	......	......	1.0	1.00	1890
39	......	......	1.0	0.66	1910
40	......	......	1.0	0.33	1940
41	......	......	1.0	.13	1970
42	......	......	1.0	......	2000

MINERALS USEFUL IN THE CERAMIC INDUSTRY

Actinolite. A member of the amphibol group. Sp. gr.=3, H.=5–6. Comp. $Ca(MgFe)_3(SiO_3)_4$, SiO_2 =59.7, CaO=14.25, MgO=21.6, FeO=3.9, Mn_2O_3 =.55. Luster pearly to vitreous, transparent to opaque; fracture conchoidal to uneven; texture granular; color white or gray, pale green to dark green. Fuses with difficulty on the edges.

Agate. A variegated chalcedony. Sp. gr.=2.6, H.=7. Comp. SiO_2. Luster vitreous, translucent to transparent; color, all kinds with different shades of streaks; feels harsh; fracture uneven; texture massive crystalline. Infusible.

Alabaster. A white compact gypsum, having a very fine grain. Sp. gr.=2.3, H.=1.5. Comp. $CaSO_4$, $2H_2O$, CaO=32.6, SO_3=46.5, H_2O=20.9. Luster pearly, subvitreous, opaque to translucent. Color white to pink, yellow or bluish, feels smooth to harsh; fracture uneven, texture massive, granular. Fuses and exfoliates B.B.

Albite. Soda feldspar. Sp. gr.=2.5–2.65, H.=6–7. Comp. Na_2O, Al_2O_3, $6SiO_2 \cdot SiO_2$=68.6, Al_2O_3=19.6, Na_2O=11.8. Triclinic massive, either granular or lamellar. Luster pearly vitreous. Color white, bluish, gray, green or reddish; fracture uneven. Fusible B.B. to a colorless glass.

Allanite. Sp. gr.=3–4, H.=5.5–6. Comp. varies, $(CaFe)_2(AlCeFe)_3(OH)(SiO_4)_3$ SiO_2=35, Al_2O_3=15, Fe_2O_3=20, CaO=14, CaO=12, H_2O=4. Luster submetallic; resinous; color brown, black, greenish; fracture uneven. Easily fusible B.B. to a dark glass.

Allophane. Sp. gr. = 1.9, H. = 2–3. Comp. $Al_2SiO_5 \cdot 5H_2O$, $SiO_2 = 23.75$, $Al_2O_3 = 40.62$, $H_2O = 35.63$. Luster vitreous; color white, pale blue, green; fracture conchoidal infusible B.B.

Allunite. Sp. gr. = 2.8, H. = 3.5–4. Comp. K_2O, $3Al_2O_3$, $4SO_3$, $6H_2O$, $Al_2O_3 = 37.1$, $K_2O = 11.4$, $SO_3 = 38.5$, $H_2O = 13$, Color white or gray, fracture uneven. Infusible B.B.

Alum. Sp. gr. = 1.8, H. = 2. Comp. K_2SO_4, $Al_2(SO_4)_3$, $24H_2O$. Potash sulphate = 18, aluminous sulphate = 36 and water = 46. Luster translucent, color white, feels smooth, fracture uneven, texture crystalline.

Amblygonite. (Very much like apatite.) Sp. gr. = 3, H. = 6. Comp. $LiAl(FOH)PO_4$. Contains 50 per cent phosphoric acid. The lithium, is often partly replaced by sodium. Color white or grayish white. Easily fusible B.B.

Amethyst. Sp. gr. = 2.6, H. = 7. Comp. $SiO_2 = 100$. Luster vitreous, transparent; color purple violet; feels harsh; fracture uneven; texture massive.

Amphibol. Sp. gr. = 2.9–3.3, H. = 5–6. Comp. vary very widely $RSiO_3 \cdot R \cdot CaMgFe$. Luster vitreous, in fibrous varieties silky color white green, yellow, black. Monoclinic imperfectly crystalline, fibrous columnar, massive granular. Fusible B.B. the fusibility varies indefinitely.

Analcite. Sp. gr. = 2.2–2.3, H. = 5–5.5. Comp. $NaAl(SiO_3)_2$, $SiO_2 = 54.46$, $Al_2O_3 = 23.30$, $Na_2O = 14.08$, $H_2O = 8.16$. Luster vitreous. Color colorless or sometimes reddish, yellowish, grayish. Fracture subconchoidal uneven. Fusible to a colorless glass.

Andalusite. Sp. gr. = 3–3.4, H. = 7.5. Comp. Al_2SiO_5, $SiO_2 = 36.8$, $Al_2O_3 = 63.2$. Luster vitreous, fracture subconchoidal. Color white, violet, red, green and brown, usually gray. Translucent to opaque. Infusible B.B.

Andesite. Sp. gr. = 2.6–2.8, H. = 5–6. Comp. $(CaNa_2)O$, Al_2O_3, $4SiO_2$, $SiO_2 = 59.8$, $Al_2O_3 = 25.5$, $CaO = 7$, $Na_2O = 7.7$. A dark grayish rock consisting essentially of triclinic feldspar. Fusible B.B.

Anglesite. Sp. gr. = 6–6.4, H. = 3. Comp. $PbSO_4$, $PbO = 73.6$, $SO_3 = 26.4$. Luster resinous vitreous. Color white or gray fracture, conchoidal. Easily fusible B.B.

Anhydrite. Sp. gr. = 2.9, H. = 3–3.5. Comp. $CaSO_4$, $2H_2O$, $CaO = 41.2$, $SO_3 = 58.8$. Luster vitreous, pearly. Color white gray, bluish reddish; fracture uneven. Fuses B.B.

Annalbergite. Comp. $Ni_3As_2O_8$, $8H_2O$, $H_3AsO_4 = 38.6$, $NiO = 37.2$, $H_2O = 24.2$. Fracture uneven. Color green, with streaks of greenish white. Fusible B.B.

Anorthite. Sp. gr. = 2.66–2.78, H = 6. Comp. CaO, Al_2O_3, $2SiO_2$, $SiO_2 = 43.1$, $Al_2O_3 = 36.8$, $CaO = 20.1$. White, grayish, reddish lime feldspar. Fuses with difficulty B.B. to a colorless glass.

Antimony. Sp. gr. = 6.7, H = 3.5–4. Comp. $Sb = 100$. Luster metallic, fracture uneven. Color tin white on charcoal easily volatilize.

Antimony glance. (Gray antimony.) Sp. gr. = 4.5, H = 2. Comp. Sb_2S_3, $Sb = 72$, $S = 28$. Luster metallic color gray, fracture conchoidal. Fuses readily in flame.

Apatite. Sp. gr. = 3–3.5, H = 5. Comp. Ca(FCl), $Ca_4(PO_4)_3$, CaO = 53.80, P_2O_5 = 40.92, Cl = 6.82, usually contains calcium phosphate with calcium chloride or fluoride or both. Luster, vitreous to resinous, transparent to opaque, color blue green, white, gray or yellow, brown; fracture uneven to conchoidal. Infusible B.B. except on the edges.

Aragonite. Sp. gr. = 2.95, H = 3.5–4. Comp. $CaCO_3$, CaO = 56, CO_2 = 44. Luster vitreous to resinous. Color white, gray, green, yellow. Fracture conchoidal. Infusible B.B.

Asbestos. Dana includes the fibrous varieties of both pyroxine and hornblende. (See Hornblende.)

Augite. Sp. gr. = 3–3.5, H. = 5–6. Comp. varies widely in the different varieties.

$$CaMg(SiO_3)_2(MgFe)(AlFe)_2SiO_6,$$

SiO_2 = 45, Al_2O_3 = 13, MgO = 13, CaO = 12. (FeO + Fe_2O_3) = 12, (K_2O + Na_2O) = 5. Luster to vitreous transparent to opaque. Fracture conchoidal to uneven, texture granular or fibrous or columnar. Color dark green, brown, black. Fuses B.B. to a black glass.

Aximite. Sp. gr. = 3.3, H = 6.5–7. Comp. in varying proportion. $HCa_2(FeMn)Al_2B(SiO_4)_4$, SiO_2 = 43.68, B_2O_3 = 5.61, Al_2O_3 = 15.63, Fe_2O_3 = 9.45, Mn_2O_3 = 3.05, CaO = 20.67, MgO = 1.70, K_2O = .64. Luster glassy; fracture conchoidal. Color, greenish brown, blue, gray. Easily fusible with intumescence to a dark glass.

Azurite. Sp. gr. = 3.5–3.8, H = 4. Comp. $Cu_3(OH)_2$, $(CO_3)_2$CuO = 69.2, CO_2 = 25.6, H_2O = 5.2. Luster vitreous; fracture conchoidal. Color deep blue. Easily fusible B.B.

Barite. Also known as heavy spar, barytes, barium sulphate. Sp. gr. = 4.5, H = 3–3.5. Comp. $BaSO_4$, $BaO = 65.7$, $SO_3 = 34.3$. Sr and Ca often replace part of Ba. Luster vitreous, translucent to opaque. Color white, yellowish, reddish bluish, feels smooth to harsh; fracture uneven. Fusible B.B.

Basalt. Sp. gr. = 3.15, H. = 6. Glassy dense dark colored basic volcanic rock. Consists of the minerals of soda-lime feldspar. Augite, pyroxene, with or without olivine in very various proportions. The following analysis showing the constituents of the basalt rock from California, $SiO_2 = 47.95$, $Al_2O_3 = 18.90$, $FeO = 8.59$, $Fe_2O_3 = 2.21$, $CaO = 9.86$, $MgO = 8.21$, $K_2O = .29$, $Na_2O = 2.81$, $TiO_2 = .57$, $P_2O_5 = .15$, $H_2O = 1.31$. Color dark gray or greenish gray, very crystalline and finely granular in texture. Fuses B.B. to a dark glass.

Bauxite. Sp. gr. = 2.5, H. = 1–3. Comp. essentially $Al_2O_3 2H_2O$ in various proportions, also containing iron hydroxide with hydrous aluminum silicate. Color white, yellowish, pale red brownish red. Luster dull, and earthy. Infusible B.B.

Bentonite. Medicinal clay, very plastic and swells immensely upon wetting. One analysis gave: $SiO_2 = 66.70$, $Al_2O_3 = 12.90$, $Fe_2O_3 = 2.46$, $CaO = .82$, $MgO = 2.09$, $K_2O = .26$, $Na_2O = .66$, $H_2O = 13.80$.

Biotite. A member of the mica group. Sp. gr. = 2.5–3, H. = 2.5–3.1. Comp. in varying proportion $(HK)_2(MgFe)_2 \cdot Al_2(SiO_4)_3$. One analysis gave: $SiO_2 = 36$, $Al_2O_3 = 20$, FeO, $Fe_2O_3 = 22$, $MgO = 5$, $K_2O = 10$, $Na_2O = 3$, $TiO_2 = 2$, $MnO = 1$, $FCl = 1$. Luster vitreous, submetallic; fracture lamellar. Color, brown red, black, greenish, white. Fuses B.B. with difficulty on the edges.

Blende. Zinc sulphide also called sphalerite and black Jack in the mines. Sp. gr. = 4.1, H. = 3.5–4. Comp. ZnS, Zn = 67, S = 33, Luster resinous, translucent. Color whitish-yellow to brown; feels harsh; fracture conchoidal, texture granular, crystalline. Fuses B.B. on charcoal yields fumes of zinc.

Boracite. Sp. gr. = 2.9, H. = 6.5–7. Comp. $Mg_7Cl_2B_{16}O_{30}$ or $2(Mg_3B_8O_{15})MgCl_2$, $B_2O_3 = 62$, MgO = 31, Cl = 7. Massive, in crystals translucent. Color white or grayish, yellowish, or greenish. Luster vitreous. Fuses B.B. very easily with intumescence.

Borax. (Boric acid, or Tinkal.) Sp. gr. = 1.7, H. = 2–2.5. Comp. $Na_2B_4O_7$, $10H_2O$, $B_2O_3 = 36.6$, $Na_2O = 16.2$, $H_2O = 47.2$, Luster resinous to vitreous, subtranslucent. Color white; feels harsh; fracture conchoidal, texture crystalline. Fuses B.B. very easily to a transparent glass.

Boronatrocalcite. (Ulexite.) Sp. gr. = 1.6, H. = 1. Comp. $NaCaB_5O_98H_2O$, $B_2O_3 = 45.6$, CaO = 12.3, Na_2O = 6.8, $H_2O = 35.5$. Luster silky, color white. Fuses very easily with intumescence.

Braunite. Sp. gr. = 4.75–4.82, H. = 6–6.5. Comp. $SiO_2 = 8.63$, BaO = .44, MnO = 80.94, CaO = 1.91, O = 8.8. Luster submetallic. Color dark brownish black, fracture uneven. Infusible B.B.

Brookite. Sp. gr. = 4.12–4.17, H. = 5.5–6. Comp. TiO_2. Luster metallic, adamantine, color brown yellowish, red, black; fracture uneven; infusible B.B.

Brucite. Sp. gr. = 2.3–2.5, H = 2.5. Comp. $MgOH_2O$, MgO = 69, $H_2O = 31$. Luster pearly, translucent, color white, grayish greenish, blackish. Infusible B.B.

Calamine. Sp. gr. = 5–5.5, H = 3–4. Comp.

$Zn_2(OH)_2SiO_3$, $ZnO = 67$, $SiO_2 = 25$, $H_2O = 8$. Luster vitreous, translucent; color white, feels harsh; fracture uneven; texture granular, crystalline. Alone almost infusible B.B.

Calcite. (Calcspar) Sp. gr. = 25–2.8, H. = 2.5–3.5 Comp. $CaCO_3$, $CaO = 56$, $CO_2 = 44$. Lustre, subvitreous, translucent ; color white; feels meagre to rough; fracture conchoidal; texture granular, crystalline. Infusible B.B.

Caledonite. Sp. gr. = 6.4, H. = 2.5–3. Comp. $Pb_2SO_5(Cu)n$, $PbO = 65$, $CuO = 11$, $SO_3 = 19$, $H_2O = 5$. Luster resinous color, green; fracture uneven. Fusible B.B.

Casiterite. Sp. gr. = 7, H. = 6.5–7. Comp. SnO_2, $Sn = 78$, $O = 22$. Luster vitreous to adamantine, translucent to opaque. Color brown to black sometimes gray, red, yellow, feels harsh; fracture uneven; texture massive. Infusible B.B.

Celestite. Sp. gr. = 3.9, H. = 3–3.5. Comp. $SrSO_4$, $SrO = 56$, $SO_3 = 44$. Luster vitreous, translucent, color, bluish white, to reddish white; feels rough; fracture uneven; fusible B.B.

Cement. Hydraulic cements, Portland natural and Puzzolan cements. Essential constituents of hydraulic cements are tricalcium silicate ($3CaSiO_3$) and dicalcium aluminate ($2CaAl_2O_4$).

Kaisermann states in (Der Portland Cement) that the constituents of Portland cements are of dicalcium silicate and tricalcium aluminate in the following proportion, $4(2CaSiO_3)3CaAl_2O_4$.

Analysis of slab cement. $SiO_2 = 27.20$, Al_2O_3, $Fe_2O_3 = 14.18$, $CaO = 50.03$, $MgO = 3.22$, $S = 1.40$. Loss on ig. = 4.25.

Analysis of Portland Cement. $SiO_2=21.82$, $Al_2O_3=8.03$, $Fe_2O_3=2.51$, $CaO=62.19$, $MgO=2.17$, $S=1.02$. Loss ig. 1.05.

Cerolite. Sp. gr. = 2.3–2.4, H. = 2–2.5. Comp. $H_2Mg_3Si_2O_8H_2O$, $SiO_2=44$, $MgO=43$, $H_2O=13$. Luster pearly translucent to opaque; color usually green; feels smooth; fracture conchoidal. Infusible B.B.

Cerussite. Sp. gr. = 5.4–6.5, H. = 3–3.4. Comp. $PbCO_3$, $PbO=83.5$, $CO_2=16.5$. Luster, vitreous to resinous, translucent; color light to dark gray; feels smooth; fracture conchoidal; texture massive granular. Fuses easily B.B.

Chabazite. Sp. gr. = 2.1–2.19, H. = 4.5. Comp. $(CaN_2)Al_2(SiO_3)_46H_2O$, $SiO_2=50.5$, $Al_2O_3=17.26$, $CaO=9.43$, $K_2O=1.98$, $H_2O=20.83$. Luster vitreous; fracture uneven; color white red. Fuses B.B. with intumescence to a white glass.

Chlorite. Sp. gr. = 2.8, H. = 2–3. Comp. $H_8(MgFe)_5Al_2(SiO_6)_3$, $SiO_2=32$, $Al_2O_3=18$, $MgO=36$, $H_2O=14$, Fe partly replace the Al, and Ca the Mg. Luster pearly to resinous translucent; color green to reddish; feels smooth to harsh; fracture even to uneven texture massive granular. Fusible B.B. with difficulty.

Chloritoid. Sp. gr. = 3.5, H. = 5.5–6. Comp FeO, $Al_2O_3SiO_2H_2O$, $SiO_2=24$, $Al_2O_3=41$, $FeO=28$, $H_2O=7$. Luster pearly; fracture lamellar; color dark gray green, black. Fuses B.B. with difficulty.

Chromite. Sp. gr. = 4.4, H. = 5.5. Comp. $FeCr_2O_4$, $Cr_2O_3=68$, $FeO=32$. Luster, submetallic, opaque, color steel gray to brownish black; feels harsh; fracture uneven. Infusible B.B.

Chrysoberyl. Sp. gr. = 3.7, H. = 8.5. Comp. $BeAl_2O_4$, $Al_2O_3 = 80$, $BeO = 20$. Luster vitreous, transparent to translucent. Color green in many shades; feels smooth; fracture conchoidal. Infusible B.B.

Chrysocolla. Sp. gr. = 2.2, H. = 3. Comp. $CuSiO_3$, $2H_2O$, $SiO_2 = 34$, $CuO = 45$, $H_2O = 21$. Luster vitreous to earthy, translucent; color green-blue, feels smooth, fracture conchoidal; texture massive, earthy. Infusible B.B.

Chrysolite. Sp. gr. = 3–3.5, H. = 6–7. Comp. $H_4Mg_3Si_2O_6$, $SiO_2 = 41.3$, $FeO = 2.4$, $MgO = 41.2$, $H_2O = 14.5$. Luster vitreous translucent; color yellow, green, brown; feels harsh; fracture conchoidal; Infusible B.B.

Cinnabar. Sp. gr. = 8–8.2, H. = 2–2.5. Comp. HgS, $Hg = 86$, $S = 14$. Luster metallic, opaque to translucent; color scarlet red, black when impure; feels harsh; fracture uneven; B.B. volatize.

Cobalt Glance. Sp. gr. = 6.2, H. = 5.5. Comp. $CoAs_2CoS_2$, $As = 45$, $Co = 35$, $S = 20$. Luster metallic, opaque; color white to reddish gray; feels harsh; fracture uneven. Fuses B.B.

Cobalt Bloom. Sp. gr. = 3, H. = 2. Comp. 3CoO, As_2O_5, $8H_2O$, $AsO = 38$, $CoO = 38$, $H_2O = 24$. Luster pearly to vitreous to full, transparent to subtranslucent, color crimson red, bluish to greenish; feels smooth; fracture mixed even to uneven. Fuses B.B.

Colomanite. Sp. gr. = 2.4, H. = 4.5. Comp. $Ca_2B_6O_{11}$, $5H_2O$, $B_2O_3 = 48$, $CaO = 32$, $H_2O = 20$. Colorless or white; fuses easily with exfoliation.

Columbite. Sp. gr. = 3.3–6.5, H. = 6. Comp. $(FeMn)(NbTa)_2O_6NbO_5 = 51.53$, $TaO_5 = 28.55$, $WO_3 = .76$, $SnO_2 = .34$, $Zr = .34$, $FeO = 13.54$, $MnO = 4.97$,

$H_2O = .16$. Luster submetallic, fracture conchoidal; color black; infusible B.B.

Cookeite. Sp. gr. = 2.7, H. = 2.5. Comp. $Al_3LiH(SiO_4)_2(OH)_3H_2O$, $SiO_2 = 35.53$, $Al_2O_3 = 44.23$, $LiO_2 = 2.73$, $Na_2O = 2.11$, $K_2O = .31$, $F = 1.46$, $H_2O = 14.18$. Luster pearly; color white to yellowish green; fuses with difficulty and exfoliates.

Corundum. Sp. gr. = 3.9–4, H. = 9. Comp. $Al_2O_3 = 100$. Luster vitreous subtranslucent; color white, gray, yellow, red; feels harsh; fracture conchoidal, uneven, infusible B.B.

Copper glance. Sp. gr. = 5.5–5.8, H. = 2.3–3. Comp. Cu_2S, $Cu = 80$, $S = 20$. Luster metallic, opaque; color gray; feels harsh; fracture conchoidal; fuses easily B.B.

Cryolite. Sp. gr. = 2.9–3, H. = 2.5–3. Comp. Al_2F_66NaF, $F = 54$, $Al_2O_3 = 13$, $Na_2O = 33$. Luster vitreous, translucent; color white; feels smooth; fracture uneven to conchoidal; texture massive crystalline. Fusible in the flame of a candle.

Cuprite. Sp. gr. = 6, H. = 3.5–4. Comp. Cu_2O, $Cu = 89$, $O = 11$. Luster adamantine, submetallic; fracture conchoidal; uneven; color red to brownish red. On charcoal fuses to a copper bottom.

Danburite. Sp. gr. = 2.9, H. = 7. Comp. $SiO_2 = 48.9$, $B_2O_3 = 28.4$, $CaO = 22.7$. Luster vitreous; yellowish, whitish. Fuses B.B. easily to colorless glass.

Deweylite. Sp. gr. = 2.1–2.3, H. = 2–2.5. Comp. $SiO_2 = 40$, $MgO = 36$, $H_2O = 24$. Luster whitish, yellowish, greenish, reddish, fuses B.B. with difficulty.

Diabase. A dark greenish crystalline igneous rock composed chiefly of plagioclase, augite, magnetite, and sometimes olivine. Their range of composition is very varying. One analysis gave: $SiO_2 = 57.21$, $Al_2O_3 = 12.99$, $Fe_2O_3 = 3.28$, $FeO = 10.18$, $CaO = 5.97$, $MgO = 1.59$, $K_2O = 1.61$, $Na_2O = 3.07$, $TiO_2 = 1.72$, $MnO = .24$ $H_2O = 2.05$. Fuses B.B. to a dark-colored glass.

Diaspore. Sp. gr. = 3–3.5, H. = 6.5–7. Comp. $Al(OH)_3$, $Al_2O_3 = 85$, $H_2O = 15$. Luster vitreous, pearly, fracture uneven; color colorless, white gray and pale colors. Infusible B.B.

Dioryte. Is a feldspatic dark-speckled greenish or grayish black rock. Sp. gr. = 2.66–3, H. = Comp. $SiO_2 = 54.65$, $Al_2O_3 = 15.72$, $Fe_2O_3 = 2$, $FeO = 6.26$, $MnO = .12$, $MgO = 5.79$, $CaO = 7.83$, $K_2O = 3.79$, $Na_2O = 2.90$. Texture granular, fuses B.B. to a colorless glass.

Dolomite. Sp. gr. = 2.8, H. = 3.5–4. Comp. $CaMg(CO_3)_2CaCO_3 = 54.35$, $MgCO_3 = 45.65$. Luster vitreous, translucent; color white; feels rough; infusible B.B.

Ekebergite. Sp. gr. = 2.7, H. = 5.5–6. Comp. $SiO_2 = 52$, $Al_2O_3 = 23$, $CaO = 16$, $Na_2O = 6$. Luster vitreous; feels soapy; fracture sub-conchoidal color; white gray, greenish, reddish; fuses with intumescence.

Enstatite. Sp. gr. 3.3, H. = 5.5–6. Comp. $MgSiO_3$, $SiO_2 = 60$, $MgO = 40$. Luster pearly, vitreous; fracture conchoidal to even; color white, gray, green, brown; feels soapy; fusible B.B. with difficulty on the edges.

Epidote. Sp. gr. = 3.4, H. = 6.5. Comp. $Ca_2(AlFe)_3(OH)(SiO_4)_3SiO_2 = 38$, $Al_2O_3 = 22$, $Fe_2O_3FeO = 12$, $CaO = 25$, $H_2O = 3$. Luster, vitreous, waxy, translucent to opaque; color yellow, green, brown, black; feels smooth; fracture uneven; fuses B.B. to a colored glass with intumescence.

Fahlunite. Sp. gr. = 2.6–2.8, H. = 3.5–5. Comp. $SiO_2 = 45$, $Al_2O_3 = 30$, $FeO = 4$, $CaO = 1$, $MnO = 2.3$, $MgO = 7$, $K_2O = 2$, $H_2O = 11$, Luster waxy; fracture lamellar; color of various shades of green, brown; fuses B.B. to white glass.

Feldspar. Includes: Orthoclase, which is a potash feldspar (see orthoclase). Albite is a soda feldspar (see albite). Anorthite is a lime soda feldspar (see anorthite). Andesite is also lime soda feldspar (see andesite). Oligoclase is also lime soda feldspar (see oligoclase). Hyalophane is a barytic potash feldspar (see Hyalophane).

Flint. Sp. gr. = 2.63, H. = 7. Comp. $SiO_2 = 100$. (Hornstone, chert.) Massive compact silica rock, translucent to opaque. Luster vitreous; fracture conchoidal; color of dark shades of smoky gray, brown, even black; infusible B.B.

Fluorspar (Fluorite). Sp. gr. = 3–3.25, H. = 4. Comp. CaF_2, $F = 49$, $Ca = 51$. Luster vitreous; fracture conchoidal; color white, yellow, green, rose red, feels rough; fuses B.B. to an white enamel.

Fosterite. Sp. gr. = 3–3.5, H. = 4. Comp. Mg_2SiO_4, $SiO_2 = 42.86$, $MgO = 47.14$. Luster vitreous; fracture conchoidal. Color white, yellow, gray greenish. Infusible B.B.

Gabbro. Sp. gr. = 2.7–3.1, H. = 6–7. One analysis gave: $SiO_2 = 46$, $Al_2O_3 = 30$, $FeO = 1$, $Fe_2O_3 = 1$, $CaO = 17$, $MgO = 2$, $Na_2O = 2K_2O = 1$. Color all shades of flesh and red. Fuses B.B. to a colored glass.

Gahnite (Zinc spinal). Sp. gr. = 4–4.6, H. = 7.5–8. Comp. $SiO_2 = 25$, $ZnO = 67$, $H_2O = 8$. Luster vitreous, translucent; fracture uneven; color white; feels harsh; infusible B.B.

Galena. Sp. gr. = 7.5, H. = 2.5. Comp. PbS, Pb = 87, S = 13. Luster metallic, opaque; color leaden gray; feels smooth; fracture even to sub-conchoidal. Easily fusible giving on charcoal a malleable button.

Ganister. (See Quartzite.)

Garnet. Sp. gr. = 4.1, H = 7. Comp. varies widely, $R^{II}_3R^{III}_2(SiO_4)_3$, $SiO_2 = 36$, $Al_2O_3 = 21$. FeO, $Fe_2O_3 = 43$. Luster vitreous, resinous; fracture conchoidal to uneven. Color nearly in all shades, red, brown, green, yellow, white and black; feels smooth; testure crystalline; fuses B.B. readily to a dark brown blackish glass.

Geocronite. Sp. gr. = 6.4–6.6, H. = 2–3. Comp. Pb = 67, Sb = 17, S = 16. Luster metallic, fracture uneven, color lead gray or bluish gray. Fuses B.B. easily.

Gibbsite. Al_2O_3, $3H_2O$, $Al_2O_3 = 66.5$, $H_2O = 34.5$. Luster pearly vitreous; color white, grayish, reddish; infusible B.B.

Glauconite. A green sand essentially a hydrous silicate of iron and potassium. Sp. gr. = 2.2–2.5, H. = 2. Comp. $RR_2O_4(SiO_2)_43H_2O$, one analysis gave: $SiO_2 = 56$, $Al_2O_3 = 8$, FeO, $Fe_2O_3 = 12$, CaO = 4, MgO = 5, $K_2O = 12$, $H_2O = 3$. Luster dull, color in various shades of green brownish, reddish. Fusible B.B. very easily.

Gneiss. Metamorphic rock, the chemical composition varying widely, one analysis gave: $SiO_2 = 77.53$, $Al_2O_3 = 13.75$, $FeOFe_2O_3 = .35$, CaO = .65, $K_2O = 4.32$, $Na_2O = 2.68$, $TiO_2 = .64$.

Granite. A granular igneous rock consisting of quartz, feldspar, and mica; the mica may be either biotite or muscovite, or both. The feldspar usually orthoclase. The quartz is generally white, the feldspar white or pinkish, and the mica is usually lead colored, of tan dark brown, or even black, and gives the ruling color to the rock. The following analysis is of dark Barre granite. (Vermont State Geologist, 1909–1910.) $SiO_2 = 69.89$, $Al_2O_3 = 15.08$, $Fe_2O_3 = 1.04$, $FeO = 1.46$, $MgO = .66$, $CaO = 2.07$, $Na_2O = 4.73$, $K_2O = 4.29$, $H_2O = 54$. Estimated mineral percentage in the same granite. Feldspar : 65.522, quartz = 26.578, mica = 7.900. The writer made some fusing tests, of three samples. All three fused at cone 10 to 11 to a dark-colored glass.

Graphite. Sp. gr. 2.1–2, H. = 1–2. Comp. C = 100. Luster metallic, opaque; color black, grayish; feels very greasy; fracture uneven; texture foliated; infusible.

Gypsum. Sp. gr. = 2.3, H. = 2. Comp. $CaSO_4$, $2H_2O$, $CaO = 33$, $SO_3 = 46$, $H_2O = 2.1$. Luster vitreous to pearly, opaque; fracture uneven; color white, gray, light yellow; feels meager; easily fusible B.B.

Halite. Sp. gr. = 2.1–2.25. Comp. NaCl, Na = 39, Cl = 61. Luster vitreous; fracture conchoidal, fusible. Color white often tinted.

Halloysite. Sp. gr. = 1.9–2.1, H. = 1.5–2.5. Comp. $Al_2O_3 2SiO_2$, $4H_2O$, $SiO_2 = 40.8$, $Al_2O_3 = 43.7$, $H_2O = = 24.5$. Luster pearly dull; fracture conchoidal, massive earthy; color white, bluish, yellowish, reddish, greenish; infusible B.B.

Hausmannite. Sp. gr. = 4.7, H. = 5–5.5. Comp. Mn_3O_4, Mn = 72, O = 28. Luster submetallic; fracture uneven; color brownish black; infusible B.B.

Hayseine. (Boro calcite.) Sp. gr. = 2.62, H. = 1. Comp. $CaB_4O_7 6H_2O$; color white chalky; fuses to a colorless glass.

Hematite. Sp. gr. = 5.19–5.28, H. = 5.5–6.5. Comp. Fe_2O_3, Fe = 70, O = 30. Luster metallic, opaque to subtranslucent; color rusty gray; feels harsh; fracture uneven, sub-conchoidal; infusible B.B.

Heavy Spar. (See Barytes: $BaSO_4$.)

Heulandite. Sp. gr. = 2.2, H. = 3.5–4. Comp. $H_4CaAl_2(SiO_3)_63H_2O$, SiO_2 = 59, Al_2O_3 = 17, CaO = 9, H_2O = 15. Luster pearly, vitreous; fracture subchonchoidal to uneven. Color white, gray, red, brown. Fuses B.B. exfoliates, and curves into vernicular forms, and fuses to a white enamel.

Hornblende. Sp. gr. = 3.2, H. = 5.5. Comp. varying very widely (Ca, Mg, Fe)O, SiO_2. One analysis gave: SiO_2 = 45, Al_2O_3 = 13, FeO, Fe_2O_3 = 12, CaO = 12, MgO = 13, K_2O = 5. Luster pearly to vitreous. transparent to opaque; fracture conchoidal to uneven; texture granular, slaty, fibrous or columnar; color green, brown, black. Feels smooth to harsh. Fuses B.B. to a black glass.

Hyalite. (opal). Sp. gr. = 2.1, H. = 5.5–6.5. Comp. SiO_2nH_2O, SiO_2 = 85 to 97, H_2O = 15 to 3. Luster, pearly vitreous, opaline transparent; fracture conchoidal to even. Massive crystalling. Color white, pale yellow, gray, green, red; feels smooth; infusible B.B.

Hydromagnesite. Sp. gr. = 2.1, H. = 1–3. Comp. $Mg_4(OH)_2(CO_3)_33H_2O$; MgO = 44, CO_2 = 36, H_2O = 20. Luster vitreous, silky; fracture flat. Color white; infusible.

Ilmenite (titaniferous ore). Sp. gr. = 4.5–5, H. = 5–6. $FeTiO_3$. Luster, submetallic, or metallic. Fe_2O_3 = 53.7, FeO = 22.4, TiO_2 = 23.7, MnO = .3. Infusible.

Iolite. Sp. gr. = 2.6, H = 7–7.5. Comp.

$(MgFe)_4Al_8(OH)_2(SiO_7)_5$. $SiO_2 = 49$, $Al_2O_3 = 34$, $MgO = 9$, $FeO = 8$. Luster vitreous; fracture subconchoidal; color yellowish gray, brownish yellow; blue.

Kaolinite (kaolin). Sp. gr. = 2.21–2.26, H. = 1. Comp. Al_2O_3, $2SiO_2$, $2H_2O$, $SiO_2 = 47$, $Al_2O_3 = 40$, $H_2O = 13$. Luster pearly to dull, opaque, color white to grayish, yellowish, feels greasy, fracture uneven; conchoidal; texture earthy massive; infusible B.B.

Kieselguhr. (Amorphous silica.)

Laboradorite. Sp. gr. = 2.6–2.75, H. = 5–6. Comp. $(Na_2Ca)O$, Al_2O_3, SiO_2, $SiO_2 = 53$, $Al_2O_3 = 30$, $CaO = 12$, $Na_2O = 5$. Luster, pearly, vitreous; fracture conchoidal, uneven; color white, gray, greenish, brown, fuses B.B. to colorless glass.

Laumonite. Sp. gr. = 2.3, H. = 3–4. Comp. $H_4CaAl_2(SiO_7)_2$, $2H_2O$, $SiO_2 = 51$, $Al_2O_3 = 22$, $CaO = 12$, $H_2O = 15$. Luster vitreous; fracture uneven; color white or reddish. Fuses B.B. with swelling to a white enamel.

Lazulite. Sp. gr. = 3, H. = 5–6. Comp. $RAl_2O_4P_2O_5$, H_2O, $P_2O_5 = 47$, $Al_2O_3 = 34$, $MgO = 13$, $H_2O = 6$.

Lead. (See Cerussite, Galena.)

Limestone. A rock composed mainly of $CaCO_3$. Includes lithographic limestone, a very fine-grained rock. Oolitic limestone. Compact and often composed of concretionary grains, resembling the roe of a fish. Chalk a compact but soft variety. Travertine (Mexican marble) is the ornamental marble deposited from rivers and springs, often in variegated layers. Stalactites and Stalagmites. The cones and cylinders found in many caves, some which represent beautiful figures. Calcerous tufa an irregular porous deposited rock. Rock milk, a white earthy-like chalk but softer. Iceland spare, a crystalline rock. Dog-tooth spar, consisting of crystals. Satin spar, a fibrous variety. (Calc spar, or calcite.) Marl, a soft earthy deposit of $CaCO_3$ containing more or less clay and sand. Luster vitreous, translucent; fracture uneven; color deep blue; infusible B.B.

Lepidolite. (Lithia-mica.) Sp. gr. = 2.6–2.75, H. = 2.5–4. Comp. Li, K, Al_2, $(FOH)_2 3SiO_2$, SiO_2 = 50.4, Al_2O_3 = 28.1, Mn_2O_3 = .9, MgO = 1.4, K_2O = 10.6, Na_2O = 1.5, Li = 1.2, F = 4.9. Luster pearly, color pink, red, lilac, white gray and green. Fuses B.B. easily with intumescence to a white glass.

Leucite. Sp. gr. = 2.4–2.5, H. = 5.5–6. Comp. K_2O, $Al_2O_3 4SiO_2$, SiO_2 = 55.40, Al_2O_3 = 23.69, CaO = .16, K_2O = 19.54, Na_2O = 1.25. Color white to gray, fuses about 1420° C. to a glass.

Limonite. Sp. gr. = 3.8, H. = 5.5. Comp. $2Fe(OH)_3$, Fa_2O_3 = 86, H_2O = 14. Luster metallic to dull, opaque, color dull brown or yellowish red, fracture uneven; infusible B.B.

Magnesite. Sp. gr. = 3.1, H. = 4–5.5. Comp. $MgCO_3$, MgO = 47.6, Co_2 = 52.4. Luster vitreous silky; color white yellowish, white brown, fracture conchoidal, infusible.

Magnetite. Sp. gr. = 5.1, H. = 6. Comp. $Fe \cdot Fe_2O_4(Fe_3O_4)$, Fe = 72, O = 28. Luster submetallic, opaque; color black to dark brown; fracture uneven, subconchoidal; fuses B.B. with great difficulty.

Malachite. Sp. gr. = 3.9, H. = 3.5–4. Comp. $Cu_2(OH)_2CO_3$, CuO = 72, CO_2 = 20, H_2O = 8. Luster vitreous, adamantine, translucent; fracture uneven, conchoidal. Color green, easily fusible B.B.

Manganite. Sp. gr. = 4.3, H. = 4. Comp.

$Mn(OH)_3Mn_2O_3$, $Mn_2O_3 = 90$, $H_2O = 10$. Luster submetallic; color gray to black; fracture uneven; infusible B.B.

Marble. Sp. gr. = 2.5–2.8, H. = 2.7–3.3. Comp. varies $CaCO_3$, $CaO = 56$, $CO_2 = 44$. Luster subvitreous, translucent, color, white fracture conchoidal; texture crystalline, granular.

Marcasite. Sp. gr. = 4.9, H. = 6–6.5. Comp. FeS, Fe = 47, S = 53. Luster metallic, fracture uneven; color pale brass yellow, with a greenish tinge.

Margarite. Sp. gr. = 3, H. = 3.5–4.5. Comp. $H_2CaAl_4(SiO_6)_2$, $SiO_2 = 30$, $Al_2O_3 = 51$, $CaO = 12$, $Na_2O = 3$, $H_2O = 4$. Luster pearly vitreous, color gray, pink, white, yellowish, reddish; fuses with difficulty.

Meerschaum. Sp. gr. = 2, H. = 2–2.5. Comp. $H_4Mg_2Si_3O_{10}$, $SiO_2 = 61$, $MgO = 27$, $H_2O = 12$. Luster refined earthy; fracture flat to conchoidal; fuses B.B. only on the edges.

Messolite. Sp. gr. = 2.2–2.4, H. = 5. Comp. $SiO_2 = 46$, $Al_2O_3 = 26$, $CaO = 10$, $Na_2O = 5$, $H_2O = 13$. Luster vitreous silky; color, white, grayish or yellowish; fuses easily B.B.

Mica. (See Ciotite, Muscovite, Lepidolite, Phlogopite.)

Microcline. Sp. gr. = 2.5, H. = 6. Comp. $KAlSi_3O_8$, $SiO_2 = 68.48$, $Al_2O_3 = 16.11$, $Fe_2O_3 = .37$, $K_2O = 13.20$, $Na_2O = 1.82$. Luster pearly to vitreous; color white gray, reddish green. Fracture uneven, fuses with difficulty B.B. to a colorless glass.

Mispickel. (arsenopyrite). Sp. gr. = 6, **H** = 5.5–6. Comp. FeAsS, As = 46, Fe = 34, S = 20. Luster metallic, opaque; color grayish white; fracture, uneven. On charcoal fuses to a magnetic globule, and gives off As.

Monazite. Sp. gr. = 5.1, H. = 5. Comp. (CeLaDi)PO_4. Phosphate rock of the cerium metals (cerium, didimium, lanthanum) including thorium and silica. Luster resinous, color yellow, yellowish brown or reddish brown. Infusible.

Muscovite. Sp. gr. = 2.8, H. = 2–2.5. Comp. $H_2KAl_3(SiO_4)_3$, $SiO_2=47$, $Al_2O_3=34$, $K_2O=9$ (MgO, CaO, FeO, Fe_2O_3) = 6, $Na_2O=2$, $H_2O=2$. Luster pearly, translucent to transparent; fracture uneven; texture foliated. Color colorless white, green, yellow, black; feels smooth. Fuses difficulty on edges.

Natrolite. Sp. gr. = 2.2, H = 5. Comp. $Na_2Al_2Si_3O_{10}2H_2O$, $SiO_2=47$, $Al_2O_3=27$, $Na_2O=16$, $H_2O=10$. Luster vitreous; fracture conchoidal, uneven; color colorless or white, sometimes grayish, yellowish. Fuses B.B.

Nephthelite. Sp. gr. = 2.6, H. = 5.5–6. Comp. $NaAlSiO_4$, $SiO_2=44$, $Al_2O_3=34$, $Na_2O=17$, $K_2O=5$. Luster vitreous, waxy, fracture subconchoidal; color white, gray or reddish. Fuses B.B. to a colorless glass.

Niccolite. Sp. 7.5, H. = 5.5. Comp. NiAs, As = 56, Ni = 44. Luster metallic; fracture uneven; color pale copper red. Fuses B.B.

Obsidian. A lava or volcanic glass which has been completely fused and cooled rapidly. Fracture conchoidal; color gray to black, opaque, composed essentially of orthoclase. One analysis gave: $SiO_2=73$, $Al_2O_3=13$, $Fe_2O_3=2$, $FeO=1$, $CaO=2$, $MgO=1$, $K_2O=3$, $Na_2O=5$. Fuses B.B. to a colored glass.

Ocher. Includes, umber, sienna, these are earthy varieties, a mixture of limonite and hematite, with clay and other impurities. Color yellowish, brown, occurring in earthy or pulverulent state.

Oligoclase. Sp. gr. = 2.65, H. = 6–7. Comp. Ab_6An, to Ab_3An. $2(Na_2Ca)O$, $2Al_2O_3$, $9SiO_2$, $SiO_2 = 62$, $Al_2O_3 = 24$, $CaO = 3$, $Na_2O = 11$. Luster vitreous to waxy; fracture, conchoidal, uneven; color, colorless, white, greenish, or reddish. Fuses B.B.

Olivine. Sp. gr. = 3.3, H. = 6.5–7. Comp. $(MgFe)_2SiO_4$, $SiO_2 = 41$, $FeO = 8$, $MgO = 51$. Color yellowish, green to bottle green. Infusible B.B.

Opal. (See Hyalite.)

Orthoclase. Sp. gr. = 2.4–2.7, H. = 6–6.5. Comp. K_2O, Al_2O_3, $6SiO_2$, $SiO_2 = 64.7$, $Al_2O_3 = 18.4$, $K_2O = 16.9$. Sodium oxide sometimes replaces part of the potassium oxide. Luster pearly to vitreous, translucent, fracture uneven, texture tabular. Color, white, red, pink, green, yellowish, feels smooth to harsh. Fuses B.B.

Pegmatite. A very coarse-grained, ill-regulated rock. The greatest part of the mass consists of feldspar (usually orthoclase) quartz in very large crystals and mica, the color mostly yellowish, grayish, reddish. The following analysis gives: $SiO_2 = 71.19$, $Al_2O_3 = 15.71$, $FeO = .13$, $Fe_2O_3 = .21$, $CaO = .70$, $MgO = .03$, $K_2O = 8.60$, $Na_2O = 2.61$, $H_2O = .27$, $CO_2 = .22$, $TiO_2 = .03$, $P_2O_5 = .11$, $SO_3 = .05$, $MnO = .02$, $BaO = .14$ (Geological Survey of New Jersey, 1908).

Pegtolite. Sp. gr. = 2.7, H. = 4.5–5. Comp. $HNaCa_2(SiO_3)_3$, $SiO_2 = 54$, $CaO = 34$, $Na_2O = 9$, $H_2O = 3$. Luster, sub-vitreous silky; fracture fibrous; color white gray, brown; easily fusible B.B.

Phlogopite. Sp. gr. = 2.8, H. = 2.5–3. Comp. $H_2KMg_3Al(SiO_4)_3$, $SiO_2 = 40.7$, $Al_2O_3 = 13.9$, $MgO = 32.6$, $K_2O = 12.8$. Luster, sub-metallic, pearly; color pale brass, yellow, brown. Fuses B.B. on the tin edges.

Pholerite. Sp. gr. = 2.5, H. = 1–2.5. Comp. SiO_2 = 39, Al_2O_3 = 45, H_2O = 16. Luster pearly, earthy, fracture scaly; color white, grayish, yellowish, violet, brown. Infusible B.B.

Phonolite. Compact grayish-blue or brown feldspatic rock. One analysis gave: SiO_2 = 54, Al_2O_3 = 21, Fe_2O_3 = 3, FeO = 1, CaO = 1, K_2O = 5, Na_2O = 10, H_2O = 4. Fuses B.B. colored glass.

Phosphate Rock. (See Apatite.)

Pitchblende. Like uranite, sp. gr. = 7.5–9.5, H. = 5.5. Comp. UO_3UO_2Pb. Luster submetallic or pitchlike; color dark brown to black, greenish consisting largely of uranium; texture massive. Infusible B.B.

Porphyry. An igneous rock, consisting entirely of large feldspar crystals, which are embedded in a compact dark glassy ground mass. One analysis gave SiO_2 = 71, Al_2O_3 = 13, FeO, Fe_2O_3 = 4, CaO = 1, MgO = 1, K_2O = 2, Na_2O = 5, TiO_2 = 1, H_2O = 2.

Prehnite. Sp. gr. = 2.9, H. = 6–6.5. Comp. $H_2Ca_2Al_2(SiO_4)_3$, SiO_2 = 44, Al_2O_3 = 25, CaO = 27, H_2O = 4. Lustre vitreous, pearly; fracture uneven. Color smoky gray, green, brown, violet. Easily fusible B.B. with intumescence.

Psilomelane. Sp. gr. = 4.2, H. = 5–6. Comp. $4MnO_2(BaK_2)O$, H_2O, MnO_2 = 70 to 90 per cent, many varieties containing Ba, K_2O and H_2O in varying proportion. Luster submetallic to dull. Opaque, color black to gray. Infusible B.B.

Pumice. A vesicular or cellular glassy lava or volcanic ash. One analysis gave: SiO_2 = 66.54, Al_2O_3 = 16.12, FeO, Fe_2O_3 = 2.17, CaO = 1.59, MgO = .58, K_2O = 6.69, Na_2O = 4.23, TiO_2 = .47. Loss on ig. = 1.61.

Pyrites. Sp. gr. = 4.8–5.2. H = 6–6.5. Comp. FeS_2, Fe=46.7, S=53.3. Luster metallic; fracture conchoidal, uneven opaque; color brassy yellow; feels harsh to smooth; texture cubic granular. Fuses B.B.

Pyrolusite. Sp. gr.=4.8, H=1–2. Comp. MnO_2, Mn=63, O=37. Luster metallic; fracture uneven. Opaque, color grayish or bluish black; feels harsh, texture granular massive. Infusible.

Pyroxene. Sp. gr.=3.2–3.5, H=5–6. Comp. consists of silicates of various bases, Ca, Mg, Fe, Al, Mn, etc. One analysis gave: SiO_2=44, Al_2O_3=12, MgO =16, CaO=11, FeO, Fe_2O_3=14, MnO=1, K_2O, Na_2O=2. Luster vitreous to waxy; fracture conchoidal, uneven. Color white green to black; the fusibility varies almost to infusible.

Quartz. Includes, rock crystal, which is pure quartz, amethyst, rose quartz. Smoky quartz, milky quartz, cat's eye, chalcedony, agate, onyx, carnelian, sard, chrysoprase, flint, jasper, heliotrope or bloodstone, granular quartz, sp. gr.=2.66, H.=7. Comp. SiO_2 conchoidal; color colorless, white, yellow, red, violet, brown, green, blue, gray, black, streaked with various shades. Infusible.

Quartzite. Composed essentially of quartz, exceedingly refractory. Infusible B.B. One analysis gave SiO_2=84.69, Al_2O_3=7.50, Fe_2O_3, FeO=1.92, MgO=28, CaO=31, K_2O=2.36, Na_2O=2.27.

Realgar. Sp. gr.=3.5, H=1.5–2. Comp. AsS, As=70, S=30. Luster resinous, translucent. Fuses on charcoal and volatilize.

Rhodonite. Sp. gr. = 3.6, H. = 5.5–6.5. Comp. $MnSiO_3$, SiO_2=46, Mn=54. Luster pearly; fracture lamellar. Color pink or red when impure, greenish or yellowish, often stained black. CaO and Fe is usually present. Fuses B.B. to a dark glass.

Rhyolite. The most common volcanic rock. A highly siliceous compact or porphyritic variously colored volcanic rock (equivalent to granite).

Ripidolite. Sp. gr. = 2.65–2.75, H. = 2–2.5. Comp. $SiO_2 = 33$, $Al_2O_3 = 19$, $MgO = 36$, $H_2O = 12$. Luster pearly; fracture lamellar; feels smooth, color red, rose, violet, green. Fuses B.B. difficulty.

Rutile. Sp. gr. = 4.2, H. = 6–6.5. Comp. TiO_2. Luster metallic adamantine; fracture subconchoidal, uneven. Color, reddish brown, yellowish, black. Infusible B.B.

Salt. (See Halite.) Sp. gr. = 2.1–2.5, H. = 2.5. Comp. NaCl.

Sanidine. Sp. gr. = 2.5, H. = 6. Comp. as orthoclase. Luster vitreous, fracture conchoidal, uneven, transparent and glassy.

Serpentine. Sp. gr. = 2.5–2.65, H. = 2.5–4. Comp. $3MgO$, $2SiO_2$, $2H_2O$, usually also contains Fe, Ca, and Al. Luster pearly to subvitreous, translucent to opaque; fracture conchoidal uneven, splintery. Texture fibrous, granular (when it is streaked with magnesian marble called Verde antique); color green, whitish, brownish red, yellowish, grayish, blackish, feels soapy to harsh. Fusible B.B. with difficulty. One analysis from Vermont gave $SiO_2 = 40.52$, $Al_2O_3 = 2.10$, $FeO = 1.97$, $MgO = 52.05$, $H_2O = 13.46$.

Sepiolite. (See Meerschaum.)

Shale. A plastic rock formed by the consolidation of fine aluminous sediments.

Schist. Fiely laminated metaphoric rock (see Muscovite, Biotite, Chlorite, Talc). One analysis gave: $SiO_2=67$, $Al_2O_3=16$, FeO, $Fe_2O_3=7$, CaO=1, MgO =3, K_2O, $Na_2O=4$, $H_2O=2$.

Shorle. (See Tourmaline.)

Siderite. Sp. gr.=3.8, H.=3.5–4. Comp. $FeCO_3$, FeO=62, $CO_2=38$. Luster to dull, opaque to translucent; fracture uneven; texture granular; color white-gray, light-brown, red. Fuses B.B. with difficulty.

Silica. (See Quartz.)

Silex. (See Quartz.)

Sillimanite. Sp. gr.=3.2, H.=6.5. Comp. Al_2SiO_5, $SiO_2=37$, $Al_2O_3=63$. Color brown, gray or white. Infusible B.B.

Slate. Thinly cleavable, fine-grained metamorphic rocks formed from shales. One analysis gave: SiO_2 =63.52, Al_2O_3, $TiO_2=16.34$, FeO, $Fe_2O_3=6.79$, CaO =.98, MgO=2.50, CO_2, $H_2O=4.86$. (The structural and industrial material of California, 1906.)

Smaltite. Sp. gr. = 6.2–7, H. = 5.5–6. Comp. $(CoNi)As_2$, Fe and S, are usually present in small amounts. One analysis gave: Co=14, Ni=6, As=70, Fe=9.5, S=.5. Luster metallic; fracture uneven; texture granular, color green brown, grayish, white; feels harsh. Fusible on charcoal gives off As.

Smithsonite. (See Zinc spar.)

Soapstone. Sp. gr.=2.7, H.=1, sometimes 4. Comp. $H_2MgO_3(SiO_3)_4$, $SiO_2=62$, MgO=33, $H_2O=5$. Luster pearly; fracture scaly, earthy; color white, gray, green, brown, red, yellowish. Fusible B.B. on the edge.

Sodalite. Sp. gr. = 2.3, H.=5.5–6. Comp. $Na_4Al_3Cl(SiO_4)_3$, $SiO_2=37$, $Al_2O_3=32$, $Na_2O=19$, Na =5, Cl=7. Luster vitreous; fracture conchoidal, uneven, color, colorless, blue, gray, white, reddish. Fuses B.B. with intumescence to a colorless glass.

Spinel. Sp. gr. = 3.5, H. = 8, Comp. $MgAl_2O_4$, $Al_2O_3 = 72$, $MgO = 28$. Luster vitreous; fracture conchoidal; color red, blue, yellow, green, black; infusible B.B.

Steatite. (See Soapstone.)

Stibnite. Sp. gr. = 4.5, H. = 2. Comp. Sb_2S_3, Ab = 72, S = 28. Luster metallic, opaque; fracture conchoidal; texture granular to massive; feels smooth to harsh. Color lead gray. On charcoal easily fusible.

Strontia. (See Clestite.) Sr. = 56, S = 44.

Strontianite. Sp. gr. = 3.7, H. = 3.5–4. Comp. $SrCO_3$, $SrO = 70$, $CO_2 = 30$. Luster vitreous, to resinous, translucent; fracture uneven; texture fibrous, granular. Color, bluish, white to reddish, green, yellow, brown. Infusible B.B. but swells up, giving a crimson flame.

Syenite. An igneous rock composed mostly of feldspar with an amount of black ferromagnesian silicates as, hornblende, augite and biotite; texture granular. Fuses B.B. to a dark colored glass. A specimen gave the following analysis: $SiO_2 = 66.64$, $Al_2O_3 = 16.18$, FeO, $Fe_2O_3 = 2.94$, $CaO = 2.36$, $MgO = 1.30$, $K_2O = 3.91$, $Na_2O = 5.06$, $TiO_2 = 1.04$.

Talc. (See Soapstone.)

Terra Sienna. (See Ocher.)

Tetrahedrite. Sp. gr. = 4.5–5.1, H. = 3–4.5. Comp. Cu_3SbS_3. The Cu is often replaced by Fe, Zn, Ag, Hg, and the Sb by As. One analysis gave: Cu = 35, Sb = 20, S = 20, As = 7, FeO = 5, Zn = 3. Luster metallic opaque; fracture conchoidal to uneven. Texture granular to massive; color dark iron gray, feels harsh. Easily fusible B.B.

Thoria. (See Monazite.)

Tincal. (See Borax.)

Titanite. Sp. gr. = 3.5, H. = 5–5.5. Comp. $CaTiSiO_5$, $SiO_2 = 31$, $TiO_2 = 41$, $CaO = 28$. Luster resinous adamantine; fracture subchoidal to uneven; color varying tints and shades of brown, red, yellow, white gray, green to black. Fusible B.B. to a colored glass.

Topaz. Sp. gr. = 3.5, H. = 8. Comp. $Al_2F_2SiO_5$ or $2AlF_3$, $Al_4(SiO_4)_3$, $SiO_2 = 15$, $Al_2O_3 = 30$, $F = 20$, $O = 35$. Luster vitreous; fracture, subconchoidal to uneven, transparent; texture crystalline; color white to colorless, yellowish, bluish, reddish. Infusible B.B.

Tourmaline. Sp. gr. = 3.1, H. = 7–7.5. Comp. $R_9Al_3B_2(OH)_2Si_4O_{19}$, $SiO_2 = 35$, $Al_2O_3 = 35$, $B_2O_3 = 10$, $FeO = 8$, $MgO = 5$, $H_2OLi = 7$. Luster vitreous, transparent, fracture, subconchoidal, to uneven. Color colorless, white, yellow, green, blue, red, black; feels smooth; fusible to infusible.

Sphene. (See Titanite.)

Trachyte. A light-colored ash-gray or pale-blue and sometimes yellowish or reddish, volcanic porous and light-weight rock composed of feldspar with some hornblende and also mica, a specimen gave the following analysis: $SiO_2 = 61.20$, $Al_2O_3 = 16.35$, FeO, $Fe_2O_3 = 4.43$, $CaO = 2.56$, $MgO = 2.98$, $K_2O = 3.75$, $Na_2O = 4.16$, $TiO_2 = 1.96$, $H_2O = 2.61$.

Trap. A general name given for a dark fine-grained igneous rock, particularly lavas, or dikes of basalt. One analysis gave $SiO_2 = 52.45$, $Al_2O_3 = 16.04$, FeO, $Fe_2O_3 = 10.36$, $MnO = .46$, $CaO = 6.85$, $MgO = 4.79$, $K_2O = 1.18$, $Na_2O = 4.94$, $TiO_2 = 1.35$. Loss on ig. = 1.54.

Trydimite. Sp. gr. = 2.25–2.3, H. = 7. Comp. SiO_2 is a variety of Si whose crystalline form belongs to the hexagonal system found in vitreous bodies also in fire bricks.

Umber. (See Ocher.)

Vesuvianite. Sp. gr. = 3.4, H. = 6.5. Comp. Ca_6, $Al_2O_3(FOH)(SiO_4)_5$, $SiO_2 = 37$, $Al_2O_3 = 17$, FeO, $Fe_2O_3 = 7$, CaO = 35, MgO = 2, $Na_2OK_2O = 1$, $H_2O = 1$. Luster vitreous to resinous; fracture conchoidal to uneven. Color green, greenish-brown, yellow-brown, blue; fuses B.B. with intumescence to a colored glass.

Volcanic Ash. Includes volcanic tuff, pumice, or rocks consisting of small fragments and dust of lava material ejected from volcanoes, glassy in character. One analysis gave $SiO_2 = 63.35$, $Al_2O_3 = 15.76$, FeO, $Fe_2O_3 = 3.12$, MnO = .12, CaO = 3.88, MgO = 1.97, $K_2O = 4.15$, $Na_2O = 3.71$, $TiO_2 = 1.09$. Loss on ig. = 1.85.

Wad. Sp. gr. = 3–4.5, H. = 1–3. Comp. MnO_2H_2O (impure) composed of different cxide Fe, Cu, Co, Li or Ba, chiefly of manganese (H_2O = 10 to 20 per cent). Color black, bluish, or brownish black. Luster dull. Infusible B.B.

Willemite. Sp. gr. = 4.1, H. = 5.5. Comp. Zn_2SiO_4, $SiO_2 = 27$, ZnO = 73. Luster vitreous; fracture conchoidal; color pale red, yellow to green. Fuses B.B. with difficulty.

Witherite. Sp. gr. = 4.3, H. = 3.5 Comp. $BaCO_3$, BaO = 78, $CO_2 = 22$. Luster vitreous, faint resinous; fracture uneven. Color white or gray. Easily fusible B.B.

Wollastonite. Sp. gr. = 2.9, H. = 4.5–5. Comp. $CaSiO_2$, $SiO_2 = 52$, CaO = 48. Luster pearly vitreous;

fracture uneven. Color white or gray. Fuses B.B. to a white glass.

Zinc Blende. Sp. gr. = 4.1, H. = 3.7. Comp. ZnS, Zn = 67, S = 33. Luster resinous, translucent; fracture conchoidal, color whitish, yellow to brown.

Zinc Spar. (Smithsonite.) Sp. gr. = 4.4; H. = 5. Comp. $ZnCO_3$, ZnO = 65, CO_2 = 35. Luster vitreous, translucent; fracture uneven. Color gray, white, yellow sometimes blue or green. Infusible B.B.

Zircon. Sp. gr. = 4.6, H. = 7.5. Comp. $ZrSiO_4SiO_2$ = 33, Zr = 67. Luster vitreous, adamantine, transparent; fracture conchoidal, texture crystalline, color yellow, red, brown, pink, infusible.

Ziosite. Sp. gr. = 3.3, H. = 6–6.5. Comp. $HCa_2Al_3(SiO_4)_3$, SiO_2 = 40, Al_2O_3 = 23, CaO = 37. Luster pearly, vitreous; fracture uneven, translucent; color usually gray, sometimes white, yellow brown, red, green. Fuses B.B. with intumescence to a white glass.

FORMATION AND MELTING TEMPERATURE OF SILICATES

Description.	Formation Temperature Degrees C.	Melting Temperature Degrees C.
EUROPE:	1392	1208
Iron slag 50% SiO_2, 17% Al_2O_3, 3% FeO, 30% CaO	1220	1160
Lead slag 36% SiO_2, 40% FeO, 8.5% Al_2O_3, 4% CaO, 3% MgO, 7.5% CaO	1273	1166
Copper slag 33% SiO_2, 60% 3FeO, 7% Al_2O_3	...	1130–1160
Syenite (Tharandt)	...	1130–1166
Hornblende	Begins to fuse	1227
Mica porphyry	1570	...
$2CaSiO_2$	1451	1367 iron blast furnace slag
(CaO, Al_2O_3)SiO_2CaO : Al_2O_3 : 4 : 1(CaO, Al_2O_3)SiO_2	4110	1203
CaO : Al_2O_3 :: 1 : 1	...	...
AMERICA:	...	...
Iron slag 43.9% SiO_2, 8.6 Al_2O_3, 31.4 CaO, 10.2 MgO, 0.3 MnO, 4.5 FeO, SiO_2 27 to 35, Al_2O_3 + Fe_2O_3 8 to 20, CaO 44 to 5, MgO .6–2.5, SO_3 1 to 3	1450	1250 bisilicate
Lead furnace slag 31.47% SiO_2, 45.68 FeO, 22.85 CaO	1190	
A possible copper furnace slag 48.80 SiO_2, 39.46 FeO, 19.74 CaO	1160	

MELTING POINTS OF FELDSPARS AND SILICATES

Substance.	Melting-point Degrees C.	Cone No.
Orthoclase	1350	About 11
Anorthite	1250	" 6
Labradorite	1190	" 3
Oligoclase	1170	" 2
Albite	1130	" .01
$CaSiO_3$	1500	" 18
$2CaO, 3SiO_2$	1410	" 14
$4CaO, 3SiO_2$	1450	" 16
$2CaO, SiO_2$	1920	" 40
$3CaO, SiO_2$	1960	" 41
$SrSiO_3$	1287	" 8
$BaSiO_3$	1368	" 12
$MgSiO_3$	1565	" 22
$MnSiO_3$	1470–1500	" 17
$FeSiO_3$	1500–1550	" 21
$ZnSiO_3$	1479	" 17
$BeSiO_3$	2000	" 42
$2BeOSiO_2$	2000	" 42
$2MgOSiO_2$	1900	" 38
$2ZnOSiO_2$	1484	" 18
$2SrOSiO_2$	1903	" 38
Al_2SiO_5	1830	" 35

In the following tables are the results of many experiments made by different ceramists upon the melting-points of silicates of different mixtures of various oxides.

TABLE I

No.	Zitt Litz Kaolin	Quartz	Feldspar	Fusing-point (Seger Cone)
1	....	15	85	9–10
2	....	30	70	14
3	....	45	55	15–16
4	....	55	45	17
5	....	70	30	26–27
6	....	85	15	30–31
7	15	....	85	9
8	15	15	70	10–11
9	15	30	55	13–14
10	15	45	40	15
11	15	55	30	17–18
12	15	70	15	26
13	15	85	....	28–29
14	30	....	70	14
15	30	15	55	16–17
16	30	30	40	17–18
17	30	45	25	26
18	30	55	15	26
19	30	70	....	27
20	45	....	55	26+
21	45	15	40	26–27
22	45	30	25	27–28
23	45	45	10	29
24	45	55	....	29–30
25	55	....	45	28
26	55	15	30	29–30
27	55	30	15	30+
28	55	45	....	30–31
29	70	....	30	31+
30	70	15	15	32
31	70	30	....	32+
32	85	....	15	33–34
33	85	15	....	33–34

TABLE II

Mol. CaO to 1 Mol. $Al_2O_3SiO_2$	Per Cent Al_2O_3	Per Cent SiO_2	Per Cent CaO	Fusing-point (Seger Cones)
0.0	62.9	37.1	....	38
0.1	60.8	35.9	3.3	34
0.25	57.9	34.2	7.9	27–28
0.5	53.6	31.7	14.7	19
0.75	50.0	29.5	20.5	14–15
0.9	48.0	28.3	23.7	11–12
1.0	46.7	27.7	25.6	9–10
1.1	45.6	26.9	27.5	11
1.5	41.4	24.5	34.1	16
1.9	38.0	22.5	39.5	20
2.0	37.2	22.0	40.8	26
2.1	36.5	21.5	42.0	+20
2.5	33.8	20.0	46.2	17
2.75	32.3	19.1	48.6	+14
2.9	31.4	18.6	50.0	12
3.0	30.9	18.3	50.8	11
3.1	30.4	18.0	51.6	11–12
3.5	28.5	16.8	54.7	12–13
4.0	26.4	15.6	58.0	13–14
4.5	24.6	14.6	60.0	14–15
5.0	23.1	13.6	63.3	15
5.5	21.7	12.8	65.5	16
6.0	20.5	12.1	67.4	16–17
6.5	10.4	11.5	69.1	+17
7.0	18.4	10.9	70.7	18
7.5	17.5	10.4	72.1	+19
8.0	16.7	9.9	73.4	17
9.0	15.3	9.1	75.6	19–20
10.0	14.1	8.4	77.5	20–26
11.0	13.1	7.8	79.1	26
12.0	9.9	5.8	84.3	26–27

TABLE III

Mol. CaO to 1 Mol. Al_2O_3, Si_2, SiO_2	Per Cent Al_2O_3	Per Cent SiO_2	Per Cent CaO	Fusing-point (Seger Cones)
0.0	45.8	54.2	....	35
0.1	44.7	52.9	2.4	34
0.2	43.6	51.6	4.8	31
0.25	43.1	51.0	5.9	28–29
0.3	42.6	50.4	7.0	26–27
0.4	41.7	49.2	9.1	18
0.45	41.2	48.7	10.1	15
0.5	40.7	48.1	11.2	15–16
0.55	40.3	47.4	12.4	16
0.75	38.6	45.6	15.8	17
0.8	38.2	45.1	16.7	17
0.9	37.4	44.2	18.4	18
1.0	36.6	43.3	20.1	18–19
1.1	35.9	42.5	21.6	17
1.25	34.9	41.2	23.9	15
1.5	33.3	39.3	27.4	13
1.75	31.8	37.7	30.5	9
1.9	31.0	36.7	32.3	7–8
2.0	30.5	36.1	33.4	7
2.1	30.0	35.5	34.5	7
2.25	29.3	34.6	36.0	8
2.5	28.1	33.3	38.6	9
3.0	26.1	30.9	43.0	11–12
3.1	25.8	30.4	43.8	12
3.5	24.4	28.8	46.8	15
3.75	23.6	27.9	48.5	17
3.9	23.1	27.4	49.5	18–19
4.0	22.9	27.0	50.1	19
4.1	22.6	26.7	50.7	18–19
4.3	22.0	26.1	51.9	18
4.5	21.5	25.4	53.1	17–18
4.6	21.3	25.1	53.6	17

TABLE III—*Continued*

Mol. CaO to 1 Mol. Al_2O_3, Si_2, SiO_2	Per Cent Al_2O_3	Per Cent SiO_2	Per Cent CaO	Fusing-point (Seger Cones)
4.8	20.8	24.6	54.6	16–17
5.0	20.3	24.0	55.7	16
5.1	20.1	23.7	56.2	15–16
5.3	19.7	23.2	57.1	15
5.5	19.2	22.8	58.0	14–15
5.75	18.7	22.2	59.1	13–14
5.9	18.5	21.8	59.7	13
6.0	18.3	21.6	60.1	14
6.25	17.8	21.1	61.1	15–16
7.5	17.4	20.6	62.0	16–17
7.0	16.6	19.6	63.8	18
7.5	15.9	18.8	65.3	19
7.75	15.5	18.4	66.1	19–20
8.0	15.2	18.0	56.8	20
8.25	14.9	17.6	67.5	20
8.5	14.6	17.3	68.1	20–26
8.75	14.3	17.0	68.7	26
9.0	14.1	16.6	69.3	26
9.25	13.8	16.3	69.9	26–27
9.5	13.5	16.0	70.5	27
10.0	13.1	15.4	71.5	27
12.	11.4	13.5	75.1	27

TABLE IV

Mol. CaO to 1 Mol. Al_2O_3, SiO_2	Per Cent Al_2O_3	Per Cent SiO_2	Per Cent CaO	Fusing-point (Seger Cones)
0.0	36.0	64.0	....	33
0.1	33.4	62.7	1.9	31
0.2	34.7	61.5	3.8	30
0.25	34.4	60.9	4.7	29
0.3	34.0	60.4	5.6	28
0.4	33.4	59.3	7.3	19
0.45	33.1	58.7	8.2	16–17
0.5	32.8	58.2	9.0	14–15
0.55	32.5	57.7	9.8	15
0.75	31.4	55.7	12.9	15
0.8	31.1	55.2	13.7	15
0.9	30.6	54.3	15.1	15–16
1.0	30.1	53.4	16.5	15–16
1.1	29.6	52.5	17.9	15
1.25	28.9	51.3	19.8	13
1.5	27.8	49.3	22.9	11–12
1.75	26.8	47.5	25.7	9
1.9	26.2	46.5	27.3	9–10
2.0	25.9	45.8	28.3	10
2.1	25.5	45.2	29.3	9–10
2.25	24.9	44.3	30.8	9
2.5	24.1	42.8	33.1	6–7
3.0	22.6	40.2	37.2	6–7
3.5	21.3	37.8	40.9	7
4.0	20.1	35.7	44.2	7
4.5	19.1	33.8	47.1	7
5.0	18.1	32.2	49.7	6
5.5	17.3	30.6	52.1	15
5.75	16.9	20.9	53.2	17
6.0	16.5	29.3	54.2	19–20
6.25	16.1	28.6	55.3	19
6.5	15.8	28.0	56.2	19
7.0	15.1	26.8	58.1	19
7.5	14.5	25.8	59.7	20
8.0	14.0	24.8	61.2	20–26
9.0	13.0	23.0	64.0	27–28
10.0	12.1	21.5	66.4	29
12.0	10.7	19.0	70.3	31–32

TABLE V

Mol. CaO to 1 Mol. Al_2O_3, SiO_2	Per Cent Al_2O_3	Per Cent SiO_2	Per Cent CaO	Fusing-point (Seger Cones)
0.0	29.7	70.3	0.0	32
0.25	28.6	67.5	3.9	27
0.5	27.5	64.9	7.6	12
1.0	25.6	60.4	14.0	10
1.5	23.9	56.4	19.7	8
2.0	22.4	53.0	24.6	5–6
2.5	21.1	49.9	29.0	6
3.0	20.0	47.1	32.9	5
4.0	18.0	42.5	39.5	6
5.0	16.4	38.7	44.9	7
6.0	15.0	35.6	49.4	7–8
8.0	12.9	30.5	56.6	17–18
10.0	11.3	26.7	62.0	26

TABLE VI

Molecular Composition, Al_2O_3	Per Cent Alumina, Al_2O_3	Per Cent Silica, SiO_2	Melting-point (Seger Cones)
Al_2O_3	100.0	....	42
Al_2O_3 + 0.13 SiO_2.....	92.9	7.4	41
" + 0.33 "	82.0	18.0	40
" + 0.66 "	71.9	28.1	39
" + 1.00 "	62.9	37.1	38
" + 1.33 "	56.0	44.0	37
" + 1.66 "	50.5	49.5	36
" + 2.00 "	45.8	54.2	35
" + 2.50 "	40.4	59.6	34
" + 3.00 "	36.1	63.9	33
" + 4.00 "	29.7	70.3	32
" + 5.00 "	25.3	74.7	31
" + 6.00 "	22.0	78.0	30
" + 8.00 "	17.5	82.5	29
" +10.00 "	14.5	85.5	28
" +13.00 "	12.8	87.2	+27
" +15.00 "	10.1	89.9	27
" +20.00 "	8.4	91.6	30
" +23.00 "	6.5	93.5	32
SiO...	....	100.0	35

TABLE VII

Per Cent of Magnesite.	Added to 100 Parts of Kaolin.	Fusing-point (Seger Cones)
1	.1 part magnesite	34
3	3.1	33
5	5.3	32
10	11.1	28–29
15	17.6	26–27
20	25.0	16–17
25	33.3	15
30	42.9	13
35	53.8	11
40	66.7	10
45	81.8	10
50	100.0	12
52	108.3	14
54	117.3	16–17
55	122.2	18
56	127.3	19
58	138.1	20
60	150.0	26
62	163.2	28
64	177.8	29

TABLE VIII

Mol. Ratio of Different Compounds.	Reaction Commence ° C.	Reaction Complete ° C.	Product.
$1CaCO_3 + 1 SiO_2$	800	1400	
$4CaCO_4 + SiO_2$	1005–1010	1350	CaO, SiO_2 formed
$1CaCO_3 + 10SiO_2$	800	1250	Soluble in acid
$1CaCO_4 + 10SiO_2$	1000–1020	1300	
$3CaCO_3 + 1SiO_2$	800	1250	$2CaO, SiO_2$ formed
$3CaCO_3 + 10SiO_2$	About 1000	1250	
$1Na_2CO_3 + 1SiO_2$	800	950	Na_2O, SiO_2 formed
$1Na_2CO_3 + 10SiO_2$	800	1150	$Na_2O, 4SiO_2$ formed
$1Na_2SO_4 + 10SiO_2$	1120	....	Na_2O, SiO_2 formed
$1Na_2SO_4 + 10SiO_2$	1080–1100		
$1Na_2CO_3 + 10Al_2O_3$	800	1000	Na_2O, Al_2O_3 formed crumble at 1150° C.
$1Na_2CO_3 + 1CaCO_3 + 10SiO_2$	800	1000	Insoluble in acid
$1Na_2SO_4 + 1CaSO_4 + 10SiO_2$	930–950		
$1Na_2CO_3 + 1Al_2O_3 + 10SiO_2$	800	1000	Insoluble in acid
$1Na_2SO_4 + 1Al_2O_3 + 10SiO_2$	935–955		
$1CaCO_3 + 1Al_2O_3 + 10SiO_2$	800	1300	
$1CaSO_4 + 1Al_2O_3 + 10SiO_2$	1000–1020	1300	
$1Na_2CO_3 + 1CaCO_3 + 1Al_2O_3 + 10SiO_2$	800	1400	Insoluble in acid

TABLE IX *

Substance.	Melting Temp. Degrees C.	Cone No.
$Al_2O_3 + SiO_2 + CaO$		
60 + 10 + 30	1400	About 14
60 + 20 + 20	1500	" 19
60 + 30 + 10	1600	" 24
30 + 60 + 10	1450	" 16
20 + 60 + 20	1300–1325	" 9–10
10 + 60 + 30	1400	" 14
30 + 10 + 60	1400–1425	" 14–15
20 + 20 + 60	1450–1475	" 16–17
10 + 30 + 60	1650	26

* Der elektrische Ofen (p. 45).

TABLE X

Melting-point.	° C.	° F.
First-class fire brick	1650–1730	3002–3146
Second-class fire brick	1570–1630	2858–2966
Kaolin class fire brick	1740	3146
Pure alumina	2050	3722
Bauxite brick	1820	3308
Bauxite clay brick	1795	3263
Pure silica brick	1750	3182
Chromite brick	2180	3956
Magnesium oxide	2800	5072
Magnesia brick	2000	3632
Calcium oxide	2572	4662
Carbon	3600	6500
Carbon arc	3500	6330
Platinum	1755	3182
Iridium	2350	4262
Tungsten	3000	5430
Titanium	1800	3272
Beryllium oxide	Over 2000	3632
Lanthanum pentoxide	1840	3344
Thorium oxide	2470	4478
Yttrium oxide	2400	4352
Zirconium oxide	2570	4658
Zirconium brick	About 2000	3632

WEIGHT OF A CUBIC FOOT OF VARIOUS MATERIALS

Material	Pounds
Aluminum	162
Anthracite, solid	93
" broken, loose	54
Ash, white dry	38
Asphaltum	87
Brass, cast	504
" rolled	524
Brick, best pressed	150
" common hard	125
" common red	100
" fire clay	150
" fire	120
Silica	128
Chrome	175
Magnesia	160
Cement, hydraulic	60
" Portland	70
Chalk	145
Cherry, dry	42
Chestnut, dry	41
Clay, pottery, dry	119
Fire clay, ground	85
Clay in lumps, loose	63
Silica cement	126
Chrome cement	134
Grain magnesite	112
Coal, bituminous, solid	84
" loose	49
Coke, loose	26
Charcoal	18
Concrete	154
Copper, cast	542
" rolled	548

Material	Pounds
Cork	15
Earth loam, dry loose	76
" packed	95
" soft, loose mud	108
" dense mud	126
Ebony, dry	76
Elm, dry	35
Flint	162
Glass, common window	157
" plate	172
" flint	192
" floor or skylight	156
Gneiss	168
Granite	170
Gravel	90-106
Gypsum	142
Hemlock, dry	25
Hickory, dry	53
Hornblende	203
Ice	59
Iron, case	450
" wrought	485
Lead	711
Lime, quick, ground, loose	53
" slaked	75
" stone large	168
" stone, irregular lumps	96
Magnesium	109
Masonry, granite or limestone	165
Mortar, rubble	154

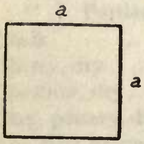
	Pounds
Sandstone, dressed	144
Mercury at ° C	849
Mica	183
Mortar, hardened	103
Mud, dry, close	80–110
Oak, white dry	50
Oils, engine	55
" other kinds	32–45
" crude	48
" petroleum	55
" gasoline	43
Pumicestone	57
Quartz	165
Salt, coarse	45
" fine	49
Shales	162

	Pounds
Slate	175
Sand, dry and loose	90–106
" dry and packed	110
" wet and packed	130
Snow, freshly fallen	5–12
" moist and compacted by rain	12–50
Steel	490
Sulphur	125
Tar	62
Turf or peat, dry	20–30
Walnut, black, dry	38.
Water	62
Wax	60
Zinc	437

MENSURATION

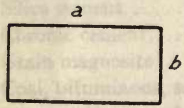
In the following formulas the letters have the meanings indicated below:

D = large diameter;
d = small diameter;
R = radius corresponding to D;
r = radius corresponding to d;
p = perimeter of circumference;
C = area of convex surface;
S = area of entire surface = C + area of the end or ends;
A = area of plane figure;
$\pi = 3.1416$ = ratio of nearly any circumference to its diameter;
V = volume of solid;
h = height;
b = base.



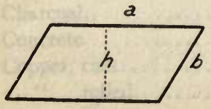
Square

$A = a \times a = a^2$



Rectangle

$A = a \times b$

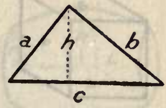


Parallelogram

$A = a \times h$

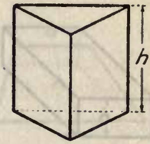
Triangle

$$A=\frac{c\times h}{2}$$



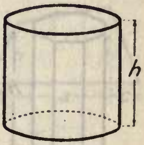
Triangular Prism

$$V=b\times h$$



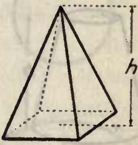
Cylinder

$$V=b\times h$$



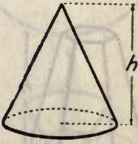
Pyramid

$$V=\frac{b\times h}{3}$$



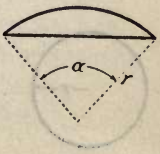
Cone

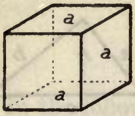
$$V=\frac{b\times h}{3}$$



Segment

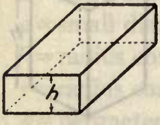
$$A=\left(\frac{\alpha\times\pi}{180}-\sin\alpha\right)\frac{r^2}{2}$$





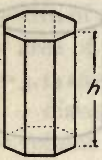
Cube

$$V = a \times a \times a = a^3$$



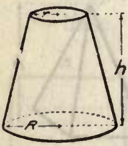
Rectangular Prism

$$C = p \times h$$
$$S = ph + 2b$$
$$V = b \times h$$



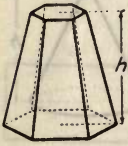
General Prism

$$C = p \times h$$
$$S = ph + 2b$$
$$V = b \times h$$



Frustum of Cone

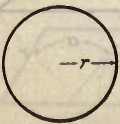
$$V = \frac{\pi h}{3}(R^2 + r^2 + (R \times r))$$



Frustum of Pyramid

$$V = \frac{h}{3}(B + b + \sqrt{B \times b})$$

B = area of lcwer base
b = area of upper base



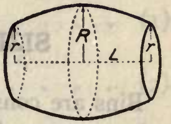
Sphere

$S = \pi d^2$, or $4\pi r^2$, or $12.5664 r^2$

$V = \frac{1}{6}\pi d^3$, or $\frac{4}{3}\pi r^3$, or $.5236 d^3$ or $4.1888 r^3$

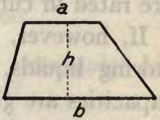
Barrel

$$V=\frac{\pi L}{3}(r^2+2R^2)$$



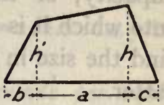
Trapezoid

$$A=\tfrac{1}{2}h(a+b)$$



Trapezium

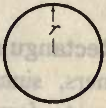
$$A=\tfrac{1}{2}bh'+\tfrac{1}{2}a(h'+h)+\tfrac{1}{2}ch$$



Circle

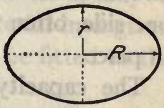
$$A=R^2\times\pi \text{ or } \frac{D\times\pi}{4}$$

$$p=2R\times\pi \text{ or } D\times\pi$$



Ellipse

$$A=R\times r\times\pi$$



Sector

$$A=\frac{\alpha\times\pi\times r^2}{360}$$

SIZE OF BINS AND TANKS

Bins are constructed to hold some more or less dry substances, such as sand, clay, etc., and their capacities are rated in cubic feet, cubic yards, or tons.

If, however, they are watertight and are used for storing liquids, they are known as tanks, and their capacities are given in gallons or barrels.

When installing a bin or tank, either the desired capacity, or the dimensions of the available space into which it is to fit, are known, and the problem is to find the size in the former case, or the capacity in the latter.

Bins

Rectangular. Bins are usually built with square corners, since planks fit best in that shape. Such concrete forms are easier and cheaper to construct and a wall of the building is frequently utilized as one side, often the bin is in a corner and two sides are in place.

The capacity of a given bin, therefore, being its volume, if

l = length of bin in feet;
b = breadth of bin in feet;
h = height of bin in feet;
v = volume, or capacity, in cubic feet;
V = volume, or capacity, in cubic yards;
w = weight in pounds per cubic yard of material to be stored;
T = capacity in tons.

Then

$$v = l \times b \times h; \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

$$V = \frac{l \times b \times h}{27}; \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

$$T = \frac{l \times b \times h \times w}{27 \times 2000} \text{ or } \frac{l \times b \times h \times w}{54000}. \quad . \quad . \quad (3)$$

Example. What is the capacity of a rectangular bin 20 feet wide, 30 feet long, and 10 feet high?

From Equation (1): $v = 30 \times 20 \times 10 = 6000$ cu.ft.

From Equation (2): $V = \frac{30 \times 20 \times 10}{27} = 222.22$ cu. yds.

Example. If clay weighing 3000 pounds per cubic yard is to be stored in it, how many tons will it hold?

From Equation (3):

$$T = \frac{30 \times 20 \times 10 \times 3000}{54000} = 333.33 \text{ tons}$$

In practice, however, the condition is usually a desire to store a given quantity of material in a given location, and the form of the bin must be fitted to the local conditions.

Example. It is desired to store 100 tons of sand, weighing 2000 pounds per cubic yard in the end of a building 20 feet of which is available for the length of the bin, shafting overhead limits the height of the bin to 8 feet, how wide must it be made?

From Equation (3): $100 = \frac{20 \times b \times 8 \times 2000}{54000} = 5.926 \times b$

$$b = \frac{100}{5.926} = 16.89 \text{ feet or } 16 \text{ feet } 10\tfrac{1}{2} \text{ inches.}$$

Cylindrical. If the bin is to be made of metal sheets, then the cylindrical shape is usually adopted, for the reasons that it is as easy to form, gives a greater capacity for like amount of metal, and the pressure being exerted equally in all directions, there is no danger of bulging.

The capacity of a cylindrical bin is likewise its volume, if

l = length of bin in feet;
d = diameter of bin in feet;
v = volume, or capacity, in cubic feet;
V = volume, or capacity in cubic yards;
w = weight in pounds per cubic yard of material to be stored;
T = capacity of tons.

Then

$$v = .7854 \times d^2 \times 1; \quad \ldots \ldots \ldots \quad (4)$$

$$V = \frac{.7854 \times d^2 \times l}{27} = .02909 \times d^2 \times l; \quad \ldots \quad (5)$$

$$T = \frac{.02909 \times d^2 \times l \times w}{2000} = .000014545 \times d^2 \times l \times w. \quad (6)$$

Example. What is the capacity of a cylindrical bin 10 feet in diameter and 20 feet high?

From Equation 4: $v = .7854 \times 10^2 \times 20 = 1570.8$ cu. ft.

From Equation (5): $V = .02909 \times 10^2 \times 20 = 58.18$ cu.yds.

Example. The top of an elevator is 20 feet above the ground. It is desired to construct a cylindrical concrete bin into which the elevator can discharge, and the raw material be withdrawn at the bottom. If the bin is to hold 50 tons of crushed quartz weighing 2700 pounds per cubic yard, what must be the diameter?

From Equation (6):

$$50 = .000014545 \times d^2 \times 20 \times 2700$$

$$50 = .78543 \times d^2$$

$$d = 63.65$$

$d = 7.97$ feet practically 8 feet

Tanks

The volume of a tank is calculated just as if it were a bin, and the capacity in gallons is the volume in cubic feet multiplied by 7.48 (the number of gallons in 1 cubic foot); and the capacity in barrels may then be found by dividing this result by 231 (the number of gallons in 1 standard barrel. This latter unit is seldom used, however, since all barrels are not of the same size).

Rectangular. From Equation (1), if

G = volume or capacity in gallons;

B = volume, or capacity, in barrels.

$$G = l \times b \times h \times 7.48 \quad \ldots \quad (7)$$

$$B = \frac{l \times b \times h \times 7.48}{231} = l \times b \times h \times .03238. \quad \ldots \quad (8)$$

Example. How many gallons will a tank 10 feet long, 6 feet wide, and 4 feet deep, hold?

Equation (7): $G = 10 \times 6 \times 4 \times 7.48 = 1795.2$ gallons.

Example. The trusses of a roof are 10 feet apart, the struts and ties will allow a tank 4 feet wide and 3 feet high to rest in them. What should be the dimensions of a tank to be supported on two trusses and hold 500 gallons?

It would be good designing to allow the tank to project at each end to insure a good support and reduce the liability to slip off, therefore, for example, assume length 12 feet.

From Equation (7):

$$500 = 12 \times b \times h \times 7.48$$

$$500 = 89.76 \times b \times h$$

$$b \times h = 5.57$$

It is evident from the result that any number of combinations may be used, the only restrictions being that the product of the breadth and the height ($b \times h$) must equal 5.57.

If breadth be taken as 3 feet, then:

$$3 \times h = 5.57$$

$$h = 1.85 \text{ feet or } 1 \text{ feet } 10\tfrac{1}{2} \text{ inches}$$

Cylindrical. From equation (4), if

G = volume, or capacity, in gallons

B = volume, or capacity, in barrels

$$G = .7854 \times d \times 1 \times 7.48 = 5.87479 \times d \times l \quad . \quad . \quad (9)$$

$$B = \frac{5.87479 \times d \times l}{231} = .02543 \times d \times l. \quad . \quad . \quad . \quad (10)$$

Example. It is desired to install a settling tank, cylindrical in shape, 5 feet high, and holding 100,000 gallons, what must be the diameter?

From Equation (9):

$$100{,}000 = 5.87479 \times d \times 5$$

$$29.37395 \times d = 100{,}000$$

$$d = 3404$$

$$d = 58.34 \text{ feet, or } 58 \text{ feet } 4 \text{ inches.}$$

Example. There is available in a corner a space sufficient to install a vertical cylindrical tank 5 feet in diameter, if it is to hold 1500 gallons, how high must it be?

From Equation (9):

$$1500 = 5.87479 = 25 \times 1$$

$$146.8697 \times 1 = 1500$$

$$1 = 10.21 \text{ feet or } 10 \text{ feet } 3\tfrac{1}{2} \text{ inches}$$

LOGARITHMS

By the use of logarithms, many mathematical calculations can be simplified. Multiplication and division are accomplished by addition and subtraction and involution and evolution solved by multiplication and division. A logarithm is the power to which a given base must be raised to produce a given number. Every logarithm consists of two parts, a positive or negative whole number called the *characteristic* or index, and a positive fraction called the *mantissa*. The mantissa is always expressed as a decimal and is the part which is given in the tables appearing without the decimal point in the columns headed 0 to 9. The numbers of the corresponding logs are shown in the column headed *N*.

In common logarithms the base is 10 since:

Log.	1 = 0	Log.	0.1 = −1
"	10 = 1	"	0.01 = −2
"	100 = 2	"	0.001 = −3
"	1000 = 3	"	0.0001 = −4

or from 1 to 9.99 it is 0, from 10 to 99.99 it is 1, and from 100 to 999.99 it is 2 and so on.

From 0.1 to 0.99 it is −1, from 0.01 to 0.099 it is −2, and from 0.001 to 0.0099 it is −3, etc.

The following table will help to explain the rule that the characteristic of a number is always *one less* than the number of its digits and that it is positive or negative according to whether it is more or less than one. The mantissa is never negative.

characteristic | mantissa

Log. of	3000 is 3.47712	
"	300 is 2.47712	
"	30 is 1.47712	
"	3 is 0.47712	
"	0.3 is −1.47712	or 9.47712−10
"	0.03 is −2.47712	or 8.47712−10
"	0.003 is −3.47712	or 7.47712−10
"	0.0003 is −4.47712	or 6.47712−10

From the tables of logarithms on the following pages, the mantissa of any number up to 1000 may be had by direct reading, as for example, the mantissa 355 is found by looking in the *N* column to 355 and opposite in the *O* column is its log which is 55023. For numbers of more than four figures, the operation is somewhat more complicated. The mantissa of 4253 is found by looking up the first three digits (425) in the *N* column opposite which in the *O* column is 62 and in the same line in the 3 column we find 870. Putting them together we have 62870.

Multiplication by the use of logarithms performed by adding together the logarithms of the numbers and then finding the number that corresponds to the log.

Example. Multiply 250 by 3.05.

characteristic | mantissa

$$\begin{array}{lr} \text{Log. } 250 = & 2.39794 \\ \text{"} \quad 3.05 = & 0.48430 \\ \hline & 2.88224 \end{array}$$

Now find the number corresponding to 2.98224. First find 88 in the *O* column and on the same line with it the 224 in the 5 column corresponding with 762 in the *N* column. The number we require therefore is 7625. But the decimal point must now be fixed. The characteristic of our answer being 2 we know that it represents a number of three digits. Placing the decimal point three places to the left, the result is 762.5.

Proof: $250 \times 3.05 = 762.5$.

Example. Find the product 3×5×6.

$$
\begin{aligned}
\text{Log. } 3 &= 0.47712 \\
\text{"} \quad 5 &= 0.69897 \\
\text{"} \quad 6 &= 0.77815 \\
\hline
1.95424 &= \text{log. } 90.00
\end{aligned}
$$

which is correct shown by the following:

Proof: $3 \times 5 = 15, \quad 15 \times 6 = 90.00$.

This method may be used for the multiplication of larger numbers by others equally large and the answers will be correct.

To divide one number by another, subtract the logarithm of the latter from that of the former.

Example. Divide 150 by 4,

characteristic

mantissa

$$
\begin{aligned}
\text{Log. } 150 &= 2.17609 \\
4 &= 0.60206 \\
\hline
1.57403 &= \text{log. } 375
\end{aligned}
$$

The characteristic being 1, it is necessary to point off two places to the left of the decimal point which gives as the quotient 37.50.

Proof: $150 \div 4 = 37.5$.

To raise a number to any power, multiply its logarithm by the number of the desired power and then find of what number the result is the logarithm.

Example. Raise 5 to the fifth power.

$$\begin{array}{r} \text{Log. } 5 = 0.69897 \\ 5 \\ \hline 3.49485 \end{array}$$

3.49485 is the log of 3125 which is the fifth power of 5.

Proof. $5 \times 5 \times 5 \times 5 \times 5 = 3125$.

Similarly to find the root of any number, divide its logarithm by the number of the desired root and find of what number the result is the logarithm.

Example. Find the cube root of 512.

$$\text{Log. } 512 = 2.70927$$

$$2.70927 \div 3 = \quad 90309$$

Referring to the table, we find that 90307 is the log. of 8 which is the cube root of 512.

Proof: $(8 \times 8 \times 8) = 512$.

Example. By an analysis we find that a sample of clay gives us .029 gm. of $Mg_2P_2O_7$ how much MgO does the sample of clay contain? To convert $Mg_2P_2O_7$ to MgO, we use the factor .36207, whose mantissa is = 55879, and .029 has 46240 for a mantissa.

$$\begin{array}{rl} \text{Therefore, log. } .36207 & = -1.55879 \\ \text{“} \quad .029 & = -2.46240 \\ \hline & -4.02119 = \text{log. we find} \end{array}$$

by looking in column headed O, 02119 and opposite in column headed N we find 105 the characteristic is -4, so we have to add 5 zeros to left of the quotient which will be then .0105, multiplying this by 100 we get the percentage of the MgO present in the sample = 1.05.

Proof: $(.36207 \times .029) \times 100 = 1.05\%$ MgO.

Example. The ultimate analysis of a sample of clay shows 2.00 per cent of K_2O. To find the amount of feldspar substance present in the clay we proceed as follows:

Mol. W. for orthoclase feldspar = 556, and for K_2O = 94.

Log. of 556 = 2.74507
" 2 = 0.30103

3.04610 = log. 1112.

The log. for 94 is 1.97313 which must be subtracted from the above quotient as follows:

Log. of 1112 = 3.04610
" 94 = 1.97313

1.07297 = log. 11.83, which is correct.

The clay theoretically contains 11.83 per cent of feldspar substances.

Prove: $\frac{556 \times 2}{94} = 11.83.$

All of the above examples have been selected for their simplicity, but the use of logarithms in making calculations will be found especially helpful when the problems are complex.

COMMON LOGARITHMS OF NUMBERS
(Base 10)

N	0	1	2	3	4	5	6	7	8	9
100	00 000	00 043	00 087	00 130	00 173	00 217	00 260	00 303	00 346	00 389
101	00 432	00 475	00 518	00 561	00 604	00 647	00 689	00 732	00 775	00 817
102	00 860	00 903	00 945	00 988	01 030	01 072	01 115	01 157	01 199	01 242
103	01 284	01 326	01 368	01 410	01 452	01 494	01 536	01 578	01 620	01 662
104	01 703	01 745	01 787	01 828	01 870	01 912	01 953	01 995	02 036	02 078
105	02 119	02 160	02 202	02 243	02 284	02 325	02 366	02 407	02 449	02 490
106	02 531	02 572	02 612	02 653	02 694	02 735	02 776	02 816	02 857	02 898
107	02 938	02 979	03 019	03 060	03 100	03 141	03 181	03 222	03 262	03 302
108	03 342	03 383	03 423	03 463	03 503	03 543	03 583	03 623	03 663	03 703
109	03 743	03 782	03 822	03 862	03 902	03 941	03 981	04 021	04 060	04 100
110	04 139	04 179	04 218	04 258	04 297	04 336	04 376	04 415	04 454	04 493
111	04 532	04 571	04 610	04 650	04 689	04 727	04 766	04 805	04 844	04 883
112	04 922	04 961	04 999	05 038	05 077	05 115	05 154	05 192	05 231	05 269
113	05 308	05 346	05 385	05 423	05 461	05 500	05 538	05 576	05 614	05 652
114	05 690	05 729	05 767	05 805	05 843	05 881	05 918	05 956	05 994	06 032
115	06 070	06 108	06 145	06 183	06 221	06 258	06 296	06 333	06 371	06 408
116	06 446	06 483	06 521	06 558	06 595	06 633	06 670	06 707	06 744	06 781
117	06 819	06 856	06 893	06 930	06 967	07 004	07 041	07 078	07 115	07 151
118	07 188	07 225	07 262	07 298	07 335	07 372	07 408	07 445	07 482	07 518
119	07 555	07 591	07 628	07 664	07 700	07 737	07 773	07 809	07 846	07 882
120	07 918	07 954	07 990	08 027	08 063	08 099	08 135	08 171	08 207	08 243
121	08 279	08 314	08 350	08 386	08 422	08 458	08 493	08 529	08 565	08 600
122	08 636	08 672	08 707	08 743	08 778	08 814	08 849	08 884	08 920	08 955
123	08 991	09 026	09 061	09 096	09 132	09 167	09 202	09 237	09 272	09 307
124	09 342	09 377	09 412	09 447	09 482	09 517	09 552	09 587	09 621	09 656
125	09 691	09 726	09 760	09 795	09 830	09 864	09 899	09 934	09 968	10 003
126	10 037	10 072	10 106	10 140	10 175	10 209	10 243	10 278	10 312	10 346
127	10 380	10 415	10 449	10 483	10 517	10 551	10 585	10 619	10 653	10 687
128	10 721	10 755	10 789	10 823	10 857	10 890	10 924	10 958	10 992	11 025
129	11 059	11 093	11 126	11 160	11 193	11 227	11 261	11 294	11 327	11 361
130	11 394	11 428	11 461	11 494	11 528	11 561	11 594	11 628	11 661	11 694
131	11 727	11 760	11 793	11 826	11 860	11 893	11 926	11 959	11 992	12 024
132	12 057	12 090	12 123	12 156	12 189	12 222	12 254	12 287	12 320	12 352
133	12 385	12 418	12 450	12 483	12 516	12 548	12 581	12 613	12 646	12 678
134	12 710	12 743	12 775	12 808	12 840	12 872	12 905	12 937	12 969	13 001
135	13 033	13 066	13 098	13 130	13 162	13 194	13 226	13 258	13 290	13 322
136	13 354	13 386	13 418	13 450	13 481	13 513	13 545	13 577	13 609	13 640
137	13 672	13 704	13 735	13 767	13 799	13 830	13 862	13 893	13 925	13 956
138	13 988	14 019	14 051	14 082	14 114	14 145	14 176	14 208	14 239	14 270
139	14 301	14 333	14 364	14 395	14 426	14 457	14 489	14 520	14 551	14 582
140	14 613	14 644	14 675	14 706	14 737	14 768	14 799	14 829	14 860	14 891
141	14 922	14 953	14 983	15 014	15 045	15 076	15 106	15 137	15 168	15 198
142	15 229	15 259	15 290	15 320	15 351	15 381	15 412	15 442	15 473	15 503
143	15 534	15 564	15 594	15 625	15 655	15 685	15 715	15 746	15 776	15 806
144	15 836	15 866	15 897	15 927	15 957	15 987	16 017	16 047	16 077	16 107

COMMON LOGARITHMS OF NUMBERS
(*Continued*)

N	0	1	2	3	4	5	6	7	8	9
145	16 137	16 167	16 197	16 227	16 256	16 286	16 316	16 346	16 376	16 406
146	16 435	16 465	16 495	16 524	16 554	16 584	16 613	16 643	16 673	16 702
147	16 732	16 761	16 791	16 820	16 850	16 879	16 909	16 938	16 967	16 997
148	17 026	17 056	17 085	17 114	17 143	17 173	17 202	17 231	17 260	17 289
149	17 319	17 348	17 377	17 406	17 435	17 464	17 493	17 522	17 551	17 580
150	17 609	17 638	17 667	17 696	17 725	17 754	17 782	17 811	17 840	17 869
151	17 898	17 926	17 955	17 984	18 013	18 041	18 070	18 099	18 127	18 156
152	18 184	18 213	18 241	18 270	18 298	18 327	18 355	18 384	18 412	18 441
153	18 469	18 498	18 526	18 554	18 583	18 611	18 639	18 667	18 696	18 724
154	18 752	18 780	18 808	18 837	18 865	18 893	18 921	18 949	18 977	19 005
155	19 033	19 061	19 089	19 117	19 145	19 173	19 201	19 229	19 257	19 285
156	19 312	19 340	19 368	19 396	19 424	19 451	19 479	19 507	19 535	19 562
157	19 590	19 618	19 645	19 673	19 700	19 728	19 756	19 783	19 811	19 838
158	19 866	19 893	19 921	19 948	19 976	20 003	20 030	20 058	20 085	20 112
159	20 140	20 167	20 194	20 222	20 249	20 276	20 303	20 330	20 358	20 385
160	20 412	20 439	20 466	20 493	20 520	20 548	20 575	20 602	20 629	20 656
161	20 683	20 710	20 737	20 763	20 790	20 817	20 844	20 871	20 898	20 925
162	20 952	20 978	21 005	21 032	21 059	21 085	21 112	21 139	21 165	21 192
163	21 219	21 245	21 272	21 299	21 325	21 352	21 378	21 405	21 431	21 458
164	21 484	21 511	21 537	21 564	21 590	21 617	21 643	21 669	21 696	21 722
165	21 748	21 775	21 801	21 827	21 854	21 880	21 906	21 932	21 958	21 985
166	22 011	22 037	22 063	22 089	22 115	22 141	22 167	22 194	22 220	22 246
167	22 272	22 298	22 324	22 350	22 376	22 401	22 427	22 453	22 479	22 505
168	22 531	22 557	22 583	22 608	22 634	22 660	22 686	22 712	22 737	22 763
169	22 789	22 814	22 840	22 866	22 891	22 917	22 943	22 968	22 994	23 019
170	23 045	23 070	23 096	23 121	23 147	23 172	23 198	23 223	23 249	23 274
171	23 300	23 325	23 350	23 376	23 401	23 426	23 452	23 477	23 502	23 528
172	23 553	23 578	23 603	23 629	23 654	23 679	23 704	23 729	23 754	23 779
173	23 805	23 830	23 855	23 880	23 905	23 930	23 955	23 980	24 005	24 030
174	24 055	24 080	24 105	24 130	24 155	24 180	24 204	24 229	24 254	24 279
175	24 304	24 329	24 353	24 378	24 403	24 428	24 452	24 477	24 502	24 527
176	24 551	24 576	24 601	24 625	24 650	24 674	24 699	24 724	24 748	24 773
177	24 797	24 822	24 846	24 871	24 895	24 920	24 944	24 969	24 993	25 018
178	25 042	25 066	25 091	25 115	25 139	25 164	25 188	25 212	25 237	25 261
179	25 285	25 310	25 334	25 358	25 382	25 406	25 431	25 455	25 479	25 503
180	25 527	25 551	25 575	25 600	25 624	25 648	25 672	25 696	25 720	25 744
181	25 768	25 792	25 816	25 840	25 864	25 888	25 912	25 935	25 959	25 983
182	26 007	26 031	26 055	26 079	26 102	26 126	26 150	26 174	26 198	26 221
183	26 245	26 269	26 293	26 316	26 340	26 364	26 387	26 411	26 435	26 458
184	26 482	26 505	26 529	26 553	26 576	26 600	26 623	26 647	26 670	26 694
185	26 717	26 741	26 764	26 788	26 811	26 834	26 858	26 881	26 905	26 928
186	26 951	26 975	26 998	27 021	27 045	27 068	27 091	27 114	27 138	27 161
187	27 184	27 207	27 231	27 254	27 277	27 300	27 323	27 346	27 370	27 393
188	27 416	27 439	27 462	27 485	27 508	27 531	27 554	27 577	27 600	27 623
189	27 646	27 669	27 692	27 715	27 738	27 761	27 784	27 807	27 830	27 852

COMMON LOGARITHMS OF NUMBERS
(*Continued*)

N	0	1	2	3	4	5	6	7	8	9
190	27 875	27 898	27 921	27 944	27 967	27 989	28 012	28 035	28 058	28 081
191	28 103	28 126	28 149	28 171	28 194	28 217	28 240	28 262	28 285	28 307
192	28 330	28 353	28 375	28 398	28 421	28 443	28 466	28 488	28 511	28 533
193	28 556	28 578	28 601	28 623	28 646	28 668	28 691	28 713	28 735	28 758
194	28 780	28 803	28 825	28 847	28 870	28 892	28 914	28 937	28 959	28 981
195	29 003	29 026	29 048	29 070	29 092	29 115	29 137	29 159	29 181	29 203
196	29 226	29 248	29 270	29 292	29 314	29 336	29 358	29 380	29 403	29 425
197	29 447	29 469	29 491	29 513	29 535	29 557	29 579	29 601	29 623	29 645
198	29 667	29 688	29 710	29 732	29 754	29 776	29 798	29 820	29 842	29 863
199	29 885	29 907	29 929	29 951	29 973	29 994	30 016	30 038	30 060	30 081
200	30 103	30 125	30 146	30 168	30 190	30 211	30 233	30 255	30 276	30 298
201	30 320	30 341	30 363	30 384	30 406	30 428	30 449	30 471	30 492	30 514
202	30 535	30 557	30 578	30 600	30 621	30 643	30 664	30 685	30 707	30 728
203	30 750	30 771	30 792	30 814	30 835	30 856	30 878	30 899	30 920	30 942
204	30 963	30 984	31 006	31 027	31 048	31 069	31 091	31 112	31 133	31 154
205	31 175	31 197	31 218	31 239	31 260	31 281	31 302	31 323	31 345	31 366
206	31 387	31 408	31 429	31 450	31 471	31 492	31 513	31 534	31 555	31 576
207	31 597	31 618	31 639	31 660	31 681	31 702	31 723	31 744	31 765	31 785
208	31 806	31 827	31 848	31 869	31 890	31 911	31 931	31 952	31 973	31 994
209	32 015	32 035	32 056	32 077	32 098	32 118	32 139	32 160	32 181	32 201
210	32 222	32 243	32 263	32 284	32 305	32 325	32 346	32 366	32 387	32 408
211	32 428	32 449	32 469	32 490	32 510	32 531	32 552	32 572	32 593	32 613
212	32 634	32 654	32 675	32 695	32 715	32 736	32 756	32 777	32 797	32 818
213	32 838	32 858	32 879	32 899	32 919	32 940	32 960	32 980	33 001	33 021
214	33 041	33 062	33 082	33 102	33 122	33 143	33 163	33 183	33 203	33 224
215	33 244	33 264	33 284	33 304	33 325	33 345	33 365	33 385	33 405	33 425
216	33 445	33 465	33 486	33 506	33 526	33 546	33 566	33 586	33 606	33 626
217	33 646	33 666	33 686	33 706	33 726	33 746	33 766	33 786	33 806	33 826
218	33 846	33 866	33 885	33 905	33 925	33 945	33 965	33 985	34 005	34 025
219	34 044	34 064	34 084	34 104	34 124	34 143	34 163	34 183	34 203	34 223
220	34 242	34 262	34 282	34 301	34 321	34 341	34 361	34 380	34 400	34 420
221	34 439	34 459	34 479	34 498	34 518	34 537	34 557	34 577	34 596	34 616
222	34 635	34 655	34 674	34 694	34 713	34 733	34 753	34 772	34 792	34 811
223	34 830	34 850	34 869	34 889	34 908	34 928	34 947	34 967	34 986	35 005
224	35 025	35 044	35 064	35 083	35 102	35 122	35 141	35 160	35 180	35 199
225	35 218	35 238	35 257	35 276	35 295	35 315	35 334	35 353	35 372	35 392
226	35 411	35 430	35 449	35 468	35 488	35 507	35 526	35 545	35 564	35 583
227	35 603	35 622	35 641	35 660	35 679	35 698	35 717	35 736	35 755	35 774
228	35 793	35 813	35 832	35 851	35 870	35 889	35 908	35 927	35 946	35 965
229	35 984	36 003	36 021	36 040	36 059	36 078	36 097	36 116	36 135	36 154
230	36 173	36 192	36 211	36 229	36 248	36 267	36 286	36 305	36 324	36 342
231	36 361	36 380	36 399	36 418	36 436	36 455	36 474	36 493	36 511	36 530
232	36 549	36 568	36 586	36 605	36 624	36 642	36 661	36 680	36 698	36 717
233	36 736	36 754	36 773	36 791	36 810	36 829	36 847	36 866	36 884	36 903
234	36 922	36 940	36 959	36 977	36 996	37 014	37 033	37 051	37 070	37 088

COMMON LOGARITHMS OF NUMBERS
(*Continued*)

N	0	1	2	3	4	5	6	7	8	9
235	37 107	37 125	37 144	37 162	37 181	37 199	37 218	37 236	37 254	37 273
236	37 291	37 310	37 328	37 346	37 365	37 383	37 401	37 420	37 438	37 457
237	37 475	37 493	37 511	37 530	37 548	37 566	37 585	37 603	37 621	37 639
238	37 658	37 676	37 694	37 712	37 731	37 749	37 767	37 785	37 803	37 822
239	37 840	37 858	37 876	37 894	37 912	37 931	37 949	37 967	37 985	38 003
240	38 021	38 039	38 057	38 075	38 093	38 112	38 130	38 148	38 166	38 184
241	38 202	38 220	38 238	38 256	38 274	38 292	38 310	38 328	38 346	38 364
242	38 382	38 399	38 417	38 435	38 453	38 471	38 489	38 507	38 525	38 543
243	38 561	38 578	38 596	38 614	38 632	38 650	38 668	38 686	38 703	38 721
244	38 739	38 757	38 775	38 792	38 810	38 828	38 846	38 863	38 881	38 899
245	38 917	38 934	38 952	38 970	38 987	39 005	39 023	39 041	39 058	39 076
246	39 094	39 111	39 129	39 146	39 164	39 182	39 199	39 217	39 235	39 252
247	39 270	39 287	39 305	39 322	39 340	39 358	39 375	39 393	39 410	39 428
248	39 445	39 463	39 480	39 498	39 515	39 533	39 550	39 568	39 585	39 602
249	39 620	39 637	39 655	39 672	39 690	39 707	39 724	39 742	39 759	39 777
250	39 794	39 811	39 829	39 846	39 863	39 881	39 898	39 915	39 933	39 950
251	39 967	39 985	40 002	40 019	40 037	40 054	40 071	40 088	40 106	40 123
252	40 140	40 157	40 175	40 192	40 209	40 226	40 243	40 261	40 278	40 295
253	40 312	40 329	40 346	40 364	40 381	40 398	40 415	40 432	40 449	40 466
254	40 483	40 500	40 518	40 535	40 552	40 569	40 586	40 603	40 620	40 637
255	40 654	40 671	40 688	40 705	40 722	40 739	40 756	40 773	40 790	40 807
256	40 824	40 841	40 858	40 875	40 892	40 909	40 926	40 943	40 960	40 976
257	40 993	41 010	41 027	41 044	41 061	41 078	41 096	41 111	41 128	41 145
258	41 162	41 179	41 196	41 212	41 229	41 246	41 263	41 280	41 296	41 313
259	41 330	41 347	41 363	41 380	41 397	41 414	41 430	41 447	41 464	414 81
260	41 497	41 514	41 531	41 547	41 564	41 581	41 597	41 614	41 631	41 647
261	41 664	41 681	41 697	41 714	41 731	41 747	41 764	41 780	41 797	41 814
262	41 830	41 847	41 863	41 880	41 896	41 913	41 929	41 946	41 963	41 979
263	41 996	42 012	42 029	42 045	42 062	42 078	42 095	42 111	42 127	42 144
264	42 160	42 177	42 193	42 210	42 226	42 243	42 259	42 275	42 292	42 308
265	42 325	42 341	42 357	42 374	42 390	42 406	42 423	42 439	42 455	42 472
266	42 488	42 504	42 521	42 537	42 553	42 570	42 586	42 602	42 619	42 635
267	42 651	42 667	42 684	42 700	42 716	42 732	42 749	42 765	42 781	42 797
268	42 813	42 830	42 846	42 862	42 878	42 894	42 911	42 927	42 943	42 959
269	42 975	42 991	43 008	43 024	43 040	43 056	43 072	43 088	43 104	43 120
270	43 136	43 152	43 169	43 185	43 201	43 217	43 233	43 249	43 265	43 281
271	43 297	43 313	43 329	43 345	43 361	43 377	43 393	43 409	43 425	43 441
272	43 457	43 473	43 489	43 505	43 521	43 537	43 553	43 569	43 584	43 600
273	43 616	43 632	43 648	43 664	43 680	43 696	43 712	43 727	43 743	43 759
274	43 775	43 791	43 807	43 823	43 838	43 854	43 870	43 886	43 902	43 917
275	43 933	43 949	43 965	43 981	43 996	44 012	44 028	44 044	44 059	44 075
276	44 091	44 107	44 122	44 138	44 154	44 170	44 185	44 201	44 217	44 232
277	44 248	44 264	44 279	44 295	44 311	44 326	44 342	44 358	44 373	44 389
278	44 404	44 420	44 436	44 451	44 467	44 483	44 498	44 514	44 529	44 545
279	44 560	44 576	44 592	44 607	44 623	44 638	44 654	44 669	44 685	44 700

COMMON LOGARITHMS OF NUMBERS
(*Continued*)

N	0	1	2	3	4	5	6	7	8	9
280	44 716	44 731	44 747	44 762	44 778	44 793	44 809	44 824	44 840	44 855
281	44 871	44 886	44 902	44 917	44 932	44 948	44 963	44 979	44 994	45 010
282	45 025	45 040	45 056	45 071	45 086	45 102	45 117	45 133	45 148	45 163
283	45 179	45 194	45 209	45 225	45 240	45 255	45 271	45 286	45 301	45 317
284	45 332	45 347	45 362	45 378	45 393	45 408	45 423	45 439	45 454	45 469
285	45 484	45 500	45 515	45 530	45 545	45 561	45 576	45 591	45 606	45 621
286	45 637	45 652	45 667	45 682	45 697	45 712	45 728	45 743	45 758	45 773
287	45 788	45 803	45 818	45 834	45 849	45 864	45 879	45 894	45 909	45 924
288	45 939	45 954	45 969	45 984	46 000	46 015	46 030	46 045	46 060	46 075
289	46 090	46 105	46 120	46 135	46 150	46 165	46 180	46 195	46 210	46 225
290	46 240	46 255	46 270	46 285	46 300	46 315	46 330	46 345	46 359	46 374
291	46 389	46 404	46 419	46 434	46 449	46 464	46 479	46 494	46 509	46 523
292	46 538	46 553	46 568	46 583	46 598	46 613	46 627	46 642	46 657	46 672
293	46 687	46 702	46 716	46 731	46 746	46 761	46 776	46 790	46 805	46 820
294	46 835	46 850	46 864	46 879	46 894	46 909	46 923	46 938	46 953	46 967
295	46 982	46 997	47 012	47 026	47 041	47 056	47 070	47 085	47 100	47 114
296	47 129	47 144	47 159	47 173	47 188	47 202	47 217	47 232	47 246	47 261
297	47 276	47 290	47 305	47 319	47 334	47 349	47 363	47 378	47 392	47 407
298	47 422	47 436	47 451	47 465	47 480	47 494	47 509	47 524	47 538	47 553
299	47 567	47 582	47 596	47 611	47 625	47 640	47 654	47 669	47 683	47 698
300	47 712	47 727	47 741	47 756	47 770	47 784	47 799	47 813	47 828	47 842
301	47 857	47 871	47 885	47 900	47 914	47 929	47 943	47 958	47 972	47 986
302	48 001	48 015	48 029	48 044	48 058	48 073	48 087	48 101	48 116	48 130
303	48 144	48 159	48 173	48 187	48 202	48 216	48 230	48 244	48 259	48 273
304	48 287	48 302	48 316	48 330	48 344	48 359	48 373	48 387	48 401	48 416
305	48 430	48 444	48 458	48 473	48 487	48 501	48 515	48 530	48 544	48 558
306	48 572	48 586	48 601	48 615	48 629	48 643	48 657	48 671	48 686	48 700
307	48 714	48 728	48 742	48 756	48 770	48 785	48 799	48 813	48 827	48 841
308	48 855	48 869	48 883	48 897	48 911	48 926	48 940	48 954	48 968	48 982
309	48 996	49 010	49 024	49 038	49 052	49 066	49 080	49 094	49 108	49 122
310	49 136	49 150	49 164	49 178	49 192	49 206	49 220	49 234	49 248	49 262
311	49 276	49 290	49 304	49 318	49 332	49 346	49 360	49 374	49 388	49 402
312	49 415	49 429	49 443	49 457	49 471	49 485	49 499	49 513	49 527	49 541
313	49 554	49 568	49 582	49 596	49 610	49 624	49 638	49 651	49 665	49 679
314	49 693	49 707	49 721	49 734	49 748	49 762	49 776	49 790	49 803	49 817
315	49 831	49 845	49 859	49 872	49 886	49 900	49 914	49 927	49 941	49 955
316	49 969	49 982	49 996	50 010	50 024	50 037	50 051	50 065	50 079	50 092
317	50 106	50 120	50 133	50 147	50 161	50 174	50 188	50 202	50 215	50 229
318	50 243	50 256	50 270	50 284	50 297	50 311	50 325	50 338	50 352	50 365
319	50 379	50 393	50 406	50 420	50 433	50 447	50 461	50 474	50 488	50 501
320	50 515	50 529	50 542	50 556	50 569	50 583	50 596	50 610	50 623	50 637
321	50 651	50 664	50 678	50 691	50 705	50 718	50 732	50 745	50 759	50 772
322	50 786	50 799	50 813	50 826	50 840	50 853	50 866	50 880	50 893	50 907
323	50 920	50 934	50 947	50 961	50 974	50 987	51 001	51 014	51 028	51 041
324	51 055	51 068	51 081	51 095	51 108	51 121	51 135	51 148	51 162	51 175

COMMON LOGARITHMS OF NUMBERS
(*Continued*)

N	0	1	2	3	4	5	6	7	8	9
325	51 188	51 202	51 215	51 228	51 242	51 255	51 268	51 282	51 295	51 308
326	51 322	51 335	51 348	51 362	51 375	51 388	51 402	51 415	51 428	51 441
327	51 455	51 468	51 481	51 495	51 508	51 521	51 534	51 548	51 561	51 574
328	51 587	51 601	51 614	51 627	51 640	51 654	51 667	51 680	51 693	51 706
329	51 720	51 733	51 746	51 759	51 772	51 786	51 799	51 812	51 825	51 838
330	51 851	51 865	51 878	51 891	51 904	51 917	51 930	51 943	51 957	51 970
331	51 983	51 996	52 009	52 022	52 035	52 048	52 061	52 075	52 088	52 101
332	52 114	52 127	52 140	52 153	52 166	52 179	52 192	52 205	52 218	52 231
333	52 244	52 257	52 270	52 284	52 297	52 310	52 323	52 336	52 349	52 362
334	52 375	52 388	52 401	52 414	52 427	52 440	52 453	52 466	52 479	52 492
335	52 504	52 517	52 530	52 543	52 556	52 569	52 582	52 595	52 608	52 621
336	52 634	52 647	52 660	52 673	52 686	52 699	52 711	52 724	52 737	52 750
337	52 763	52 776	52 789	52 802	52 815	52 827	52 840	52 853	52 866	52 879
338	52 892	52 905	52 917	52 930	52 943	52 956	52 969	52 982	52 994	53 007
339	53 020	53 033	53 046	53 058	53 071	53 084	53 097	53 110	53 122	53 135
340	53 148	53 161	53 173	53 186	53 199	53 212	53 224	53 237	53 250	53 263
341	53 275	53 288	53 301	53 314	53 326	53 339	53 352	53 364	53 377	53 390
342	53 403	53 415	53 428	53 441	53 453	53 456	53 479	53 491	53 504	53 517
343	53 529	53 542	53 555	53 567	53 580	53 593	53 605	53 618	53 631	53 643
344	53 656	53 668	53 681	53 694	53 706	53 719	53 732	53 744	53 757	53 769
345	53 782	53 794	53 807	53 820	53 832	53 845	53 857	53 870	53 882	53 895
346	53 908	53 920	53 933	53 945	53 958	53 970	53 983	53 995	54 008	54 020
347	54 033	54 045	54 058	54 070	54 083	54 095	54 108	54 120	54 133	54 145
348	54 158	54 170	54 183	54 195	54 208	54 220	54 233	54 245	54 258	54 270
349	54 283	54 295	54 307	54 320	54 332	54 345	54 357	54 370	54 382	54 394
350	54 407	54 419	54 432	54 444	54 456	54 469	54 481	54 494	54 506	54 518
351	54 531	54 543	54 555	54 568	54 580	54 593	54 605	54 617	54 630	54 642
352	54 654	54 667	54 679	54 691	54 704	54 716	54 728	54 741	54 753	54 765
353	54 777	54 790	54 802	54 814	54 827	54 839	54 851	54 864	54 876	54 888
354	54 900	54 913	54 925	54 937	54 949	54 962	54 974	54 986	54 998	55 011
355	55 023	55 035	55 047	55 060	55 072	55 084	55 096	55 108	55 121	55 133
356	55 145	55 157	55 169	55 182	55 194	55 206	55 218	55 230	55 242	55 255
357	55 267	55 279	55 291	55 303	55 315	55 328	55 340	55 352	55 364	55 376
358	55 388	55 400	55 413	55 425	55 437	55 449	55 461	55 473	55 485	55 497
359	55 509	55 522	55 534	55 546	55 558	55 570	55 582	55 594	55 606	55 618
360	55 630	55 642	55 654	55 666	55 678	55 691	55 703	55 715	55 727	55 739
361	55 751	55 763	55 775	55 787	55 799	55 811	55 823	55 835	55 847	55 859
362	55 871	55 883	55 895	55 907	55 919	55 931	55 943	55 955	55 967	55 979
363	55 991	56 003	56 015	56 027	56 038	56 050	56 062	56 074	56 086	56 098
364	56 110	56 122	56 134	56 146	56 158	56 170	56 182	56 194	56 205	56 217
365	56 229	56 241	56 253	56 265	56 277	56 289	56 301	56 312	56 324	56 336
366	56 348	56 360	56 372	56 384	56 396	56 407	56 419	56 431	56 443	56 455
367	56 467	56 478	56 490	56 502	56 514	56 526	56 538	56 549	56 561	56 573
368	56 585	56 597	56 608	56 620	56 632	56 644	56 656	56 667	56 679	56 691
369	56 703	56 714	56 726	56 738	56 750	56 761	56 773	56 785	56 797	56 808

COMMON LOGARITHMS OF NUMBERS
(Continued)

N	0	1	2	3	4	5	6	7	8	9
370	56 820	56 832	56 844	56 855	56 867	56 879	56 891	56 902	56 914	56 926
371	56 937	56 949	56 961	56 972	56 984	56 996	57 008	57 019	57 031	57 043
372	57 054	57 066	57 078	57 089	57 101	57 113	57 124	57 136	57 148	57 159
373	57 171	57 183	57 194	57 206	57 217	57 229	57 241	57 252	57 264	57 276
374	57 287	57 299	57 310	57 322	57 334	57 345	57 357	57 368	57 380	57 392
375	57 403	57 415	57 426	57 438	57 449	57 461	57 473	57 484	57 496	57 507
376	57 519	57 530	57 542	57 553	57 565	57 576	57 588	57 600	57 611	57 623
377	57 634	57 646	57 657	57 669	57 680	57 692	57 703	57 715	57 726	57 738
378	57 749	57 761	57 772	57 784	57 795	57 807	57 818	57 830	57 841	57 852
379	57 864	57 875	57 887	57 898	57 910	57 921	57 933	57 944	57 955	57 967
380	57 978	57 990	58 001	58 013	58 024	58 035	58 047	58 058	58 070	58 081
381	58 092	58 104	58 115	58 127	58 138	58 149	58 161	58 172	58 184	58 195
382	58 206	58 218	58 229	58 240	58 252	58 263	58 274	58 286	58 297	58 309
383	58 320	58 331	58 343	58 354	58 365	58 377	58 388	58 399	58 410	58 422
384	58 433	58 444	58 456	58 467	58 478	58 490	58 501	58 512	58 524	58 535
385	58 546	58 557	58 569	58 580	58 591	58 602	58 614	58 625	58 636	58 647
386	58 659	58 670	58 681	58 692	58 704	58 715	58 726	58 737	58 749	58 760
387	58 771	58 782	58 794	58 805	58 816	58 827	58 838	58 850	58 861	58 872
388	58 883	58 894	58 906	58 917	58 928	58 939	58 950	58 961	58 973	58 984
389	58 995	59 006	59 017	59 028	59 040	59 051	59 062	59 073	59 084	59 095
390	59 106	59 118	59 129	59 140	59 151	59 162	59 173	59 184	59 195	59 207
391	59 218	59 229	59 240	59 251	59 262	59 273	59 284	59 295	59 306	59 318
392	59 329	59 340	59 351	59 362	59 373	59 384	59 395	59 406	59 417	59 428
393	59 439	59 450	59 461	59 472	59 483	59 494	59 506	59 517	59 528	59 539
394	59 550	59 561	59 572	59 583	59 594	59 605	59 616	59 627	59 638	59 649
395	59 660	59 671	59 682	59 693	59 704	59 715	59 726	59 737	59 748	59 759
396	59 770	59 780	59 791	59 802	59 813	59 824	59 835	59 846	59 857	59 868
397	59 879	59 890	59 901	59 912	59 923	59 934	59 945	59 956	59 966	59 977
398	59 988	59 999	60 010	60 021	60 032	60 043	60 054	60 065	60 076	60 086
399	60 097	60 108	60 119	60 130	60 141	60 152	60 163	60 173	60 184	60 195
400	60 206	60 217	60 228	60 239	60 249	60 260	60 271	60 282	60 293	60 304
401	60 314	60 325	60 336	60 347	60 358	60 369	60 379	60 390	60 401	60 412
402	60 423	60 433	60 444	60 455	60 466	60 477	60 487	60 498	60 509	60 520
403	60 531	60 541	60 552	60 563	60 574	60 584	60 595	60 606	60 617	60 627
404	60 638	60 649	60 660	60 670	60 681	60 692	60 703	60 713	60 724	60 735
405	60 746	60 756	60 767	60 778	60 788	60 799	60 810	60 821	60 831	60 842
406	60 853	60 863	60 874	60 885	60 895	60 906	60 917	60 927	60 938	60 949
407	60 959	60 970	60 981	60 991	61 002	61 013	61 023	61 034	61 045	61 055
408	61 066	61 077	61 087	61 098	61 109	61 119	61 130	61 140	61 151	61 162
409	61 172	61 183	61 194	61 204	61 215	61 225	61 236	61 247	61 257	61 268
410	61 278	61 289	61 300	61 310	61 321	61 331	61 342	61 352	61 363	61 374
411	61 384	61 395	61 405	61 416	61 426	61 437	61 448	61 458	61 469	61 479
412	61 490	61 500	61 511	61 521	61 532	61 542	61 553	61 563	61 574	61 584
413	61 595	61 606	61 616	61 627	61 637	61 648	61 658	61 669	61 679	61 690
414	61 700	61 711	61 721	61 731	61 742	61 752	61 763	61 773	61 784	61 794

COMMON LOGARITHMS OF NUMBERS
(*Continued*)

N	0	1	2	3	4	5	6	7	8	9
415	61 805	61 815	61 826	61 836	61 847	61 857	61 868	61 878	61 888	61 899
416	61 909	61 920	61 930	61 941	61 951	61 962	61 972	61 982	61 993	62 003
417	62 014	62 024	62 034	62 045	62 055	62 066	62 076	62 086	62 097	62 107
418	62 118	62 128	62 138	62 149	62 159	62 170	62 180	62 190	62 201	62 211
419	62 221	62 232	62 242	62 252	62 263	62 273	62 284	62 294	62 304	62 315
420	62 325	62 335	62 346	62 356	62 366	62 377	62 387	62 397	62 408	62 418
421	62 428	62 439	62 449	62 459	62 469	62 480	62 490	62 500	62 511	62 521
422	62 531	62 542	62 552	62 562	62 572	62 583	62 593	62 603	62 613	62 624
423	62 634	62 644	62 655	62 665	62 675	62 685	62 696	62 706	62 716	62 726
424	62 737	62 747	62 757	62 767	62 778	62 788	62 798	62 808	62 818	62 829
425	62 839	62 849	62 859	62 870	62 880	62 890	62 900	62 910	62 921	62 931
426	62 941	62 951	62 961	62 972	62 982	62 992	63 002	63 012	63 022	63 033
427	63 043	63 053	63 063	63 073	63 083	63 094	63 104	63 114	63 124	63 134
428	63 144	63 155	63 165	63 175	63 185	63 195	63 205	63 215	63 225	63 236
429	63 246	63 256	63 266	63 276	63 286	63 296	63 306	63 317	63 327	63 337
430	63 347	63 357	63 367	63 377	63 387	63 397	63 407	63 417	63 428	63 438
431	63 448	63 458	63 468	63 478	63 488	63 498	63 508	63 518	63 528	63 538
432	63 548	63 558	63 568	64 579	63 589	63 599	63 609	63 619	63 629	63 639
433	63 649	63 659	63 669	63 679	63 689	63 699	63 709	63 719	63 729	63 739
434	63 749	63 759	63 769	63 779	63 789	63 799	63 809	63 819	63 829	63 839
435	63 849	63 859	63 869	63 879	63 889	63 899	63 909	63 919	63 929	63 939
436	63 949	63 959	63 969	63 979	63 988	63 998	64 008	64 018	64 028	64 038
437	64 048	64 058	64 068	64 078	64 088	64 098	64 108	64 118	64 128	64 137
438	64 147	64 157	64 167	64 177	64 187	64 197	64 207	64 217	64 227	64 237
439	64 246	64 256	64 266	64 276	64 286	64 296	64 306	64 316	64 326	64 335
440	64 345	64 355	64 365	64 375	64 385	64 395	64 404	64 414	64 424	64 434
441	64 444	64 454	64 464	64 473	64 483	64 493	64 503	64 513	64 523	64 532
442	64 542	64 552	64 562	64 572	64 582	64 591	64 601	64 611	64 621	64 631
443	64 640	64 650	64 660	64 670	64 680	64 689	64 699	64 709	64 719	64 729
444	64 738	64 748	64 758	64 768	64 777	64 787	64 797	64 807	64 816	64 826
445	64 836	64 846	64 856	64 865	64 875	64 885	64 895	64 904	64 914	64 924
446	64 933	64 943	64 953	64 963	64 972	64 982	64 992	65 002	65 011	65 021
447	65 031	65 040	65 050	65 060	65 070	65 079	65 089	65 099	65 108	65 118
448	65 128	65 137	65 147	65 157	65 167	65 176	65 186	65 196	65 205	65 215
449	65 225	65 234	65 244	65 254	65 263	65 273	65 283	65 292	65 302	65 312
450	65 321	65 331	65 341	65 350	65 360	65 369	65 379	65 389	65 398	65 408
451	65 418	65 427	65 437	65 447	65 456	65 466	65 475	65 485	65 495	65 504
452	65 514	65 523	65 533	65 543	65 552	65 562	65 571	65 581	65 591	65 600
453	65 610	65 619	65 629	65 639	65 648	65 658	65 667	65 677	65 686	65 696
454	65 706	65 715	65 725	65 734	65 744	65 753	65 763	65 772	65 782	65 792
455	65 801	65 811	65 820	65 830	65 839	65 849	65 858	65 868	65 877	65 887
456	65 896	65 906	65 916	65 925	65 935	65 944	65 954	65 963	65 973	65 982
457	65 992	66 001	66 011	66 020	66 030	66 039	66 049	66 058	66 068	66 077
458	66 087	66 096	66 106	66 115	66 124	66 134	66 143	66 153	66 162	66 172
459	66 181	66 191	66 200	66 210	66 219	66 229	66 238	66 247	66 257	66 266

COMMON LOGARITHMS OF NUMBERS
(Continued)

N	0	1	2	3	4	5	6	7	8	9
460	66 276	66 285	66 295	66 304	66 314	66 323	66 332	66 342	66 351	66 361
461	66 370	66 380	66 389	66 398	66 408	66 417	66 427	66 436	66 445	66 455
462	66 464	66 474	66 483	66 492	66 502	66 511	66 521	66 530	66 539	66 549
463	66 558	66 567	66 577	66 586	66 596	66 605	66 614	66 624	66 633	66 642
464	66 652	66 661	66 671	66 680	66 689	66 699	66 708	66 717	66 727	66 736
465	66 745	66 755	66 764	66 773	66 783	66 792	66 801	66 811	66 820	66 829
466	66 839	66 848	66 857	66 867	66 876	66 885	66 894	66 904	66 913	66 922
467	66 932	66 941	66 950	66 960	66 969	66 978	66 987	66 997	67 006	67 015
468	67 025	67 034	67 043	67 052	67 062	67 071	67 080	67 089	67 099	67 108
469	67 117	67 127	67 136	67 145	67 154	67 164	67 173	67 182	67 191	67 201
470	67 210	67 219	67 228	67 237	67 247	67 256	67 265	67 274	67 284	67 293
471	67 302	67 311	67 321	67 330	67 339	67 348	67 357	67 367	67 376	67 385
472	67 394	67 403	67 413	67 422	67 431	67 440	67 449	67 459	67 468	67 477
473	67 486	67 495	67 504	67 514	67 523	67 532	67 541	67 550	67 560	67 569
474	67 578	67 587	67 596	67 605	67 614	67 624	67 633	67 642	67 651	67 660
475	67 669	67 679	67 688	67 697	67 706	67 715	67 724	67 733	67 742	67 752
476	67 761	67 770	67 779	67 788	67 797	67 806	67 815	67 825	67 834	67 843
477	67 852	67 861	67 870	67 879	67 888	67 897	67 906	67 916	67 925	67 934
478	67 943	67 952	67 961	67 970	67 979	67 988	67 997	68 006	68 015	68 024
479	68 034	68 043	68 052	68 061	68 070	68 079	68 088	68 097	68 106	68 115
480	68 124	68 133	68 142	68 151	68 160	68 169	68 178	68 187	68 196	68 205
481	68 215	68 224	68 233	68 242	68 251	68 260	68 269	68 278	68 287	68 296
482	68 305	68 314	68 323	68 332	68 341	68 350	68 359	68 368	68 377	68 386
483	68 395	68 404	68 413	68 422	68 431	68 440	68 449	68 458	68 467	68 476
484	68 485	68 494	68 502	68 511	68 520	68 529	68 538	68 547	68 556	68 565
485	68 574	68 583	68 592	68 601	68 610	68 619	68 628	68 637	68 646	68 655
486	68 664	68 673	68 681	68 690	68 699	68 708	68 717	68 726	68 735	68 744
487	68 753	68 762	68 771	68 780	68 789	68 797	68 806	68 815	68 824	68 833
488	68 842	68 851	68 860	68 869	68 878	68 886	68 895	68 904	68 913	68 922
489	68 931	68 940	68 949	68 958	68 966	68 975	68 984	68 993	69 002	69 011
490	69 020	69 028	69 037	69 046	69 055	69 064	69 073	69 082	69 090	69 099
491	69 108	69 117	69 126	69 135	69 144	69 152	69 161	69 170	69 179	69 188
492	69 197	69 205	69 214	69 223	69 232	69 241	69 249	69 258	69 267	69 276
493	69 285	69 294	69 302	69 311	69 320	69 329	69 338	69 346	69 355	69 364
494	69 373	69 381	69 390	69 399	69 408	69 417	69 425	69 434	69 443	69 452
495	69 461	69 469	69 478	69 487	69 496	69 504	69 513	69 522	69 531	69 539
496	69 548	69 557	69 566	69 574	69 583	69 592	69 601	69 609	69 618	69 627
497	69 636	69 644	69 653	69 662	69 671	69 679	69 688	69 697	69 705	69 714
498	69 723	69 732	69 740	69 749	69 758	69 767	69 775	69 784	69 793	69 801
499	69 810	69 819	69 827	69 836	69 845	69 854	69 862	69 871	69 880	69 888
500	69 897	69 906	69 914	69 923	69 932	69 940	69 949	69 958	69 966	69 975
501	69 984	69 992	70 001	70 010	70 018	70 027	70 036	70 044	70 053	70 062
502	70 070	70 079	70 088	70 096	70 105	70 114	70 122	70 131	70 140	70 148
503	70 157	70 165	70 174	70 183	70 191	70 200	70 209	70 217	70 226	70 234
504	70 243	70 252	70 260	70 269	70 278	70 286	70 295	70 303	70 312	70 321

COMMON LOGARITHMS OF NUMBERS
(*Continued*)

N	0	1	2	3	4	5	6	7	8	9
505	70 329	70 338	70 346	70 355	70 364	70 372	70 381	70 389	70 398	70 406
506	70 415	70 424	70 432	70 441	70 449	70 458	70 467	70 475	70 484	70 492
507	70 501	70 509	70 518	70 526	70 535	70 544	70 552	70 561	70 569	70 578
508	70 586	70 595	70 603	70 612	70 621	70 629	70 638	70 646	70 655	70 663
509	70 672	70 680	70 689	70 697	70 706	70 714	70 723	70 731	70 740	70 749
510	70 757	70 766	70 774	70 783	70 791	70 800	70 808	70 817	70 825	70 834
511	70 842	70 851	70 859	70 868	70 876	70 885	70 893	70 902	70 910	70 919
512	70 927	70 935	70 944	70 952	70 961	70 969	70 978	70 986	70 995	71 003
513	71 012	71 020	71 029	71 037	71 046	71 054	71 063	71 071	71 079	71 088
514	71 096	71 105	71 113	71 122	71 130	71 139	71 147	71 155	71 164	71 172
515	71 181	71 189	71 198	71 206	71 214	71 223	71 231	71 240	71 248	71 257
516	71 265	71 273	71 282	71 290	71 299	71 307	71 315	71 324	71 332	71 341
517	71 349	71 357	71 366	71 374	71 383	71 391	71 399	71 408	71 416	71 425
518	71 433	71 441	71 450	71 458	71 466	71 475	71 483	71 492	71 500	71 508
519	71 517	71 525	71 533	71 542	71 550	71 559	71 567	71 575	71 584	71 592
520	71 600	71 609	71 617	71 625	71 634	71 642	71 650	71 659	71 667	71 675
521	71 684	71 692	71 700	71 709	71 717	71 725	71 734	71 742	71 750	71 759
522	71 767	71 775	71 784	71 792	71 800	71 809	71 817	71 825	71 834	71 842
523	71 850	71 858	71 867	71 875	71 883	71 892	71 900	71 908	71 917	71 925
524	71 933	71 941	71 950	71 958	71 966	71 975	71 983	71 991	71 999	72 008
525	72 016	72 024	72 032	72 041	72 049	72 057	72 066	72 074	72 082	72 090
526	72 099	72 107	72 115	72 123	72 132	72 140	72 148	72 156	72 165	72 173
527	72 181	72 189	72 198	72 206	72 214	72 222	72 230	72 239	72 247	72 255
528	72 263	72 272	72 280	72 288	72 296	72 304	72 313	72 321	72 329	72 337
529	72 346	72 354	72 362	72 370	72 378	72 387	72 395	72 403	72 411	72 419
530	72 428	72 436	72 444	72 452	72 460	72 469	72 477	72 485	72 493	72 501
531	72 509	72 518	72 526	72 534	72 542	72 550	72 558	72 567	72 575	72 583
532	72 591	72 599	72 607	72 616	72 624	72 632	72 640	72 648	72 656	72 665
533	72 673	72 681	72 689	72 697	72 705	72 713	72 722	72 730	72 738	72 746
534	72 754	72 762	72 770	72 779	72 787	72 795	72 803	72 811	72 819	72 827
535	72 835	72 843	72 852	72 860	72 868	72 876	72 884	72 892	72 900	72 908
536	72 916	72 925	72 933	72 941	72 949	72 957	72 965	72 973	72 981	72 989
537	72 997	73 006	73 014	73 022	73 030	73 038	73 046	73 054	73 062	73 070
538	73 078	73 086	73 094	73 102	73 111	73 119	73 127	73 135	73 143	73 151
539	73 159	73 167	73 175	73 183	73 191	73 199	73 207	73 215	73 223	73 231
540	73 239	73 247	73 255	73 263	73 272	73 280	73 288	73 296	73 304	73 312
541	73 320	73 328	73 336	73 344	73 352	73 360	73 368	73 376	73 384	73 392
542	73 400	73 408	73 416	73 424	73 432	73 440	73 448	73 456	73 464	73 472
543	73 480	73 488	73 496	73 504	73 512	73 520	73 528	73 536	73 544	73 552
544	73 560	73 568	73 576	73 584	73 592	73 600	73 608	73 616	73 624	73 632
545	73 640	73 648	73 656	73 664	73 672	73 679	73 687	73 695	73 703	73 711
546	73 719	73 727	73 735	73 743	73 751	73 759	73 767	73 775	73 783	73 791
547	73 799	73 807	73 815	73 823	73 830	73 838	73 846	73 854	73 862	73 870
548	73 878	73 886	73 894	73 902	73 910	73 918	73 926	73 933	73 941	73 949
549	73 957	73 965	73 973	73 981	73 989	73 997	74 005	74 013	74 020	74 028

COMMON LOGARITHMS OF NUMBERS
(*Continued*)

N	0	1	2	3	4	5	6	7	8	9
550	74 036	74 044	74 052	74 060	74 068	74 076	74 084	74 092	74 099	74 107
551	74 115	74 123	74 131	74 139	74 147	74 155	74 162	74 170	74 178	74 186
552	74 194	74 202	74 210	74 218	74 225	74 233	74 241	74 249	74 257	74 265
553	74 273	74 280	74 288	74 296	74 304	74 312	74 320	74 327	74 335	74 343
554	74 351	74 359	74 367	74 374	74 382	74 390	74 398	74 406	74 414	74 421
555	74 429	74 437	74 445	74 453	74 461	74 468	74 476	74 484	74 492	74 500
556	74 507	74 515	74 523	74 531	74 539	74 547	74 554	74 562	74 570	74 578
557	74 586	74 593	74 601	74 609	74 617	74 624	74 632	74 640	74 648	74 656
558	74 663	74 671	74 679	74 687	74 695	74 702	74 710	74 718	74 726	74 733
559	74 741	74 749	74 757	74 764	74 772	74 780	74 788	74 796	74 803	74 811
560	74 819	74 827	74 834	74 842	74 850	74 858	74 865	74 873	74 881	74 889
561	74 896	74 904	74 912	74 920	74 927	74 935	74 943	74 950	74 958	74 966
562	74 974	74 981	74 989	74 997	75 005	75 012	75 020	75 028	75 035	75 043
563	75 051	75 059	75 066	75 074	75 082	75 089	75 097	75 105	75 113	75 120
564	75 128	75 136	75 143	75 151	75 159	75 166	75 174	75 182	75 189	75 197
565	75 205	75 213	75 220	75 228	75 236	75 243	75 251	75 259	75 266	75 274
566	75 282	75 289	75 297	75 305	75 312	75 320	75 328	75 335	75 343	75 351
567	75 358	75 366	75 374	75 381	75 389	75 397	75 404	75 412	75 420	75 427
568	75 435	75 442	75 450	75 458	75 465	75 473	75 481	75 488	75 496	75 504
569	75 511	75 519	75 526	75 534	75 542	75 549	75 557	75 565	75 572	75 580
570	75 587	75 595	75 603	75 610	75 618	75 626	75 633	75 641	75 648	75 656
571	75 664	75 671	75 679	75 686	75 694	75 702	75 709	75 717	75 724	75 732
572	75 740	75 747	75 755	75 762	75 770	75 778	75 785	75 793	75 800	75 808
573	75 815	75 823	75 831	75 838	75 846	75 853	75 861	75 868	75 876	75 884
574	75 891	75 899	75 906	75 914	75 921	75 929	75 937	75 944	75 952	75 959
575	75 967	75 974	75 982	75 989	75 997	76 005	76 012	76 020	76 027	76 035
576	76 042	76 050	76 057	76 065	76 072	76 080	76 087	76 095	76 103	76 110
577	76 118	76 125	76 133	76 140	76 148	76 155	76 163	76 170	76 178	76 185
578	76 193	76 200	76 208	76 215	76 223	76 230	76 238	76 245	76 253	76 260
579	76 268	76 275	76 283	76 290	76 298	76 305	76 313	76 320	76 328	76 335
580	76 343	76 350	76 358	76 365	76 373	76 380	76 388	76 395	76 403	76 410
581	76 418	76 425	76 433	76 440	76 448	76 455	76 462	76 470	76 477	76 485
582	76 492	76 500	76 507	76 515	76 522	76 530	76 537	76 545	76 552	76 559
583	76 567	76 574	76 582	76 589	76 597	76 604	76 612	76 619	76 626	76 634
584	76 641	76 649	76 656	76 664	76 671	76 678	76 686	76 693	76 701	76 708
585	76 716	76 723	76 730	76 738	76 745	76 753	76 760	76 768	76 775	76 782
586	76 790	76 797	76 805	76 812	76 819	76 827	76 834	76 842	76 849	76 856
587	76 864	76 871	76 879	76 886	76 893	76 901	76 908	76 916	76 923	76 930
588	76 938	76 945	76 953	76 960	76 967	76 975	76 982	76 989	76 997	77 004
589	77 012	77 019	77 026	77 034	77 041	77 048	77 056	77 063	77 070	77 078
590	77 085	77 093	77 100	77 107	77 115	77 122	77 129	77 137	77 144	77 151
591	77 159	77 166	77 173	77 181	77 188	77 195	77 203	77 210	77 217	77 225
592	77 232	77 240	77 247	77 254	77 262	77 269	77 276	77 283	77 291	77 298
593	77 305	77 313	77 320	77 327	77 335	77 342	77 349	77 357	77 364	77 371
594	77 379	77 386	77 393	77 401	77 408	77 415	77 422	77 430	77 437	77 444

COMMON LOGARITHMS OF NUMBERS
(*Continued*)

N	0	1	2	3	4	5	6	7	8	9
595	77 452	77 459	77 466	77 474	77 481	77 488	77 495	77 503	77 510	77 517
596	77 525	77 532	77 539	77 546	77 554	77 561	77 568	77 576	77 583	77 590
597	77 597	77 605	77 612	77 619	77 627	77 634	77 641	77 648	77 656	77 663
598	77 670	77 677	77 685	77 692	77 699	77 706	77 714	77 721	77 728	77 735
599	77 743	77 750	77 757	77 764	77 772	77 779	77 786	77 793	77 801	77 808
600	77 815	77 822	77 830	77 837	77 844	77 851	77 859	77 866	77 873	77 880
601	77 837	77 895	77 902	77 909	77 916	77 924	77 931	77 938	77 945	77 952
602	77 960	77 967	77 974	77 981	77 988	77 996	78 003	78 010	78 017	78 025
603	78 032	78 039	78 046	78 053	78 061	78 068	78 075	78 082	78 089	78 097
604	78 104	78 111	78 118	78 125	78 132	78 140	78 147	78 154	78 161	78 168
605	78 176	78 183	78 190	78 197	78 204	78 211	78 219	78 226	78 233	78 240
606	78 247	78 254	78 262	78 269	78 276	78 283	78 290	78 297	78 305	78 312
607	78 319	78 326	78 333	78 340	78 347	78 355	78 362	78 369	78 376	78 383
608	78 390	78 398	78 405	78 412	78 419	78 426	78 433	78 440	78 447	78 455
609	78 462	78 469	78 476	78 483	78 490	78 497	78 504	78 512	78 519	78 526
610	78 533	78 540	78 547	78 554	78 561	78 569	78 576	78 583	78 590	78 597
611	78 604	78 611	78 618	78 625	78 633	78 640	78 647	78 654	78 661	78 668
612	78 675	78 682	78 689	78 696	78 704	78 711	78 718	78 725	78 732	78 739
613	78 746	78 753	78 760	78 767	78 774	78 781	78 789	78 796	78 803	78 810
614	78 817	78 824	78 831	78 838	78 845	78 852	78 859	78 866	78 873	78 880
615	78 888	78 895	78 902	78 909	78 916	78 923	78 930	78 937	78 944	78 951
616	78 958	78 965	78 972	78 979	78 986	78 993	79 000	79 007	79 014	79 021
617	79 029	79 036	79 043	79 050	79 057	79 064	79 071	79 078	79 085	79 092
618	79 099	79 106	79 113	79 120	79 127	79 134	79 141	79 148	79 155	79 162
619	79 169	79 176	79 183	79 190	79 197	79 204	79 211	79 218	79 225	79 232
620	79 239	79 246	79 253	79 260	79 267	79 274	79 281	79 288	79 295	79 302
621	79 309	79 316	79 323	79 330	79 337	79 344	79 351	79 358	79 365	79 372
622	79 379	79 386	79 393	79 400	79 407	79 414	79 421	79 428	79 435	79 442
623	79 449	79 456	79 463	79 470	79 477	79 484	79 491	79 498	79 505	79 511
624	79 518	79 525	79 532	79 539	79 546	79 553	79 560	79 567	79 574	79 581
625	79 588	79 595	79 602	79 609	79 616	79 623	79 630	79 637	79 644	79 650
626	79 657	79 664	79 671	79 678	79 685	79 692	79 699	79 706	79 713	79 720
627	79 727	79 734	79 741	79 748	79 754	79 761	79 768	79 775	79 782	79 789
628	79 796	79 803	79 810	79 817	79 824	79 831	79 837	79 844	79 851	79 858
629	79 865	79 872	79 879	79 886	79 893	79 900	79 906	79 913	79 920	79 927
630	79 934	79 941	79 948	79 955	79 962	79 969	79 975	79 982	79 989	79 996
631	80 003	80 010	80 017	80 024	80 030	80 037	80 044	80 051	80 058	80 065
632	80 072	80 079	80 085	80 092	80 099	80 106	80 113	80 120	80 127	80 134
633	80 140	80 147	80 154	80 161	80 168	80 175	80 182	80 188	80 195	80 202
634	80 209	80 216	80 223	80 229	80 236	80 243	80 250	80 257	80 264	80 271
635	80 277	80 284	80 291	80 298	80 305	80 312	80 318	80 325	80 332	80 339
636	80 346	80 353	80 359	80 366	80 373	80 380	80 387	80 393	80 400	80 407
637	80 414	80 421	80 428	80 434	80 441	80 448	80 455	80 462	80 468	80 475
638	80 482	80 489	80 496	80 502	80 509	80 516	80 523	80 530	80 536	80 543
639	80 550	80 557	80 564	80 570	80 577	80 584	80 591	80 598	80 604	80 611

COMMON LOGARITHMS OF NUMBERS
(*Continued*)

N	0	1	2	3	4	5	6	7	8	9
640	80 618	80 625	80 632	80 638	80 645	80 652	80 659	80 665	80 672	80 679
641	80 686	80 693	80 699	80 706	80 713	80 720	80 726	80 733	80 740	80 747
642	80 754	80 760	80 767	80 774	80 781	80 787	80 794	80 801	80 808	80 814
643	80 821	80 828	80 835	80 841	80 848	80 855	80 862	80 868	80 875	80 882
644	80 889	80 895	80 902	80 909	80 916	80 922	80 929	80 936	80 943	80 949
645	80 956	80 963	80 969	80 976	80 983	80 990	80 996	81 003	81 010	81 017
646	81 023	81 030	81 037	81 043	81 050	81 057	81 064	81 070	81 077	81 084
647	81 090	81 097	81 104	81 111	81 117	81 124	81 131	81 137	81 144	81 151
648	81 158	81 164	81 171	81 178	81 184	81 191	81 198	81 204	81 211	81 218
649	81 224	81 231	81 238	81 245	81 251	81 258	81 265	81 271	81 278	81 285
650	81 291	81 298	81 305	81 311	81 318	81 325	81 331	81 338	81 345	81 351
651	81 358	81 365	81 371	81 378	81 385	81 391	81 398	81 405	81 411	81 418
652	81 425	81 431	81 438	81 445	81 451	81 458	81 465	81 471	81 478	81 485
653	81 491	81 498	81 505	81 511	81 518	81 525	81 531	81 538	81 544	81 551
654	81 558	81 564	81 571	81 578	81 584	81 591	81 598	81 604	81 611	81 617
655	81 624	81 631	81 637	81 644	81 651	81 657	81 664	81 671	81 677	81 684
656	81 690	81 697	81 704	81 710	81 717	81 723	81 730	81 737	81 743	81 750
657	81 757	81 763	81 770	81 776	81 783	81 790	81 796	81 803	81 809	81 816
658	81 823	81 829	81 836	81 842	81 849	81 856	81 862	81 869	81 875	81 882
659	81 889	81 895	81 902	81 908	81 915	81 921	81 928	81 935	81 941	81 948
660	81 954	81 961	81 968	81 974	81 981	81 987	81 994	82 000	82 007	82 014
661	82 020	82 027	82 033	82 040	82 046	82 053	82 060	82 066	82 073	82 079
662	82 086	82 092	82 099	82 105	82 112	82 119	82 125	82 132	82 138	82 145
663	82 151	82 158	82 164	82 171	82 178	82 184	82 191	82 197	82 204	82 210
664	82 217	82 223	82 230	82 236	82 243	82 249	82 256	82 263	82 269	82 276
665	82 282	82 289	82 295	82 302	82 308	82 315	82 321	82 328	82 334	82 341
666	82 347	82 354	82 360	82 367	82 373	82 380	82 387	82 393	82 400	82 406
667	82 413	82 419	82 426	82 432	82 439	82 445	82 452	82 458	82 465	82 471
668	82 478	82 484	82 491	82 497	82 504	82 510	82 517	82 523	82 530	82 536
669	82 543	82 549	82 556	82 562	82 569	82 575	82 582	82 588	82 595	82 601
670	82 607	82 614	82 620	82 627	82 633	82 640	82 646	82 653	82 659	82 666
671	82 672	82 679	82 685	82 692	82 698	82 705	82 711	82 718	82 724	82 730
672	82 737	82 743	82 750	82 756	82 763	82 769	82 776	82 782	82 789	82 795
673	82 802	82 808	82 814	82 821	82 827	82 834	82 840	82 847	82 853	82 860
674	82 866	82 872	82 879	82 885	82 892	82 898	82 905	82 911	82 918	82 924
675	82 930	82 937	82 943	82 950	82 956	82 963	82 969	82 975	82 982	82 988
676	82 995	83 001	83 008	83 014	83 020	83 027	83 033	83 040	83 046	83 052
677	83 059	83 065	83 072	83 078	83 085	83 091	83 097	83 104	83 110	83 117
678	83 123	83 129	83 136	83 142	83 149	83 155	83 161	83 168	83 174	83 181
679	83 187	83 193	83 200	83 206	83 213	83 219	83 225	83 232	83 238	83 245
680	83 251	83 257	83 264	83 270	83 276	83 283	83 289	83 296	83 302	83 308
681	83 315	83 321	83 327	83 334	83 340	83 347	83 353	83 359	83 366	83 372
682	83 378	83 385	83 391	83 398	83 404	83 410	83 417	83 423	83 429	83 436
683	83 442	83 448	83 455	83 461	83 467	83 474	83 480	83 487	83 493	83 499
684	83 506	83 512	83 518	83 525	83 531	83 537	83 544	83 550	83 556	83 563

COMMON LOGARITHMS OF NUMBERS
(*Continued*)

N	0	1	2	3	4	5	6	7	8	9
685	83 569	83 575	83 582	83 588	83 594	83 601	83 607	83 613	83 620	83 626
686	83 632	83 639	83 645	83 651	83 658	83 664	83 670	83 677	83 683	83 689
687	83 696	83 702	83 708	83 715	83 721	83 727	83 734	83 740	83 746	83 753
688	83 759	83 765	83 771	83 778	83 784	83 790	83 797	83 803	83 809	83 816
689	83 822	83 828	83 835	83 841	83 847	83 853	83 860	83 866	83 872	83 879
690	83 885	83 891	83 897	83 904	83 910	83 916	83 923	83 929	83 935	83 942
691	83 948	83 954	83 960	83 967	83 973	83 979	83 985	83 992	83 998	84 004
692	84 011	84 017	84 023	84 029	84 036	84 042	84 048	84 055	84 061	84 067
693	84 073	84 080	84 086	84 092	84 098	84 105	84 111	84 117	84 123	84 130
694	84 136	84 142	84 148	84 155	84 161	84 167	84 173	84 180	84 186	84 192
695	84 198	84 205	84 211	84 217	84 223	84 230	84 236	84 242	84 248	84 255
696	84 261	84 267	84 273	84 280	84 286	84 292	84 298	84 305	84 311	84 317
697	84 323	84 330	84 336	84 342	84 348	84 354	84 361	84 367	84 373	84 379
698	84 386	84 392	84 398	84 404	84 410	84 417	84 423	84 429	84 435	84 442
699	84 448	84 454	84 460	84 466	84 473	84 479	84 485	48 491	84 497	84 504
700	84 510	84 516	84 522	84 528	84 535	84 541	84 547	84 553	84 559	84 566
701	84 572	84 578	84 584	84 590	84 597	84 603	84 609	84 615	84 621	84 628
702	84 634	84 640	84 646	84 652	84 658	84 665	84 671	84 677	84 683	84 689
703	84 696	84 702	84 708	84 714	84 720	84 726	84 733	84 739	84 745	84 751
704	84 757	84 763	84 770	84 776	84 782	84 788	84 794	84 800	84 807	84 813
705	84 819	84 825	84 831	84 837	84 844	84 850	84 856	84 862	84 868	84 874
706	84 880	84 887	84 893	84 899	84 905	84 911	84 917	84 924	84 830	84 936
707	84 942	84 948	84 954	84 960	84 967	84 973	84 979	84 985	84 991	84 997
708	85 003	85 009	85 016	85 022	85 028	85 034	85 040	85 046	85 052	85 058
709	85 065	85 071	85 077	85 083	85 089	85 095	85 101	85 107	85 114	85 120
710	85 126	85 132	85 138	85 144	85 150	85 156	85 163	85 169	85 175	85 181
711	85 187	85 193	85 199	85 205	85 211	85 217	85 224	85 230	85 236	85 242
712	85 248	85 254	85 260	85 266	85 272	85 278	85 285	85 291	85 297	85 303
713	85 309	85 315	85 321	85 327	85 333	85 339	85 345	85 352	85 358	85 364
714	85 370	85 376	85 382	85 388	85 394	85 400	85 406	85 412	85 418	85 425
715	85 431	85 437	85 443	85 449	85 455	85 461	85 467	85 473	85 479	85 485
716	85 491	85 497	85 503	85 509	85 516	85 522	85 528	85 534	85 540	85 546
717	85 552	85 558	85 564	85 570	85 576	85 582	85 588	85 594	85 600	85 606
718	85 612	85 618	85 625	85 631	85 637	85 643	85 649	85 655	85 661	85 667
719	85 673	85 679	85 685	85 691	85 697	85 703	85 709	85 715	85 721	85 727
720	85 733	85 739	85 745	85 751	85 757	85 763	85 769	85 775	85 781	85 788
721	85 794	85 800	85 806	85 812	85 818	85 824	85 830	85 836	85 842	85 848
722	85 854	85 860	85 866	85 872	85 878	85 884	85 890	85 896	85 902	85 908
723	85 914	85 920	85 926	85 932	85 938	85 944	85 950	85 956	85 962	85 968
724	85 974	85 980	85 986	85 992	85 998	86 004	86 010	86 016	86 022	86 028
725	86 034	86 040	86 046	86 052	86 058	86 064	86 070	86 076	86 082	86 088
726	86 094	86 100	86 106	86 112	86 118	86 124	86 130	86 136	86 141	86 194
727	86 153	86 159	86 165	86 171	86 177	86 183	86 189	86 195	86 201	86 27[illegible]
728	86 213	86 219	86 225	86 231	86 237	86 243	86 249	86 255	86 261	86 207
729	86 273	86 279	86 285	86 291	86 297	86 303	86 308	86 314	86 320	86 377

COMMON LOGARITHMS OF NUMBERS
(*Continued*)

N	0	1	2	3	4	5	6	7	8	9
730	86 332	86 338	86 344	86 350	86 356	86 362	86 368	86 374	86 380	86 386
731	86 392	86 398	86 404	86 410	86 415	86 421	86 427	86 433	86 439	86 445
732	86 451	86 457	86 463	86 469	86 475	86 481	86 487	86 493	86 499	86 504
733	86 510	86 516	86 522	86 528	86 534	86 540	86 546	86 552	86 558	86 564
734	86 570	86 576	86 581	86 587	86 593	86 599	86 605	86 611	86 617	86 623
735	86 629	86 635	86 641	86 646	86 652	86 658	86 664	86 670	86 676	86 682
736	86 688	86 694	86 700	86 705	86 711	86 717	86 723	86 729	86 735	86 741
737	86 747	86 753	86 759	86 764	86 770	86 776	86 782	86 788	86 794	86 800
738	86 806	86 812	86 817	86 823	86 829	86 835	86 841	86 847	86 853	86 859
739	86 864	86 870	86 876	86 882	86 888	86 894	86 900	86 906	86 911	86 917
740	86 923	86 929	86 935	86 941	86 947	86 953	86 958	86 964	86 970	86 976
741	86 982	86 988	86 994	86 999	87 005	87 011	87 017	87 023	87 029	87 035
742	87 040	87 046	87 052	87 058	87 064	87 070	87 075	87 081	87 087	87 093
743	87 099	87 105	87 111	87 116	87 122	87 128	87 134	87 140	87 146	87 151
744	87 157	87 163	87 169	87 175	87 181	87 186	87 192	87 198	87 204	87 210
745	87 216	87 221	87 227	87 233	87 239	87 245	87 251	87 256	87 262	87 268
746	87 274	87 280	87 286	87 291	87 297	87 303	87 309	87 315	87 320	87 326
747	87 332	87 338	87 344	87 349	87 355	87 361	87 367	87 373	87 379	87 384
748	87 390	87 396	87 402	87 408	87 413	87 419	87 425	87 431	87 437	87 442
749	87 448	87 454	87 460	87 466	87 471	87 477	87 483	87 489	87 495	87 500
750	87 506	87 512	87 518	87 523	87 529	87 535	87 541	87 547	87 552	87 558
751	87 564	87 570	87 576	87 581	87 587	87 593	87 599	87 604	87 610	87 616
752	87 622	87 628	87 633	87 639	87 645	87 651	87 656	87 662	87 668	87 674
753	87 679	87 685	87 691	87 697	87 703	87 708	87 714	87 720	87 726	87 731
754	87 737	87 743	87 749	87 754	87 760	87 766	87 772	87 777	87 783	87 789
755	87 795	87 800	87 806	87 812	87 818	87 823	87 829	87 835	87 841	87 846
756	87 852	87 858	87 864	87 869	87 875	87 881	87 887	87 892	87 898	87 904
757	87 910	87 915	87 921	87 927	87 933	87 938	87 944	87 950	87 955	87 961
758	87 967	87 973	87 978	87 984	87 990	87 996	88 001	88 007	88 013	88 018
759	88 024	88 030	88 036	88 041	88 047	88 053	88 058	88 064	88 070	88 076
760	88 081	88 087	88 093	88 098	88 104	88 110	88 116	88 121	88 127	88 133
761	88 138	88 144	88 150	88 156	88 161	88 167	88 173	88 178	88 184	88 190
762	88 195	88 201	88 207	88 213	88 218	88 224	88 230	88 235	88 241	88 247
763	88 252	88 258	88 264	88 270	88 275	88 281	88 287	88 292	88 298	88 304
764	88 309	88 315	88 321	88 326	88 332	88 338	88 343	88 349	88 355	88 360
765	88 366	88 372	88 377	88 383	88 389	88 395	88 400	88 406	88 412	88 417
766	88 423	88 429	88 434	88 440	88 446	88 451	88 457	88 463	88 468	88 474
767	88 480	88 485	88 491	88 497	88 502	88 508	88 513	88 519	88 525	88 530
768	88 536	88 542	88 547	88 553	88 559	88 564	88 570	88 576	88 581	88 587
769	88 593	88 598	88 604	88 610	88 615	88 621	88 627	88 632	88 638	88 643
770	88 649	88 655	88 660	88 666	88 672	88 677	88 683	88 689	88 694	88 700
771	88 705	88 711	88 717	88 722	88 728	88 734	88 739	88 745	88 750	88 756
772	88 762	88 767	88 773	88 779	88 784	88 790	88 795	88 801	88 807	88 812
773	88 818	88 824	88 829	88 835	88 840	88 846	88 852	88 857	88 863	88 868
774	88 874	88 880	88 885	88 891	88 897	88 902	88 908	88 913	88 919	88 925

COMMON LOGARITHMS OF NUMBERS
(*Continued*)

N	0	1	2	3	4	5	6	7	8	9
775	88 930	88 936	88 941	88 947	88 953	88 958	88 964	88 969	88 975	88 981
776	88 986	88 992	88 997	89 003	89 009	89 014	89 020	89 025	89 031	89 037
777	89 042	89 048	89 053	89 059	89 064	89 070	89 076	89 081	89 087	89 092
778	89 098	89 104	89 109	89 115	89 120	89 126	89 131	89 137	89 143	89 148
779	89 154	89 159	89 165	89 170	89 176	89 182	89 187	89 193	89 198	89 204
780	89 209	89 215	89 221	89 226	89 232	89 237	89 243	89 248	89 254	89 260
781	89 265	89 271	89 276	89 282	89 287	89 293	89 298	89 304	89 310	89 315
782	89 321	89 326	89 332	89 337	89 343	89 348	89 354	89 360	89 365	89 371
783	89 376	89 382	89 387	89 393	89 398	89 404	89 409	89 415	89 421	89 426
784	89 432	89 437	89 443	89 448	89 454	89 459	89 465	89 470	89 476	89 481
785	89 487	89 492	89 498	89 504	89 509	89 515	89 520	89 526	89 531	89 537
786	89 542	89 548	89 553	89 559	89 564	89 570	89 575	89 581	89 586	89 592
787	89 597	89 603	89 609	89 614	89 620	89 625	89 631	89 636	89 642	89 647
788	89 653	89 658	89 664	89 669	89 675	89 680	89 686	89 691	89 697	89 702
789	89 708	89 713	89 719	89 724	89 730	89 735	89 741	89 746	89 752	89 757
790	89 763	89 768	89 774	89 779	89 785	89 790	89 796	89 801	89 807	89 812
791	89 818	89 823	89 829	89 834	89 840	89 845	89 851	89 856	89 862	89 867
792	89 873	89 878	89 883	89 889	89 894	89 900	89 905	89 911	89 916	89 922
793	89 927	89 933	89 938	89 944	89 949	89 955	89 960	89 966	89 971	89 977
794	89 982	89 988	89 993	89 998	90 004	90 009	90 015	90 020	90 026	90 031
795	90 037	90 042	90 048	90 053	90 059	90 064	90 069	90 075	90 080	90 086
796	90 091	90 097	90 102	90 108	90 113	90 119	90 124	90 129	90 135	90 140
797	90 146	90 151	90 157	90 162	90 168	90 173	90 179	90 184	90 189	90 195
798	90 200	90 206	90 211	90 217	90 222	90 227	90 233	90 238	90 244	90 249
799	90 255	90 260	90 266	90 271	90 276	90 282	90 287	90 293	90 298	90 304
800	90 309	90 314	90 320	90 325	90 331	90 336	90 342	90 347	90 352	90 358
801	90 363	90 369	90 374	90 380	90 385	90 390	90 396	90 401	90 407	90 412
802	90 417	90 423	90 428	90 434	90 439	90 445	90 450	90 455	90 461	90 466
803	90 472	90 477	90 482	90 488	90 493	90 499	90 504	90 509	90 515	90 520
804	90 526	90 531	90 536	90 542	90 547	90 553	90 558	90 563	90 569	90 574
805	90 580	90 585	90 590	90 596	90 601	90 607	90 612	90 617	90 623	90 628
806	90 634	90 639	90 644	90 650	90 655	90 660	90 666	90 671	90 677	90 682
807	90 687	90 693	90 698	90 703	90 709	90 714	90 720	90 725	90 730	90 736
808	90 741	90 747	90 752	90 757	90 763	90 768	90 773	90 779	90 784	90 789
809	90 795	90 800	90 806	90 811	90 816	90 822	90 827	90 832	90 838	90 843
810	90 849	90 854	90 859	90 865	90 870	90 875	90 881	90 886	90 891	90 897
811	90 902	90 907	90 913	90 918	90 924	90 929	90 934	90 940	90 945	90 950
812	90 956	90 961	90 966	90 972	90 977	90 982	90 988	90 993	90 998	91 004
813	91 009	91 014	91 020	91 025	91 030	91 036	91 041	91 046	91 052	91 057
814	91 062	91 068	91 073	91 078	91 084	91 089	91 094	91 100	91 105	91 110
815	91 116	91 121	91 126	91 132	91 137	91 142	91 148	91 153	91 158	91 164
816	91 169	91 174	91 180	91 185	91 190	91 196	91 201	91 206	91 212	91 217
817	91 222	91 228	91 233	91 238	91 243	91 249	91 254	91 259	91 265	91 270
818	91 275	91 281	91 286	91 291	91 297	91 302	91 307	91 312	91 318	91 323
819	91 328	91 334	91 339	91 344	91 350	91 355	91 360	91 365	91 371	91 376

COMMON LOGARITHMS OF NUMBERS
(Continued)

N	0	1	2	3	4	5	6	7	8	9
820	91 381	91 387	91 392	91 397	91 403	91 408	91 413	91 418	91 424	91 429
821	91 434	91 440	91 445	91 450	91 455	91 461	91 466	91 471	91 477	91 482
822	91 487	91 492	91 498	91 503	91 508	91 514	91 519	91 524	91 529	91 535
823	91 540	91 545	91 551	91 556	91 561	91 566	91 572	91 577	91 582	91 587
824	91 593	91 598	91 603	91 609	91 614	91 619	91 624	91 630	91 635	91 640
825	91 645	91 651	91 656	91 661	91 666	91 672	91 677	91 682	91 687	91 693
826	91 698	91 703	91 709	91 714	91 719	91 724	91 730	91 735	91 740	91 745
827	91 751	91 756	91 761	91 766	91 772	91 777	91 782	91 787	91 793	91 798
828	91 803	91 808	91 814	91 819	91 824	91 829	91 834	91 840	91 845	91 850
829	91 855	91 861	91 866	91 871	91 876	91 882	91 887	91 892	91 897	91 903
830	91 908	91 913	91 918	91 924	91 929	91 934	91 939	91 944	91 950	91 955
831	91 960	91 965	91 971	91 976	91 981	91 986	91 991	91 997	92 002	92 007
832	92 012	92 018	92 023	92 028	92 033	92 038	92 044	92 049	92 054	92 059
833	92 065	92 070	92 075	92 080	92 085	92 091	92 096	92 101	92 106	92 111
834	92 117	92 122	92 127	92 132	92 137	92 143	92 148	92 153	92 158	92 163
835	92 169	92 174	92 179	92 184	92 189	92 195	92 200	92 205	92 210	92 215
836	92 221	92 226	92 231	92 236	92 241	92 247	92 252	92 257	92 262	92 267
837	92 273	92 278	92 283	92 288	92 293	92 298	92 304	92 309	92 314	92 319
838	92 324	92 330	92 335	92 340	92 345	92 350	92 355	92 361	92 366	92 371
839	92 376	92 381	92 387	92 392	92 397	92 402	92 407	92 412	92 418	92 423
840	92 428	92 433	92 438	92 443	92 449	92 454	92 459	92 464	92 469	92 474
841	92 480	92 485	92 490	92 495	92 500	92 505	92 511	92 516	92 521	92 526
842	92 531	92 536	92 542	92 547	92 552	92 557	92 562	92 567	92 572	92 578
843	92 583	92 588	92 593	92 598	92 603	92 609	92 614	92 619	92 624	92 629
844	92 634	92 639	92 645	92 650	92 655	92 660	92 665	92 670	92 675	92 681
845	92 686	92 691	92 696	92 701	92 706	92 711	92 716	92 722	92 727	92 732
846	92 737	92 742	92 747	92 752	92 758	92 763	92 768	92 773	92 778	92 783
847	92 788	92 793	92 799	92 804	92 809	92 814	92 819	92 824	92 829	92 834
848	92 840	92 845	92 850	92 855	92 860	92 865	92 870	92 875	92 881	92 886
849	92 891	92 896	92 901	92 906	92 911	92 916	92 921	92 927	92 932	92 937
850	92 942	92 947	92 952	92 957	92 962	92 967	92 973	92 978	92 983	92 988
851	92 993	92 998	93 003	93 008	93 013	93 018	93 024	93 029	93 034	93 039
852	93 044	93 049	93 054	93 059	93 064	93 069	93 075	93 080	93 085	93 090
853	93 095	93 100	93 105	93 110	93 115	93 120	93 125	93 131	93 136	93 141
854	93 146	93 151	93 156	93 161	93 166	93 171	93 176	93 181	93 186	93 192
855	93 197	93 202	93 207	93 212	93 217	93 222	93 227	93 232	93 237	93 242
856	93 247	93 252	93 258	93 263	93 268	93 273	93 278	93 283	93 288	93 293
857	93 298	93 303	93 308	93 313	93 318	93 323	93 328	93 334	93 339	93 344
858	93 349	93 354	93 359	93 364	93 369	93 374	93 379	93 384	93 389	93 394
859	93 399	93 404	93 409	93 414	93 420	93 425	93 430	93 435	93 440	93 445
860	93 450	93 455	93 460	93 465	93 470	93 475	93 480	93 485	93 490	93 495
861	93 500	93 505	93 510	93 515	93 520	93 526	93 531	93 536	93 541	93 546
862	93 551	93 556	93 561	93 566	93 571	93 576	93 581	93 586	93 591	93 596
863	93 601	93 606	93 611	93 616	93 621	93 626	93 631	93 636	93 641	93 646
864	93 651	93 656	93 661	93 666	93 671	93 676	93 682	93 687	93 692	93 697

COMMON LOGARITHMS OF NUMBERS
(*Continued*)

N	0	1	2	3	4	5	6	7	8	9
865	93 702	93 707	93 712	93 717	93 722	93 727	93 732	93 737	93 742	93 747
866	93 752	93 757	93 762	93 767	93 772	93 777	93 782	93 787	93 792	93 797
867	93 802	93 807	93 812	93 817	93 822	93 827	93 832	93 837	93 842	93 847
868	93 852	93 857	93 862	93 867	93 872	93 877	93 882	93 887	93 892	93 897
869	93 902	93 907	93 912	93 917	93 922	93 927	93 932	93 937	93 942	93 947
870	93 952	93 957	93 962	93 967	93 972	93 977	93 982	93 987	93 992	93 997
871	94 002	94 007	94 012	94 017	94 022	94 027	94 032	94 037	94 042	94 047
872	94 052	94 057	94 062	94 067	94 072	94 077	94 082	94 086	94 091	94 096
873	94 101	94 106	94 111	94 116	94 121	94 126	94 131	94 136	94 141	94 146
874	94 151	94 156	94 161	94 166	94 171	94 176	94 181	94 186	94 191	94 196
875	94 201	94 206	94 211	94 216	94 221	94 226	94 231	94 236	94 240	94 245
876	94 250	94 255	94 260	94 265	94 270	94 275	94 280	94 285	94 290	94 295
877	94 300	94 305	94 310	94 315	94 320	94 325	94 330	94 335	94 340	94 345
878	94 349	94 354	94 359	94 364	94 369	94 374	94 379	94 384	94 389	94 394
879	94 399	94 404	94 409	94 414	94 419	94 424	94 429	94 433	94 438	94 443
880	94 448	94 453	94 458	94 463	94 468	94 473	94 478	94 483	94 488	94 493
881	94 498	94 503	94 507	94 512	94 517	94 522	94 527	94 532	94 537	94 542
882	94 547	94 552	94 557	94 562	94 567	94 571	94 576	94 581	94 586	94 591
883	94 596	94 601	94 606	94 611	94 616	94 621	94 626	94 630	94 635	94 640
884	94 645	94 650	94 655	94 660	94 665	94 670	94 675	94 680	94 685	94 689
885	94 694	94 699	94 704	94 709	94 714	94 719	94 724	94 729	94 734	94 738
886	94 743	94 748	94 753	94 758	94 763	94 768	94 773	94 778	94 783	94 787
887	94 792	94 797	94 802	94 807	94 812	94 817	94 822	94 827	94 832	94 836
888	94 841	94 846	94 851	94 856	94 861	94 866	94 871	94 876	94 880	94 885
889	94 890	94 895	94 900	94 905	94 910	94 915	94 919	94 924	94 929	94 934
890	94 939	94 944	94 949	94 954	94 959	94 963	94 968	94 973	94 978	94 983
891	94 988	94 993	94 998	95 002	95 007	95 012	95 017	95 022	95 027	95 032
892	95 036	95 041	95 046	95 051	95 056	95 061	95 066	95 071	95 075	95 080
893	95 085	95 090	95 095	95 100	95 105	95 109	95 114	95 119	95 124	95 129
894	95 134	95 139	95 143	95 148	95 153	95 158	95 163	95 168	95 173	95 177
895	95 182	95 187	95 192	95 197	95 202	95 207	95 211	95 216	95 221	95 226
896	95 231	95 236	95 240	95 245	95 250	95 255	95 260	95 265	95 270	95 274
897	95 279	95 284	95 289	95 294	95 299	95 303	95 308	95 313	95 318	95 323
898	95 328	95 332	95 337	95 342	95 347	95 352	95 357	95 361	95 366	95 371
899	95 376	95 381	95 386	95 390	95 395	95 400	95 405	95 410	95 415	95 419
900	95 424	95 429	95 434	95 439	95 444	95 448	95 453	95 458	95 463	95 468
901	95 472	95 477	95 482	95 487	95 492	95 497	95 501	95 506	95 511	95 516
902	95 521	95 525	95 530	95 535	95 540	95 545	95 550	95 554	95 559	95 564
903	95 569	95 574	95 578	95 583	95 588	95 593	95 598	95 602	95 607	95 612
904	95 617	95 622	95 626	95 631	95 636	95 641	95 646	95 650	95 655	95 660
905	95 665	95 670	95 674	95 679	95 684	95 689	95 694	95 698	95 703	95 708
906	95 713	95 718	95 722	95 727	95 732	95 737	95 742	95 746	95 751	95 756
907	95 761	95 766	95 770	95 775	95 780	95 785	95 789	95 794	95 799	95 804
908	95 809	95 813	95 818	95 823	95 828	95 832	95 837	95 842	95 847	95 852
909	95 856	95 861	95 866	95 871	95 875	95 880	95 885	95 890	95 895	95 899

COMMON LOGARITHMS OF NUMBERS
(*Continued*)

N	0	1	2	3	4	5	6	7	8	9
910	95 904	95 909	95 914	95 918	95 923	95 928	95 933	95 938	95 942	95 947
911	95 952	95 957	95 961	95 966	95 971	95 976	95 980	95 985	95 990	95 995
912	95 999	96 004	96 009	96 014	96 019	96 023	96 028	96 033	96 038	96 042
913	96 047	96 052	96 057	96 061	96 066	96 071	96 076	96 080	96 085	96 090
914	96 095	96 099	96 104	96 109	96 114	96 118	96 123	96 128	96 133	96 137
915	96 142	96 147	96 152	96 156	96 161	96 166	96 171	96 175	96 180	96 185
916	96 190	96 194	96 199	96 204	96 209	96 213	96 218	96 223	96 227	96 232
917	96 237	96 242	96 246	96 251	96 256	96 261	96 265	96 270	96 275	96 280
918	96 284	96 289	96 294	96 298	96 303	96 308	96 313	96 317	96 322	96 327
919	96 332	96 336	96 341	96 346	96 350	96 355	96 360	96 365	96 369	96 374
920	96 379	96 384	96 388	96 393	96 398	96 402	96 407	96 412	96 417	96 421
921	96 426	96 431	96 435	96 440	96 445	96 450	96 454	96 459	96 464	96 468
922	96 473	96 478	96 483	96 487	96 492	96 497	96 501	96 506	96 511	96 515
923	96 520	96 525	96 530	96 534	96 539	96 544	96 548	96 553	96 558	96 562
924	96 567	96 572	96 577	96 581	96 586	96 591	96 595	96 600	96 605	96 609
925	96 614	96 619	96 624	96 628	96 633	96 638	96 642	96 647	96 652	96 656
926	96 661	96 666	96 670	96 675	96 680	96 685	96 689	96 694	96 699	96 703
927	96 708	96 713	96 717	96 722	96 727	96 731	96 736	96 741	96 745	96 750
928	96 755	96 759	96 764	96 769	96 774	96 778	96 783	96 788	96 792	96 797
929	96 802	96 806	96 811	96 816	96 820	96 825	96 830	96 834	96 839	96 844
930	96 848	96 853	96 858	96 862	96 867	96 872	96 876	96 881	96 886	96 890
931	96 895	96 900	96 904	96 909	96 914	96 918	96 923	96 928	96 932	96 937
932	96 942	96 946	96 951	96 956	96 960	96 965	96 970	96 974	96 979	96 984
933	96 988	96 993	96 997	97 002	97 007	97 011	97 016	97 021	97 025	97 030
934	97 035	97 039	97 044	97 049	97 053	97 058	97 063	97 067	97 072	97 077
935	97 081	97 086	97 090	97 095	97 100	97 104	97 109	97 114	97 118	97 123
936	97 128	97 132	97 137	97 142	97 146	97 151	97 155	97 160	97 165	97 169
937	97 174	97 179	97 183	97 188	97 192	97 197	97 202	97 206	97 211	97 216
938	97 220	97 225	97 230	97 234	97 239	97 243	97 248	97 253	97 257	97 262
939	97 267	97 271	97 276	97 280	97 285	97 290	97 294	97 299	97 304	97 308
940	97 313	97 317	97 322	97 327	97 331	97 336	97 340	97 345	97 350	97 354
941	97 359	97 364	97 368	97 373	97 377	97 382	97 387	97 391	97 396	97 400
942	97 405	97 410	97 414	97 419	97 424	97 428	97 433	97 437	97 442	97 447
943	97 451	97 456	97 460	97 465	97 470	97 474	97 479	97 483	97 488	97 493
944	97 497	97 502	97 506	97 511	97 516	97 520	97 525	97 529	97 534	97 539
945	97 543	97 548	97 552	97 557	97 562	97 566	97 571	97 575	97 580	97 585
946	97 589	97 594	97 598	97 603	97 607	97 612	97 617	97 621	97 626	97 630
947	97 635	97 640	97 644	97 649	97 653	97 658	97 663	97 667	97 672	97 [illegible]
948	97 681	97 685	97 690	97 695	97 699	97 704	97 708	97 713	97 717	97 722
949	97 727	97 731	97 736	97 740	97 745	97 749	97 754	97 759	97 763	97 768
950	97 772	97 777	97 782	97 786	97 791	97 795	97 800	97 804	97 809	97 813
951	97 818	97 823	97 827	97 832	97 836	97 841	97 845	97 850	97 855	97 859
952	97 864	97 868	97 873	97 877	97 882	97 886	97 891	97 896	97 900	97 905
953	97 909	97 914	97 918	97 923	97 928	97 932	97 937	97 941	97 946	97 950
954	97 955	97 959	97 964	97 968	97 973	97 978	97 982	97 987	97 991	97 996

COMMON LOGARITHMS OF NUMBERS
(Continued)

N	0	1	2	3	4	5	6	7	8	9
955	98 000	98 005	98 009	98 014	98 019	98 023	98 028	98 032	98 037	98 041
956	98 046	98 050	98 055	98 059	98 064	98 068	98 073	98 078	98 082	98 087
957	98 091	98 096	98 100	98 105	98 109	98 114	98 118	98 123	98 127	98 132
958	98 137	98 141	98 146	98 150	98 155	98 159	98 164	98 168	98 173	98 177
959	98 182	98 186	98 191	98 195	98 200	98 204	98 209	98 214	98 218	98 223
960	98 227	98 232	98 236	98 241	98 245	98 250	98 254	98 259	98 263	98 268
961	98 272	98 277	98 281	98 286	98 290	98 295	98 299	98 304	98 308	98 313
962	98 318	98 322	98 327	98 331	98 336	98 340	98 345	98 349	98 354	98 358
963	98 363	98 367	98 372	98 376	98 381	98 385	98 390	98 394	98 399	98 403
964	98 408	98 412	98 417	98 421	98 426	98 430	98 435	98 439	98 444	98 448
965	98 453	98 457	98 462	98 466	98 471	98 475	98 480	98 484	98 489	98 493
966	98 498	98 502	98 507	98 511	98 516	98 520	98 525	98 529	98 534	98 538
967	98 543	98 547	98 552	98 556	98 561	98 565	98 570	98 574	98 579	98 583
968	98 588	98 592	98 597	98 601	98 605	98 610	98 614	98 619	98 623	98 628
969	98 632	98 637	98 641	98 646	98 650	98 655	98 659	98 664	98 668	98 673
970	98 677	98 682	98 686	98 691	98 695	98 700	98 704	98 709	98 713	98 717
971	98 722	98 726	98 731	98 735	98 740	98 744	98 749	98 753	98 758	98 762
872	98 767	98 771	98 776	98 780	98 784	98 789	98 793	98 798	98 802	98 807
973	98 811	98 816	98 820	98 825	98 829	98 834	98 838	98 843	98 847	98 851
974	98 856	98 860	98 865	98 869	98 874	98 878	98 883	98 887	98 892	98 896
975	98 900	98 905	98 909	98 914	98 918	98 923	98 927	98 932	98 936	98 941
976	98 945	98 949	98 954	98 958	98 963	98 967	98 972	98 976	98 981	98 985
977	98 989	98 994	98 998	99 003	99 007	99 012	99 016	99 021	99 025	99 029
978	99 034	99 038	99 043	99 047	99 052	99 056	99 061	99 065	99 069	99 074
979	99 078	99 083	99 087	99 092	99 096	99 100	99 105	99 109	99 114	99 118
980	99 123	99 127	99 131	99 136	99 140	99 145	99 149	99 154	99 158	99 162
981	99 167	99 171	99 176	99 180	99 185	99 189	99 193	99 198	99 202	99 207
982	99 211	99 216	99 220	99 224	99 229	99 233	99 238	99 242	99 247	99 251
983	99 255	99 260	99 264	99 269	99 273	99 277	99 282	99 286	99 291	99 295
984	99 300	99 304	99 308	99 313	99 317	99 322	99 326	99 330	99 335	99 339
985	99 344	99 348	99 352	99 357	99 361	99 366	99 370	99 374	99 379	99 383
986	99 388	99 392	99 396	99 401	99 405	99 410	99 414	99 419	99 423	99 427
987	99 432	99 436	99 441	99 445	99 449	99 454	99 458	99 463	99 467	99 471
988	99 476	99 480	99 484	99 489	99 493	99 498	99 502	99 506	99 511	99 515
989	99 520	99 524	99 528	99 533	99 537	99 542	99 546	99 550	99 555	99 559
990	99 564	99 568	99 572	99 577	99 581	99 585	99 590	99 594	99 599	99 603
991	99 607	99 612	99 616	99 621	99 625	99 629	99 634	99 638	99 642	99 647
992	99 651	99 656	99 660	99 664	99 669	99 673	99 677	99 682	99 686	99 691
993	99 695	99 699	99 704	99 708	99 712	99 717	99 721	99 726	99 730	99 734
994	99 739	99 743	99 747	99 752	99 756	99 760	99 765	99 769	99 774	99 778
995	99 782	99 787	99 791	99 795	99 800	99 804	99 808	99 813	99 817	99 822
996	99 826	99 830	99 835	99 839	99 843	99 848	99 852	99 856	99 861	99 865
997	99 870	99 874	99 878	99 883	99 887	99 891	99 896	99 900	99 904	99 909
998	99 913	99 917	99 922	99 926	99 930	99 935	99 939	99 944	99 948	99 952
999	99 957	99 961	99 965	99 970	99 974	99 978	99 983	99 987	99 991	99 996
1000	00 000	00 004	00 009	00 013	00 017	00 022	00 026	00 030	00 035	00 039

TRANSMISSION OF POWER

Shafts

Power is transmitted along a straight line by means of shafts which should be of sufficient size to resist the torsional strains set up in them. These shafts, if horizontal, are supported by hangers, which are fitted with suitable bearings and should be close enough to one another to prevent any appreciable sag to the shaft, for such conditions not only cause a liability to spring, but wear the bearings bell shaped at the edges. No fixed distance can be given for hangers, to be used in all cases, since the number, size, and arrangement of pulleys on the shafts are vital factors and so each case must be left to the judgment or calculation of an experienced engineer. In general, though, hangers should not be placed more than 6 or 8 feet apart.

Power is taken from shafts either by means of gears, pulleys and belts, or sprockets and chains.

Gears

Gears are wheels or pulleys upon the rim of which are projections called teeth. All of the teeth on a given gear are exactly alike, and the spaces between are of sufficient size to permit the teeth of a corresponding gear to fit into them without binding and yet without excess play—thus the gears are said to roll together, to mate, or to mesh. The size of the teeth varies for different kinds of work and conditions of operation, and are designated by a factor called the *pitch.*

There are two systems of pitches in use to-day:

1. Circular pitch, which is the distance, in inches or fractions thereof, from a point on the face of one tooth to a corresponding point on an adjoining one, measured along an arc of the pitch circle, which is a circle drawn with the center of the gear as its center, and of a radius to pass a circumference that will make the arc on the tooth and the arc in the space the same size (strictly speaking the one in the space should be slightly larger, but the difference is too small for consideration here). In standard practice this circular pitch is given in simple fractions of the inch, as for example $\frac{1}{2}$, 1, $1\frac{3}{4}$ inches, etc., but not in the higher fractions such as $\frac{31}{64}$, $1\frac{1}{32}$, 1.76 inches.

To determine the circular pitch of a given gear, then, with a pair of dividers find the point at which the tooth and the space are the same size, draw on a piece of paper an arc with a radius equal to the distance from this point to the center of the gear, lay off a definite arc by stepping the dividers twice, and then carefully measure this arc—this distance is the circular pitch. For instance if it should seem to be $1\frac{1}{64}$ inches, then, in all probability the real circular pitch is 1 inch, and the $\frac{1}{64}$ inch represents an error due to wear of the gear, or in laying off.

2. Diametral pitch, which is the number of teeth per inch of diameter of the pitch circle which is as described above. For instance if the pitch diameter (diameter of the pitch circle) is 12 inches and the number of teeth is 72, then the diametral pitch is 72 divided by 12 or 6. In general the length of the teeth is such that the outside diameter of the gear (from tip of tooth to tip of tooth) is equal to the *number of teeth plus 2*

divided by the diametral pitch; for example, if the gear has 72 teeth of 6 diametral pitch, then the outside diameter would be $72+2\div 6$, or 12.33 inches.

To determine the diametral pitch of a given gear, then; count the number of teeth, add two to this number, and divide by the outside diameter carefully measured. In standard practice the diametral pitch is given in simple fractions of the inch, or in whole inches. For example if the number of teeth is 88 and the outside diameter is 11.25 inches, then the diametral pitch is $88+2\div 11.25$ or 8.

All gears of any pitch (either circular or diametrical) no matter what may be the number of teeth, will mesh with one another.

In two gears working together, it is evident that when a tooth of one passes through any certain distance, a tooth of the other must necessarily pass through a similar distance, and, therefore if one gear has 24 teeth and the other 12, when 12 teeth of the former have passed a given point, 12 of the latter also will have passed a given point; the former will have made a half revolution, and the latter a complete revolution. From this it will be seen that the number of revolutions, or the angular velocities of two meshing gears are indirectly as the number of teeth, and may be expressed in a proportion as follows: if

n = number of teeth of the driver { the one from which power is to be taken

N = number of teeth of the driven { the one to which power is to be delivered

v = number of revolutions per minute of driver;

V = number of revolutions per minute of driven;
then

$$V : v :: n : N$$

Example. If a 15-tooth pinion on a motor has a speed of 1150 r.p.m., is to mesh with a gear on a grinder shaft and give to it a velocity of 200 r.p.m., how many teeth must the latter have?

$$V : v = n : N$$

$$200 : 1150 :: 15 : N$$

$$200\,N = 17250$$

$$N = 86.25$$

That is $86\frac{1}{4}$ teeth. It is impossible to have a fraction of a tooth, and so the gear should have 86 teeth, and the speed of the grinder will be a little in excess of 200 r.p.m.

$$V : 1150 :: 15 : 86$$

$$86V = 17250$$

$$V = 200.58 \text{ r.p.m.}$$

Example. If the diametral pitch of the teeth is 3, how far from the center of the grinder shaft should the motor shaft be placed?

Note.—The pitch circles should roll together, so that the distance would be equal to the sum of their radii.

$15 \div 3 = 5$ pitch diameter of pinion, or driver
2.5 pitch radius of pinion, or driver
$86 \div 3 = 28.66$ pitch diameter of spur, or driven
14.33 pitch radius of spur, or driven
$2.5 + 14.33 = 16.83$ inches, distance between shafts.

It will be noted that as far as the speed is concerned the size of the teeth makes no difference. They are controlled by the conditions under which the gears are to work, and should be left to a competent engineer. It often happens, however, that a machine is to be fitted up for operation, and the gear to be driven is already in place; in which case it may be assumed safely that the designer has considered the matter of strength and provided correct teeth, so no ill results should follow using them.

Pulleys

Pulleys accomplish the same results as do gears with the advantage that they do not require a fixed distance between centers, since a belt traverses the intervening space, and they may be used to transmit power considerable distances. It is assumed that the belt does not slip upon the pulleys, and so a similar proportion for relative speeds may be written for pulleys as for gears if

d = the diameter of the driver in inches;

D = the diameter of the driven in inches;

v = number of revolutions per minute of driver;

V = number of revolutions per minute of driven;

then

$$V : v :: d : D$$

Example. The pulley on a dry-pan is 36 inches in diameter should make 150 r.p.m. The line shaft from which power is to be taken makes 250 r.p.m., what size pulley should be ordered for the shaft?

$$V : v :: d : D$$

$$150 : 250 :: d : 36$$

$$250d = 5400$$

$$d = 21.6 \text{ inches}$$

The nearest standard size to this should be used, perhaps 22 inches.

The width of the pulley should be slightly greater than the width of belt to be used upon it in order to protect the edges of the latter.

The width of belt is controlled by the amount of power to be transmitted, the velocity, and the tensile strength of the belt, and may be determined best from the specifications of the maker of the belt to be used, usually printed in a circular or catalog.

In the case of a machine, the face of the pulley is always given, and the designer has considered the power and provided for it, so a belt to fit the pulley is usually the correct width. The thickness of the belt, or the "ply" can be determined from the catalog.

The length of the belt is the commonest question to arise, and if both pulleys are in place, the simplest method is to measure the length directly by stretching a tape-line over them. A fine wire, or inelastic cord may be used in place of the tape, and the length carefully measured.

It often happens, however, that it is desired to place the order for the belt before the pulleys are in place, or even on hand, and then calculations must be resorted to for a length.

These are divided into three cases:

1. Open belt and both pulleys the same size. The belt passes around one-half of each pulley, an equivalent of once around one, and twice across the distance between centers, so that if

D = diameter of the pulleys in *inches;*

B = distance between centers in *feet;*

L = length of belt in *feet;*

then

$$L = (.2618 \times D) + (2 \times B)$$

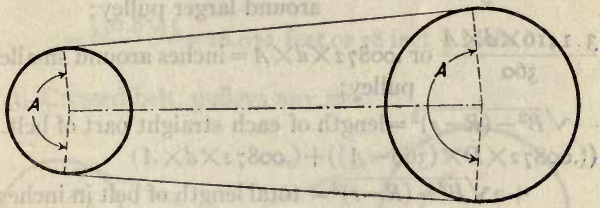
Example. *A line shaft has a speed of 250 r.p.m.; it is desired to operate a jack-shaft 15 feet from it at the same speed and two pulleys each 2 feet in diameter are on hand; how long should an open belt be?*

$L = (.2618 \times D) + (2 \times B);$

$L = (.2618 \times 24) + (2 \times 15);$

$L = 6.28 + 30$ or 36.28 feet or 36 feet $3\frac{3}{8}$ inches.

2. Open belt and both pulleys *not* the same size.



It is evident in this case that the belt passes around more than one-half of the larger and less than one-half of the smaller, and that the lengths of straight belt are not equal to the distance between the centers.

Let D = diameter of larger pulley in inches;
R = radius of larger pulley in inches;
d = diameter of smaller pulley in inches;
r = radius of smaller pulley in inches;
B = distance between centers of pulleys in inches;
L = length of belt in *feet;*

then

$\frac{R-r}{B}$ = cosine of one-half the angle representing the part of the larger pulley *not covered* by the belt, and also the part of the smaller that *is covered.*

From a table of *Natural Trigonometrical Functions* find the angle whose cosine is $\frac{R-r}{B}$ and multiply this by 2, call this angle A and reduce it to degrees of a decimal of degrees. (Note.—Do *not* multiply $\frac{R-r}{B}$ by 2, and then find angle, for there will be a wide difference.)

$3.1416 \times D =$ circumference of larger pulley.

$\frac{3.1416 \times D \times (360-A)}{360}$ or $.00872 \times D \times (360-A) =$ inches around larger pulley;

$\frac{3.1416 \times d \times A}{360}$ or $.00872 \times d \times A =$ inches around smaller pulley;

$\sqrt{B^2-(R-r)^2} =$ length of each straight part of belt.

$((.00872 \times D \times (360-A)) + (.00872 \times d \times A) + 2\sqrt{B^2-(R-r)^2} =$ total length of belt in inches.

$\frac{((.00872 \times D \times (360-A)) + (.00872 \times d \times A) + 2\sqrt{B^2-(R-r)^2}}{12} =$ total length of belt in feet.

Example. One pulley 48 inches in diameter and 10 feet from another 12 inches in diameter is to be driven from it by an open belt; how much belt should be ordered?

$D = 48$ inches

$R = 24$ "

$d = 12$ "

$r = 6$ "

$B = 10$ feet or 120 inches

$$\frac{R-r}{B} = \frac{24-6}{120} = \frac{18}{120} = .15000$$

From table's angle whose cosine is .15000 = about $81° - 22\frac{1}{2}'$ or $81.374°$ $2 \times 81.374 = 162.748 =$ angle A

$$\frac{((.00872 \times D \times (360 - A)) + (.00872 \times d \times A) + 2\sqrt{B^2 - (R-r)^2}}{12} =$$

total length of belt in feet.

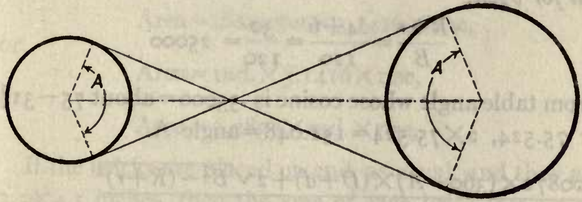
$$\frac{((.00872 \times 48 \times (360 - 162.748))}{12}$$

$$+ \frac{(.00872 \times 12 \times 162.748) + 2\sqrt{120^2 - (24-6)^2}}{12}$$

$$\frac{82.5600 + 17.0299 + 237.2846}{12}$$

$$= \frac{336.8745}{12} = 28.072 \text{ feet or } 28 \text{ feet } \tfrac{7}{8} \text{ inch.}$$

3. Crossed belt, pulleys any size.



In this case the belt passes around more than one-half of each pulley, and the angle left uncovered is the same for both no matter what the sizes may be, and as in case 2, the lengths of straight belt are not equal to the distance between centers.

Using same notation as in case 2 then $\frac{R+r}{B} =$ cosine of one-half of the angle uncovered in each pulley and two times angle whose cosine is $\frac{R+r}{B} =$ angle A

$\frac{3.1416 \times D(360-A)}{360}$ or $.00872 \times D \times (360-A)$ = inches around larger pulley

$\frac{3.1416 \times d(360-A)}{360}$ or $.00872 \times d \times (360-A)$ = inches around smaller pulley

$\sqrt{B^2-(R+r)^2}$ = length of each straight part of belt

$$((.00872 \times D \times (360-A)) + ((.00872 \times d \times (360-A)) + 2\sqrt{B^2-(R+r)^2}$$

or

$$(.00872 \times (360-A) \times (D+d) + 2\sqrt{B^2-(R+r)^2}$$

$$\frac{(.00872 \times (360-A) \times (D+d) + 2\sqrt{B^2-(R+r)^2}}{12} = \text{total length in feet.}$$

Example. Same as last example, but substitute crossed belt for open.

$$\frac{R+r}{B} = \frac{24+6}{120} = \frac{30}{120} = .25000$$

From table angle whose cosine is .35000 = about $75-31\frac{1}{2}$ or 75.524, $2 \times 75.524 = 151.048$ = angle A.

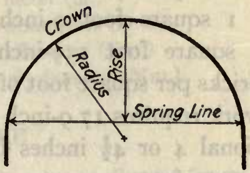
$$\frac{(.00872 \times (360-A) \times (D+d) + 2\sqrt{B^2-(R+r)^2}}{12} = \text{total length in feet}$$

$$\frac{((.00872(360-151.048) \times (48+12)) + 2\sqrt{120^2-(24+6)^2}}{12}$$

$$\frac{109.3236+232.3790}{12} = \frac{341.7026}{12} = 28.45 \text{ feet or } 28 \text{ feet } 5\tfrac{1}{2} \text{ inches}$$

CALCULATING THE NUMBER OF BRICKS IN THE CROWN OF A CIRCULAR KILN

If the crown is part of a true sphere, then its surface is a zone and its area is equal to the circumference of the sphere times the altitude of the zone. The circumference of the sphere is equal to the diameter times 3.1416, or twice the radius times 3.1416, and the altitude of the zone is equal to the rise of the crown, so that the area then, may be expressed by the equation:



$$\text{Area} = \text{diameter} \times 3.1416 \times \text{rise},$$

or

$$\text{Area} = \text{rad.} \times 3.1416 \times \text{rise},$$

or

$$\text{Area} = 6.2832 \times \text{rad.} \times \text{rise}.$$

If the bricks are placed on end, as usual, and they are 2.5×4.5 inches, then the area of each brick is 2.5×4.5 inches or 11.25 square inches, and there being 144 square inches in a square foot there will be $144 \div 11.25$ or 12.8 bricks required per square foot of crown area.

The total number of bricks, therefore, will be equal to the area of the crown times the number of bricks per foot, or Area $\times$ 12.8, and the third equation above then becomes

$$\text{Number of bricks} = (6.2832 \times \text{rad.} \times \text{rise}) \times 12.8$$

or

$$\text{Number of bricks} = 80.42 \times \text{rad.} \times \text{rise}.$$

For a crown of radius of 16 feet and a rise of 9 feet then

$$\text{Number of bricks} = 80.42 \times 16 \times 9$$

or

Number of bricks = 11,580, not allowing for broken ones that may not be used.

Bricks required in plain walls: 1 square foot $4\frac{1}{2}$-inch wall require 7 bricks.

1 square foot 9-inch wall requires 14-inch bricks. 1 square foot $13\frac{1}{2}$-inch wall requires 21 bricks. 30 bricks per square foot of 18-inch wall, 1 cubic foot brick work requires 17 9-inch bricks; $7\frac{1}{2}$ bricks to each additional 4 or $4\frac{1}{2}$ inches in thickness of plain walls per square foot.

To lay 1000 bricks requires from 250 to 320 pounds of fire clay or silica cement.

METRIC MEASURES

LINEAR

10 millimeters (mm.)	= 1 centimeter (cm.)
10 centimeters	= 1 decimeter (dm)
10 decimeters	= 1 meter (m.)
10 meters	= 1 dekameter (Dm.)
10 dekameters	= 1 kilometer (Km.)
10 kilometers	= 1 myriameter (Mm.)

SQUARE

100	square millimeters (sq.mm.)	= 1	sq.	centimeter (sq.cm.)
100	" centimeters	= 1	"	decimeter (sq.dm.)
100	" decimeters	= 1	"	meter (sq.m.)
100	" meters	= 1	"	dekameter (sq.Dm.)
100	" dekameters	= 1	"	hektometer (sq.Hm.)
100	" hektometers	= 1	"	kilometer (sq.Km.)

WEIGHTS

10 milligrams (mgm.)	= 1 centigram (cgm.)
10 centigrams	= 1 decigram (dgm.)
10 decigrams	= 1 gram (gm.)
10 grams	= 1 dekagram (Dgm.)
10 dekagrams	= 1 hektogram (Hgm.)
10 hektograms	= 1 kilogram (Kgm.)
100 kilograms	= 1 metric quintal (Mq.)
1000 kilograms	= 1 metric ton (T.)

MEASURE OF VOLUME

1000	cubic millimeters (cu.mm.)	= 1	cubic	centimeter (c.c.)
1000	" centimeters	= 1	"	decimeter (cu.dm.)
1000	" decimeters	= 1	"	meter (cu.m.)
	10 milliliters (ml.)	= 1		centiliter (cl.)

10 centiliters	=	1 deciliter (dl.)
10 deciliters	=	1 liter (L.)
10 liters	=	1 dekaliter (Dl.)
10 dekaliters	=	1 hektoliter (Hl.)
10 hektoliters	=	1 kiloliter (Kl.)

CONVERSION OF METRIC TO ENGLISH

LINEAR MEASURES

1 millimeter (mm.)	=	0.039 inch
1 centimeter (cm.)	=	0.3937 inch
1 centimeter (cm.)	=	0.0328 foot
1 meter (m.)	=	3.28 feet
1 meter (m.)	=	1.09 yards
1 kilometer (km.)	=	0.621 mile
1 inch (in.)	=	2.54 centimeters
1 foot (ft.)	=	30.48 centimeters
1 yard (yd.)	=	0.914 meter
1 mile (m.)	=	1609.33 meters

SQUARE MEASURE

1 sq. centimeter (sq.cm.)	=	0.155 sq. in.
1 sq. meter (sq. cm.)	=	10.764 sq. ft.
1 sq. meter (sq. M.)	=	1.196 sq. yd.
1 sq. kilometer (sq.KM.)	=	0.3861 sq. mile
1 sq. inch (sq. in.)	=	6.451 sq. cm.
1 sq. foot (sq.ft.)	=	929 sq. cm.
1 sq. yard (sq.yd.)	=	8361.13 sq. cm.
1 sq. acre (sq.ac.)	=	4046.7 sq. M.
1 sq. mile (sq.M.)	=	2.59 sq. KM.

CUBIC MEASURE

1 cubic centimeter (c.c.)	=	0.061 cu. in
1 cubic meter (C.M.)	=	35.29 cu. ft.
1 cubic meter (C.M.)	=	1.308 cu. yds.
1 cubic inch (cu.in.)	=	16.383 c.c.
1 cubic foot (cu.ft.)	=	28316 c.c.
1 cubic foot (cu.ft.)	=	0.28 C.M.
1 cubic yard (cu.yd.)	=	.765 C.M.

1 Litre (L.)	=	61.027 cu. in.
1 Litre (L.)	=	0.0352 cu.ft.
1 Litre (L.)	=	0.2642 gallon (U.S.)
1 Litre (L.)	=	2.202 pounds of water
	=	at 62° F.
1 Litre (L.)	=	1.06 pints
1 Litre (L.)	=	.22 gallon
1 pint	=	568.23 CC.
1 gallon (U.S.) of water weighs	=	8.385 pounds
1 gallon	=	4541 CC.
1 gallon (U. S.)	=	3.785 litre
1 cu.ft. of water weight	=	62.278 pounds
1 cu.ft.	=	28.32 litres
1 N. S. liquid oz.	=	29.574 CC.
1 cubic inch of water	=	.3617 lb.
1 gallon of water	=	231 cu. in.
1 cubic foot of water	=	1728 cu. in.
1 cubic foot of water	=	7.4805 gallons

WEIGHTS

1 gram	=	15.432 grains
1 gram	=	.0353 ounce
1 kilogram	=	2.204 pounds
1 kilogram	=	35.274 ounces
1 kilogram	=	.0011 ton
1 ton	=	2000 pounds
1 ounce	=	28.35 gms.
1 pound	=	453.59 gms.
1 pound	=	.454 K.gm.
1 ton	=	907.18 K.gms.

USEFUL INFORMATION

To find diameter of a circle multiply circumference by .31831.

To find circumference of a circle multiply diameter by 3.1416.

To find area of a circle multiply square of diameter by .7854.

To find surface of a ball multiply square of diameter by 3.1416.

To find side of an equal square multiply diameter by .8862.

To find cubic inches in a ball multiply cube of diameter by .5236.

Doubling the diameter of a pipe increases its capacity four times.

Double riveting is from 16 to 20 per cent stronger than single.

A gallon of water (U. S.) standard weighs $8\frac{1}{3}$ pounds and contains 231 cubic inches.

There are 9 square feet of heating surface to each square foot of grate surface.

A cubic foot of water contains $7\frac{1}{2}$ gallons, 1728 cubic inches and weighs $62\frac{1}{2}$ pounds.

Each nominal horse-power of a boiler requires 30 to 35 pounds of water per hour.

A horse-power is equivalent to raising 33,000 pounds 1 foot per minute, or 550 pounds 1 foot per second.

The average consumption of coal for a steam boiler is 12 pounds per hour for each square of grate surface.

To find the pressure in pounds per square inch of a column of water, multiply the height of the column in feet by .434.

Steam rising from water at its boiling-point (212° F.) has a pressure equal to the atmosphere (14.7 pounds to the square inch).

To evaporate 1 cubic foot of water requires the consumption of $7\frac{1}{2}$ pounds of ordinary coal, or about 1 pound of coal to 1 gallon of water.

One-sixth of tensile strength of plate multiplied by thickness and divided by one-half the diameter of boiler gives the safe working pressure for tubular boilers. For marine boilers add 20 per cent for drilled holes.

To find the pressure in pounds per square inch of a column of water, multiply the height of the column in feet by .434.

Steam rising from water at its boiling point (212° F.) has a pressure equal to the atmosphere (14.7 pounds to the square inch).

To evaporate 1 cubic foot of water requires the consumption of 7½ pounds of ordinary coal, or about 1 pound of coal to 1 gallon of water.

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