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3,093,513

CURRENT GENERATOR CELL

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This invention relates to current generating cells, particularly to primary cells having negative electrodes (anodes) comprising titanium alloys in conjunction with alkaline electrolytes having the properties of avoiding formation on the surface of the negative electrode (anode) of a highly resistant or current-blocking film or coating. The present application is a divisional application of our application Serial No. 706,890, filed January 3, 1958, now U.S. Patent 2,979,553, which was a continuation-in-part of applications Serial No. 349,098, filed April 15, 1953; Serial No. 405,252, filed January 20, 1954; Serial No. 405,494, filed January 21, 1954; and Serial No. 466,582, filed November 3, 1954. All four of the last-mentioned applications are now abandoned.

It is well known that certain metals including aluminum, magnesium, and titanium in contact with many electrolytes acquire a surface film that effectively blocks the flow of electrons. Advantage has long been taken of this property of such metals in the construction of such electrolytic apparatus as rectifiers, capacitors, and lightning arrestors. Titanium, by reason of its film-forming properties, has frequently been mentioned as a metal suitable for use in electrolytic devices of this character. Because of such film-forming properties, titanium has not been seriously considered as a possible useful material for the negative electrode (anode) of a primary cell.

On the other hand, it is well known that certain electrolytes severely attack titanium metal. Hydrofluoric acid, for example, is commonly used to clean titanium products, and hydrogen gas is vigorously evolved thereby. Red fuming nitric acid can attack titanium metal with explosive violence. Prior to this invention, then, titanium was regarded as either too passive because of current blocking films in many electrolytes, or too active because of spontaneous corrosion by other electrolytes. Either situation rendered titanium substantially useless as a negative electrode (anode) for a primary cell.

It has been discovered as a part of the present invention that certain alloying elements added to titanium make titanium alloys that are electrochemically active, but at the same time prevent chemical activity and spontaneous corrosion. When the alloys are used as primary cell anodes (negative electrodes) both the titanium and the alloying elements are consumed in the delivery of useful energy.

By varying the type and amount of alloying elements added to titanium, in accordance with the present invention, the chemical and electrochemical properties of titanium can be controlled to provide novel primary cell anodes (negative electrodes) with a variety of desirable properties, depending on the desired end use.

This invention includes the discovery that concentrated alkaline electrolytes have the property of inhibiting or greatly retarding the formation of nonconductive or rectifying films on the surfaces of various titanium alloys and instead maintain the surfaces substantially free from any current blocking film, and permit the use of light-weight durable titanium alloys as primary cell negative electrodes (anodes).

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Certain preferred electrolytes provide best results for various purposes. Proper combinations of negative electrodes (anodes), electrolytes, and positive electrodes (cathodes), in accordance with this invention, provide novel primary cells that may be custom designed to have combinations of characteristics not obtained in prior cells. For example, such cells can be made to have long shelf life and low drain, or to provide high currents at high voltage, or to have small size and light weight. Combinations of these properties in various degrees can also be obtained.

The cathodes or depolarizers (positive electrodes) used in cells of the present invention may be those well known in the art, such as mercuric oxide, lead dioxide, manganese dioxide, nickel oxides. The depolarizers (positive electrodes) may or may not be formed on special supports such as the titanium supports of U.S. Patent 2,631,115 of Fox. The support for the depolarizer (positive electrode) is another part of the cell, and has no material bearing on the function of the anode (negative electrode). The Fox patent asserts that titanium, used as a supporting structure for the depolarizer (the positive electrode in a current generating cell), improves the depolarizer voltage and operating characteristics without taking part in the electrochemical reaction. The titanium alloy anodes (negative electrodes) of the present invention have nothing to do with the behavior of the cell depolarizers or cathodes (positive electrodes), and the alloy anodes are electrochemically consumed as an integral part of cell discharge. These facts are mentioned here to avoid any confusion between these two essentially different uses of titanium.

Primary cell anodes according to the present invention comprise titanium-rich alloys containing at least 50 atomic percent titanium. The addition of alloying materials such as molybdenum, vanadium, chromium, cobalt, nickel, niobium, tantalum, and tungsten, from periodic groups V, VI, and VIII decreases the spontaneous corrosion of the anode and thereby increases the shelf life of the cell. Such alloying elements can be called "titanium passivating elements." Alloying additions of materials such as aluminum, beryllium, and boron, from periodic groups II and III, increase the voltage and current capacity of the cell. Such alloying elements can be called "voltage-improving and current-improving elements." Various combinations of these and other materials may be used in titanium alloys to obtain desired properties, as described herein. The anodes of this invention are free from any substantial current blocking film and are in direct contact with the electrolytes. The alloys are consumed in the discharge of cells by the flow of ions from the anodes to the electrolytes.

The present invention contemplates the use of alloys of titanium as the active anode materials that directly furnish electrical energy in primary cells. It has been discovered that many of these titanium alloys exhibit unique properties as primary cell anodes. In particular, certain alloy additions to titanium decrease spontaneous corrosion, thereby improving shelf life. Alloying additions can also increase the closed circuit voltage of titanium containing cells, increase the available current density, or reduce the weight and size of the anode. Various combinations of these advantages may also be obtained by controlling the titanium alloy composition.

The titanium alloy anodes may be made in the form of shaped solid alloys, rolled foils, sintered powders, or compressed powders, by methods well known in the primary cell art. It is important to avoid gross heterogeneity of the alloy, as nonuniformity may result in local galvanic action, which destroys shelf life of the cell. The electrolyte must contact the titanium alloy anode but it may

be either liquid or gelled in accordance with common practices in the primary cell art. The cathode depolarizer may also be made in conventional forms and shapes.

ANODE MATERIALS

We have discovered that titanium alloys with various elements of groups V, VI, and VIII of the periodic table used as primary cell anodes have low enough spontaneous corrosion to provide long shelf life for the cells containing them as anodes. In this group of alloys, increasing the concentration of the alloying addition results in increasing the chemical passivity of the anode. However, when the alloying addition is present in a certain minimum desired amount, further additions do not appreciably affect the chemical passivity or corrosion resistance. For example, in a titanium molybdenum alloy, the corrosion resistance of the alloy in primary cell electrolytes gradually increases with increase in molybdenum concentration until the molybdenum concentration is about 25 to 29 weight percent. Further increases of molybdenum do not materially increase the corrosion resistance.

To illustrate this discovery, corrosion rates were measured by hydrogen evolution in saturated potassium hydroxide solutions containing a small amount of solubilized potassium tartrate. Results are shown in Table I below, together with anodic closed circuit voltages at an anode current density of 5.0 milliamperes per square inch. The closed circuit voltages are measured against a saturated calomel electrode (SCE) for purposes of experimentation. In primary cells containing this electrolyte, conventional cathodes such as mercuric oxide, nickel oxides, and manganese oxides may be used.

Table I

Anode, numbers refer to weight percent	Gassing rate, cc. H ₂ /day-in. ²	Closed circuit voltage at 5.0 ma./in. ² vs. SCE ^a
Ti.....	3.5	-1.34
Ti-0.5 Mo.....	3.5	-1.28
Ti-5.0 Mo.....	1.5	-1.23
Ti-16.0 Mo.....	0.24	-1.13
Ti-20.0 Mo.....	0.031	-1.07
Ti-30.0 Mo.....	0.0021	-1.05
Ti-50.0 Mo.....	0.0014	-1.01

^a Saturated calomel electrode.

We have discovered further that this chemical passivation effect can be obtained by alloying titanium metal with other transition metals from periodic groups V, VI, and VIII. A certain minimum concentration of alloy additions appears to be desirable for the minimum of chemical activity plus maximum of electrochemical activity as a primary cell anode. It appears that there are electronic interactions between atoms of the alloys and when the total number of valence electrons is about five for each titanium atom, we have a preferred alloy for a primary cell anode. In this instance, "valence electrons" means the total number of electrons in the transition metal outside of the preceding inert gas electronic core as described in the periodic table. Thus, titanium can be considered to have 4 valence electrons, vanadium 5, chromium 6, iron 8, cobalt 9, nickel 10, and so forth.

To illustrate this discovery, various titanium alloys were given corrosion tests in primary cell electrolytes, and the following results were obtained:

Table II

Alloying element with titanium	Calculated weight percent of alloying element for passivation	Weight percent at which passivation was observed to be present
Vanadium.....	17.5	16
Chromium.....	17.8	20
Molybdenum.....	25	30

For best cell performance, the minimum amounts by weight of the passivating elements in titanium alloy anodes should be: 29 percent molybdenum, 13 percent vanadium, 18 percent chromium, 29 percent cobalt, 38 percent nickel, 24 percent niobium, 35 percent tantalum, and 39 percent tungsten.

To obtain optimum results in the chemical passivation of titanium by alloying, the alloy should be one phase and homogeneous. Titanium metal has a hexagonal close-packed crystalline structure below 882° C. When alloyed with some of the other transition metals, however, titanium assumes a body centered cubic crystalline structure in which greater solid solubility is possible. Titanium forms intermetallic compounds with some metals. It is important for optimum performance and minimum self-discharge that only one crystalline structure be present for the entire alloy, and that mixed phases, structures, or compounds be absent. To illustrate this point, two Ti—30Mo alloys were prepared, one by quenching the alloy rapidly from melting temperature, the other by slowly annealing from melting temperature to ambient room temperature over a period of days. Spontaneous corrosion tests were then made, as described earlier, and results were as follows:

Table III

Alloy:	Gassing Rate, cc. H ₂ /day-in. ²
Ti—30Mo (quenched)	0.0021
Ti—30Mo (slow annealed).....	0.018

The slow annealed sample has a mixture of crystalline structures (hexagonal close packed plus body centered cubic). Each structure has a different alloy composition, and corrosion resistance is thereby decreased.

Mixtures of various metals may be alloyed with titanium to decrease chemical activity and increase electrochemical activity. For best results, the concentration of valence electrons should be at least about five for each titanium atom and the resulting alloy should be one phase and homogeneous. The required concentrations for alloying additions are accurate to within about plus or minus 20 percent of the values calculated on this basis. To attain homogeneity, the usual techniques of metallurgy such as quenching, remelting, annealing, should be employed. Since titanium atoms and all atoms of the alloying additions participate in the primary cell anode reaction, it is possible to devise a variety of anodes with a variety of electrochemical properties.

Titanium alloys passivated according to the principles of this invention have exceptional stability as primary cell electrodes at elevated temperatures. To illustrate this discovery various primary cell anodes were placed in 14 molar potassium hydroxide and corrosion rates were measured by hydrogen evolution. Results were as follows:

Table IV

Anode	At 80±20° F.		At 165±5° F.	
	Gassing rate, cc. H ₂ /day-in. ²	Open circuit voltage vs. SCE	Gassing rate, cc. H ₂ /day-in. ²	Open circuit voltage vs. SCE
Amalgamated zinc.....	0.17	-1.66	29	-1.73
Titanium.....	0.31	-1.55	93	-1.63
Titanium, 30 weight percent molybdenum.....	<0.005	-1.05	1.2	-1.40
Titanium, 14.9 weight percent vanadium.....	0.3	-1.28	0.45	-1.48
Titanium, 40 weight percent vanadium.....	0.045	-1.22	1.8	-1.46
Titanium, 35 weight percent molybdenum, 5 weight percent aluminum.....	<0.005	-1.15	0.42	-1.40

These data show that for a titanium alloy anode containing 14.9 percent vanadium, the gassing rate increases by only one-half when the temperature is increased from 80° F. to 165° F.; while, in contrast, the gassing rate for

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an amalgamated zinc anode (commonly used in commercial primary cells) increases 170 times, and the gassing rate for an unalloyed titanium anode increases 300 times, for the same temperature increase. Furthermore, the gassing rates at 165° F. for the other titanium alloy anodes listed above are less than one-tenth of the gassing rate for an amalgamated zinc anode, and less than one-fiftieth of the gassing rate for an unalloyed titanium anode at the same temperature. In addition, the voltages for the titanium alloys increase by at least two-tenths volt compared to a voltage increase of less than one-tenth volt for amalgamated zinc or titanium anodes.

The solid products formed on the surface of some titanium alloy anodes during discharge of cells are not current-blocking films as might be encountered on pure and unalloyed titanium anodes in the same electrolyte. For example, pure titanium anodes in primary cells having saturated KOH electrolytes and mercuric oxide cathodes polarize after a short drainage because of the build-up of current-blocking films. Ti—30Mo alloy anodes in the same cells deliver energy at practically constant voltage until the alloys are completely consumed by the primary cell reactions.

Sintered titanium alloy anodes provide higher currents and higher closed-circuit voltages than rolled anodes of equal weight, because the sintered anodes have greater surface area per unit weight. In addition, high open-circuit voltages are obtained, without additional anode pretreatment, upon immersion of the sintered anodes in the cell electrolytes. The high voltages indicate active surfaces, which make sintered anodes still more advantageous over rolled metal anodes, many of which must be cleaned and given an activation treatment before immersion in the cell. For example, a sintered Ti—27Mo—10Al anode had an initial open-circuit voltage of 1.540 volts vs. SCE in 14 M KOH electrolyte, while a solid Ti—27Mo—10Al anode had an initial open-circuit voltage of 1.298 volts in anotherwise identical cell.

A cell having a Ti—27Mo—10Nb anode made and tested in connection with this invention illustrates typical results obtainable with small cells using titanium alloy anodes. The cell was enclosed in a small cylinder 0.54 inch in diameter and 0.34 inch high. The anode comprised a disc about 0.455 inch in diameter and 0.01 inch thick, weighing 0.15 gram. The disk had been cold rolled to the desired thickness, stamped to shape and anodically etched in a saturated aqueous solution of potassium hydroxide containing 0.25 M of potassium tartrate.

The cell electrolyte was 0.5 cubic centimeter of a solution of 55 weight percent (14 M) potassium hydroxide in distilled water.

The cathode was made of 1.33 grams of compacted powder comprising 92 weight percent red mercuric oxide and 8 weight percent graphite.

The cell reached an equilibrium closed circuit voltage of 0.88 volt instantaneously on a load of about 10,000 ohms and maintained this voltage within ± 1 percent throughout 90 days of continuous drain at a temperature of $70 \pm 2^\circ$ F. An additional 70 days of continuous drain was obtained before the cell voltage fell to 0.81 volt.

This cell illustrates the advantage of an extremely constant closed-circuit voltage at constant temperature. The constancy of closed-circuit voltage is useful in a primary cell to provide a reference voltage while on drain. Such a cell is useful for control instruments, electric clocks, transistor circuits, etc.

This cell also has the advantage that it can be discharged at 32° F. at about 0.4 volt until all the active materials are consumed; while commercial cells employing amalgamated zinc anodes and mercuric oxide cathodes yield only a small fraction of their designed ampere-hour capacity at 32° F. Furthermore, since the titanium alloy anode, electrolyte, and cathode of this cell are completely stable and do not gas appreciably, a cell of this type has exceptionally long shelf life and does not leak on stor-

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age as presently available commercial primary cells are prone to do.

When alloys of titanium with aluminum, beryllium, and boron are used as primary cell anodes, the cells have greater anode potential at high current densities than cells having titanium metal anodes. To illustrate this, various titanium containing anodes were studied in saturated potassium hydroxide containing 0.25 molar potassium tartrate. Experimental results are listed in Table V below, where the anode voltages are shown as measured against a reference SCE electrode.

Table V

Anode	Closed circuit voltage vs. SCE at 5.0 ma./in. ²	Polarizing current density, ma./in. ²	Closed circuit voltage of cells with commercial HgO electrodes, volts
Titanium	-1.34	90	0.94
Ti-33 Al	-1.03	200	1.23
Ti-13.0 B	-1.46	>250	1.06
Ti-15.0 Be	-1.66	600	1.26

Both the titanium and the alloying addition, aluminum, beryllium, or boron, are consumed during the cell reaction. This leads to extremely low equivalent weight. Therefore, small, light-weight, high capacity primary cells may be made with anodes of these materials. Above certain maximum concentrations of alloying additions, however, these alloys exhibit increased spontaneous corrosion, and, therefore, decreased shelf life of the primary cells using them. When the alloying addition is present in the anode in an amount below a certain weight percentage, the cell provides increased potential at high anode current density without having significantly reduced shelf life. For example, the shelf life is best for beryllium contents less than 9 weight percent, aluminum contents less than 25 weight percent, and boron contents less than 10 weight percent. Anodes containing higher concentrations of these alloying materials provide still higher currents at high closed circuit voltages. Such highly concentrated alloys give the higher currents and voltages with greater efficiency than the alloying elements alone and provide unusually high wattage per unit of weight or volume. Cells using such anodes are useful for various purposes requiring high drains for short periods, despite their shorter shelf lives.

Another part of our discovery is that ternary and quaternary alloys of titanium can provide unique anode materials for primary cell anodes. For example, the addition of aluminum to a chemically passivated titanium-molybdenum alloy increases both the closed circuit voltage and the maximum anode current density. This advantage is illustrated by drainage experiments in saturated potassium hydroxide electrolyte.

Table VI

Anode (numbers refer to weight percent)	Closed circuit voltage at 5.0 ma./in. ² vs. SCE	Gassing rate cc. H ₂ /day-in. ²	Polarising current density ma./in. ²
Ti-30 Mo	-0.84	0.018	6.0
Ti-35 Mo-5 Al	-1.10	<0.002	>200

Other ternary additions to a binary alloy of titanium with a group V, VI, or VIII metal improve drainage properties when the ternary alloy is used as a primary cell anode. For example, 10 weight percent niobium or 10 weight percent vanadium added to a titanium—30 weight percent molybdenum alloy anode allows longer continuous drains at a more constant closed circuit voltage and at larger anode current densities. Similar improvements with ternary additions of other elements in the periodic table to binary alloys of titanium with an element of group V, VI, or VIII are obtained where the two main principles of this invention are followed: (1)

The total concentration of valence electrons should be at least about five for each titanium atom in the alloy, and (2) all elements should be in solid solution in one another, one phase, and homogeneous, in accordance with the well-known principles of metallurgy. For a nontransi-
5 tion element, the number of valence electrons is equal to the number of the periodic group in which the element appears.

ELECTROLYTES

The preferred electrolytes for primary cells containing titanium alloy anodes are concentrated alkalis. They may be in the form of liquids, gelled liquids, or pastes. Liquid electrolytes are preferred for those cells requiring high drainage rates. Gelled liquids or pastes are preferred for cells designed for low drainage rates. Gelling agents such as starch or glutens or others well known in the primary cell art can be used.

Generally, the more concentrated the cell electrolyte, the greater is the watt-minute capacity of the cell for a given size. Thus, saturated solutions or saturated solutions having also a minor amount of solid phase are desirable. The hydroxide concentration should be at least about 5 moles per liter, preferably at least about 11 moles per liter.

The cathode or depolarizer is preferably an oxygen yielding compound, such as mercuric oxide, the oxide or peroxide of silver, cupric or cuprous oxide, lead peroxide, potassium permanganate or another alkaline permanganate, as is well known in the primary cell art.

A significant advantage of this invention is that where a suitable combination of cathode and electrolyte is chosen for stability, high drain, small size, light weight, or some combination of these properties, then a titanium alloy anode can be constructed for the cathode-electrolyte combination that enhances these properties even further. For example, we have found Ti—30Mo anodes in conjunction with alkaline electrolytes and mercuric oxide cathodes to be more stable, and thus to provide longer shelf life for the cells, than any other known anode with same cathode-electrolyte combination. For best results the titanium alloy should be constructed with elements such that one or more of the reaction products is

soluble in the chosen electrolyte, and the amounts of alloying additions to titanium should be such that the total concentration of valence electrons is at least about five or each titanium atom and the alloy anode is one phase.

The electrolytes are preferably made with potassium hydroxide or alkaline potassium salts. Most titanium alloys provide slightly higher open circuit voltage with saturated sodium hydroxide electrolytes than with saturated potassium hydroxide electrolytes. However, the titanium alloy anodes can be drained at larger current densities with the alkaline potassium electrolytes, and for most applications this makes the alkaline potassium electrolytes generally more desirable.

The concentration of a potassium hydroxide electrolyte affects the voltage characteristics, especially at high current densities. In the range from 11 molar to saturation, increasing concentration of the KOH increases the voltage at a given current density and provides useful output at higher current densities.

Zincate, tartrate, and aluminate additions to KOH of 11 M and higher concentrations increase the voltage at a given current density and provide useful output at higher current densities.

Typical experiments illustrating the characteristics of various titanium alloy anode primary cells are shown in the data of Table VII. Data for titanium metal anodes are included for comparison. The anode voltages were measured in reference to a saturated calomel electrode.

For actual cell operation, various well-known cathodes, such as mercuric oxide, nickel oxide, or carbon-air electrode were used. The cell potentials in these cases may be readily calculated by known methods.

The extended drainages indicated in Table VII were taken at times varying from two hours to four weeks.

In Table VII, column 5 indicates whether current at the density shown may be drawn for several hours from the primary cells at constant potential. Column 6 is a critical current density at which the voltage of the primary cell abruptly decreases. Column 7 denotes shelf life as measured by corrosion of the anode, the shelf life being inversely proportional to the gassing rate.

Table VII.—Properties of Primary Cells Comprising Anodes of Titanium and its Alloys at Ambient Room Temperatures (25° C.±5)

A. TITANIUM METAL ANODES

Anode	Electrolyte	Additive	Drainage			Shelf life, open circuit gassing rate, cc./day/sq. in.
			Potential in volts (vs. SCE) at ma./sq. in.	Is extended drainage possible? at ma./sq. in.	Polarizing current density, ma./sq. in.	
(1) Ti metal ¹	5.0 M KOH	None	−1.10 at 1.0	No		(²)
(2) Ti metal ¹	10.0 M KOH	do	−1.32 at 1.3	No		0.4
(3) Ti metal ¹	Sat'd KOH	do	−1.33 at 1.5	No		0.31
(4) Ti metal ¹	10.0 M NaOH	do	−1.39 at 2.3	No		0.13
(5) Ti metal ¹	Sat'd KOH	0.25 M K ₂ C ₄ H ₄ O ₆ (potassium tartrate).	−1.34 at 5.0, −1.26 at 10.0, −1.20 at 20.0.	Yes, at 5.0	90.0	2.7

B. ANODES COMPRISING ALLOYS OF TITANIUM WITH METALS OF GROUPS V, VI, AND VIII

(1) Ti-2.0 Cr ¹	Sat'd KOH	0.25 M K ₂ C ₄ H ₄ O ₆	−1.11 at 5.0	Yes, at 5.0	10.0	2.6
(2) Ti-20.0 Cr	Sat'd KOH	0.25 M K ₂ C ₄ H ₄ O ₆	Polarized at 0.5 ma./sq. in.			0.0008
(3) Ti-0.5 Mo	Sat'd KOH	0.25 M K ₂ C ₄ H ₄ O ₆	−1.28 at 5.0	Yes, at 5.0	40.0	3.5
(4) Ti-5.0 Mo	Sat'd KOH	0.25 M K ₂ C ₄ H ₄ O ₆	−1.23 at 5.0	do	40.0	1.5
(5) Ti-16.0 Mo	Sat'd KOH	0.25 M K ₂ C ₄ H ₄ O ₆	−1.13 at 5.0	do	30.0	0.24
(6) Ti-20.0 Mo	Sat'd KOH	0.25 M K ₂ C ₄ H ₄ O ₆	−1.07 at 5.0	do	>30.0	0.031
(7) Ti-30.0 Mo (quenched)	Sat'd KOH	0.25 M K ₂ C ₄ H ₄ O ₆	−1.05 at 5.0	do	60.0	0.0044
(8) Ti-30.0 Mo (quenched)	Sat'd KOH	None	−0.98 at 3.0	Yes, at 3.0	6.0	(¹)
(9) Ti-30.0 Mo (slow annealed)	Sat'd KOH	0.25 M K ₂ C ₄ H ₄ O ₆				0.007
(10) Ti-50.0 Mo ²	Sat'd KOH	0.25 M K ₂ C ₄ H ₄ O ₆	−1.01 at 5.0	Yes, at 5.0	90.0	0.0014
(11) Ti-38.0 Ni	Sat'd KOH	0.25 M K ₂ C ₄ H ₄ O ₆	−1.09 at 2.0	Yes, at 2.0	10.0	1.5
(12) Ti-16.0 V	Sat'd KOH	0.25 M K ₂ C ₄ H ₄ O ₆	−1.09 at 5.0	Yes, at 5.0	30.0	0.65
(13) Ti-40.0 V (quenched)	Sat'd KOH	0.25 M K ₂ C ₄ H ₄ O ₆	−1.0 at 5.0	do	>40.0	0.0017
(14) Ti-40.0 V (slow annealed)	Sat'd KOH	0.25 M K ₂ C ₄ H ₄ O ₆				0.0042
(15) Ti-14.9 V (quenched)	Sat'd KOH	0.25 M K ₂ C ₄ H ₄ O ₆	−1.15 at 5.0	Yes, at 5.0	40.0	0.24
(16) Ti-14.9 V (slow annealed)	Sat'd KOH	0.25 M K ₂ C ₄ H ₄ O ₆	−1.19 at 5.0	do	30.0	0.70
(17) Ti-40.0 V (quenched)	Sat'd KOH	None	−1.0 at 2.0	Yes, at 2.0	40.0	(¹)
(18) Ti-3.0 V	Sat'd KOH	0.25 M K ₂ C ₄ H ₄ O ₆				3.0

See footnotes at end of table.

Table VII—Continued

C. ANODES COMPRISING ALLOYS OF TITANIUM WITH METALS OF GROUPS II AND III

Anode	Electrolyte	Additive	Drainage			Shelf life, open circuit /gassing rate, cc./day/sq. in.
			Potential in volts (vs. SCE) at ma./sq. in.	Is extended drainage Possible: at ma./sq. in.	Polarizing current density, ma./sq. in.	
(1) Ti-3.0 Al ¹	Sat'd KOH	0.25 M K ₂ C ₄ H ₄ O ₆	-1.40 at 5.0	Yes, at 5.0	60.0	5.0
(2) Ti-10.0 Al	Sat'd KOH	0.25 M K ₂ C ₄ H ₄ O ₆	-1.35 at 5.0	do.	30.0	>28.6
(3) Ti-33.0 Al	Sat'd KOH	0.25 M K ₂ C ₄ H ₄ O ₆	-1.63 at 5.0	do.	200.0	>50.0
(4) Ti-60.0 Al	Sat'd KOH	0.25 M K ₂ C ₄ H ₄ O ₆	-1.57 at 5.0	do.	700.0	2,300.0
(5) Ti-33.0 Al	10.0 M KOH	0.3 M V ₂ O ₅	-1.73 at 1.0	(?)	2.0	(⁶)
(6) Ti-33.0 Al	Sat'd KOH	0.5 M V ₂ O ₅	-1.6 at 5.0	(?)		(⁶)
(7) Ti-33.0 Al	Sat'd KOH	0.02 M K ₂ CrO ₄	-1.67 at 5.0	(?)		(⁶)
(8) Ti-33.0 Al	Sat'd KOH	0.05 M K ₂ CrO ₄	Polarized at 5.0 ma.			(⁷)
(9) Ti-0.12 B ²	Sat'd KOH	0.25 M K ₂ C ₄ H ₄ O ₆	-1.24 at 5.0	Yes, at 5.0	30.0	>6.0
(10) Ti-1.2 B	Sat'd KOH	0.25 M K ₂ C ₄ H ₄ O ₆	-1.327 at 5.0	do.	30.0	>10.0
(11) Ti-13.0 B	Sat'd KOH	0.25 M K ₂ C ₄ H ₄ O ₆	-1.46 at 5.0	do.	>250.0	48.0
(12) Ti-13.0 B	10.0 M KOH	None	-1.35 at 6.0	Yes, at 6.0	>120.0	(²)
(13) Ti-13.0 B	Sat'd KOH	do.	-1.33 at 5.0	Yes, at 5.0	>80.0	(³)
(14) Ti-1.0 Be	Sat'd KOH	0.25 M K ₂ C ₄ H ₄ O ₆	-1.41 at 5.0	do.	15.0	4.3
(15) Ti-15.0 Be	Sat'd KOH	0.25 M K ₂ C ₄ H ₄ O ₆	-1.66 at 5.0	do.	600.0	97.0
(16) Ti-28.0 Be	Sat'd KOH	0.25 M K ₂ C ₄ H ₄ O ₆	-1.78 at 5.0	do.	900.0	1,000.0
(17) Ti-40.0 Be	Sat'd KOH	0.25 M K ₂ C ₄ H ₄ O ₆	-1.66 at 6.0	do.	900.0	2,300.0

D. ANODES COMPRISING TERNARY ALLOYS OF TITANIUM

(1) Ti-35.0 Mo-5.0 Al ¹	Sat'd KOH	0.25 M K ₂ C ₄ H ₄ O ₆	-1.15 at 5.0	Yes, at 5.0	>200.0	0.0035
(2) Ti-35.0 Mo-5.0 Al	Sat'd KOH	None	-1.10 at 5.0	do.	>200.0	(⁹)

¹ Commercial Rem-Cru 55 sheet titanium.² Not measured.³ Numbers indicate weight percents of alloyed elements.⁴ Negligible, but not measured.⁵ Not measured, but slight.⁶ Not measured, but vigorous gassing.⁷ Not measured, but gassing inhibited.⁸ Not measured, but gassing rate high.⁹ Not measured, but negligible.

What is claimed is:

1. A primary cell having an anode consisting essentially of titanium and about 33 to 60 weight percent aluminum, a cathode, and an electrolyte comprising potassium hydroxide.

2. A primary cell having an alkaline electrolyte and an anode that is an alloy consisting essentially of titanium and about 15 to 40 weight percent beryllium.

3. A primary cell having an anode consisting essentially of titanium and about 15 to 40 weight percent beryllium, a cathode, and an electrolyte comprising potassium hydroxide.

4. A primary cell having an alkaline electrolyte and an anode that is an alloy consisting essentially of at least 50 atomic percent titanium with a voltage-improving and current-improving element present in an effective amount

and selected from the group consisting of up to 25 weight percent aluminum, up to 9 weight percent beryllium and up to 10 weight percent boron.

5. A primary cell having an alkaline electrolyte and an anode that is an alloy consisting essentially of titanium with a voltage-improving and current-improving element present in an effective amount and selected from the group consisting of up to 60 weight percent aluminum, up to 40 weight percent beryllium, and up to 13 weight percent boron.

References Cited in the file of this patent

UNITED STATES PATENTS

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2,941,909	Johnson et al.	June 21, 1960