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Original Papers

Fabrication of a Phosphate Ion Selective Electrode Based on Modified Molybdenum Metal

Kebin XU*, Yuki KITAZUMI*, Kenji KANO*, Takayuki SASAKI**, Osamu SHIRAI†

* Division of Applied Life Sciences, Graduate School of Agriculture, Kyoto University, Kitashirakawa Oiwake-cho, Sakyo, Kyoto 606-8502, Japan
** Department of Nuclear Engineering, Graduate School of Engineering and Faculty of Engineering, Kyoto University, Nishikyo, Kyoto 615-8530, Japan
† To whom correspondence should be addressed.
E-mail: shiraio@kais.kyoto-u.ac.jp
Abstract

A phosphate ion selective electrode using a molybdenum metal was constructed. The modified molybdenum electrode responded to $\text{HPO}_4^{2-}$ in the presence of molybdenum dioxide and molybdophosphate ($\text{PMO}_{12}\text{O}_{40}^{3-}$) on the surface. The electrode exhibited a linear response to $\text{HPO}_4^{2-}$ in the concentration range between $1.0 \times 10^{-5}$ and $1.0 \times 10^{-1}$ M (mol dm$^{-3}$) in the pH range from 8.0 to 9.5 with a detection limit of $1.0 \times 10^{-6}$ M. The sensor showed a near Nernstian characteristics ($-27.8 \pm 0.5$ mV dec$^{-1}$) at pH 9.0. Since the responding potential was attributed to the activity of $\text{HPO}_4^{2-}$, the potential at a given concentration of phosphate depended on pH. The electrode indicated a good selectivity with respect to other common anions such as $\text{NO}_3^-$, $\text{SO}_4^{2-}$, $\text{Cl}^-$, $\text{HCO}_3^-$ and $\text{CH}_3\text{COO}^-$. The modified molybdenum electrode can be continuously used over a 1 month with good reproducibility. The feasibility of the electrochemical sensor was proved by successful detection of phosphate in real samples.

**Keywords:** Phosphate sensor, ion selective electrode, molybdenum, oxide, molybdophosphate, electrodeposition.
**Introduction**

Phosphate is considered as one of main components of ground and surface water, and it is also an essential nutrient for all plants.\(^1\)-\(^3\) In modern agriculture, phosphate is supplied to cultivate crops as an important fertilizer.\(^4\)-\(^6\) An excess release of phosphate derived from the fertilizer and a man-made waste to the natural environment however causes eutrophication.\(^7\)-\(^10\) The concentration control of phosphate based on the monitoring data is important in order to preserve the environment. On the other hand, it is important to evaluate the concentrations of phosphate in body fluids in clinical diagnosis of various disorders such as hyperparathyroidism, hypertension, deficiency of vitamin D, mineral and bone disorder and Franconia syndrome.\(^11\)-\(^14\)

As for phosphate measurement, there are many analytical methods such as spectrophotometry, ion chromatography, flow injection analysis, and potentiometry.\(^15\)-\(^18\) Although the molybdenum blue method is excellent as an analytical method to detect the concentration of phosphate, some pretreatments such as filtration, dilution, etc. are required.\(^19\) Potentiometric evaluation of the concentration of phosphate using ion selective electrodes (ISEs) is one of prime candidates, since it is a fast, portable, simple, low cost and accurate analytical method.\(^18\),\(^20\)-\(^22\) Several phosphate ISEs constructed by metal|metal phosphate electrodes,\(^23\)-\(^28\) surface modified electrodes\(^29\) and liquid membrane electrodes\(^30\) have been reported. It is well known that a cobalt electrode can respond to the concentration of dihydrogen phosphate.\(^24\)-\(^26\) However, the electrochemical properties of the ISE were unstable and the responding mechanism had not been clarified. Meruva and Meyerhoff suggested a mixed potential mechanism in the presence of cobalt oxide and dihydrogen phosphate.\(^25\) The author’s group successfully explained the responding mechanism based on the mixed potential of oxidation and phosphorylation of cobalt and proposed the best condition suitable for the measurement.\(^26\) The electrode showed a linear potential response in the concentration range
from $1.0 \times 10^{-1}$ to $1.0 \times 10^{-6}$ mol dm$^{-3}$ (M) in the pH range from 4.0 to 6.5. The concentration of phosphate in environmental waters is usually measured under a mild-acidic condition. However, in medical and food industrial fields, the analysis of the phosphate concentration under a mild-alkaline condition is also required. On the other hand, several research groups have reported that molybdenum electrodes can be used for the detection of monohydrogen phosphate ($\text{HPO}_4^{2-}$) around pH 8.0.$^{27,28}$ Although the formation of molybdophosphate is involved in the potential response of the modified molybdenum electrode,$^{28}$ the detailed mechanism remains to be clarified.

In the present study, the potential response of the modified molybdenum electrode to$\text{HPO}_4^{2-}$ and its pH dependence were examined. Based on the formation of molybdophosphate from molybdenum oxide and $\text{HPO}_4^{2-}$, the responding mechanism of the modified molybdenum electrode to the concentration of $\text{HPO}_4^{2-}$ in the solution and optimum conditions for the detection of $\text{HPO}_4^{2-}$ were investigated.

**Experimental**

**Chemicals**

Molybdenum wire (diameter: 2 mm, length: 100 mm, 99.9%) was purchased from the Nilaco Co., Ltd. Molybdenum (IV) oxide, sodium dihydrogenphosphate (NaH$_2$PO$_4$), sodium hydrogenphosphate (Na$_2$HPO$_4$), sodium nitrate (NaNO$_3$), sodium chloride (NaCl), sodium sulfate (Na$_2$SO$_4$), sodium acetate (CH$_3$COONa), sodium hydrogen carbonate (NaHCO$_3$), and sodium hydroxide (NaOH) were purchased from Wako Co. Ltd. Hydrochloric acid (HCl) was obtained from Kishida Co. Ltd. Phosphomolybdic acid hydrate (H$_3$PMo$_{12}$O$_{40}$$\cdot$$x$$\cdot$H$_2$O) was obtained from Tokyo Chemical Industry Co. Ltd. Hexaammonium heptamolybdate tetrahydrate, L($+$)-ascorbic acid, antimony potassium tartrate trihydrate, sulfuric acid used for determination.
of phosphate by the molybdenum blue method were purchased from Wako Co. Ltd. All chemical reagents were of analytical grade and were used without further purification.

**Apparatus**

Electrochemical measurements were conducted using an electrometer HE-106A (Hokuto Denko Co., Ltd.), a potentiostat/galvanostat HA1010mM1A (Hokuto Denko Co., Ltd.), a function generator HB305 (Hokuto Denko Co., Ltd.), and an A/D converter (GL900, Graphtec Co., Ltd). The electrode surface before and after electrolysis treatment to modify the surface was observed by a field emission scanning electron microscope SU8000 (Hitachi High-Technologies Co.). By use of a pH meter PH-230SD (Lutron Co., Ltd. Taiwan), the pH of the solution was measured.

UV-Vis absorption spectra were observed using an UV-Vis spectrophotometer (UV-2550 (Shimadzu Co., Ltd). UV-Vis spectra of electrolyzed solutions were compared with those of a solution of phosphomolybdic acid hydrate (H$_3$PMo$_{12}$O$_{40}$$\cdot$x-H$_2$O).

**Preparation of Mo modified electrodes**

In the potentiometric measurement of a modified molybdenum electrode as a phosphate-ion selective electrode, the surface of the molybdenum wire was polished by sandpapers of #80, #240, and #1000, respectively. It was then washed in an ultrapure water for 30 min using an ultrasonic cleaner. The molybdenum wire was covered with a silicone tube except both ends of the electrode, and one end of the silicone tube was coated with epoxy resin to avoid the soakage of the solution into the gap. Thus, one end of the molybdenum wire was used as a working electrode. A platinum wire electrode was used as a counter electrode. The constant-potential electrodeposition was undertaken at +0.2 V vs. Ag/AgCl|sat. KCl in 0.1 M Na$_2$HPO$_4$ at pH 9 for about 2 h until the color of the electrode surface turned to black totally.
After the electrolysis, the color of the electrolyzed solution changed yellow green. On the other hand, in the measurement of cyclic voltammograms, a molybdenum wire (outer diameter: 2 mm) was inserted to a polytetrafluoroethylene (PTFE) tube (inner diameter: 2 mm), and the bare molybdenum electrode (surface area: 0.0314 cm²) was used as a working electrode.

All potentiometric measurements were carried out in a two-electrode system using an Ag|AgCl|sat. KCl electrode and three phosphate-sensing electrodes (3 sets as parallel circuits). Cyclic voltammetry was carried out in a three-electrode system using the molybdenum electrode (a working electrode), an Ag|AgCl|sat. KCl electrode (a reference electrode) and a platinum wire electrode (a counter electrode).

**Results and Discussion**

*Response characteristics of HPO₄²⁻-ISE*

Figure 1 illustrates the response characteristics of the modified molybdenum electrode to the total concentration of phosphate ion [Pi] at various pHs. In this case, the pH value of the phosphate solution was adjusted with NaOH and HCl solutions. The detection limit was 10⁻⁶ M in the pH region between 8.0 and 9.5. The modified molybdenum electrode showed a linear response with a slope of −27.8 ± 0.5 mV dec⁻¹ to the concentration of monohydrogen phosphate ion ([HPO₄²⁻]) in the range from 10⁻⁵ to 10⁻¹ M at pH 9.0, where [Pi] ≈ [HPO₄²⁻]. The potential ($E_{ISE}$) of the modified molybdenum electrode used as an ion-selective electrode (ISE) at pH 9.0 was expressed by Eq. (1).

$$E_{ISE} (pH 9.0) = - (0.312 ± 0.005) \text{ V} - (0.0278 ± 0.0005) \text{ V} \times \log ([Pi]/M)$$  \hspace{1cm} (1)

Although the linear response was held in the region between pH 8.0 and pH 9.5, the potential at a given value of [Pi] decreased with an increase of pH. At pH 10.0, the detection limit increased...
around $10^{-3}$ M.

The pH dependence of the $E_{\text{ISE}}$ value suggests that $\text{H}^+$ or $\text{OH}^-$ is involved in the responding reaction to $\text{HPO}_4^{2-}$. Thus the $E_{\text{ISE}}$ value depended on pH. The $E_{\text{ISE}}$ value at $[\text{HPO}_4^{2-}] = 10^{-3}$ M was written by Eq. (2).

$$E_{\text{ISE}} = (0.0478 \pm 0.0005) \text{ V} - (0.0308 \pm 0.0005) \text{ V} \times \text{pH} \quad (2)$$

The selectivity ($K_{\text{B,A}}^{\text{pot}}$) of the objective ion (B) to a coexisting ion (A) was evaluated at pH 9.0 by the mixed-solution method. The $E_{\text{ISE}}$ value was represented by Eq. (3).

$$E_{\text{ISE}} = E' + \frac{RT}{n_B F} \ln \left( a_B + K_{\text{B,A}}^{\text{pot}} a_A^{n_B} n_A^{n_A} \right)$$

Here, $E'$ is a constant value that depends on the identity of ionic species B ($\text{HPO}_4^{2-}$) and on the cell construction, $n_A$ and $n_B$ are the charge numbers of the ions A and B, $F$ is the Faraday constant, $a_A$ and $a_B$ are the activities of ions A and B, $R$ is the gas constant, and $T$ is the temperature. As shown in Table 1, all log $K_{\text{B,A}}^{\text{pot}}$ values of common anions (NO$_3^-$, Cl$^-$, SO$_4^{2-}$, HCO$_3^-$ and CH$_3$COO$^-$) were below $-2$; the modified molybdenum electrode showed a good performance on selectivity. Figure 2 shows the dynamic response time of the modified molybdenum electrode. The response time was less than 5 min. As shown in the inset, the fluctuation of the potential was less than ±5 mV within 24 h, and the properties remained unchanged one month after. When a bare molybdenum electrode was used as an ISE electrode, the responding potential was not constant in the beginning and varied. But it gradually became to respond stably to [HPO$_4^{2-}$], as shown in Fig. 3(a). After the measurement (5 times observation), the color of the electrode surface was turned to dark brown. On the other hand, the responding characteristics of the modified electrode became stable, as shown in Fig. 3(b).

**SEM images, XRD patterns of the deposit and UV-Vis absorption spectra**

SEM images of the surface of both the bare and modified molybdenum electrodes were...
observed, as indicated in Fig. S1. The surface of the polished bare molybdenum electrode was smooth, while that of the modified molybdenum electrode was not smooth. Variously shaped crystals adhered to the surface of the electrode.

In order to construct a stable modified molybdenum electrode, the potential-controlled electrolysis was performed at 0.2 V vs. the Ag|AgCl|sat. KCl reference electrode for about 2 h. The color of the electrodeposited on the surface of the modified molybdenum electrode was dark brown and the electrodeposited was stripped off with a sand-paper. After the electrodeposited was dried, the XRD pattern of the electrodeposited was measured. As shown in Fig. 4, the main peaks of electrodeposited were identified to molybdenum and molybdenum dioxide (MoO₃). Here, there are several clear peaks assigned as Zr₃P. These seem to be caused by Zr which is one of components of abrasives.

The diffraction data of samples were collected on a Rigaku MiniFlex 600 diffractometer, using the Cu Kα line at 40 kV and 15 mA. The samples were scanned from 2θ = 10 – 90 degree (°) at a scanning speed of 5 deg min⁻¹.

When the molybdenum wire was electrolyzed at 0.2 V in 0.1 M Na₂HPO₄, the color of the electrolyzed solution was turned from colorless to yellow green. The solution was picked up and was diluted. The UV-Vis absorption spectrum of the diluted solution was observed as indicated by curve a in Fig. 5. Similarly, the UV-Vis absorption spectrum of 0.1 mM phosphomolybdic acid hydrate (H₃PMo₁₂O₄₀•x H₂O) was measured (curve b). The spectra were almost overlapped with each other. The results clearly verify that molybdophosphate complexes were formed in the electrolyzed solution by the electrolysis.

**Electrochemical reaction on the surface of the molybdenum electrode**

Figure 6 shows cyclic voltammograms at a bare molybdenum electrode. Curves a and b were obtained in 0.1 M NaCl and 0.1 M Na₂HPO₄, respectively. The anodic current slightly
flowed in the potential region more positive than −0.3 V. This would be caused by oxidation of molybdenum metal to MoO$_2$ based on the Pourbaix diagram, as shown in Fig. SI2.$^{31}$ Above 0.25 V, the anodic current increased. The anodic waves might be attributed to the oxidation of MoO$_2$ to MoO$_4^{2-}$. In addition, it has been reported that MoO$_3$ is formed by the reaction of MoO$_2$ with H$_2$O, as follows:

$$\text{MoO}_2 \rightarrow \text{MoO}_2^{+} + e^- \quad (4)$$

$$\text{MoO}_2^{+} \rightarrow \text{MoO}_4^{2+} + e^- \quad (5)$$

$$\text{MoO}_4^{2+} + \text{H}_2\text{O} \rightarrow \text{MoO}_3(\text{s}) + 2\text{H}^+ \quad (6)$$

In the presence of HPO$_4^{2-}$ in the aqueous phase, two anodic current peaks appeared around 0.15 V and 0.25 V, respectively. The anodic peaks seem to be caused by the reactions (4) and (5), respectively, facilitated by the reaction of MoO$_3$ and HPO$_4^{2-}$. In order to construct a stable modified-molybdenum electrode for the HPO$_4^{2-}$-ISE electrode, a bare molybdenum electrode was oxidized for about 2 h at 0.2 V. During the electrolysis, the color of the solution turned to yellow green. The wave form of the UV-Vis absorption spectrum (curve a in Fig. 5) of the electrolyzed solution obtained by the electrolysis was almost identical with that of the solution of phosphomolybdic acid (12MoO$_3$•H$_3$PO$_4$). This means that molybdophosphate complexes including PMo$_{12}$O$_{40}^{3-}$ was formed by the electrolysis in the solution. Therefore, the reaction written below appear to occur on the electrode surface.

$$12\text{MoO}_3 + \text{HPO}_4^{2-} \rightarrow \text{H}^+ + \text{PMo}_{12}\text{O}_{40}^{3-} \quad (7)$$

As shown in Fig. 4, a XRD pattern indicates the existence of MoO$_2$ alone on the surface of the modified molybdenum electrode. The broad peak around 25°-50° might be caused by other compounds such as MoO$_3$, Mo(OH)$_3$, and Na$_2$HPMo$_{12}$O$_{40}$. Since MoO$_3$ is not stable in the absence of H$_2$O, any clear peak to be assigned to MoO$_3$ was not observed. Figure 7 indicates cyclic voltammograms of HPO$_4^{2-}$ at the bare molybdenum electrode and its concentration dependence. The anodic peak currents (I$_{pa}$ and I$_{pb}$) of peaks a (about 0.12 V) and b (about 0.23
V) were in proportion to [HPO$_4^{2-}$]. Thus, it is clear that the two anodic peaks are attributable to the reaction of molybdenum oxide and phosphate (probably HPO$_4^{2-}$). Although PMo$_{12}$O$_{40}^{3-}$ is soluble in aqueous phase, it is well known that PMo$_{12}$O$_{40}^{3-}$ adsorbs on the electrode surface.$^{34,35}$ Since PMo$_{12}$O$_{40}^{3-}$ is adsorbed on the electrode surface in the present case, the rest potential seems to be stabilized. It is considered that the pH dependence of $E_{\text{ISE}}$, which is expressed by Eq. (2), is caused by the pH dependence of the oxidation of MoO$_2$ to MoO$_3$. The potential response became unstable below pH 7.5. This appeared to be ascribed to a decrease in the ratio of [HPO$_4^{2-}$]/[Pi] at pH 7.0 and 7.5 are about 0.4 and 0.8, respectively, it is thought that the current heights at pH 7.0 and 7.5 were less than those at other pH values. Similarly, by considering the dissociation of HPO$_4^{2-}$ represented by Eqs. (11) and (12), it is predictable that the responding characteristics varies above pH 11.

$$
H_2PO_4^- + H_2O \rightleftharpoons HPO_4^{2-} + H_3O^+,
$$  \( \text{(9)} \)

$$
K_{2} = \frac{[HPO_4^{2-}][H_3O^+]}{[H_2PO_4^-]} = 6.23 \times 10^{-8} \ \text{M.}
$$  \( \text{(10)} \)

Figure 8 indicates cyclic voltammograms of HPO$_4^{2-}$ at various pH values. Since [HPO$_4^{2-}$]/[Pi] at pH 7.0 and 7.5 are about 0.4 and 0.8, respectively, it is thought that the current heights at pH 7.0 and 7.5 were less than those at other pH values. Similarly, by considering the dissociation of HPO$_4^{2-}$ represented by Eqs. (11) and (12), it is predictable that the responding characteristics varies above pH 11.

$$
HPO_4^{2-} + H_2O \rightleftharpoons PO_4^{3-} + H_3O^+\n$$  \( \text{(11)} \)

$$
K_{3} = \frac{[PO_4^{3-}][H_3O^+]}{[HPO_4^{2-}]} = 2.2 \times 10^{-13} \ \text{M}
$$  \( \text{(12)} \)

Considering the above relations, it is predicted that the modified molybdenum electrode can respond in the pH region between pH 8.0 and pH 11.0. Although the modified molybdenum electrode responded the concentration of HPO$_4^{2-}$ at pH 10.0, the detection limit changed to $10^{-3}$ M. This might result from the change of the oxidation of MoO$_2$ judging from the Pourbaix diagram.$^{31}$

The cathodic peak-current in the cyclic voltammograms increased with an increase in pH
of phosphate solutions. In the inset of Fig. 8, the horizontal ordinate shows the $\text{HPO}_4^{2-}$ concentration calculated on Eq. (11). There is a clear linear relationship between the $\text{HPO}_4^{2-}$ concentration and the peak current.

*Determinaton of phosphate concentration by the ISE method and comparison with the colorimetry method*

Table 2 indicates phosphate concentrations in coca cola, nutrient solution, and waste water determined by the present ISE method and the molybdenum blue colorimetric method. After the pH values of these samples were adjusted at 9.0, the phosphate concentrations were determined. The values determined by the present ISE method agreed with those by the molybdenum blue colorimetric method. On the other hand, the recovery measurement of phosphate in distilled water, tap water, and coca cola was performed. As shown in Table 3, it can be seen that the recovery was found to be 95 - 98 %, indicating that the present sensor was feasible to determine phosphate ($\text{HPO}_4^{2-}$) in real samples.

*Conclusion*

In this study, we designed stable modified-molybdenum electrode as a phosphate-ion selective electrode which can be used under mild-alkaline condition. The electrode showed a good performance responding to the logarithm of the relative concentration of phosphate ion ($\text{HPO}_4^{2-}$) with a Nernstian slope. The electrode showed acceptable selectivity to common anions such as $\text{SO}_4^{2-}$, $\text{NO}_3^-$, $\text{Cl}^-$ and so on. The responding mechanism can be explained by considering both the formation of molybdophosphate complexes including $\text{PMo}_{12}\text{O}_{40}^{3-}$ from MoO$_3$ and $\text{HPO}_4^{2-}$ and the absorption of $\text{PMo}_{12}\text{O}_{40}^{3-}$ on the electrode surface. The feasibility of phosphate detection in real samples using the present electrode was proved.
Acknowledgement

This work was supported by the donation from Mr. Nobuo Takeshige.
References


Table 1. Selective coefficients of the modified Mo electrode for other anions.

<table>
<thead>
<tr>
<th>Anion</th>
<th>( \log K_{B,A}^{\text{pot}} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \text{NO}_3^- )</td>
<td>(-3.5 \pm 0.2)</td>
</tr>
<tr>
<td>( \text{Cl}^- )</td>
<td>(-3.0 \pm 0.3)</td>
</tr>
<tr>
<td>( \text{SO}_4^{2-} )</td>
<td>(-2.0 \pm 0.3)</td>
</tr>
<tr>
<td>( \text{HCO}_3^- )</td>
<td>(-2.9 \pm 0.2)</td>
</tr>
<tr>
<td>( \text{CH}_3\text{COO}^- )</td>
<td>(-3.1 \pm 0.2)</td>
</tr>
</tbody>
</table>
Table 2. Determination of phosphate in coca cola, nutrient solution and waste water.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Mo-ISE (mM)</th>
<th>Colorimetry (mM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coca Cola</td>
<td>8.9 ± 0.2</td>
<td>9.1 ± 0.1</td>
</tr>
<tr>
<td>Nutrient solution</td>
<td>8.0 ± 0.2</td>
<td>8.3 ± 0.1</td>
</tr>
<tr>
<td>Waste water</td>
<td>1.0 ± 0.2</td>
<td>1.1 ± 0.2</td>
</tr>
</tbody>
</table>
Table 3. Recovery measurement of phosphate in distilled water, tap water, and coca cola.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Added (mM)</th>
<th>Found (mM)</th>
<th>Recovery rate (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distilled water</td>
<td>10.0</td>
<td>9.8 ± 0.1</td>
<td>98</td>
</tr>
<tr>
<td>Tap water</td>
<td>10.0</td>
<td>9.8 ± 0.2</td>
<td>98</td>
</tr>
<tr>
<td>Coca Cola</td>
<td>10.0</td>
<td>9.5 ± 0.3</td>
<td>95</td>
</tr>
</tbody>
</table>
Figure captions

Fig. 1  Influence of pH on the potential response of the modified molybdenum electrode.

(a) pH 7.0, (b) pH 7.5, (c) pH 8.0, (d) pH 8.5, (e) pH 9.0 ,and (f) pH 9.5 and (g) pH 10.0.

Fig. 2  Response time of the modified molybdenum electrode in Na$_2$HPO$_4$ solution at pH 9.0. 
Inset: Stability of the modified Mo electrode in 0.1 M NaH$_2$PO$_4$ solution at pH 9.0.

Fig. 3 Potential response characteristics in 0.1 M Na$_2$HPO$_4$ solution at pH 9.0 on (a) the Mo electrode and (b) the modified Mo electrode. Exposure time of these electrodes in the solution: a: 0 - 30 min, b: 30 – 60 min, c: 60 – 90 min, d: 90 – 120 min, e: 120 - 150 min.

Fig. 4  XRD pattern of the electrodeposit on the surface of the modified Mo electrode.

Fig. 5 UV-Vis absorption spectra of (a) the electrolyzed solution and (b) 0.01 mM phosphomolybdic acid hydrate.

Fig. 6  Cyclic voltammograms of a molybdenum metal electrode in 0.1 M NaCl (a) and 0.1 M NaH$_2$PO$_4$ (b) at pH 9.
Potential scanning rate: 50 mV s$^{-1}$. Electrode area: 0.0314 mm$^2$.

Fig. 7  Cyclic voltammograms of a molybdenum metal electrode in (a) 0.02 M, (b) 0.04 M, (c) 0.06 M, (d) 0.08 M, and (e) 0.10 M Na$_2$HPO$_4$ at pH 9.0.
Potential scanning rate: 50 mV s$^{-1}$. Electrode area: 0.0314 cm$^2$.
Inset: Concentration dependence of the cathodic peak current ($I_p$).

Fig. 8  Cyclic voltammograms of a molybdenum metal electrode in the presence of 0.1 M Na$_3$HPO$_4$ at various pH values: (a) 7.0, (b) 7.5, (c) 8.0, (d) 8.5, and (e) 9.0.

Potential scanning rate: 50 mV s$^{-1}$. Electrode area: 0.0314 cm$^2$.

Inset: HPO$_4^{2-}$ concentration dependence of the cathodic peak current ($I_p$).
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(a) pH 7.0, (b) pH 7.5, (c) pH 8.0, (d) pH 8.5, (e) pH 9.0, (f) pH 9.5 and (g) pH 10.0.
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Inset: Concentration dependence of the cathodic peak current ($I_p$).

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Inset: HPO$_4^{2-}$ concentration dependence of the cathodic peak current ($I_p$).
Graphical Index

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