July 8, 1930. E. D. MARTIN 1,770,177

PRODUCTION OF COATED METALLIC OBJECTS

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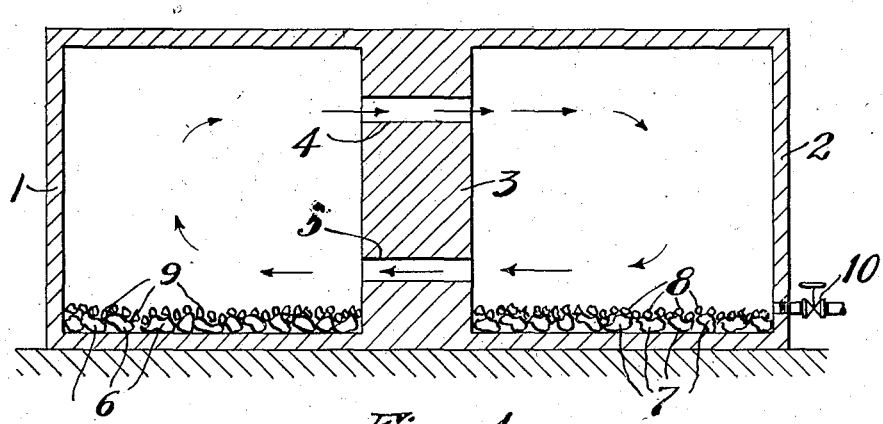

Fig. 1

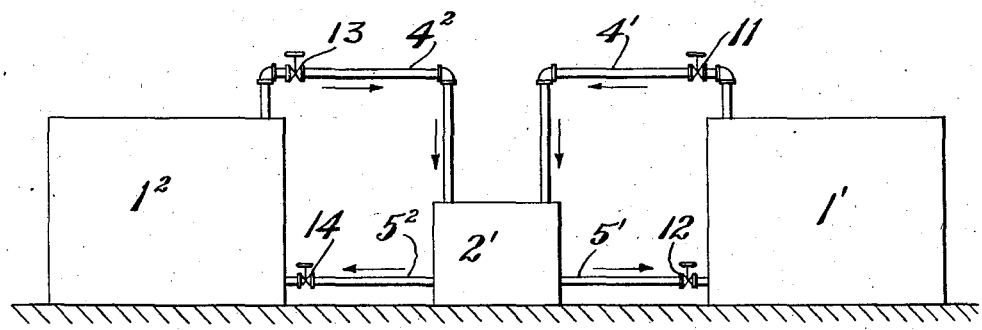

Fig. 2

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UNITED STATES PATENT OFFICE

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PRODUCTION OF COATED METALLIC OBJECTS

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My invention relates, in general, to a process for coating one metal with another which involves the deposition of the latter metal by a dry chemical reaction, and also to apparatus for carrying out this process and to the products resulting from such process.

The principal object of my invention resides in the provision of an improved process for coating or depositing one metal on another whereby a metallic object covered by employing such process will be provided with an outer surface layer consisting of an alloy of the deposited metal and the metal of the coated object having one or more of certain desirable properties, such as resistance to oxidation at ordinary temperatures or at high temperatures such as those encountered in furnaces, toughness, malleability, hardness and enhanced appearance, depending upon the metals employed and upon the purposes for which the coated objects are designed to be used. It is practicable by my improved process to cover an object formed of any of a number of different metals, notably either iron, steel, cast iron, copper or nickel, with an alloy of aluminum and the metal of which the object is formed.

Various processes are already known for covering one metal by another, that most generally used being electroplating. Zinc has also been deposited on iron by the process called "sherardization," aluminum on iron by the process called "calorization," and chromium on iron by the process called "chromization." To these may be added "tinning," which consists in plunging the metallic object to be coated in a bath of molten tin, and also the process known as "metallization," which consists in the projection upon the metal object to be covered of a metal either in a molten state or in the form of fine dust. The results obtained by these processes, however, are not comparable with those obtained by my improved process either in the appearance or other physical characteristics of the coatings or outer surface layers of the metallic object covered. My improved process differs radically from the various processes referred to in that an object covered by my process has the metal deposited thereon by a dry chemical reaction and involves neither the step of "dipping," nor the necessity of bringing the two metals into direct physical contact such as is necessary in the process known as calorization.

My improved process depends essentially on the principle that when a volatile salt of any metal in which the latter is combined with a suitable negative radical is brought into contact with another metal under proper conditions of temperature and pressure, a chemical reaction will be effected wherein the latter metal will reduce said salt and combine with the negative radical while the metal reduced will be deposited on, and in practically all cases will diffuse at a greater or less rate, depending on the temperature employed and on the metallographic nature of the metals, into the other metal and become alloyed therewith. This principle on which my improved process is based may be explained in a general way as follows: Let it be assumed that the problem consists in obtaining at the surface of any metal A the deposit of any other metal B. A suitable negative radical c (chlorine, for example) is chosen which is combinable with the metals A and B to form the salts Ac and Bc which are volatile at high temperatures. If the two metals A and B and also their volatile salts Ac and Bc are placed in a closed vessel containing no oxidizing agents and maintained at a high temperature, there tends to be established a chemical equilibrium which may be represented by the following equation:

$$\underset{\text{solid}}{A} + \underset{\text{gaseous}}{Bc} \leftrightarrows \underset{\text{gaseous}}{Ac} + \underset{\text{solid.}}{B}$$

In the equilibrium which is thus sought to be established the reaction as represented by the above equation may be either:

(1) Completely to the left, or

(2) Completely to the right, or

(3) In both directions,

depending upon the conditions of temperature and pressure to which the contents of the vessel are subjected, and also upon the relative stabilities of the volatilized salt Ac in the presence of the metal B and of the volatilized salt Bc in the presence of the

metal A, under such conditions. If in case (1) the volatile salt Bc is sent about the metal A, no chemical reaction will take place and accordingly none of the metal B will be deposited and the indicated negative radical therefor cannot be made use of; but if this is done in case (2) the metal A will reduce and replace the metal B in the volatile salt Bc and accordingly in this case the metal B will deposit on the metal A and the said negative radical may be utilized, and this is also true in case (3) for a part of the metal B will be reduced in a like manner from the volatile salt Bc and deposit on the metal A.

As indicated in the example just given wherein the problem consisted of depositing a metal B on a metal A, my improved process is of general application, for in every case and whatever the two metals A and B may be, it is possible by said process under proper conditions of temperature and pressure and by the choice of a suitable negative radical to effect the deposition of one of the metals on the other. However, as indicated above, my improved process is not limited to the production of coatings of metals on other metals consisting merely of the deposited metals; and in this connection it may be well to emphasize the fact that in nearly every case the coating obtained in depositing one metal on the other consists of an alloy of the deposited metal and the metal of the object being coated. This fact is very important for in many cases the properties of the alloy thus formed are much superior to those of each of the selected metals considered separately; for example, where by the use of my improved process aluminum is deposited on iron or another metal it forms an alloy with such metal which is harder, tougher and much less fusible than aluminum.

A further object of my invention is to provide an improved process such as described whereby a metallic object may be provided with a coating of any desired thickness depending upon the time during which the object is subjected to the process.

A still further object of my invention is to provide a processs of the character described in which it is unnecessary and undesirable to bring the object to be coated into physical contact with a salt of the coating metal when such salt is in the solid state.

My invention also resides in a process such as described wherein the various steps may be carried on in a complete cycle and wherein the gaseous products of the dry chemical reaction which results in the deposition of the coating metal may be effectively regenerated or recuperated.

Other objects and features of my invention will be hereinafter more fully described and claimed.

In the drawing accompanying and forming part of this specification:

Figure 1 is a somewhat diagrammatic view showing in section a simple form of apparatus which may be employed for carrying out my improved process; and

Figure 2 is a diagrammatic view in elevation of another form of apparatus for carrying out my improved process which enables the operations of coating one metal with another to be carried on continuously.

As concrete examples of the application of my invention, I shall now describe the covering of iron with aluminum by my improved process and the use of the different forms of apparatus shown in Figures 1 and 2.

The apparatus shown in Figure 1 consists essentially of two chambers 1 and 2 separated by a thick heat insulating wall 3 having two openings 4 and 5 extending therethrough at different levels establishing communication between the said chambers. The metallic objects 6 to be coated, which in the present case are of iron or of an alloy of iron, are placed in the chamber 1, while aluminum preferably in the form of small pieces, shavings, turnings or other scraps, is placed in the chamber 2. A quantity of salammoniac 8 is also disposed in the chamber 2 on the aluminum pieces 7 and some naphthaline 9 is disposed in the chamber 1 on the iron objects 6. The chamber 2 is provided adjacent the bottom thereof with a suitable discharge controlled by a valve 10.

The two chambers 1 and 2 are now heated in any suitable manner so that chamber 1 will be brought to a temperature of from 700 to 1200 degrees C., but preferably to a temperature of from 950 to 1000 degrees C., and so that the chamber 2 is brought to a temperature of from 100 to 700 degrees C., but preferably to a temperature of approximately 500 degrees C. Upon thus heating the chambers the naphthaline 9 will first volatilize, rise in the chamber 1 and pass into the chamber 2 through the opening 4, expelling before it the air contained in the two chambers, the evacuation of the air being effected through the valve 10 which, after this evacuation has been completed, is closed. The chambers 1 and 2 will now be free or practically free from air and other oxidizing agents. The contents of the chambers 1 and 2 are preferably maintained substantially at atmospheric pressure by providing one of the chambers with a valve (not shown) comprising a liquid seal. As the heating of the two chambers is continued the salammoniac 8 volatilizes and reacts with the aluminum 7 to form gaseous aluminum chloride which passes from the chamber 2 to the chamber 1 through the opening 5. A dry chemical reaction then takes place between the volatilized aluminum chloride or a part thereof and some of the iron of the objects 6, resulting in the deposition on the said objects of

some of the aluminum contained in the aluminum chloride and in the simultaneous formation of volatilized chlorides of iron. The iron chlorides formed by the reaction just described rise in the chamber 1 and pass through the opening 4 into the chamber 2 where, because of the lower temperature maintained in this chamber, a part of the iron chlorides are deposited while the rest being unstable in the presence of aluminum at such temperature, reacts with the aluminum to form free iron, which is deposited, and aluminum chloride, the aluminum chloride thus formed returning to the chamber 1 through the opening 5 where it reacts with the iron objects 6 as described above. Due to the difference in temperatures in the chambers 1 and 2, the gases used and produced in the operations described will automatically continue to circulate or move in a circuitous path through the two chambers, as indicated by the arrows in Figure 1, so that the gaseous products of the reaction between the aluminum chloride and the iron being coated will be continually removed from the vicinity of the latter; and likewise the gaseous products of the reaction taking place between any of the iron chlorides and the aluminum in the chamber 2 will be continually removed from the vicinity of such aluminum. In carrying on the process the gaseous products of the reaction between the aluminum chloride and the iron being coated do not act to check or limit such reaction, for in addition to being continually removed from the vicinity of the iron the return of these gaseous products, as such, to the vicinity of the iron is prevented. It will thus be apparent that the various operations embodied in the process will continue in a closed cycle as indicated.

When the iron objects 6 have been coated to the extent desired, which under given conditions of temperature and concentration of the aluminum chloride, will depend upon the period during which said objects are subjected to the treatment described, the gases then remaining in the chambers 1 and 2 are removed in any suitable manner as by introducing into one of the chambers either some more naphthaline or an inert or reducing gas and opening the valve 10 so as to effect the evacuation of the gases through the discharge controlled by said valve; or these gases can be drawn into the chamber 2 and there deposited by sufficiently cooling this chamber. The chamber 1 is then cooled and the coated iron objects 6 removed therefrom.

Where it is desired to cover different lots of objects such as objects formed of iron or iron alloys, with aluminum, the process may be carried on continuously by use of apparatus such as shown in Figure 2. In this figure, 2′ is a chamber corresponding to the chamber 2 of Figure 1 and in which the same materials 7 and 8 are placed, while 1′ and 1^2 are two chambers each corresponding to the single chamber 1 of Figure 2 and each containing the iron objects 6 to be covered and the naphthaline 9. The chamber 2′ is connected to the chamber 1′ at different levels by the conduits 4′ and 5′, and to the chamber 1^2 at different levels by the conduits 4^2 and 5^2, the said conduits 4′ and 5′ being respectively controlled by suitable valves 11 and 12 and the conduits 4^2 and 5^2 by valves 13 and 14. The three chambers being charged with the materials as described, the operations involved in the process are first conducted, for example, by way of the chambers 1′ and 2′ in the same manner as when the apparatus of Figure 1 is used, by maintaining valves 11 and 12 open and valves 13 and 14 closed; and when the iron objects in the chamber 1′ have been coated to the desired extent, the valves 11 and 12 are closed and said objects are withdrawn from the chamber 1′, while at the same time the valves 13 and 14 are opened and the operations of the process are continued without interruption by way of the chambers 1^2 and 2′.

It will be apparent that in the type of apparatus shown in Figure 2, the number of chambers containing the metallic objects to be coated, employed, is not limited to two, but that this number may be augmented as desired with like advantageous results. It will also be apparent that in apparatus such as shown in Figure 2 the circulation of the gases will be automatically effected in the same manner as in the apparatus shown in Figure 1. Such circulation of the gases in this form of apparatus may, however, be accentuated by making each of the conduits 4′ and 4^2 in the form of an inverted U so that the hot gases in passing from the chamber 1′ and 1^2 to the chamber 2′ will be cooled during their passage through the said conduits 4′ and 4^2.

In carrying on the process of coating iron with aluminum, as described above, the supply of chlorine may become deficient. Any such deficiency may, however, be readily compensated for by adding to the gases at a suitable point in the path in which they are circulated, hydrochloric acid, aluminum chloride, or ammonium chloride, preferably in a volatilized state, or chlorine itself. Also, if desired, the circulating gases used in my process and resulting from the reactions which occur therein may be diluted by adding thereto a suitable inert gas such as hydrogen, illuminating gas or the gas from gas producers.

The presence of the iron in the solid aluminum employed in coating iron with aluminum, as described above, does not constitute a source of trouble for at the temperature at which the aluminum is maintained while the process is carried on, iron does not enter into stable combination with chlo-

rine in the presence of aluminum. Accordingly aluminum scrap containing iron or other metals acting in the same manner as iron, may be employed in the process.

The gases produced in the course of the operations in the process of depositing aluminum on iron, as described above, may be regenerated or recuperated by three different methods, as follows:

One method consists in bringing the said gases into contact with pieces of aluminum heated to a temperature considerably less than that employed in effecting the deposition of aluminum on iron, it being immaterial whether or not said pieces of aluminum contain iron or metals acting in the same manner as iron. Because of the fact that the chemical reaction involved in the depositing of aluminum on iron is reversible, this results in the iron chlorides or a part thereof being converted into aluminum chloride, and this aluminum chloride may be returned to the chamber containing the iron and brought to react upon the iron, as described above, so as to effect the deposition of the aluminum contained therein. This method results in a regeneration of the gases, as the iron chloride (a degenerated condition for the chlorine since the latter is then of no use in effecting the deposition of aluminum) is converted into aluminum chloride, a volatile salt which can be used to effect the deposition of the aluminum.

A second method consists in conducting the gases produced in the course of the operations of depositing aluminum on iron, namely, the volatilized iron and aluminum chlorides, into a suitable chamber which is maintained at a temperature sufficiently lower than that of the chamber in which the deposition of the aluminum on the iron takes place to effect the deposition of the less volatile of these gases, that is, the iron chloride or chlorides. This method results in what may be suitably described as a recuperation of the gases, as the objectionable iron chloride or chlorides are eliminated, thus making valuable and capable for re-use the remaining aluminum chloride.

The third method also results in a recuperation of the gases, and consists in bringing such gases into contact with a sufficient quantity of iron at such a temperature that all the iron chlorides will be converted into the least volatile chloride of iron, namely, ferrous chloride, and then effecting the deposition of the latter by lowering the temperature.

The ferrous chloride obtained by either of the last two methods may be employed as a source of chlorine to produce aluminum chloride as follows: The ferrous chloride is brought to a red heat and water vapor passed over the same, producing in a gaseous state, hydrochloric acid and hydrogen and in a solid state, an oxide of iron. The gases thus produced are then brought into contact with aluminum, or with alloys thereof and other metals which in the presence of aluminum do not react to an appreciable degree with hydrochloric acid, under such conditions of temperature and pressure as to effect a reaction between the aluminum and the hydrochloric acid to form aluminum chloride which is capable of being used in the process as hereinbefore described. If desired, the formation of aluminum chloride from ferrous chloride in this manner may comprise or be made one of the steps of my process when the operations thereof are carried on in a cycle.

My improved process is applicable to the depositing of any metal on any other metal in the same manner as it is applied to the coating of iron with aluminum, as described above, and by making use of the same apparatus, subject to the reservations that a proper negative radical be chosen and that the operations involved in the process be carried on under suitable conditions of temperature and pressure. In general, it will suffice to employ a negative radical which forms with the two metals to be treated, salts which are volatile at temperatures which it is practicable to employ. For example, in case it is desired to coat copper or nickel with aluminum or iron with copper, the negative radical most convenient to employ will again be chlorine and the temperatures used will not differ greatly from those whose limits have already been indicated in describing the application of the process to the depositing of aluminum on iron. In a majority of cases the halogens constitute the most suitable negative radicals to employ, as the salts formed with these radicals are generally volatile. It is advisable, where possible, to use a negative radical such that the reaction involved in depositing one metal on another in accordance with my process will be reversible at temperatures which it is practicable to employ. While in some cases it might be necessary to look beyond the common negative radicals, such as the halogens, in order to find one such that the reaction would be reversible at practicable temperatures, experience leads me to believe that in practically any given case a negative radical can be found such that the reaction will be reversible at such temperatures.

In its general application, my improved process involves the diffusion of the metal being deposited into the metal being coated. The rapidity with which this diffusion takes place for given conditions of temperature and pressure under which the process is carried on and the question as to whether the coating formed consists of a chemical combination of the metals or a solid solution thereof, depend upon the metallographic charac-

teristics of the particular metals being treated in accordance with the process.

My process does not involve or result in an increase in the amount of metal in the object being coated, either by applying thereto an outer surface layer formed only of the deposited metal, or by infusing additional metal into the object. What does occur in the formation of the coating is a replacement of one metal by the other atom for atom. An analogy to this action is found in nature when one substance takes the place of another while preserving the form of the original substance; this phenomenon being commonly called "replacement" by geologists. As a result of this replacement action an object coated with a metal in accordance with my process will retain all of the minute surface details of the original object and will have the same atomic content as the latter, while the volume of the object will not be changed except perhaps to a slight extent due solely to the difference in the volumes of the atoms of the two metals. A further advantage resulting from the use of my improved process is that there is produced on the object being coated an adherent coating of unvarying thickness which is, in fact, integral with the object and which in all cases consists wholly of an alloy containing the metal of the object and the deposited metal.

In all cases where metals other than aluminum and iron are treated in accordance with my process, the regeneration or recuperation of the gases produced in carrying out the process may be effected by any of the three methods above described, subject, however, to the reservations that in the case of the method first described the chemical reaction involved in the deposition of one metal on the other must be reversible, and that in the case of the third method, the metal being coated must be capable of forming with the negative radical employed more than one volatile salt and that the least volatile of these salts must be that which contains the metal to be coated in its lowest state of oxidation.

Having now described my invention, what I claim as new and desire to protect by Letters Patent is as follows:

1. The process of depositing one metal on another which consists in circulating volatilized salts of such metals in a path including said metals at different points therein, maintaining the temperature at the place in said path where the metal to be coated is located at such a point as to effect a chemical reaction between such metal and a volatilized salt of the metal to be deposited, and maintaining the temperature at the point in said path where the metal to be deposited is located at such a point as to effect a chemical reaction between such metal and a volatilized salt of the metal to be coated, substantially as described.

2. The process of coating one metal with another which consists in moving volatilized compounds of said metals in a circuitous path including the metal to be coated, and heating the metal to be coated at such a temperature as to effect a chemical reaction between the same and a volatilized compound of the metal to be applied, substantially as described.

3. The process of depositing one metal on another which consists in effecting movement of volatilized salts of such metals in a circuitous path including the metal to be coated by maintaining a temperature difference between spaced points in said path, and effecting a chemical reaction between the metal to be coated and a volatilized salt of the metal to be deposited, substantially as described.

4. The process of depositing one metal on another which consists in effecting movement of volatilized salts of such metals in a circuitous path including such metals by maintaining a temperature difference between spaced points in said path, effecting a chemical reaction between the metal to be coated and a volatilized salt of the metal to be deposited, and effecting a chemical reaction between the metal to be deposited and a volatilized salt of the metal to be coated, substantially as described.

5. The process of coating one metal with another which consists in bringing a volatilized compound of the metal to be applied into contact with the metal to be coated at such a temperature as to effect a chemical reaction therebetween, removing volatilzed products of the reaction from the vicinity of the metal to be coated, regenerating such volatilized products and returning the regenerated volatilized products to the vicinity of the metal to be coated, substantially as described.

6. The process of coating one metal with another which consists in bringing a volatilized compound of the metal to be applied into contact with the metal to be coated at such a temperature as to effect a chemical reaction therebetween, removing volatilized products of the reaction from the vicinity of the metal to be coated, recuperating such volatilized products and then returning the same to the vicinity of the metal to be coated, substantially as described.

7. The process of coating one metal with another which consists in moving volatilized compounds of such metals in a circuitous path including the metal to be coated, maintaining the temperature at the place in said path where the metal to be coated is located at such a point as to effect a chemical reaction between such metal and a volatilized compound of the metal to be deposited, and subjecting the volatilized compounds at a point in said path beyond the metal to be coated to a sufficiently lower temperature to effect the deposit in a solid state of the least volatile of such compounds, substantially as described.

8. The process of coating one metal with

another which consists in moving volatilized compounds of such metals in a circuitous path including the metal to be coated, maintaining the temperature at the place in said path where the metal to be coated is located at such a point as to effect a chemical reaction between such metal and a volatilized compound of the metal to be deposited, and at a point in said path beyond the metal to be coated converting a volatilized compound of the metal to be coated into a volatilized compound of the metal to be applied, substantially as described.

9. The process of coating one metal with another which consists in moving volatilized compounds of such metals in a circuitous path including the metal to be coated, maintaining the temperature at the place in said path where the metal to be coated is located at such a point as to effect a chemical reaction between such metal and a volatilized compound of the metal to be deposited, subjecting the volatilized compound at a point in said path beyond the metal to be coated to a sufficiently lower temperature to effect the deposit in a solid state of a volatile compound of the metal to be coated, subjecting the deposited compound of the metal to be coated to chemical reactions so as to form a volailized compound of the metal to be applied and returning the latter volatilized compound to said path, substantially as described.

10. In a process of coating a metal with an alloy of said metal and another metal, the step which consists in producing a direct reaction between hot, solid metal to be coated and a hot volatile compound of the desired coating metal while maintaining said volatile compound exclusively in the vapor phase, and excluding from the reaction all solid or liquid materials except the metal to be coated.

11. Process of coating a metal with an alloy of said metal and another metal which comprises bringing into direct contact in a reaction chamber the unobstructed solid surface of the metal to be coated and a continuously introduced current of a vaporized salt of the metal to be deposited, said salt reacting with said metal to be coated to liberate said metal to be deposited in the elemental state and to form a volatile compound of the metal to be coated, and controlling the temperature in said reaction chamber to maintain said salt and said compound in vapor phase and said metals in solid phase.

12. Process of coating a metal with an alloy of said metal and another metal which consists in subjecting the metal to be coated in a heated condition to the direct action of a continuous current containing the hot vapor of a volatile compound of the desired coating metal to produce a reaction between the metal to be coated and the vapor of the compound of the coating metal, whereby a portion of said vapor is reduced and the coating metal deposited on the metal to be coated, and continuously restoring said compound of the coating metal to said current of vapor, until the desired coating is produced.

13. Process of coating a metal with an alloy of said metal and another metal which consists in subjecting the metal to be coated in a heated condition to the direct action of a continuous current containing the hot vapor of a volatile compound of the desired coating metal to produce a reaction between the metal to be coated and the vapor of the compound of the coating metal, whereby a portion of said vapor is reduced and the coating metal deposited on the metal to be coated and a volatile compound of the coated metal produced, continuously removing said volatile compound of the coated metal, and continuously restoring compound of the coating metal to said current of vapor, until the desired coating is produced.

14. Process of coating a metal with an alloy of said metal and a second metal which comprises disposing the metal to be coated in one of two inter-communicating chambers, disposing the coating metal in the other of said chambers, continuously maintaining in each of said chambers a reversible reaction between the metal to be coated, the coating metal, a volatile compound of the coating metal, and a volatile compound of the metal to be coated, and adjusting the reaction conditions in each of said chambers so that in the former chamber the direction of the reaction is such that the metal to be coated reacts with the volatile compound of the coating metal to reduce said compound and deposit the coating metal on the metal to be coated and produce a volatile compound of the coated metal, and in the latter chamber the direction of the reaction is such that the volatile compound of the coated metal reacts with the coating metal to deposit the coated metal and regenerate the volatile compound of the coating metal.

15. Process of coating a metal with an alloy of said metal and a coating metal which comprises producing in one of two inter-communicating reaction chambers a reaction between the metal to be coated and a volatile compound of the coating metal and regulating said reaction so as to deposit the coating metal on the metal to be coated and produce a volatile compound of the coated metal; withdrawing said volatile compound of the coated metal from said first chamber and returning it to the second of said chambers; and producing in said second chamber a reaction between the coating metal and said volatile compound of the coated metal and regulating said reaction so as to deposit the coated metal and regenerate the volatile compound of the coating metal.

16. Process of coating a metal with an alloy of said metal and another metal which comprises subjecting the metal to be coated

to the action of hot vapor of a vaporizable compound of the desired coating metal under such conditions as to produce a reaction whereby the compound of the coating metal is reduced and the coating metal is deposited on the metal to be coated and forms an alloy therewith and a vaporized compound of the metal being coated is produced; withdrawing said vaporized compound of the metal being coated; regenerating the vapor of the compound of the coating metal by causing said compound of the metal being coated to react with a further quantity of the desired coating metal; and recirculating the vaporized compound of the coating metal thus regenerated until the desired amount of the coating metal is deposited on the metal being coated.

17. Process of coating a metal with an alloy of said metal and aluminum which comprises subjecting the metal to be coated to the action of hot vapor of an aluminum halide under such conditions as to produce a reaction whereby the aluminum halide is reduced and aluminum is deposited on the metal to be coated and alloys therewith and a volatile halide of the metal being coated is produced; withdrawing said volatile halide of the metal being coated; regenerating the aluminum halide by causing said halide of the metal being coated to react with metallic aluminum; and recirculating the aluminum halide thus regenerated until the desired amount of aluminum is deposited on the metal to be coated.

18. Process of coating a metal with an alloy of said metal and another metal which comprises arranging the metal to be coated at one point in a closed system; arranging the desired coating metal at another point in said system; circulating a current of hot vapor of a vaporizable compound of said coating metal from said coating metal through said closed system to said metal to be coated; adjusting the temperature, pressure and concentrations at the point in said system where the metal to be coated is located so as to produce a reaction between said metal to be coated and said vaporized compound of the coating metal whereby the vapor is reduced and the coating metal is deposited on the metal to be coated and forms an alloy therewith and a vaporized compound of the metal being coated is produced; circulating said vaporized compound of the metal being coated from said metal being coated through said closed system back to said coating metal; adjusting the temperature, pressure and concentrations at the point in said system where the coating metal is located so as to produce a reaction between said coating metal and said vaporized compound of the metal being coated whereby the vaporized compound is reduced and the metal being coated is deposited and the compound of the coating metal is regenerated and vaporized; and recirculating through said system the vaporized compound of the coating metal thus regenerated until the desired amount of the coating metal is deposited on the metal being coated.

19. Process of coating a metal with an alloy of said metal and aluminum which comprises arranging the metal to be coated at one point in a closed system; arranging metallic aluminum at another point in said system; circulating a current of hot vapor of an aluminum halide from said metallic aluminum through said closed system to said metal to be coated; adjusting the temperature, pressure and concentrations at the point in said system where the metal to be coated is located so as to produce a reaction between said metal to be coated and said vaporized aluminum halide whereby the aluminum halide is reduced and metallic aluminum is deposited on the metal to be coated and forms an alloy therewith and a vaporized halide of the metal being coated is produced; circulating said vaporized halide of the metal being coated from said metal being coated through said closed system back to said metallic aluminum; adjusting the temperature, pressure and concentrations at the point in said system where said metallic aluminum is located so as to produce a reaction between said metallic aluminum and said vaporized halide of the metal being coated whereby the halide is reduced and the metal being coated is deposited and aluminum halide is regenerated and vaporized; and recirculating through said system the vaporized aluminum halide thus regenerated until the desired amount of aluminum is deposited on the metal being coated.

This specification signed this 3rd day of September, 1925.

EDWIN D. MARTIN.