

CCXLIX.—*The Positions of Tungsten and Molybdenum
in the Normal Potential Series.*

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TUNGSTEN and molybdenum, which resemble each other closely in physical and chemical properties, appear to behave in some reactions as relatively reactive, and in others as relatively noble metals. It has been stated that sexavalent tungsten or molybdenum cannot be reduced below the trivalent state by zinc or cadmium in hydrochloric or sulphuric acid solution, and on these observations accurate volumetric methods for determining these metals have been based (*U.S. Bureau of Mines*,

Bull. No. 212, 1923, 199; Someya, Z. anorg. Chem., 1925, 145, 168). This suggests that these metals are at least as reactive as nickel, for metals on the noble side of nickel in the normal potential series are known to be easily reduced to the metallic state from solutions of their ions. This conclusion may be approached in a somewhat different way. We find that solutions of tervalent tungsten and tervalent molybdenum in 2*N*-sulphuric acid have the reducing power of a metal intermediate in activity between tin and copper in that they reduce copper from the bivalent to the metallic state and partly reduce titanium from the quadrivalent to the bivalent state. Since the potential differences $W|W^{III}$ and $Mo|Mo^{III}$ are more negative than those of $W^{III}|W^{VI}$ and $Mo^{III}|Mo^{VI}$, respectively, it follows that tungsten and molybdenum are more reactive than copper and probably than tin also. The difficulty of reduction of the trioxides of tungsten and molybdenum to the metals by hydrogen at high temperatures is also evidence in favour of their reactive character. In this they resemble cadmium, cobalt, and nickel, rather than copper, mercury, and silver.

On the other hand, in their behaviour towards acids they resemble mercury and silver. They are unattacked by dilute hydrochloric and sulphuric acids at the ordinary temperature, but are attacked slowly by concentrated hydrochloric and sulphuric acids, and with some vigour by oxidising acids only. Further, although they are able to displace mercury and silver from solutions of their salts, they displace copper only partly, and more reactive metals like bismuth and cadmium not at all (Smith, *Z. anorg. Chem.*, 1892, **1**, 360; de Benneville, *J. Amer. Chem. Soc.*, 1894, **16**, 735).

The published values of the electrode potentials of tungsten and molybdenum do not help towards a decision between these opposing views. Like iron, these metals show the phenomenon of passivity, so that the values obtained for the electrode potentials depend greatly on the treatment to which the metals have been subjected immediately before measurement; consequently, widely different results have been obtained. These will be discussed later.

In order to throw light on this problem from a new point of view, we have investigated the order, relative to other metals of known normal potential, in which these metals are removed from mercury by oxidising solutions. Our main conclusion is that both as elements and as ions these metals behave as noble metals, and that, probably as metals and possibly as ions, they behave also as reactive metals.

EXPERIMENTAL.

Possible Deposition of Metallic Tungsten on Zinc.—It is stated definitely in the literature that tungsten has not been deposited as metal from aqueous solutions of its ions, those who imagine they have done so having confused a lower oxide with the metal. Molybdenum, according to Smith ("Electroanalysis," 1919, p. 172), may be deposited as metal quantitatively on a mercury cathode; it is difficult to understand, therefore, in view of the close resemblance between the properties of molybdenum and tungsten, why the latter also cannot be deposited. We agree, however, that by electrolysis it cannot be deposited in weighable quantity. We find nevertheless that to a small extent tungsten may be deposited on zinc from aqueous solution by mere shaking: 10 mg. of sodium tungstate (78% WO_3) were dissolved in water and shaken vigorously with 200 g. of a 1% zinc amalgam and 50 c.c. of 2*N*-sulphuric acid. It is known that the sexavalent tungsten is in these circumstances reduced first to the quinquevalent state (blue), then to the quadri-valent state (brown), and finally to the trivalent state (green). At the same time, however, a very small proportion of the ions present was reduced apparently to the metallic state, because the amalgam, which had at first evolved no bubbles of hydrogen, began to evolve them in the same way as if a little platinum had been deposited upon it. The evolution of gas was sometimes so vigorous that it became dangerous to continue shaking the stoppered bottle. This vigorous reaction in these circumstances has been previously noticed by Someya (*loc. cit.*) with amalgams of zinc and of cadmium, and by Centnerszwer and Straumanis (*Z. physikal. Chem.*, 1925, **118**, 429) with metallic zinc. Someya did not pursue the matter further or suggest an explanation of it. The latter authors considered and rejected the idea that metallic tungsten was deposited on the zinc because the tungsten solution which they used did not appear to have been reduced below the quinquevalent state. The marked evolution of hydrogen is ascribed by them to the presence of highly oxygenated compounds. Our work was completed before the publication of that of these authors, so that we were uninfluenced by this conclusion, with which, however, we do not agree. We ascribe the marked evolution of hydrogen to the catalytic action of metallic tungsten, deposited on the surface of the zinc amalgam, upon the reaction $2\text{H} \rightarrow \text{H}_2$, and reasons for this will be given below. This action is so great that tungsten may be detected in solution by means of it at concentrations such that the usual qualitative test—the production of a blue colour on reduction with zinc—is not obtained. To carry out a test a 1% zinc amalgam is shaken for 30 seconds in a reagent bottle with

2*N*-sulphuric acid containing the tungsten in solution, the whole poured into an evaporating dish, and the amount of bubbles on the surface compared after 1 minute with that on the surface of a similar amalgam used as a blank. Vanadium, titanium, chromium, manganese, iron, cobalt, nickel, copper, etc. in solution do not interfere, but molybdenum, gold, and the metals of the palladium and platinum transition groups show a similar effect. In the absence of the latter set of metals, 10^{-4} g. of tungsten may be detected with certainty in 200 c.c. of solution.

The fraction of tungsten atoms deposited on the amalgam cannot be greater than 1% of the ions potentially in solution for two reasons: (1) the volumetric method of determining tungsten, by reduction to the tervalent state with zinc and reoxidation with permanganate, which ignores the loss of tungsten by its deposition as metal on the zinc, is accurate to within 1% (Someya, *loc. cit.*); (2) the removal of the tungsten from an amalgam which had been shaken with a solution of known concentration of tungsten until it was no longer safe to do so, gave an amount just detectable analytically. This point has still to be investigated quantitatively.

Electrolytic Deposition of Tungsten on Mercury.—All our attempts to deposit tungsten quantitatively on mercury by electrolytic means failed. With the method recommended by Smith (*op. cit.*, p. 172) for molybdenum, we succeeded in obtaining sufficient tungsten on the mercury to show a marked catalytic effect on the reaction $2H \rightarrow H_2$, but not to be detected with certainty by weighing.

Proof that the Catalyst is Metallic Tungsten.—The chief objections to our view that the catalyst is metallic tungsten are, we think (i) that if the catalyst be tungsten, it is not the metal but an oxide, and (ii) that if it be a metal, it is not tungsten, but an impurity such as platinum. In favour of the first objection is the fact that the catalyst may be almost entirely removed from the amalgam by passing the latter thrice through chamois leather. This point is discussed below. Our reasons for not accepting the first objection are: (a) no oxide or impurity is visible through a microscope on the surface of the amalgam, (b) no oxide of tungsten lower than WO_2 is known, and this is not likely to be deposited in presence of 2*N*-sulphuric acid, (c) no oxide of any metal is known to catalyse the reaction $2H \rightarrow H_2$, (d) the catalyst behaves as though it were deposited platinum. This is shown by the following series of experiments. Liquid amalgams of chromium, manganese, iron, and cobalt were obtained by electrolysing acid solutions of chromium sulphate, manganous chloride, ferrous sulphate, and cobalt sulphate, respectively. Liquid copper amalgam was obtained by

shaking 200 g. of mercury, containing 0.5 g. of zinc, with excess of acidified copper sulphate solution until the whole of the zinc had been replaced by copper. Amalgams of zinc and platinum, zinc and tungsten, zinc and palladium, and zinc and molybdenum were obtained by shaking different portions of a 1% zinc amalgam with solutions of the salts of the second metal, tungsten being deposited as described above, and molybdenum either similarly from a solution of sodium molybdate in 2*N*-sulphuric acid or by electrolysis (Smith, *op. cit.*, p. 172). From these amalgams, 1% zinc amalgams containing one of each of the other metals just mentioned were obtained, and the catalytic effect of the second metal on the formation of bubbles of hydrogen (from the atomic hydrogen generated by the zinc and acid) was measured by finding the smallest concentration of acid necessary to produce bubbles on the surface of the amalgam. As is well known, liquid zinc amalgam and *N*-sulphuric acid do not produce bubbles of hydrogen owing to the high overvoltage of both zinc and mercury. If a third metal causes the appearance of bubbles of hydrogen at a lower concentration of acid than this, it is presumed that it is a catalyst for the reaction $2\text{H} \rightarrow \text{H}_2$, and that the smaller the concentration the greater is the catalytic effect of this third metal, other things being equal. Preliminary experiments with an amalgam of zinc and platinum showed that the platinum deposited on the zinc, provided it exceeded a minimum amount, did not cause an appreciable variation in the concentration of acid at which bubbles of hydrogen appeared, so that this amount is relatively unimportant. All measurements were carried out at 15° and as nearly as possible in the same way. A bubble was considered to have appeared if it were visible 30 seconds after the acid had been poured upon the surface of the amalgam.

The results obtained for different acids acting at 15° on a 1% zinc amalgam containing different catalytic metals are included in the table below.

	H_2SO_4 .		H_2SO_4 .	HCl.	HNO_3 .	$(\text{CO}_2\text{H})_2$.	$\text{CH}_3\cdot\text{CO}_2\text{H}$.
Zn	1.8	Pt	0.002	0.003	0.003	0.004	0.02
Cu	1.8	Mo (deposited)	0.003	0.0025	0.005	0.0045	0.05
Fe	0.27	Mo (electrolytic)	0.0025	0.0025	—	—	—
Co	0.03	W (deposited)	0.002	0.002	0.004	0.0045	0.02
Mn	0.009	W (electrolytic)	0.002	0.002	—	—	—
Pd	0.009						
Cr	0.002						

It is seen that the results obtained with sulphuric acid are of the same order for manganese, palladium, chromium, platinum, molybdenum, and tungsten, the last four, however, being superior to the first two and approximately equal to one another in catalytic effect. The last three behave similarly with all the acids examined,

molybdenum being possibly slightly inferior to platinum and tungsten. Now chromium, manganese, and molybdenum are certainly in the metallic condition, because the method of preparation is a quantitative method for their determination. It can scarcely be questioned that palladium and platinum from their method of preparation are in the metallic condition also. The inference is, therefore, that tungsten too is in the metallic condition and not present as a lower oxide or compound other than an intermetallic one.

It remains to be shown that the catalytic metal is not an impurity of the palladium or platinum transition groups present in the tungsten preparation. A solution of 10 mg. of Kahlbaum's sodium tungstate in water was carefully filtered, shaken with a 1% zinc amalgam, and the reduced liquid filtered from any deposit after being decanted from the amalgam. Any platinum or similar metal originally present in the sodium tungstate would be either on the surface of the amalgam or retained by the filter-paper. The reduced liquid was oxidised by permanganate which caused partial precipitation of the tungsten as WO_3 . The whole was treated with caustic soda to dissolve this compound, acidified to a clear solution, and again shaken with a fresh 1% zinc amalgam. This procedure was repeated twice. Each zinc amalgam was as catalytically active as another, showing that the activity could not be due to an initial impurity of platinum or similar metal but was due very probably to metallic tungsten deposited from simple tungsten ions in equilibrium with complex tungsten ions in the acid solution. Sodium tungstate from different makers, and metallic tungsten itself, gave similar catalytic effects when solutions of them were shaken with zinc. This is, we think, the first established proof that tungsten may be deposited from aqueous solution.

Solubility of Elements of Atomic Numbers 24, 25, 26, 27, 29, 42 and 74 in Mercury.—Our observation, mentioned above, that the tungsten deposited from solution was largely removed from the amalgam by pressing the latter through chamois leather suggests that the tungsten is present as a compound. We find, however, that this behaviour is characteristic of all the transition and pre-transition elements we have examined. It has been known for some years that copper and iron dissolve in mercury to the extent of only a few parts per 100,000 parts of mercury (Richards and Garrod Thomas, *Z. physikal. Chem.*, 1910, **56**, 758) and the solubility of the latter metal has been recently confirmed in a determination by a new method (Russell and Evans, J., 1925, **127**, 2227). Using this method, we find that the solubilities (or the amounts adsorbed by the mercury in our experiments) at 15° of

chromium, manganese, and cobalt in mercury are of the same order as those of copper and iron, our results varying with different metals and in different conditions from 1 to 5 g. per 10^5 g. of mercury. We find also that the solubilities of molybdenum and tungsten are much smaller than these figures. The insolubility of tungsten in mercury cannot therefore be regarded as evidence against the view that tungsten is in the metallic state.

The Position of Tungsten relative to Other Metals.—This was obtained in two ways: (1) by finding the least reactive metal on which metallic tungsten can be deposited by shaking an amalgam of the metal with a solution of a tungsten compound; (2) by finding what metals of known normal potentials lie on either side of tungsten in the series showing the order in which they are removed from mercury by an oxidising agent. In (1), amalgams of cadmium, tin, copper, iron, and bismuth were prepared, and each was shaken for 1 minute with 100 mg. of sodium tungstate in 2*N*-sulphuric acid. Pure mercury was treated in the same way. Each amalgam was then washed free from salts of tungsten, covered with 100 c.c. of *N*/*10*-sulphuric acid and stirred with a rod of zinc (which dissolves in the amalgam) for 5 seconds. A portion of the same amalgam which had not been shaken with the sodium tungstate solution was treated exactly similarly to serve as a blank experiment. Bubbles of hydrogen formed on all the amalgams except that which had been pure mercury, but not on any of the blanks. The inference is that tungsten lies on the noble side of bismuth, the least reactive of the metals examined in mercury (Russell and Evans, *loc. cit.*), but possibly on the reactive side of mercury itself. In (2), 500 g. of a 0.04% zinc amalgam containing as large an amount of tungsten as possible was prepared. To this were added small quantities of the amalgams of cadmium, tin, copper, iron, and bismuth containing about 0.1 g. of each of these metals, and the metals successively removed from the mercury by shaking the whole with *N*/*10*-permanganate and 2*N*-sulphuric acid. Whenever one metal had been removed completely from the amalgam by oxidation, as shown by analysis, the presence or absence of the tungsten was shown by the presence or absence of bubbles of hydrogen from a portion of the amalgam which had been treated with zinc and *N*/*10*-sulphuric acid. It was thus found that the tungsten was removed from the mercury after the bismuth but before the mercury itself. When the last trace of bismuth had gone into solution, tungsten could still be detected in the mercury. On further shaking with permanganate, however, the mercury went into solution and with the first portion of mercury went the whole of the tungsten. Both methods suggest

that tungsten lies between bismuth and mercury in its susceptibility of being oxidised when dissolved in mercury, and the latter method shows that tungsten is nearer to mercury than to the more reactive bismuth.

If the position of tungsten determined by both methods is the same, as it appears to be, it may be said that the electronic state of the metal corresponds with that of the ion from which it is reduced (compare preceding paper), that is to say the configuration of the electrons in the metallic atom is that of its ion of lowest valency with the addition of the valency electrons in the outermost orbit. This is not so with chromium, iron, cobalt, and nickel in mercury. These metals, it has been shown in the preceding paper, lie on the noble side of copper when passive in mercury, but the ions of these metals in sulphuric acid solution do not behave like cupric or bismuth ions in being reduced to the metallic state on being shaken with amalgams of zinc, cadmium or tin. In this respect, these ions behave as though derived from the active state of the metals, all of which lie in activity between zinc and tin. Relative to the electronic states of the ions of chromium, iron, cobalt, and nickel, the active state of these metals may be regarded as normal and the passive state in mercury as abnormal. With tungsten, however, the state of activity, which lies near that of mercury, is a normal one and may be regarded as a fundamental property of the element rather than the result of some superficial cause such as the protection of an oxide film.

Deposition of Molybdenum on Amalgams of Zinc and Other Metals.—It was found that molybdenum could be deposited on zinc and other metals in mercury under similar conditions to tungsten. When 10 mg. of sodium molybdate, dissolved in water, were shaken vigorously with 200 g. of a 1% zinc amalgam and 50 c.c. of 2*N*-sulphuric acid, the catalytic effect of the deposited molybdenum, although noticeable, was less marked than that of tungsten. This suggests that the fraction of true ions in solution is smaller in these circumstances than that for tungsten, since the alternative explanation, that molybdenum is less noble than tungsten, was found later to be invalid. We found, however, that by dissolving (metallic) molybdenum powder in equal parts of water and concentrated hydrochloric acid and shaking the solution with zinc amalgam, a catalytic effect equal to that of tungsten was obtained. Molybdenum, in contradistinction to tungsten, may be quantitatively deposited from an acid solution of its salt electrolytically on to a mercury cathode. For some unexplained reason we failed on several occasions to repeat this deposition, although on other occasions we partly succeeded. Molybdenum, whether

prepared by shaking with zinc amalgam or by electrolytic deposition, had the same catalytic properties with respect to the reaction $2\text{H} \rightarrow \text{H}_2$, and this catalytic effect, as we have shown above, is approximately that of tungsten and platinum.

The Position of Molybdenum relative to Other Metals.—This was obtained by the two methods used for finding the position of tungsten. Molybdenum appears to be just on the noble side of mercury. When a solution of molybdenum was shaken with pure mercury for 1 minute and the molybdenum salts were completely removed from the mercury, the addition of a little zinc and $N/10$ -sulphuric acid to the latter caused a marked evolution of hydrogen bubbles. A blank experiment in which the shaking with the molybdate solution was omitted gave no bubbles. The zinc-molybdenum amalgam was then shaken with $N/10$ -permanganate and $2N$ -sulphuric acid till the last trace of zinc was just oxidised. At this stage the molybdenum was proved to be still present in the mercury by its catalytic effect. On further shaking with more permanganate, however, molybdenum itself began to go into solution and, when about 0.2 g. of mercury had been oxidised, the whole, or nearly the whole, of the molybdenum was found to have accompanied it into solution.

Since molybdenum is deposited on mercury itself from solution, it follows that it must be deposited on all metals more reactive than mercury. This was confirmed for amalgams of zinc, cadmium, manganese, thallium, tin, lead, copper, iron, and bismuth. It was also confirmed that the deposited molybdenum did not go into solution when a mixture of any of these amalgams was shaken with $N/10$ -permanganate until the last traces of the most noble metal (other than mercury) were themselves going into solution. This was done by shaking the solution resulting from the interaction of permanganate and the reactive metal at different stages with a second zinc amalgam. Until the last traces of the least reactive metal were reached, neither did the colour of quinquevalent molybdenum appear, nor did the zinc amalgam show the catalytic effect of molybdenum. When the last traces were going into solution and just as the mercury was being attacked by the permanganate, the catalytic effect of molybdenum on the surface of the second zinc amalgam was shown and simultaneously the greenish-brown colour of a molybdenum ion appeared. With molybdenum, the state of activity which lies just on the noble side of mercury must be regarded as a normal one, since it corresponds with that of the ion from which it has been reduced.

Active Tungsten and Active Molybdenum.—Having shown that tungsten and molybdenum exist in a normal state which is approxim-

ately as reactive as mercury, we may now inquire if these metals can exist also in a more active state. Certain facts already known and others disclosed by our work suggest that they can, but direct experimental proof is equivocal. It was mentioned above that the fact that all but a small fraction of tungsten and molybdenum ions in solution cannot be reduced by zinc and acid below the trivalent state is suggestive of the reactive character of these elements. This evidence is valid only if such ions are not complex, for a complex ion is invariably harder to reduce than a simple metallic ion; for these metals, however, it is invalid, since it is well known that acid solutions of tungsten and of molybdenum contain these elements almost entirely as complex ions. For this reason, the published values of the electrode potentials of these metals are not necessarily normal potentials in the ordinary sense. For tungsten and molybdenum rendered active, Muthmann and Fraunberger (*Sitzungsber. Bayer. Akad.*, 1904, **34**, 201) found values of ${}_0E_h$ — 0.62 and — 0.74, respectively, which implies that these metals lie close to zinc in the normal potential series. But potentials measured in presence of a small concentration of metallic ion are theoretically more negative than true normal potentials; the potential between copper and water, for example, is 0.7 volt more negative than that between copper and normal cuprion (von Hevesy, *Phil. Mag.*, 1912, **23**, 628). Muthmann and Fraunberger's negative values may therefore be ignored. Under conditions likely to avoid passivity, Fischer (*Z. anorg. Chem.*, 1913, **81**, 170) and Koerner (*Trans. Amer. Electrochem. Soc.*, 1917, **31**, 221) found values for tungsten of + 0.61 and + 0.31, respectively, and values + 0.55 and + 0.41 have been found by other workers for molybdenum. This implies that these metals are about as active as copper. This state is close to the one we have investigated and is not the active one we are seeking.

The heats of formation of the oxides of tungsten and molybdenum suggest that these metals are more active than copper and mercury and of the same order of activity as cadmium, cobalt, and nickel, the values for which (in large calories) are 66, 62, and 60, respectively, per g.-atom of oxygen. It may be objected that the order of metals in the normal potential series is not that of the heats of formation of their oxides. Nevertheless there is some correspondence between the two series, so that the above conclusion is not altogether without value. On the other hand, the partial displacement of copper from its salts by both tungsten and molybdenum (Smith, *loc. cit.*; de Benneville *loc. cit.*) is evidence that they lie just on the reactive side of copper.

A consideration of the four elements which, with molybdenum

and tungsten, compose group VIA of the periodic classification is also strongly suggestive of this view. In every investigated group of the periodic table the metals become increasingly reactive or increasingly noble with increase of atomic weight. Now uranium, since it decomposes water, is more reactive than chromium, which has a potential similar to that of cadmium, and the inference is therefore that tungsten and molybdenum would lie in potential between these two. It would be exceptional to find, as we go from the lightest to the heaviest metal of this series, that the potential falls approximately from that of cadmium to that of mercury, then stays nearly at this value and lastly rises to a potential more negative than that of zinc. The fact that chromium can exist—as it does in mercury—in a form less reactive than the ordinary has a bearing on the discussion, suggesting that when not in mercury tungsten and molybdenum may exist in active forms (compare the table, this vol., p. 1880). The argument implies, of course, that the metals of the palladium and platinum transitions groups should exist in active forms, and for this there is no definite experimental evidence. But there is a closer similarity between tungsten, molybdenum, and chromium than between osmium, ruthenium, and iron, or iridium, rhodium, and cobalt, or platinum, palladium, and nickel. The first three all have coloured ions which are easily oxidised and reduced; further, the same chemical treatment of these three metals results in similar electrode potentials over a range of ${}_0E_h$ from about -0.7 to $+0.9$ volt (Muthmann and Fraunberger, *loc. cit.*).

Granted that an active form of each of these metals is possible, it is not without interest to estimate what place—they would probably all occupy the same place—these active metals would occupy in the normal potential series. These estimates are : on the reactive side of chromium, from a consideration of the normal potentials of chromium and uranium; near cobalt and nickel, from the data of the table cited above (this vol., p. 1880); near cadmium, cobalt, and nickel, from a consideration of the heats of formation of the oxides; just on the reactive side of copper, from their ability to displace metals from solution; on the noble side of (active) chromium, from Muthmann and Fraunberger's work on chromium, tungsten, and molybdenum rendered active and passive.

On the whole, therefore, there is a body of evidence pointing to the existence of tungsten and molybdenum in a state which is approximately as active as (active) cobalt and nickel. This conclusion is consistent with the known action of acids upon these metals, and the difficulty, discussed in the opening paragraph, of reducing their ions below the trivalent state.

Summary.

(1) It is shown that when acid solutions of tungsten and of molybdenum salts are shaken with amalgams of different metals, although the greater part of the ions is reduced only to the trivalent state of oxidation, a small part is reduced to the metallic state and may be identified by its catalytic action on the change $2\text{H} \rightarrow \text{H}_2$. This serves as a delicate reaction for identifying tungsten in solution.

(2) The catalytic actions of tungsten, molybdenum, platinum, palladium, chromium, manganese, cobalt, and iron on the reaction $2\text{H} \rightarrow \text{H}_2$, initiated by zinc amalgam in contact with sulphuric acid, have been compared. The actions of the first three are very similar and greater than those of the other metals. Chromium and manganese are the best catalysts among the metals of the iron group for this reaction.

(3) The position of both tungsten and molybdenum in the normal potential series has been found to be approximately that of mercury by finding both the most noble metal which can displace them from solution and the order, relative to metals of known normal potential, in which they are removed from mercury by oxidation with permanganate. Both methods give approximately the same result for each metal.

(4) It is found that chromium, manganese, iron, cobalt, copper, molybdenum and tungsten go into true solution in mercury at room temperature to a small extent only, the solubility varying for the first five metals under different conditions from 10^{-5} to 5×10^{-5} g. per g. of mercury. This work is of a preliminary character only.

(5) The possibility of the existence of a more active form of tungsten and molybdenum is discussed. It is concluded that there is a body of evidence in favour of such a possibility and that each of these metals when active is approximately as active as cobalt and nickel in the active state.

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