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JAEA Thermodynamic Database for Performance Assessment of Geological Disposal of High-level Radioactive and TRU Wastes

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JAEA Thermodynamic Database for Performance Assessment of Geological Disposal of
High-level Radioactive and TRU Wastes

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A thermodynamic database was established for performance assessment of geological disposal of high-level radioactive and TRU wastes based on the thermodynamic database developed by the Japan Nuclear Cycle Development Institute in 1999 (JNC-TDB). Twenty-five elements (actinides, fission products and their daughters) which are important for the performance assessment of geological disposal have been selected. The fundamental plan was in principle based on the guidelines established by the Nuclear Energy Agency in the Organisation for Economic Co-operation and Development (OECD/NEA). Additional unique guidelines were established due to a requirement from the performance assessment to select tentative thermodynamic values obtained from chemical analogues and/or models for elements and species with insufficient thermodynamic values. Selected thermodynamic data will be compiled for geochemical calculation programs.

Keywords: Thermodynamic Database, Performance Assessment, Geological Disposal, High-Level Radioactive Waste, TRU Waste, Fundamental Plan, Data Selection, Geochemical Calculation Program

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高レベルおよび TRU 廃棄物地層処分の性能評価のための JAEA 熱力学データベース

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高レベル放射性廃棄物および TRU 廃棄物の地層処分の性能評価に用いるための熱力学データベースの整備を、1999 年に核燃料サイクル開発機構が整備した熱力学データベース (JNC-TDB) を基に行った。熱力学データ整備の対象として、地層処分の性能評価の対象である 25 元素（アクチニド元素、核分裂生成物元素およびそれらの娘核種となる元素）を選定した。熱力学データベース整備の基本方針については、基本的には経済協力開発機構原子力機関 (OECD/NEA) のガイドラインにしたがうこととするものの、性能評価上の必要性から、熱力学データが十分に公開されていない元素および化学種については、化学アナログやモデル等を用いて得た推定値を暫定値として採用するなど、一部に独自の熱力学データ選定基準を設けることとした。選定された熱力学データについては、各種地球化学計算コード用フォーマットに対応する形式で編集される予定である。

本報告書の一部は、平成 20 および 21 年度経済産業省委託事業「高レベル放射性廃棄物処分関連：処分システム化学影響評価高度化開発」により実施した研究成果である。

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1. Introduction

Many radionuclides are contained in high-level radioactive waste (HLW) and are part of TRU waste packages and some of them have long half-lives (more than 10^4 year). It is necessary to estimate the solubility of the radionuclides in groundwaters and pore waters for performance assessment of geological disposal of HLW and TRU wastes. Thermodynamic data, e.g., the solubility product of solubility limiting solids and equilibrium constant of aqueous complexes at standard state (i.e. ionic strength of 0), are needed to estimate the solubility and aqueous species in the groundwaters and pore waters; these data are fundamental to estimating sorption and diffusion behaviors on/in engineered barriers and host rocks. Therefore, the most reliable thermodynamic data with transparency and objectivity should be published to carry out the reliable performance assessment by an implementation and regulatory organizations.

The Power Reactor and Nuclear Fuel Development Cooperation (PNC) and the Japan Nuclear Cycle Development Institute (JNC) (successor of the PNC and one of the predecessors of the Japan Atomic Energy Agency (JAEA)) developed thermodynamic databases (TDBs) for the performance assessment in the first (“H3” in 1992) and second (“H12” in 1999) progress reports on research and development for geological disposal of HLW^{1,2)}. The thermodynamic database developed by JNC (JNC-TDB)²⁾ contains solubility products of solubility limiting solids and stability constants of aqueous complexes for 21 elements which are of importance for the performance assessment of geological disposal of HLW (actinides, fission products and their daughters). Selection of thermodynamic data for technetium (Tc) (draft document), uranium (U), and americium (Am) was referred to the thermodynamic data published by the Nuclear Energy Agency in the Organisation for Economic Co-operation and Development (OECD/NEA)³⁻⁵⁾. Thermodynamic data for tin (Sn), antimony (Sb), lead (Pb), bismuth (Bi), niobium (Nb) and palladium (Pd) were developed by Lothenbach *et al.*⁶⁾ for the JNC-TDB. Based on analogy of chemical properties, the values for Am were used for samarium (Sm), actinium (Ac), and curium (Cm). The electronic versions of the JNC-TDB are available via the internet using the geochemical calculation programs PHREEQE, PHREEQC, EQ3/6 and Geochemist’s Workbench (GWB). The JNC-TDB was considered to be the first thermodynamic database available for these geochemical calculation programs for the performance assessment of geological disposal of HLW.

An international project for development of chemical thermodynamic databases was initiated in 1984 by the OECD/NEA⁷⁾. As of the end of 2008, thermodynamic databases of

nickel (Ni)⁸⁾, selenium (Se)⁹⁾, zirconium (Zr)¹⁰⁾, technetium (Tc)¹¹⁾, thorium (Th)¹²⁾, uranium (U)¹¹⁾, neptunium (Np)¹¹⁾, plutonium (Pu)¹¹⁾ and americium (Am)¹¹⁾ have been developed, updated and published, and those of iron (Fe) and tin (Sn) are in progress. These thermodynamic databases by the OECD/NEA (NEA-TDB) were developed from a basic science point of view, and some thermodynamic values on chemical species of importance for the performance assessment were not selected due to low reliability of the value even though the data are important for performance assessment of the geological disposal.

Yamaguchi *et al.*^{13,14)} and the Paul Scherrer Institut (PSI)¹⁵⁾ developed other thermodynamic databases for the performance assessment of geological disposal. In principle they selected the thermodynamic data published by the OECD/NEA, and some additional thermodynamic values of importance for the performance assessment have been adopted. The thermodynamic databases developed by Yamaguchi *et al*^{13,14)} and the PSI (PSI-TDB)¹⁵⁾ also contain some estimated values and exclude some selected values by the OECD/NEA due to their unimportance in geological disposal conditions. We consider that the additional selection and/or estimation of thermodynamic data based on more recent publications or estimation schemes is necessary to improve the previous TDBs for reliable performance assessment of the geological disposal.

Considering these circumstances, we established a fundamental plan for updating the thermodynamic database (JAEA-TDB) from the JNC-TDB²⁾, collected and reviewed the latest thermodynamic data through the literature survey, selected the accepted thermodynamic data especially from the latest NEA-TDBs⁸⁻¹²⁾ including the formation constants with some organic ligands. We also mentioned current status of modeling of complexation of metal ions with natural organic substances (e.g. humic and fulvic acids). We assigned the uncertainties for the obtained thermodynamic data as many as possible, while no uncertainties were assigned in the JNC-TDB²⁾. Comparing with the JNC-TDB²⁾, we improved the quality of the selected thermodynamic data based on the TDB guidelines by the OECD/NEA¹⁶⁻¹⁹⁾, and assured the traceability of the selected thermodynamic data through publishing some supporting reports for some elements. Following chapters will describe the detail of the fundamental plan, review and selection of the thermodynamic data for the JAEA-TDB.

2. Guidelines for Selection of Thermodynamic Data

2.1 Basic Information

The objective of developing the JAEA-TDB is to provide an appropriate thermodynamic database for the performance assessment of geological disposal of radioactive waste (especially for HLW and TRU waste). The traceability and transparency of selection of thermodynamic values in the JAEA-TDB should be guaranteed.

The thermodynamic values to be selected in the JAEA-TDB fall in two categories, those that are necessary and those that would be desirable (recommended) to have if adequate data are available. These are further elaborated below:

- Necessary:

equilibrium constant of reaction at standard state (K°) or
standard Gibbs free energy of reaction ($\div_r G_m^\circ = -RT \ln K^\circ$, where R and T is gas constant and absolute temperature, respectively).

- Recommended:

standard Gibbs free energy of formation ($\div_f G_m^\circ$),
standard enthalpy change of formation ($\div_f H_m^\circ$) and that of reaction ($\div_r H_m^\circ$),
standard molar entropy (S_m°) and standard entropy change of reaction ($\div_r S_m^\circ$),
heat capacity (C_p°)

Twenty-six elements of interest were selected in the safety assessment in JNC's 2nd progress report on research and development of geological disposal of HLW (H12 report)²⁰⁾ and that of TRU waste (TRU-2)²¹⁾ as follows:

- cobalt (Co)
- nickel (Ni)
- selenium (Se)
- strontium (Sr)
- zirconium (Zr)
- niobium (Nb)
- molybdenum (Mo)
- technetium (Tc)
- palladium (Pd)
- tin (Sn)

- antimony (Sb)
- iodine (I)
- cesium (Cs)
- samarium (Sm)
- lead (Pb)
- bismuth (Bi)
- polonium (Po)
- radium (Ra)
- actinium (Ac)
- thorium (Th)
- protactinium (Pa)
- uranium (U)
- neptunium (Np)
- plutonium (Pu)
- americium (Am)
- curium (Cm)

Although some thermodynamic data for cesium have been selected in the JNC-TDB, these data have been regarded as auxiliary data. The same principle will be applied in the JAEA-TDB because most cesium compounds are very soluble. Therefore, 25 elements of interest will be included in the JAEA-TDB as shown in Figure 1. Carbon (C), which is one of the elements of interest in TRU-2²¹⁾, will be taken from the auxiliary data of the NEA-TDB¹²⁾.

Considering the stability and abundance of anions in the geological disposal environment that can form complexes with the radioactive elements of interest, complexes of the following dominant anions will be considered emphasized for selecting thermodynamic data:

- hydroxyl ion (OH^-)
- hydrogen carbonate and carbonate ions (HCO_3^- , CO_3^{2-})
- sulfate and sulfide ions (SO_4^{2-} , S^{2-})
- nitrate ion and ammine (NO_3^- , NH_3)
- dihydrogen and hydrogen phosphate ion (H_2PO_4^- , HPO_4^{2-})
- halide ions (F^- , Cl^- , etc.).

Thermodynamic data of several elements with the following organic ligands, which have been published as the NEA-TDB²²⁾, will be incorporated into the JAEA-TDB due to importance for the performance assessment of TRU waste:

- Ethylenediaminetetraacetic acid (EDTA; $(HOOCCH_2)_2NCH_2CH_2N(CH_2COOH)_2$)
- Citric acid ($HOOCCH_2CCOOHOHCH_2COOH$)
- Oxalic acid ($HOOCOOH$)
- Isosaccharic acid (ISA; $CH_2OHCHOHCH_2COHCH_2OHCOOH$).

Although it is important to select formation constants with natural organic substances (e.g. humic and fulvic acids) for the JAEA-TDB, it is currently not possible to do so because the humic substances are complex with multiple functional groups, and the proposed models for interpreting complexation behavior of the humic substances are empirical, too simplified, and not able to unambiguously assign values of formation constants for them. Formation constants with organic ligands other than those mentioned above will be excluded from the compilation of the JAEA-TDB.

2.2 General Procedure for the Selection of Thermodynamic Data

2.2.1 Collecting Thermodynamic Values

Thermodynamic values for nickel, selenium, zirconium, technetium, thorium, uranium, neptunium, plutonium and americium which have been critically reviewed by the OECD/NEA⁸⁻¹²⁾ should be collected. Other thermodynamic values for these elements, which were not reviewed by the OECD/NEA, may have to be collected as necessary. Selected or referred thermodynamic values in the JNC-TDB and the PSI-TDB should also be collected. Thermodynamic values for elements excluded in the above TDBs should be collected through literature survey. Thermodynamic values for some elements with poor or no experimental values should be estimated using chemical analogues and/or models.

2.2.2 Procedure for Review and Selection of Thermodynamic Values

Review and selection of thermodynamic values obtained from experimental data should be based on OECD/NEA's "TDB-1" guideline¹⁶⁾, which describes how to review and select thermodynamic data based on the number of data source available. Even though the "TDB-1" mentions that only original experimental data are evaluated, not estimates, values from

compilations or secondary citations, thermodynamic values or databases selected by OECD/NEA can be transferred to the JAEA-TDB after checking the consistency of these values with the existing database. Based on the same (unique) policy, thermodynamic values contained in TDBs developed on the basis of the “TDB-1” guideline¹⁶⁾, which are the PSI-TDB¹⁵⁾ and part of the JNC-TDB (Lothenbach *et al.*⁶⁾), can be treated as already reviewed values. If the latest thermodynamic values and/or non-selected values in the above TDBs are considered to be reliable, the review and selection of thermodynamic values should be performed for all candidate values, and the consistency of the database should be reevaluated in a manner similar to the reevaluation of the NEA-TDB.

Most of thermodynamic data at mineral/water interface and those for related aqueous reactions were taken from the JNC-TDB²⁾. We took the auxiliary data selected by the OECD/NEA¹²⁾ in priority to those in the JNC-TDB²⁾ after comparing the selected values and checking consistencies.

2.2.3 Correction of Ionic Strength

In JAEA-TDB, all thermodynamic values should be standardized at zero ionic strength. Correction of ionic strength to determine the thermodynamic values at zero ionic strength should be performed on the basis of the OECD/NEA’s “TDB-2” guideline¹⁷⁾, which recommends a model called “specific ion interaction theory (SIT)”.

2.2.4 Temperature Corrections

All thermodynamic values should be selected at 298.15 °K. If thermodynamic values are available only at other temperatures, those should be converted to 298.15 °K on the basis of the “TDB-4” guideline by the OECD/NEA¹⁸⁾.

2.2.5 Assignment of Uncertainties

Uncertainties of experimental and thermodynamic values should be assigned on the basis of the OECD/NEA’s “TDB-3” guideline.¹⁹⁾ Assignment of uncertainties for values obtained from chemical analogues and/or models, however, should be discussed because no guidelines are available. Assignment of uncertainties by an expert judgment (or “educated guess” in the TDB-1¹⁶⁾) would not be avoidable for some thermodynamic values. Propagation of uncertainties should be carefully treated so as not to overestimate uncertainties.

2.2.6 Use of Chemical Analogues and Models for Estimation of Thermodynamic Data

Some thermodynamic values which are important for the performance assessment of geological disposal of radioactive wastes should be selected even if the reliability of the values is questionable. In this case, the value may be selected as a tentative value, specifying low reliability of the value and the need for the value to be more reliably determined.

Application of chemical analogues should be considered to estimate thermodynamic values on some species which have no published values based on experimental data. At the moment, application of a chemical analogue among actinides with the same oxidation state should be considered. Some chemical analogues may be combined with chemical models that have been proposed to estimate thermodynamic values where no values based on experimental data exist. Some of the models are able to estimate thermodynamic values by semi-empirical and/or qualitative interactions between central atom and coordinated species²³⁻²⁵⁾.

The selection of tentative values should be carried out with special care, and we should explain the procedure of the selection logically.

2.3 External Review for the Selection of Thermodynamic Data

Proposed thermodynamic data and database should be carefully peer reviewed by both internal and external experts carefully. An expert committee on development of the thermodynamic database may be organized.

3. Selection of Thermodynamic Data for Elements of Interest

3.1 Lanthanide and Actinoids

3.1.1 Americium, Curium and Samarium

Thermodynamic data for americium have been reviewed and selected by the OECD/NEA^{5,11)}. We have accepted $\log K^\circ$ values only for trivalent americium because americium would exist only in the trivalent oxidation state in the geological disposal system. Even if the $\log_{10} K^\circ$ values are provided in the NEA-TDB, we excluded the $\log_{10} K^\circ$ values for some species and compounds unrelated to key (master) species (Am^{3+}), e.g.,



Selection of thermodynamic data for samarium(III) and curium(III) has been based on those for americium(III) in the NEA-TDB^{5,11)}. Selected equilibrium constants have been applied to those of curium and samarium without any modifications after checking the applicability of the chemical analogue. Detailed selection of these thermodynamic data is summarized in the supporting report.²⁶⁾

3.1.2 Actinium

Selection of thermodynamic data for actinium has been based on those for americium(III) in the NEA-TDB^{5,11)}. We have found that some stability constants of actinium(III) are similar to those of americium(III), while solubility product of $\text{Ac(OH)}_3(\text{s})$ is much larger than that of $\text{Am(OH)}_3(\text{am})$. We have also found that crystalline actinium(III) compounds such as $\text{Ac(OH)}_3(\text{cr})$ are not stable because of self irradiation of α -emitter of actinium. Based on these observations, we decided to exclude $\log K^\circ$ values of crystalline actinium(III) compounds. Furthermore, we decided to set the same $\log K^\circ$ values for actinium(III) amorphous compounds and aqueous species as those for americium(III), with the addition of larger uncertainties (4 and 0.2 orders of magnitude for amorphous compounds and aqueous species, respectively).

Detailed selection of these thermodynamic data for actinium is summarized in the supporting report.²⁶⁾

3.1.3 Thorium

Thermodynamic data for thorium were recently reviewed and selected by the OECD/NEA.

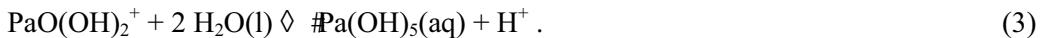
¹²⁾ We basically agreed with the selected values by the OECD/NEA ¹²⁾, and investigated the latest papers for complexes with calcium and silicon. We found and critically reviewed papers for $\text{Ca}_4[\text{Th}(\text{OH})_8]^{4+}$ by Brendebach *et al.* ²⁷⁾ and Altmaier *et al.* ²⁸⁾ and for $\text{Th}(\text{OH})_3(\text{H}_3\text{SiO}_4)_3^{2-}$ Rai *et al.* ²⁹⁾, which are expected to be important in highly alkaline Ca-rich and Si-rich environments, respectively. The obtained equilibrium constants for these species are shown in Table 1, and we selected the obtained data additionally to the JAEA-TDB.

Detailed selection of these thermodynamic data for thorium is summarized in the supporting report. ³⁰⁾

3.1.4 Protactinium

Thermodynamic values for protactinium were reviewed by Shibutani *et al.* ³¹⁾ for the JNC-TDB ²⁾. We basically agreed with the review by Shibutani *et al.* ³¹⁾, investigated some of the latest literatures, and additionally selected equilibrium constants for protactinium.

Trubert *et al.* ³²⁾ determined hydrolysis constants for protactinium by a solvent extraction method using thenoyltrifluoroacetone (TTA). They obtained apparent hydrolysis constants of following reactions at ionic strength of 0.1, 1 and 3 mol·dm⁻³ and determined those at zero ionic strength using the SIT model:



We selected the $\log_{10} K^\circ$ values shown in Table 2 after reviewing the literatures ³²⁾. Although Trubert *et al.* ³³⁾ modified the selected $\log_{10} K^\circ$ values for the reactions (2) and (3), we selected the older data due to the consistency between $\log_{10} K^\circ$ and the ion interaction coefficients.

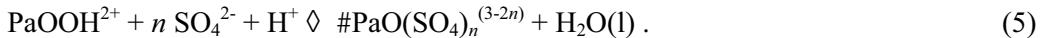
Le Naour *et al.* ³⁴⁾ determined the formation constant of the chloride complex (PaOOHCl^+) by the solvent extraction using TTA. They derived the apparent formation constant at ionic strength of 3.0 mol·dm⁻³ (adjusted with NaClO_4) of 1.09 ± 0.05 (i.e. $\log_{10} K' = (3.74 \pm 2.04) \times 10^{-2}$) for the following reaction:



We extrapolated this value to determine the $\log_{10} K^\circ$ value of 0.567 ± 0.020 using the SIT model, assuming the ion interaction coefficients of $\varepsilon(\text{PaOOH}^{2+}, \text{ClO}_4^-) = -0.03 \pm 0.02$ derived by Trubert

*et al.*³²⁾ and $\varepsilon(\text{PaOOHCl}^+, \text{ClO}_4^-) = 0.19 \pm 0.64$, which we derived from an average value among those for hydroxide and chloride complexes of metal ions with a net positive charge of one in ClO_4^- media listed in the NEA-TDB¹²⁾, i.e. from values for CdCl^+ , HgCl^+ , NiCl^+ , PuO_2Cl^+ , NpO_2Cl^+ , UO_2Cl^+ , NiOH^+ , Am(OH)_2^+ , NpO_2OH^+ , UO_2OH^+ and Th(OH)_3^+ with ClO_4^- . We also selected these $\log_{10} K^\circ$ value for the JAEA-TDB. It was found that the obtained $\log_{10} K^\circ$ value for PaOOHCl^+ was similar to those for UO_2Cl^+ (0.17 ± 0.02) and for NpO_2Cl^+ (0.40 ± 0.17) in the NEA-TDB¹¹⁾.

Giandomenico *et al.*³⁵⁾ determined the formation constants for sulfate complexes $(\text{PaO}(\text{SO}_4)_n)^{(3-2n)}$: $n = 1 - 3$ by the solvent extraction using TTA. They obtained apparent hydrolysis constants of the following reactions at ionic strength of 0.78, 1.05, 1.60, 2.17 and 2.90 mol·kg⁻³ and determined those at zero ionic strength using the SIT model:



We selected the $\log_{10} K^\circ$ values shown in Table 2 after reviewing the journal article³⁵⁾.

We took other thermodynamic data in the JNC-TDB²⁾ without any modifications except for PaOOH^{2+} .

3.1.5 Uranium

3.1.5.1 Tetravalent Uranium

Thermodynamic database of uranium was published by the OECD/NEA in 1992⁴⁾ and updated in 2003¹¹⁾. We basically agreed with the values selected by the OECD/NEA but made some modifications for selection of thermodynamic data for uranium(IV).

The NEA-TDB¹¹⁾ contains only the first and fourth hydrolysis constants. Fujiwara *et al.*³⁰⁾ determined from the first through the third hydrolysis constants by solvent extraction method with TTA. We selected the obtained hydrolysis constants instead of those in the NEA-TDB¹¹⁾.

The solubility product of $\text{UO}_2(\text{am})$ was determined from the experimental study by Rai *et al.*³⁶⁾ and estimated hydrolysis constants by Neck and Kim²⁵⁾ in the NEA-TDB¹¹⁾. We reevaluated the solubility product of $\text{UO}_2(\text{am})$ using the experimental study by Rai *et al.*³⁶⁾ and hydrolysis constants by Fujiwara *et al.*³⁷⁾. Furthermore, the fourth hydrolysis constant was also modified by changing the selected value for the solubility product of $\text{UO}_2(\text{am})$. Uncertainty of the fourth hydrolysis constant was raised to 1.4 of \log_{10} unit, due to potential increase of the solubility at higher pH range (e.g. above 12).

We also additionally selected thermodynamic values for silicate and mixed carbonato-hydroxo complexes of uranium(IV) based on articles by Langmuir³⁸⁾ and Rai *et al.*³⁹⁾, respectively, along with the presently selected solubility product of UO₂(am) and adding large uncertainties.

The thermodynamic data for uranium(IV) selected in addition to or in replacement for the one selected by the NEA are summarized in Table 3. Detailed selection of these thermodynamic data for uranium(IV) is summarized in the supporting report.³⁰⁾

3.1.5.2 Other Thermodynamic Data for Uranium

In addition to the data discussed above, we took thermodynamic data in the NEA-TDB¹¹⁾ without any modifications.

3.1.6 Neptunium

3.1.6.1 Tetravalent Neptunium

The thermodynamic database for neptunium was published by the OECD/NEA in 2001⁴⁰⁾ and updated in 2003¹¹⁾. We basically agreed with the selected values by the OECD/NEA¹¹⁾ but made some modifications for selection of thermodynamic data for neptunium(IV).

The NEA-TDB¹¹⁾ does not contain the third hydrolysis constants. Fujiwara and Kohara⁴¹⁾ determined the first through third hydrolysis constants by solvent extraction method with TTA. We selected the obtained hydrolysis constants instead of those in the NEA-TDB¹¹⁾.

Solubility product of NpO₂(am) was determined from the experimental study by Rai *et al.*⁴²⁾ and estimated hydrolysis constants by “Duplessis and Guillaumont”⁴³⁾ and “Neck and Kim”²⁵⁾ in the NEA-TDB¹¹⁾. We reevaluated the solubility product of NpO₂(am) using the experimental study by Rai *et al.*⁴²⁾ and hydrolysis constants by Fujiwara and Kohara⁴¹⁾. Furthermore, the fourth hydrolysis constant was also modified to be consistent with the selected value for the solubility product of NpO₂(am).

We also additionally selected thermodynamic values for the mixed carbonato-hydroxo complexes of neptunium(IV). This was done by using an average value between “Kitamura and Kohara”⁴⁴⁾ and Rai *et al.*⁴⁵⁾ after applying the presently selected solubility product of NpO₂(am).

The thermodynamic data selected in addition to or in replacement for the one selected by the NEA for neptunium(IV) are summarized in Table 4. Detailed selection of these thermodynamic data for neptunium(IV) is summarized in the supporting report.³⁰⁾

3.1.6.2 Other Thermodynamic Data for Neptunium

In addition to the data discussed above, we took thermodynamic data in the NEA-TDB¹¹⁾ without any modifications.

3.1.7 Plutonium

3.1.7.1 Trivalent Plutonium

The thermodynamic database for plutonium was published by the OECD/NEA in 2001⁴⁰⁾ and updated in 2003¹¹⁾. We basically agreed with the selected values by the OECD/NEA¹¹⁾ but made some modifications for selection of thermodynamic data for plutonium(III). This modification included accepting americium data for corresponding plutonium(III) reactions for which no plutonium(III) data were selected by the NEA, because performance assessment calculations using limited plutonium(III) data may lead to wrong conclusions.

Comparing selected equilibrium constants for plutonium(III) species and compounds with those for americium(III), it was found that the equilibrium constants were almost consistent with each other even for solubility products. Furthermore, the ionic radius of Pu³⁺ is quite similar to that of Am³⁺, therefore interaction between a central ion (i.e. Am³⁺ or Pu³⁺) and ligands is considered to be quite similar. Thus equilibrium constants for americium(III) species and compounds were considered to be applicable to use as those for plutonium(III).

Detailed selection of these thermodynamic data for plutonium(III) is summarized in the supporting report.²⁶⁾

3.1.7.2 Tetravalent Plutonium

We made some modifications for selection of thermodynamic data for plutonium(IV).

Yun *et al.*⁴⁶⁾ determined the first through third hydrolysis constants by absorption spectroscopy. We selected the obtained hydrolysis constants instead of those in the NEA-TDB¹¹⁾.

We additionally selected a thermodynamic values for mixed carbonato-hydroxo complexes of plutonium(IV) with a larger uncertainty which covers the values reported by Yamaguchi *et al.*⁴⁷⁾ and Rai *et al.*⁴⁸⁾.

The thermodynamic data for plutonium(IV) selected in addition to or in replacement for the one selected by NEA are summarized in Table 5. Detailed selection of these thermodynamic data for plutonium(IV) is summarized in the supporting report.³⁰⁾

3.1.7.3 Other Thermodynamic Data for Plutonium

In addition to the the data discussed above, we took thermodynamic data in the NEA-TDB¹¹⁾ without any modifications.

3.2 Alkaline Earth Metals

3.2.1 Calcium

Thermodynamic data for calcium were selected as the auxiliary data in the JNC-TDB²⁾. To check internal consistency in the JAEA-TDB, we performed a literature survey, reviewed the surveyed papers, and re-selected equilibrium constants for calcium at Ca^{2+} - OH^- and Ca^{2+} - HCO_3^- - CO_3^{2-} systems.

The selected equilibrium constants are summarized in Table 6. Detailed selection of these thermodynamic data for calcium is summarized in the supporting report.⁴⁹⁾

3.2.2 Strontium

Thermodynamic data for strontium were selected as the auxiliary data in the JNC-TDB²⁾. Due to lack of traceability of the selected data in the JNC-TDB²⁾, we performed literature survey, reviewed the surveyed papers, and re-selected equilibrium constants for strontium for the Sr^{2+} - OH^- , Sr^{2+} - HCO_3^- - CO_3^{2-} and Sr^{2+} - SO_4^{2-} systems. We confirmed internal consistency in the selected thermodynamic data for calcium and strontium..

The selected equilibrium constants are summarized in Table 6. Detailed selection of these thermodynamic data for strontium is summarized in the supporting report.⁴⁹⁾

3.2.3 Barium and Radium

Thermodynamic data for radium were selected in the JNC-TDB²⁾. Due to lack of traceability of the selected data in the JNC-TDB²⁾, we performed a literature survey for equilibrium constants for radium. However, there are no experimental data for solubility of radium in aqueous solutions. Hence we decided to estimate the equilibrium constants for radium based on a systematics among alkaline earth metals (i.e. calcium, strontium, barium and radium) complexes.

Because 1) the ionic radius of radium is quite similar to that of barium⁵⁰⁾, and 2) both barium and radium are expected to have similar properties and form isostructural compounds, we made a reasonable assumption that the equilibrium constants for various barium reactions

could directly be used for corresponding radium reactions without any modifications. Based on this consideration, we performed a literature survey, reviewed the surveyed papers, and re-selected equilibrium constants for barium for the $\text{Ba}^{2+}\text{-OH}^-$, $\text{Ba}^{2+}\text{-HCO}_3^-$ - CO_3^{2-} and $\text{Ba}^{2+}\text{-SO}_4^{2-}$ systems and by analogy for the corresponding radium systems.

The selected equilibrium constants are summarized in Table 6. Detailed selection of thermodynamic data for radium is summarized in the supporting report.⁴⁹⁾ However, a trace amount of radium can co-precipitate and/or form a solid-solution with other alkaline metal earth ions,. Solid-solution system should be considered for precise estimation of solubility of radium under geological disposal conditions.

3.3 Transition Metals

3.3.1 Cobalt and Nickel

The thermodynamic database for nickel was published by the OECD/NEA in 2005⁸⁾, and no thermodynamic databases for cobalt have been published by the OECD/NEA. We decided to select thermodynamic data for cobalt(II). More than 60 articles about thermodynamic data for cobalt(II) were collected, carefully reviewed and compiled on the basis of the guidelines by the OECD/NEA¹⁶⁾. Selection of equilibrium constants for cobalt(II) hydroxide, hydrolysis species and some aqueous complexes was performed, and the selected values are summarized in Table 7. Selection of thermodynamic data for nickel(II) was based on those by the OECD/NEA⁸⁾ with additional selection of thermodynamic data for some species and compounds. It was found that $\log K^\circ$ values of cobalt(II) species have a good linear correlation with those of nickel(II) as shown in Figure 2. Some additional equilibrium constants were estimated using the correlation as shown in Table 8.

Detailed selection of thermodynamic data for cobalt(II) and nickel(II) is summarized in the supporting report.⁵¹⁾ No thermodynamic data for those at other oxidation states were selected.

3.3.2 Zirconium

The thermodynamic database of Zr was published by the OECD/NEA in 2005¹⁰⁾. Although we found latest articles by Cho *et al.*⁵²⁾, Kobayashi *et al.*⁵³⁾ and Sasaki *et al.*^{54,55)}, which determined the solubility product of $\text{ZrO}_2(\text{am})$ and some hydrolysis constants of zirconium, we took all thermodynamic data from the NEA-TDB¹⁰⁾ due to its internal consistency. We confirmed reliability of the selected data in the NEA-TDB¹⁰⁾. We would like to point out that estimation of solubility using the NEA-TDB¹⁰⁾ did not fit to the solubility

data by Sasaki *et al.*⁵⁵⁾, hence further discussion should be necessary.

Formation constants for the third and fourth chloride complexes and the third nitrate complex, which the NEA-TDB did not select, were additionally and tentatively selected. The selected values will be effective under highly ionic strength conditions, especially for the chloride complexes.

Altmaier *et al.*²⁸⁾ performed solubility experiments for zirconium(IV) in basic solutions containing calcium and determined formation constants for $\text{Ca}_2[\text{Zr}(\text{OH})_6]^{2+}$ and $\text{Ca}_3[\text{Zr}(\text{OH})_6]^{4+}$ which were specified using an X-ray absorption spectroscopy²⁷⁾. They obtained the formation constants at zero ionic strength using the SIT model, and we selected the obtained data to the JAEA-TDB.

We took other thermodynamic data, e.g. those for hydrolysis constants from the NEA-TDB¹⁰⁾ after confirming their reliability.

Additionally selected thermodynamic data for zirconium(IV) were summarized in Table 9. Detailed selection of these thermodynamic data is summarized in the supporting report.⁵⁶⁾

3.3.3 Niobium

3.3.3.1 Selected Values in Previous TDBs

Selected thermodynamic values in the JNC-TDB²⁾ were taken from those by Lothenbach *et al.*⁶⁾, who conducted an extensive literature survey and review of thermodynamic data of niobium (mainly pentavalent). They found thermodynamic data of some aqueous species of niobium, e.g., hydrolysis species, polyniobate complexes, halide complexes. However, they found only one study on solubility of niobium(V) performed by Yajima *et al.*⁵⁷⁾ and Yajima⁵⁸⁾. Therefore, Lothenbach *et al.*⁶⁾ determined equilibrium constants of $\text{Nb}(\text{OH})_5(\text{aq})$ and $\text{Nb}(\text{OH})_6^{2-}$ against solubility limiting solid of $\text{Nb}_2\text{O}_5(\text{s})$ using the solubility data of Yajima⁵⁸⁾. We basically agreed with the selection of these thermodynamic data. However, we consider that the equilibrium constant between $\text{Nb}_2\text{O}_5(\text{s})$ and $\text{Nb}(\text{OH})_5(\text{aq})$ should be treated as an upper limit because the solubility data of Yajima⁵⁸⁾ show only an upper limit. Furthermore, the procedure for determination of $\log K^\circ$ values from the experimental data is not clear. Therefore, thermodynamic data should be re-determined with transparency.

Hummel *et al.*¹⁵⁾ selected thermodynamic data of NbO_3^- , $\text{Nb}(\text{OH})_4^+$ and $\text{Nb}(\text{OH})_5(\text{aq})$, $\text{NbO}_2(\text{cr})$ and $\text{Nb}_2\text{O}_5(\text{cr})$ for the PSI-TDB. For this compilation they used $\Delta_f G_m^\circ$ values from the National Bureau of Standards (NBS) Table⁵⁹⁾. Although Hummel *et al.*¹⁵⁾ reviewed the literature by Lothenbach *et al.*⁶⁾, they did not select their reported values. Duro *et al.*⁶⁰⁾

selected for the SKB-TDB the same data as recommended values by Hummel *et al.*¹⁵⁾ but in addition proposed estimated uncertainties to the recommended values. However, there are no descriptions about basis of the selected $\Delta_f G^\circ_m$ values in the NBS Table⁵⁹⁾.

3.3.3.2 Determination of Thermodynamic Data of Niobium(V)

Although we support the selection of thermodynamic data for niobium by Lothenbach *et al.*⁶⁾, we decided to re-determine equilibrium constants with slight modification. Solubility data by Yajima *et al.* are shown in Figure 3 with the first and second runs published in 1992⁵⁷⁾ and 1994⁵⁸⁾, respectively. Yajima *et al.*^{57, 58)} performed the experiments under anoxic conditions, at ambient temperature, by both oversaturation (OS) and undersaturation (US) batch method, with contact time from 7 to 28 days, ionic strength of 0.1 mol·dm⁻³ (adjusted with NaCl), initial concentration of niobium of 10⁻² mol·dm⁻³ and analysis of precipitate with X-ray diffractmetry. Determination of concentration of niobium in the second run was carried out with inductively-coupled plasma mass spectrometry (ICP-MS), while the first run was with inductively-coupled plasma optical emission spectroscopy (ICP-OES). The detection limit of samples analyzed by ICP-OES is higher than those analyzed by ICP-MS. Therefore, we discarded the solubility data with pH < 7 in the first run. Furthermore, solubility data around 10⁻⁸ mol·dm⁻³ at the second run should be treated as a maximum value.

Based on above circumstances, we decided to determine equilibrium constants of the following reactions:



Logarithm of apparent equilibrium constants $\log K_{\text{sI}}'$ and $\log K_{5-6}'$ for the reactions (6) and (7), respectively, were determined sequentially with a least-squares fitting at $-\log [\text{H}^+]$ range below 11. Results on the least-squares fitting are shown in Figure 3 as solid and dashed lines, and obtained equilibrium constants at ionic strength of 0.1 mol·dm⁻³ ($\log K'$) and zero ionic strength ($\log K^\circ$) are shown in Table 10. Determination of $\log K^\circ$ values is carried out using the SIT model¹⁷⁾ for the following reactions:

$$\log K_{\text{sI}}' = \log K_{\text{sI}}^\circ + 4 D - 2 I_m (\varepsilon(\text{Nb(OH)}_6^-, \text{Na}^+) + \varepsilon(\text{H}^+, \text{Cl}^-)) \quad (8)$$

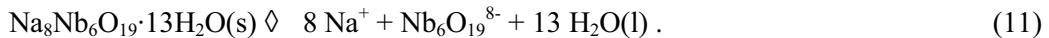
$$\log K_{5-6}' = \log K_{5-6}^\circ + 2 D - I_m (\varepsilon(\text{Nb(OH)}_6^-, \text{Na}^+) + \varepsilon(\text{H}^+, \text{Cl}^-)), \quad (9)$$

where I_m denotes molal ionic strength and D denotes the Debye-Hückel term:

$$D \mid \frac{0.509\sqrt{I_m}}{121.5\sqrt{I_m}} . \quad (10)$$

The ion interaction coefficient of $\varepsilon(\text{H}^+, \text{Cl}^-) = 0.12 \pm 0.01$ was taken from the NEA-TDB ¹²⁾ and that of $\varepsilon(\text{Nb}(\text{OH})_6^-, \text{Na}^+) = -0.07 \pm 0.11$ was estimated as an average value among hydrolysis species with a net charge of -1, i.e. $\varepsilon(\text{SiO}(\text{OH})_3^-, \text{Na}^+)$, $\varepsilon(\text{Si}_2\text{O}_2(\text{OH})_5^-, \text{Na}^+)$, $\varepsilon(\text{B}(\text{OH})_4^-, \text{Na}^+)$, $\varepsilon(\text{NpO}_2(\text{OH})_2^-, \text{Na}^+)$ and $\varepsilon(\text{UO}_2(\text{OH})_3^-, \text{Na}^+)$ in the NEA-TDB ¹²⁾. Hydrogen-ion concentration exponent was also estimated from pH values reported in the literature ^{57,58)} using the SIT model.

Solubility of niobium by Yajima *et al.* ^{57,58)} at $-\log [\text{H}^+]$ range above 11 does not depend on $-\log [\text{H}^+]$ as shown in Figure 3, and the solubility value using Reaction (2) is overestimated. Some articles (e.g. Wu *et al.* ⁶¹⁾) indicate that $\text{Nb}_2\text{O}_5(\text{s})$ transforms to $\text{Na}_8\text{Nb}_6\text{O}_{19} \cdot 13\text{H}_2\text{O}(\text{s})$ and hexaniobate ions $\text{H}_m\text{Nb}_6\text{O}_{19}^{(8-m)-}$ ($m: 1 - 3$) form an aqueous species (e.g. Neumann ⁶²⁾) in alkaline solutions. The obtained solubility data at $-\log [\text{H}^+] > 11$ could be interpreted using solubility limiting solid of $\text{Na}_8\text{Nb}_6\text{O}_{19} \cdot 13\text{H}_2\text{O}(\text{s})$ and aqueous species of $\text{Nb}_6\text{O}_{19}^{8-}$ as following reactions:



However, we have found thermodynamic data for neither $\text{Na}_8\text{Nb}_6\text{O}_{19} \cdot 13\text{H}_2\text{O}(\text{s})$ nor $\text{Nb}_6\text{O}_{19}^{8-}$. Furthermore, there is an article concerning the solubility of niobium under cementitious conditions ⁶³⁾ showing that the solubility of niobium(V) decreases with increasing concentration of calcium. Thus further investigations are required for determination of thermodynamic data in highly alkaline solutions.

3.3.4 Molybdenum

No thermodynamic database for molybdenum has been published by the OECD/NEA. We surveyed and reviewed more than 70 articles. We focused selection on equilibrium constants for monomeric molybdenum species (e.g. molybdate MoO_4^{2-}) which were considered to be important for the performance assessment of geological disposal, while most studies focused on determining equilibrium constants for polymeric (mainly heptameric ($\text{Mo}_7\text{O}_{24}^{6-}$))

species which were considered to form only under acidic conditions. We also selected the equilibrium constants for solid molybdates.

The selected values are shown in Table 11. Detailed selection of these thermodynamic data for molybdenum is summarized in the supporting report.⁶⁴⁾

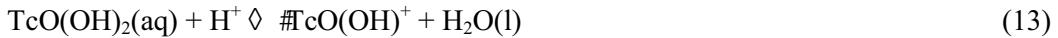
3.3.5 Technetium

The thermodynamic database of technetium was published by the OECD/NEA in 1999³⁾ and revised in 2003¹¹⁾. We surveyed the latest literature and found solubility data of technetium(IV) by Hess *et al.*⁶⁵⁾

Hess *et al.*⁶⁵⁾ carefully measured the solubility of $TcO_2 \cdot xH_2O(am)$ in NaCl media under acidic and anoxic conditions. The ionic strength of the solution was varied from dilute (only containing a reducing agent) solutions through $5.0 \text{ mol} \cdot \text{dm}^{-3}$, and correction of ionic strength was performed using the Pitzer model. Since the correction of ionic strength for the JAEA-TDB should be carried out using the SIT model, we tried to reinterpret the solubility data in 0.8 and $2.5 \text{ mol} \cdot \text{dm}^{-3}$ NaCl solutions. We did not use the solubility data in $5.0 \text{ mol} \cdot \text{dm}^{-3}$ NaCl solution because of the applicable upper limit of the ionic strength for the SIT model (around $3 \text{ mol} \cdot \text{dm}^{-3}$)⁶⁶⁾. Both the NEA-TDB¹¹⁾ and Hess *et al.*⁶⁵⁾ derived thermodynamic data of formation for TcO^{2+} as an upper limit value, and we found that the contribution of TcO^{2+} against other species/compounds was arbitrary. Hence we assumed the selected (upper limit) value of $\log_{10} K^\circ$ of < 4 for the following reaction:



We applied a least-squares regression to the experimental values at respective ionic strength, and obtained apparent equilibrium constants ($\log_{10} K^*$) and $\log_{10} K^\circ$ values for the following reactions:



The obtained values are shown in Table 12, and we select these values for the JAEA-TDB. The ion interaction coefficient $\varepsilon(TcOOH^+, Cl^-)$ of 0.11 ± 0.01 was obtained from the regression. It is notable that the obtained $\log_{10} K^\circ$ value for reaction (13) is two orders of magnitude larger

than the value selected in the NEA-TDB¹¹⁾.

For other thermodynamic data, we took the values selected in the NEA-TDB¹¹⁾, with excluding those unlikely to be useful in applying thermodynamic data for geochemical calculations.

3.3.6 Palladium

3.3.6.1 Selected Values in Previous TDBs

Thermodynamic data for palladium(II) in the JNC-TDB²⁾ were taken from Lothenbach *et al.*⁶⁾, which selected monomeric palladium (Pd(cr)), equilibrium constants of chloride complexes (PdCl_n^{2-n} , $n = 1 - 4$), mixed chloride-hydroxide complexes ($\text{PdCl}_3\text{OH}^{2-}$ and $\text{PdCl}_2(\text{OH})_2^{2-}$) and ammonium complexes ($\text{Pd}(\text{NH}_3)_n^{2+}$, $n = 1 - 4$) of palladium(II). The solubility product of palladium(II) hydroxide and hydrolysis constants were not selected by Lothenbach *et al.*⁶⁾, although the solubility product and hydrolysis constants are quite important for performance assessment of geological disposal of radioactive waste. The solubility product of $\text{Pd}(\text{OH})_2(\text{s})$ and hydrolysis constants of $\text{Pd}(\text{OH})_n^{2-n}$ ($n = 2$ and 3) were roughly estimated with a large uncertainty in PSI-TDB¹⁵⁾, in addition to the data selected by Lothenbach *et al.*⁶⁾

3.3.6.2 Hydroxides and Hydrolysis Species

To obtain thermodynamic data for the Pd-OH system, we reinterpreted the thermodynamic data using solubility data^{67, 68)} shown in Figure 6 using the SIT model. We took the solubility data only in NaClO_4 and NaOH media and excluded those in KCl medium to avoid complexation and precipitation with chloride ion. A least-squares regression was applied to the solubility data after correcting their activity using the SIT model as shown in Figure 6. The solubility product of $\text{Pd}(\text{OH})_2(\text{s})$, hydrolysis constants of $\text{Pd}(\text{OH})_n^{2-n}$ ($n = 1, 2$ and 3) were obtained as shown in Table 13, and ion interaction coefficients of $\varepsilon(\text{Pd}^{2+}, \text{ClO}_4^-) = 0.34 \pm 0.06$, $\varepsilon(\text{PdOH}^+, \text{ClO}_4^-) = 0.41 \pm 0.72$ and $\varepsilon(\text{Pd}(\text{OH})_3^-, \text{Na}^+) = -0.10 \pm 0.28$ were obtained. Detail of determination of the solubility product and the hydrolysis constants is summarized in the supporting article⁶⁹⁾. We selected the obtained values for JAEA-TDB.

3.3.6.3 Aqueous Chloride Complexes

Boily and Seward⁷⁰⁾ determined equilibrium constants of chloride complexes of Pd with UV-Vis spectrophotometry from 278.15 to 398.15 K. They also carried out review of previous literature concerning equilibrium constants of chloride complexes, including those by Elding⁷¹⁾

and Levanda *et al.*⁷²⁾, which have been selected in JNC-TDB²⁾ and PSI-TDB¹⁵⁾, respectively. The strong ligand-to-metal charge transfer bands of the palladium complexes below 350 nm were used to constrain the stepwise thermodynamic formation constants at each temperature. The temperature-dependent constants were used to obtain changes in enthalpy and entropy for each reaction. The equilibrium constants of chloride complexes ($\text{PdCl}_{r-1}^{3-r} + \text{Cl}^- \rightleftharpoons \text{PdCl}_r^{2-r}$; $r = 1 - 4$) from 5 to 125 °C corresponding to the following equation were obtained:



The equilibrium constants at 298.15 °K were obtained by interpolating the dependence of the equilibrium constant on temperature.

Boily and Seward⁷⁰⁾ exhaustively reviewed previous literatures about thermodynamic values of chloride complexes of palladium, and they obtained thermodynamic values for chloride complexes of Pd by their own detailed experiments. However, they derived $\log K^\circ$ values using an extended Debye-Hückel equation rather than the SIT model. Therefore, we selected their thermodynamic values with the addition of larger uncertainties of $\pm 0.200 \log_{10}$ units for equation (15). The selected equilibrium constants are summarized in Table 13.

3.3.6.4 Aqueous Nitrate Complexes

We found an article by Frias *et al.*⁷³⁾, wherein they reported equilibrium constants for PdNO_3^+ , $\text{Pd}(\text{NO}_3)_2(\text{aq})$ and $\text{PdNO}_3\text{OH}(\text{aq})$ using the spectrophotometric method. Frias *et al.* carefully prepared solutions with the activity of water of 0.75 using perchlorate and nitrate media, measured absorption spectra, obtained molar absorption coefficient at 380, 392 and 415 nm, and estimated the equilibrium constants at 298.15 °K. They found that an absorption maximum of Pd^{2+} (in perchlorate media) was around 380 nm and that of nitrate complexes of Pd (in nitrate media) was around 415 nm. The equilibrium constants were estimated with a least-squares fitting to the molar absorption coefficient. The obtained equilibrium constants are shown in Table 13. We did not find any other experimental works or thermodynamic values for the $\text{Pd}^{2+}\text{-NO}_3^-$ system. Therefore, we selected the equilibrium constants reported by Frias *et al.* as tentative values.

3.3.6.5 Other Species and Summary

Other thermodynamic data for mixed chloride-hydroxide complexes and ammonium

complexes for palladium(II) were taken from those in the JNC-TDB.²⁾

3.4 Elements of Groups 14 (carbon group) – 17 (halogen)

3.4.1 Selenium

The thermodynamic database of Se was published by the OECD/NEA in 2005⁹⁾. We basically agreed with the selected values by the OECD/NEA⁹⁾ but made some modifications in the selection of thermodynamic data for selenium. The JNC-TDB²⁾ selected the equilibrium constant for iron diselenide (FeSe_2) which is based on transformation of selenium precipitate from $\text{Se}(\text{cr})$ to $\text{FeSe}_2(\text{cr})$ ⁷⁴⁾. This was not selected in the NEA-TDB⁹⁾. The equilibrium constants for iron-selenide precipitates could be estimated using the $\delta_f G_m^\circ$ values listed in “the best values currently available” in the NEA-TDB⁹⁾, though the listed values were not critically reviewed and selected.

We estimated and tentatively selected the equilibrium constants for $\text{FeSe}_2(\text{cr})$, $\beta\text{-Fe}_{1.04}\text{Se}$, $\gamma\text{-Fe}_3\text{Se}_4$ and $\alpha\text{-Fe}_7\text{Se}_8$ as shown in Table 14. In this estimation, the $\delta_f G_m^\circ$ value for Fe^{2+} ($-90.20 \pm 2.00 \text{ kJ}\cdot\text{mol}^{-1}$) was taken from Robie and Hemingway⁷⁵⁾ and uncertainties were estimated by us.

In addition to the data discussed above, we took thermodynamic data in the NEA-TDB⁹⁾ without any modifications. Detailed selection of thermodynamic data for selenium is summarized in the supporting report.⁷⁶⁾

3.4.2 Tin

Lothenbach *et al.*⁶⁾ reviewed the thermodynamic data for tin which the JNC-TDB²⁾ selected. Although literature was surveyed, we did not find any later articles than those reviewed by Lothenbach *et al.*⁶⁾ Therefore, we decided to accept the values selected in the JNC-TDB.²⁾

3.4.3 Iodine

Thermodynamic values of iodine, which are considered to be important for performance assessment of geological disposal of TRU, have been selected in auxiliary data in the NEA-TDB¹²⁾. The JNC-TDB²⁾ additionally selected the equilibrium constants by Cross *et al.*⁷⁷⁾ Although the values selected in the JNC-TDB were not carefully reviewed, we tentatively took these values in the NEA-TDB¹²⁾ and by Cross *et al.*⁷⁷⁾ for the JAEA-TDB.

3.4.4 Antimony

Lothenbach *et al.*⁶⁾ reviewed the thermodynamic data for antimony which the JNC-TDB²⁾ selected. Although literature surveyed, we did not find any later articles than those reviewed by Lothenbach *et al.*⁶⁾ Therefore, we decided to accept the values selected in the JNC-TDB.²⁾

3.4.5 Lead

Lothenbach *et al.*⁶⁾ reviewed the thermodynamic data for lead which the JNC-TDB²⁾ selected. We surveyed the latest literature and found two papers which appeared in print since the Lothenbach *et al.*⁶⁾ review. One of these papers dealt with hydrolysis constants (Perera *et al.*⁷⁸⁾) and the other with chloride complexes (Luo and Millero⁷⁹⁾). We carefully reviewed these papers and decided to accept them. Together with accepted values by Lothenbach *et al.*⁶⁾, we obtained $\log K^\circ$ and the ion interaction coefficient values of hydrolysis species ($\text{Pb}(\text{OH})_n^{2-n}$, $n = 1 - 4$) and chloride complexes (PbCl_m^{2-m} , $m = 1 - 3$) for the following equations using the SIT model:



The additionally selected and modified equilibrium constants are summarized in Table 15. Detailed selection of thermodynamic data for lead is summarized in the supporting report.⁸⁰⁾

3.4.6 Bismuth

Lothenbach *et al.*⁶⁾ conducted a review of thermodynamic data for bismuth. This review was used as a thermodynamic data source in the JNC-TDB²⁾ and was also the basis for thermodynamic data selection by the Swiss repository program. We conducted a literature survey of data published since 1999 and find that with the exception of a publication by Rai *et al.*⁸¹⁾ no additional data have become available.

Rai *et al.*⁸¹⁾ conducted extensive studies on the solubility of $\text{BiPO}_4(\text{cr})$ in a wide range of pH values (0 – 15), phosphate concentrations (0.0003 – 1.0 mol·kg⁻¹), and chloride concentrations (0 – 0.7 mol·kg⁻¹). They interpreted their data using the SIT that included the values for the equilibrium constants for the formation of Bi-Cl complexes based on their critical review of the literature data. Their study showed that $\text{BiPO}_4(\text{cr})$ is stable at pH values below 9

and converts to $\text{Bi}(\text{OH})_3(\text{am})$ at pH values above 9. They presented new data for the bismuth-phosphate system for which no data were previously available. They also reported data on the key bismuth-hydroxide system along with thermodynamic data of the bismuth-chloride system which was verified by experiments in the mixed chloride-hydroxide systems.

For use in our repository program we have selected the thermodynamic data (equilibrium constants and SIT ion interaction parameters) given by Rai *et al.*⁸¹⁾, supplemented by data from Lothenbach *et al.*⁶⁾. The additionally selected and modified equilibrium constants are summarized in Table 16.

3.4.7 Polonium

The JNC-TDB²⁾ selected only an equilibrium constant for polonium from the NBS Table⁵⁹⁾. Although we surveyed literatures, we did not find any later publications. Therefore, we decided to take the values selected in the JNC-TDB.²⁾

3.5 Thermodynamic Data with Selected Organic Ligands

3.5.1 Thermodynamic Data with Organic Ligands Contained in Groundwaters

Thermodynamic constants for metal-ion bindings by natural organic ligands, e.g. humic substances, are not rigorously characterized, because stoichiometries are difficult to determine in these poorly characterized and heterogeneous systems. Although it is difficult to select the unique thermodynamic values for the humic substances, semi-empirical binding constants, which can act like a thermodynamic constant, have been used to describe the metal-ion bindings by humic substances. These binding constants are parameters that are obtained by fitting of humic ion binding models to experimental datasets (i.e., metal-ion binding isotherms). The humic ion-binding models consider site heterogeneity, multicomponent competition and electrostatic interactions. The semi-empirical binding constants obtained are independent on solution conditions (e.g., concentration of metal ions, pH, salt concentration and concentration of competitive metal ions). Thus it is obvious that semi-empirical binding constants are of more advantage for modeling the metal-ion bindings by humic substances over a wide range of solution conditions, compared with apparent binding constants that are depend on the solution conditions.

Several ion-binding models, together with the semi-empirical binding constants, are available to date. Among them the Model VI⁸²⁾ and the Non-Ideal Competitive Adsorption

(NICA)-Donnan model⁸³⁾ are typical, useful and advanced for modeling the interactions between metal ions and humic substances. The noteworthy difference between the two models is known to be a treatment of heterogeneity: the Model VI⁸²⁾ assumes discrete the binding constants, while the NICA-Donnan model⁸³⁾ assumes a continuous distribution of the binding constants. However, this is not the real difference in underlying principle between the two models, because it would be possible to increase the number of sites in Model VI⁸²⁾ to get closer to a continuous description, and without involving more parameters.

Although metal-ion binding parameter sets need to calculate the speciation of metal ions in the presence of humic substances over a wide range of solution conditions, generic metal-ion binding parameters for 23 metal ions have been already built for the two models. For the Model VI, Tipping^{82,84)} proposed the generic parameters for the following metal ions: aluminum, americium, barium, calcium, cadmium, curium, cobalt, chromium(III), copper, dysprosium, europium, iron(II,III), mercury, magnesium, manganese, nickel, lead, strontium, thorium(IV), uranyl, vanadanyl and zinc. In the same manner, Milne *et al.*^{85,86)} proposed the generic NICA-Donnan model parameters for the metal ions. The generic parameters for the two models have been built for fulvic and humic acids from different origins. Thus little difference in the generic parameter sets between the two models is found from exhaustive and reliable point of view.

Based on the above findings, it is concluded that the two models with the generic parameters can almost equally perform in prediction of the metal-ion bindings by humic substances. In fact, Unsworth *et al.*⁸⁷⁾ have shown that the Model VI and the NICA-Donnan model using the generic parameters can predict the distribution of dominant species of trace metals (e.g., cadmium, copper, nickel, lead) in freshwater with reasonable accuracy. However, the NICA-Donnan model is considered to be more familiar than the Model VI for applying to the geochemical calculation programs, because the NICA-Donnan model is a much simpler model in terms of the number of equations required for its description. Metal ion binding in the NICA-Donnan model is computed as a distribution from the outset, while, in Model VI, each of its 80 binding sites has to be considered separately at each iteration⁸⁴⁾. Therefore, we believe that the NICA-Donnan model is slightly better than the Model VI to incorporate into the thermodynamic database. However, we need further discussions for describing the metal-ion bindings by humic substances and incorporation of the semi-empirical binding constants into the thermodynamic database.

3.5.2 Thermodynamic Data with Organic Ligands from Waste Packages

The thermodynamic database of nickel, selenium, zirconium, technetium, uranium, neptunium, plutonium and americium with selected organic ligands was published by the OECD/NEA in 2005²²⁾. Oxalic acid, citric acid, ethylenediaminetetraacetic acid (EDTA) and isosaccharinic acid (ISA) were of interest in the NEA-TDB²²⁾. We took the equilibrium constants selected in the NEA-TDB²²⁾. We also tentatively select formation constants by Smith and Martell^{88, 89)} and those obtained from a linear free energy relationship for some organic complexes shown in Table 17. At the moment, the selected values in the NEA-TDB²²⁾ are neither comprehensive nor sufficient for the performance assessment of geological disposal, hence further investigation for selection of the formation constants for excluded organic ligands using chemical analogues or models should be carried out as shown in the supporting report⁹⁰⁾.

4. Conclusions and Future Tasks

The thermodynamic database developed by Japan Nuclear Cycle Development Institute in 1999 (JNC-TDB) was updated after review and selection of the latest thermodynamic data and databases. Most of the equilibrium constants were revised from the JNC-TDB with evaluation or estimation of uncertainties which showed reliability of the selected values. The presently developed thermodynamic database (JAEA-TDB) will be ready for some geochemical calculation programs (PHREEQC, EQ3/6, Geochemist's Workbench, etc.) at the Website: <http://migrationdb.jaea.go.jp/>.

We would like to mention some future tasks to improve reliability of the JAEA-TDB for use with the geochemical calculation programs. Although selected equilibrium constants have been extrapolated to zero ionic strength with the Brønsted-Guggenheim-Scatchard model (SIT model), evaluation of apparent equilibrium constants in given groundwater conditions is neither able to perform directly nor easy. In our preliminary investigation⁹¹⁾, solubility of elements of interest using the SIT model for activity corrections are a few times larger than that using the Davies model available in the PHREEQC program. Development or installation of the SIT model into the geochemical calculation programs should be carried out. Furthermore, propagation of error is not applicable in the present geochemical calculation programs. We should also try to develop or install the error propagation calculations to the geochemical calculation programs. Needless to say, the latest thermodynamic data should be reviewed and updated periodically.

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Table 1 Additionally selected thermodynamic data for thorium for JAEA-TDB

Reaction	$\log_{10} K^\circ$	Ref.
$\text{Th}^{4+} + 8 \text{OH}^- + 4 \text{Ca}^{2+} \rightleftharpoons \text{Ca}_4[\text{Th}(\text{OH})_8]^{4+}$	49.3 ± 0.9	28 *
$\text{Th}^{4+} + 3 \text{H}_4\text{SiO}_4(\text{aq}) + 3 \text{H}_2\text{O(l)} \rightleftharpoons \text{Th}(\text{OH})_3(\text{H}_3\text{SiO}_4)_3^{2-} + 6 \text{H}^+$	-27.8 ± 0.7	29 *

* Based on the data in the quoted reference in combination with the solubility product ($\log_{10} K^\circ = -46.7 \pm 0.9$) of $\text{ThO}_2(\text{am})$ quoted in the NEA-TDB.¹²⁾

Table 2 Additionally selected or modified thermodynamic data for protactinium(V) for JAEA-TDB

Reaction	$\log_{10} K^\circ$	Ref.
$\text{PaOOH}^{2+} + \text{H}_2\text{O(l)} \rightleftharpoons \text{PaO(OH)}_2^+ + \text{H}^+$	-1.260 ± 0.150	32
$\text{PaO(OH)}_2^+ + 2 \text{H}_2\text{O(l)} \rightleftharpoons \text{Pa(OH)}_5(\text{aq}) + \text{H}^+$	-7.150 ± 0.400	32
$\text{PaOOH}^{2+} + \text{Cl}^- \rightleftharpoons \text{PaOOHCl}^+$	0.567 ± 0.020	present
$\text{PaOOH}^{2+} + \text{SO}_4^{2-} + \text{H}^+ \rightleftharpoons \text{PaOSO}_4^+ + \text{H}_2\text{O(l)}$	3.890 ± 0.180	35
$\text{PaOOH}^{2+} + 2 \text{SO}_4^{2-} + \text{H}^+ \rightleftharpoons \text{PaO(SO}_4)_2^- + \text{H}_2\text{O(l)}$	7.000 ± 0.200	35
$\text{PaOOH}^{2+} + 3 \text{SO}_4^{2-} + \text{H}^+ \rightleftharpoons \text{PaO(SO}_4)_3^{3-} + \text{H}_2\text{O(l)}$	8.590 ± 0.230	35

Table 3 Additionally selected or modified thermodynamic data for uranium(IV)
for JAEA-TDB

Reaction	$\log_{10} K^\circ$	
	JAEA-TDB ³⁰⁾	NEA-TDB ¹¹⁾
$\text{U}^{4+} + 4 \text{OH}^4 \rightleftharpoons \text{UO}_2(\text{am}) + 2 \text{H}_2\text{O}$	53.70 ± 1.00	54.50 ± 1.00
$\text{U}^{4+} + \text{H}_2\text{O(l)} \rightleftharpoons \text{UOH}^{3+} + \text{H}^+$	-0.29 ± 0.31	-0.54 ± 0.06
$\text{U}^{4+} + 2 \text{H}_2\text{O(l)} \rightleftharpoons \text{U(OH)}_2^{2+} + 2 \text{H}^+$	-1.78 ± 0.21	—
$\text{U}^{4+} + 3 \text{H}_2\text{O(l)} \rightleftharpoons \text{U(OH)}_3^+ + 3 \text{H}^+$	-5.15 ± 0.21	—
$\text{U}^{4+} + 4 \text{H}_2\text{O(l)} \rightleftharpoons \text{U(OH)}_4(\text{aq}) + 4 \text{H}^+$	-10.80 ± 1.40	-10.00 ± 1.40
$\text{U}^{4+} + 5 \text{CO}_3^{2-} \rightleftharpoons \# \text{U}(\text{CO}_3)_5^{6-}$	31.50 ± 1.00	34.00 ± 0.90
$\text{U}^{4+} + 2 \text{CO}_3^{2-} + 2 \text{OH}^- \rightleftharpoons \# \text{U}(\text{CO}_3)_2(\text{OH})_2^{2-}$	41.56 ± 1.00	—
$\text{U}^{4+} + \text{Si}(\text{OH})_4 \rightleftharpoons \text{USiO}_4(\text{s}) + 4 \text{H}^+$	2.98 ± 2.00	—

Table 4 Additionally selected or modified thermodynamic data for neptunium(IV)
for JAEA-TDB

Reaction	$\log_{10} K^\circ$	
	JAEA-TDB ³⁰⁾	NEA-TDB ¹¹⁾
$\text{Np}^{4+} + 4 \text{OH}^4 \rightleftharpoons \text{NpO}_2(\text{am}) + 2 \text{H}_2\text{O}$	55.40 ± 1.00	56.70 ± 0.50
$\text{Np}^{4+} + \text{H}_2\text{O(l)} \rightleftharpoons \text{NpOH}^{3+} + \text{H}^+$	-0.09 ± 0.30	0.55 ± 0.20
$\text{Np}^{4+} + 2 \text{H}_2\text{O(l)} \rightleftharpoons \text{Np(OH)}_2^{2+} + 2 \text{H}^+$	0.87 ± 0.15	0.35 ± 0.30
$\text{Np}^{4+} + 3 \text{H}_2\text{O(l)} \rightleftharpoons \text{Np(OH)}_3^+ + 3 \text{H}^+$	4.30 ± 0.30	—
$\text{Np}^{4+} + 4 \text{H}_2\text{O(l)} \rightleftharpoons \text{Np(OH)}_4(\text{aq}) + 4 \text{H}^+$	-9.60 ± 1.10	-8.30 ± 1.10
$\text{Np}^{4+} + 2 \text{CO}_3^{2-} + 2 \text{OH}^- \rightleftharpoons \# \text{Np}(\text{CO}_3)_2(\text{OH})_2^{2-}$	44.39 ± 1.21	—
$\text{Np}^{4+} + \text{CO}_3^{2-} + 4 \text{OH}^- \rightleftharpoons \# \text{NpCO}_3(\text{OH})_4^{2-}$	49.20 ± 1.02	—

Table 5 Additionally selected or modified thermodynamic data for plutonium(IV)
for JAEA-TDB

Reaction	$\log_{10} K^\circ$	
	JAEA-TDB ³⁰⁾	NEA-TDB ¹¹⁾
$\text{Pu}^{4+} + \text{H}_2\text{O(l)} \rightleftharpoons \text{PuOH}^{3+} + \text{H}^+$	0.00 ± 0.20	0.60 ± 0.20
$\text{Pu}^{4+} + 2 \text{H}_2\text{O(l)} \rightleftharpoons \text{Pu(OH)}_2^{2+} + 2 \text{H}^+$	-1.20 ± 0.60	0.60 ± 0.30
$\text{Pu}^{4+} + 3 \text{H}_2\text{O(l)} \rightleftharpoons \text{Pu(OH)}_3^+ + 3 \text{H}^+$	-3.10 ± 0.90	-2.30 ± 0.40
$\text{Pu}^{4+} + 4 \text{H}_2\text{O(l)} \rightleftharpoons \text{Pu(OH)}_4(\text{aq}) + 4 \text{H}^+$	-8.50 ± 0.50	-8.50 ± 0.50
$\text{Pu}^{4+} + 2 \text{CO}_3^{2-} + 2 \text{OH}^- \rightleftharpoons \# \text{Pu}(\text{CO}_3)_2(\text{OH})_2^{2-}$	47.18 ± 1.25	—

Table 6 Selected thermodynamic data for alkaline metal earths for JAEA-TDB

Reaction	$\log_{10} K^\circ$	Ref.
$\text{Ca}^{2+} + \text{H}_2\text{O} = \text{CaOH}^+ + \text{H}^+$	-12.85 ± 0.05	92
$\text{CaCO}_3(\text{calcite}) = \text{Ca}^{2+} + \text{CO}_3^{2-}$	-8.46 ± 0.01	49
$\text{Sr}^{2+} + \text{H}_2\text{O} = \text{SrOH}^+ + \text{H}^+$	-13.29 ± 0.50	49
$\text{SrCO}_3(\text{strontianite}) = \text{Sr}^{2+} + \text{CO}_3^{2-}$	-9.25 ± 0.01	49
$\text{Sr}^{2+} + \text{SO}_4^{2-} = \text{SrSO}_4(\text{aq})$	1.86 ± 0.03	49
$\text{SrSO}_4(\text{celestite}) = \text{Sr}^{2+} + \text{SO}_4^{2-}$	-6.62 ± 0.02	49
$\text{Ba}^{2+} + \text{H}_2\text{O} = \text{BaOH}^+ + \text{H}^+$	-13.47 ± 0.50	49
$\text{BaCO}_3(\text{witherite}) = \text{Ba}^{2+} + \text{CO}_3^{2-}$	-8.54 ± 0.03	49
$\text{Ba}^{2+} + \text{SO}_4^{2-} = \text{BaSO}_4(\text{aq})$	2.72 ± 0.09	49
$\text{BaSO}_4(\text{barite}) = \text{Ba}^{2+} + \text{SO}_4^{2-}$	-10.05 ± 0.05	49
$\text{Ra}^{2+} + \text{H}_2\text{O} = \text{RaOH}^+ + \text{H}^+$	-13.47 ± 0.50	49
$\text{RaCO}_3(\text{cr}) = \text{Ra}^{2+} + \text{CO}_3^{2-}$	-8.54 ± 0.20	49
$\text{Ra}^{2+} + \text{SO}_4^{2-} = \text{RaSO}_4(\text{aq})$	2.72 ± 0.09	49
$\text{RaSO}_4(\text{cr}) = \text{Ra}^{2+} + \text{SO}_4^{2-}$	-10.05 ± 0.39	49

Table 7 Selected thermodynamic data for cobalt compounds and aqueous species for
JAEA-TDB⁵¹⁾

Reaction	$\log_{10} K^\circ$
$\text{Co(cr)} \rightleftharpoons \text{Co}^{2+} + 2 \text{e}^-$	9.530 ± 0.175
$\text{CoO(cr)} + 2 \text{H}^+ \rightleftharpoons \text{Co}^{2+} + \text{H}_2\text{O(l)}$	$12.399 \pm 0.326^*$
$\text{H}_2\text{O(l)} + \text{Co}^{2+} \rightleftharpoons \text{H}^+ + \text{CoOH}^+$	-9.470 ± 0.020
$2 \text{H}_2\text{O(l)} + \text{Co}^{2+} \rightleftharpoons 2 \text{H}^+ + \beta\text{-Co(OH)}_2$	-12.430 ± 0.170
$2 \text{H}_2\text{O(l)} + \text{Co}^{2+} \rightleftharpoons 2 \text{H}^+ + \text{Co(OH)}_2(\text{aq})$	-18.000 ± 1.100
$3 \text{H}_2\text{O(l)} + \text{Co}^{2+} \rightleftharpoons 3 \text{H}^+ + \text{Co(OH)}_3^-$	-31.500 ± 0.500
$\text{H}_2\text{O(l)} + 2 \text{Co}^{2+} \rightleftharpoons \text{H}^+ + \text{Co}_2\text{OH}^{3+}$	$-10.548 \pm 0.861^*$
$4 \text{H}_2\text{O(l)} + 4 \text{Co}^{2+} \rightleftharpoons 4 \text{H}^+ + \text{Co}_4(\text{OH})_4^{4+}$	$-27.371 \pm 0.211^*$
$\text{F}^- + \text{Co}^{2+} \rightleftharpoons \text{CoF}^+$	1.470 ± 0.040
$\text{Cl}^- + \text{Co}^{2+} \rightleftharpoons \text{CoCl}^+$	0.810 ± 0.070
$\text{CoCl}_2 \cdot 4\text{H}_2\text{O(cr)} \rightleftharpoons \text{H}_2\text{O(g)} + \text{CoCl}_2 \cdot 2\text{H}_2\text{O(cr)}$	$-4.085 \pm 0.076^*$
$\text{CoCl}_2 \cdot 6\text{H}_2\text{O(cr)} \rightleftharpoons 2 \text{H}_2\text{O(g)} + \text{CoCl}_2 \cdot 4\text{H}_2\text{O(cr)}$	$-3.764 \pm 0.063^*$
$2 \text{Cl}^- + 6 \text{H}_2\text{O(l)} + 2 \text{Co}^{2+} \rightleftharpoons \text{CoCl}_2 \cdot 6\text{H}_2\text{O(cr)}$	$-3.037 \pm 0.018^*$
$2 \text{IO}_3^- + \text{Co}^{2+} \rightleftharpoons \beta\text{-Co(IO}_3)_2$	$4.395 \pm 0.088^*$
$2 \text{H}_2\text{O(l)} + 2 \text{IO}_3^- + \text{Co}^{2+} \rightleftharpoons \text{Co(IO}_3)_2 \cdot 2\text{H}_2\text{O(cr)}$	$5.101 \pm 0.177^*$
$\text{S}^{2-} + \text{Co}^{2+} \rightleftharpoons \text{CoS(aq)}$	19.600 ± 0.500
$\text{HS}^- + \text{Co}^{2+} \rightleftharpoons \alpha\text{-CoS} + \text{H}^+$	7.440 ± 0.120
$\text{HS}^- + \text{Co}^{2+} \rightleftharpoons \beta\text{-CoS} + \text{H}^+$	11.100 ± 1.700
$\text{HS}^- + \text{Co}^{2+} \rightleftharpoons \text{CoHS}^+$	$5.141 \pm 0.277^*$
$6 \text{H}_2\text{O(l)} + \text{Co}^{2+} + \text{SO}_4^{2-} \rightleftharpoons \alpha\text{-CoSO}_4 \cdot 6\text{H}_2\text{O}$	$2.229 \pm 0.279^*$
$\alpha\text{-CoSO}_4 \cdot 6\text{H}_2\text{O} \rightleftharpoons \beta\text{-CoSO}_4 \cdot 6\text{H}_2\text{O}$	$-0.105 \pm 0.374^*$
$7 \text{H}_2\text{O(l)} + \text{Co}^{2+} + \text{SO}_4^{2-} \rightleftharpoons \text{CoSO}_4 \cdot 7\text{H}_2\text{O(cr)}$	$2.245 \pm 0.058^*$
$\text{Co}^{2+} + \text{SO}_4^{2-} \rightleftharpoons \text{CoSO}_4(\text{aq})$	2.200 ± 0.050
$\text{Co}^{2+} + 2 \text{SO}_4^{2-} \rightleftharpoons \text{Co}(\text{SO}_4)_2^{2-}$	2.870 ± 0.050
$\text{NO}_3^- + \text{Co}^{2+} \rightleftharpoons \text{CoNO}_3^+$	-1.020 ± 0.060
$\text{NH}_3(\text{aq}) + \text{Co}^{2+} \rightleftharpoons \text{CoNH}_3^{2+}$	2.200 ± 0.100
$2 \text{NH}_3(\text{aq}) + \text{Co}^{2+} \rightleftharpoons \text{Co}(\text{NH}_3)_2^{2+}$	3.900 ± 0.200
$3 \text{NH}_3(\text{aq}) + \text{Co}^{2+} \rightleftharpoons \text{Co}(\text{NH}_3)_3^{2+}$	5.400 ± 0.400
$4 \text{NH}_3(\text{aq}) + \text{Co}^{2+} \rightleftharpoons \text{Co}(\text{NH}_3)_4^{2+}$	6.400 ± 0.400
$5 \text{NH}_3(\text{aq}) + \text{Co}^{2+} \rightleftharpoons \text{Co}(\text{NH}_3)_5^{2+}$	6.700 ± 0.400
$6 \text{NH}_3(\text{aq}) + \text{Co}^{2+} \rightleftharpoons \text{Co}(\text{NH}_3)_6^{2+}$	5.900 ± 0.400
$\text{HPO}_4^{2-} + \text{Co}^{2+} \rightleftharpoons \text{CoHPO}_4(\text{aq})$	2.950 ± 0.140
$\text{P}_2\text{O}_7^{4-} + \text{Co}^{2+} \rightleftharpoons \text{CoP}_2\text{O}_7^{2-}$	$8.671 \pm 0.375^*$
$\text{HP}_2\text{O}_7^{3-} + \text{Co}^{2+} \rightleftharpoons \text{HCoP}_2\text{O}_7^-$	$5.101 \pm 0.327^*$
$2 \text{H}_2\text{O(l)} + 2 \text{HAsO}_2(\text{aq}) + 3 \text{Co}^{2+} \rightleftharpoons 6 \text{H}^+ + \text{Co}_3(\text{AsO}_3)_2(\text{cr,hyd})$	$-28.544 \pm 0.320^*$
$2 \text{AsO}_4^{3-} + 8 \text{H}_2\text{O(l)} + 3 \text{Co}^{2+} \rightleftharpoons \text{Co}_3(\text{AsO}_4)_2 \cdot 8\text{H}_2\text{O(cr)}$	$27.929 \pm 0.883^*$
$\text{HAsO}_4^{2-} + \text{Co}^{2+} \rightleftharpoons \text{CoHAsO}_4(\text{aq})$	$2.874 \pm 0.346^*$

Table 7 (Continued)

Reaction	$\log_{10} K^\circ$
$\text{CO}_2(\text{g}) + \text{H}_2\text{O}(\text{l}) + \text{Co}^{2+} \rightleftharpoons \text{H}^+ + \text{CoCO}_3(\text{cr})$	$-7.128 \pm 0.092^*$
$\text{CO}_2(\text{g}) + 6.5 \text{ H}_2\text{O}(\text{l}) + \text{Co}^{2+} \rightleftharpoons \text{H}^+ + \text{CoCO}_3 \cdot 5.5\text{H}_2\text{O}(\text{cr})$	$-10.578 \pm 0.034^*$
$\text{CO}_3^{2-} + \text{Co}^{2+} \rightleftharpoons \text{CoCO}_3(\text{aq})$	4.400 ± 0.100
$\text{HCO}_3^- + \text{Co}^{2+} \rightleftharpoons \text{CoHCO}_3^+$	1.400 ± 0.200
$4 \text{ CN}^- + \text{Co}^{2+} \rightleftharpoons \text{Co}(\text{CN})_4^{2-}$	$30.017 \pm 0.533^*$
$5 \text{ CN}^- + \text{Co}^{2+} \rightleftharpoons \text{Co}(\text{CN})_5^{3-}$	$28.327 \pm 0.888^*$
$\text{SCN}^- + \text{Co}^{2+} \rightleftharpoons \text{CoSCN}^+$	$1.790 \pm 0.073^*$
$2 \text{ SCN}^- + \text{Co}^{2+} \rightleftharpoons \text{Co}(\text{SCN})_2(\text{aq})$	$2.665 \pm 0.115^*$
$3 \text{ SCN}^- + \text{Co}^{2+} \rightleftharpoons \text{Co}(\text{SCN})_3^-$	$2.993 \pm 0.229^*$

^{*}tentative valueTable 8 Additionally selected thermodynamic data for nickel compounds and aqueous species for JAEA-TDB ⁵¹⁾

Reaction	$\log_{10} K^\circ$
$\text{NiO}(\text{cr}) + 2 \text{ H}^+ \rightleftharpoons \text{Ni}^{2+} + \text{H}_2\text{O}(\text{l})$	$12.483 \pm 0.154^*$
$2 \text{ H}_2\text{O}(\text{l}) + \text{Ni}^{2+} \rightleftharpoons 2 \text{ H}^+ + \beta\text{-Ni(OH)}_2$	$-11.029 \pm 0.280^*$
$\beta\text{-Ni(OH)}_2 \rightleftharpoons \text{Ni(OH)}_2(\text{aq})$	$< -7.000^*$
$\text{S}^{2-} + \text{Ni}^{2+} \rightleftharpoons \text{NiS}(\text{aq})$	$19.723 \pm 0.228^*$
$\alpha\text{-NiS} + 2 \text{ H}^+ \rightleftharpoons \text{Ni}^{2+} + \text{H}_2\text{S}(\text{aq})$	$-2.518 \pm 0.432^*$
$\beta\text{-NiS} + 2 \text{ H}^+ \rightleftharpoons \text{Ni}^{2+} + \text{H}_2\text{S}(\text{aq})$	$-3.138 \pm 0.432^*$
$\text{Ni}^{2+} + 2 \text{ SO}_4^{2-} \rightleftharpoons \text{Ni}(\text{SO}_4)_2^{2-}$	$2.896 \pm 0.002^*$
$\text{NH}_3(\text{aq}) + \text{Ni}^{2+} \rightleftharpoons \text{NiNH}_3^{2+}$	$2.222 \pm 0.061^*$
$2 \text{ NH}_3(\text{aq}) + \text{Ni}^{2+} \rightleftharpoons \text{Ni}(\text{NH}_3)_2^{2+}$	$3.932 \pm 0.139^*$
$3 \text{ NH}_3(\text{aq}) + \text{Ni}^{2+} \rightleftharpoons \text{Ni}(\text{NH}_3)_3^{2+}$	$5.440 \pm 0.320^*$
$4 \text{ NH}_3(\text{aq}) + \text{Ni}^{2+} \rightleftharpoons \text{Ni}(\text{NH}_3)_4^{2+}$	$6.446 \pm 0.306^*$
$5 \text{ NH}_3(\text{aq}) + \text{Ni}^{2+} \rightleftharpoons \text{Ni}(\text{NH}_3)_5^{2+}$	$6.748 \pm 0.302^*$
$6 \text{ NH}_3(\text{aq}) + \text{Ni}^{2+} \rightleftharpoons \text{Ni}(\text{NH}_3)_6^{2+}$	$5.943 \pm 0.313^*$
$\text{HCO}_3^- + \text{Ni}^{2+} \rightleftharpoons \text{NiHCO}_3^+$	$1.417 \pm 0.173^*$

^{*}tentative value

Table 9 Additionally selected thermodynamic data for zirconium(IV) for JAEA-TDB

Reaction	$\log_{10} K^\circ$ ^{*1}	
$Zr^{4+} + 3 Cl^4 \rightleftharpoons ZrCl_3^+$	3.00 ± 0.45 ⁵⁶⁾	—
$Zr^{4+} + 4 Cl^4 \rightleftharpoons ZrCl_4(aq)$	-1.23 ± 0.50 ⁵⁶⁾	—
$Zr^{4+} + 3 NO_3^- \rightleftharpoons Zr(NO_3)_3^+$	1.04 ± 1.50 ⁵⁶⁾	—
$Zr^{4+} + 2 Ca^{2+} + 6 OH^- \rightleftharpoons \#Ca_2[Zr(OH)_6]^{2+}$	61.40 ± 0.30 ²⁸⁾	—
$Zr^{4+} + 3 Ca^{2+} + 6 OH^- \rightleftharpoons \#Ca_3[Zr(OH)_6]^{2+}$	60.80 ± 0.30 ²⁸⁾	—

^{*1} Selected values in this table should be treated as tentative values.

Table 10 Apparent equilibrium constants (K') and equilibrium constants at zero ionic strength (K°) for niobium determined in the present study

reaction	$\log K'$	$\log K^\circ$
$Nb_2O_5(s) + 7 H_2O \rightleftharpoons 2 Nb(OH)_6^- + 2 H^+$	-28.486 ± 0.455	-28.913 ± 0.507
$Nb(OH)_5(aq) + H_2O \rightleftharpoons Nb(OH)_6^- + H^+$	> -6.322	> -6.758

Table 11 Selected thermodynamic data for molybdenum compounds and aqueous species for
JAEA-TDB⁶⁴⁾

Reaction	$\log_{10} K^\circ$	Ref.
$\text{MoO}_4^{2-} + 8 \text{H}^+ + 3 \text{e}^- \rightleftharpoons \text{Mo}^{3+} + 4 \text{H}_2\text{O(l)}$	29.39	96
$\text{MoO}_4^{2-} + \text{H}^+ \rightleftharpoons \text{HMoO}_4^-$	4.1 ± 0.1	64
$\text{MoO}_4^{2-} + 2 \text{H}^+ \rightleftharpoons \text{H}_2\text{MoO}_4(\text{aq})$	6.7 ± 0.2	64
$7 \text{MoO}_4^{2-} + 8 \text{H}^+ \rightleftharpoons \text{Mo}_7\text{O}_{24}^{6-} + 4 \text{H}_2\text{O(l)}$	53.0 ± 0.2	64
$7 \text{MoO}_4^{2-} + 9 \text{H}^+ \rightleftharpoons \text{HMo}_7\text{O}_{24}^{5-} + 4 \text{H}_2\text{O(l)}$	59.8 ± 0.5	64
$\text{Nd}^{3+} + 2 \text{MoO}_4^{2-} \rightleftharpoons \text{Nd}(\text{MoO}_4)_2^4$ $(\text{Sm}^{3+} + 2 \text{MoO}_4^{2-} \rightleftharpoons \text{Sm}(\text{MoO}_4)_2^4)$	11.2 $\partial 0.3$	97
$\text{Mo}(\text{metal}) + 4 \text{H}_2\text{O(l)} \rightleftharpoons \text{MoO}_4^{2-} + 8 \text{H}^+ + 6 \text{e}^-$	-19.28	96
$\text{MoO}_2(\text{cr}) + 2 \text{H}_2\text{O(l)} \rightleftharpoons \text{MoO}_4^{2-} + 4 \text{H}^+ + 2 \text{e}^-$	-29.57	96
$\text{PbMoO}_4(\text{cr}) \rightleftharpoons \text{MoO}_4^{2-} + \text{Pb}^{2+}$	-12.98 ± 0.05	98
$\text{CaMoO}_4(\text{cr}) \rightleftharpoons \text{MoO}_4^{2-} + \text{Ca}^{2+}$	-7.95 $\partial 0.05$	96
$\text{Nd}_2(\text{MoO}_4)_3 \cdot x \text{H}_2\text{O(cr)} \rightleftharpoons 3 \text{MoO}_4^{2-} + 2 \text{Nd}^{3+}$	~ -26.1 $\partial 0.3$	97

Table 12 Alternatively selected thermodynamic data for technetium(IV) compounds and complexes for JAEA-TDB

Reaction	$\log_{10} K'$		$\log_{10} K^\circ$
	$0.8 \text{ mol}\cdot\text{dm}^{-3}$ NaCl	$2.5 \text{ mol}\cdot\text{dm}^{-3}$ NaCl	
$\text{TcO(OH)}_2(\text{aq}) + \text{H}^+ \rightleftharpoons \text{TcO(OH)}^+ + \text{H}_2\text{O(l)}$	4.551 ± 0.300	4.552 ± 0.378	4.563 ± 0.216
$\text{TcO}_2 \cdot 1.6 \text{H}_2\text{O(s)} \rightleftharpoons \text{TcO(OH)}_2(\text{aq}) + 0.6 \text{H}_2\text{O(l)}$	-8.620 ± 0.275	-8.210 ± 0.341	-8.415 ± 0.180

Table 13 Additionally or alternatively selected thermodynamic data for palladium(II) compounds and complexes for JAEA-TDB

Reaction	$\log_{10} K^\circ$	Ref.
Pd(OH) ₂ (s) + 2 H ⁺ ⇌ Pd ²⁺ + 2 H ₂ O(l)	-4.040 ± 0.290	69
Pd ²⁺ + H ₂ O(l) ⇌ PdOH ⁺ + H ⁺	-0.680 ± 0.450	69
Pd ²⁺ + 2 H ₂ O(l) ⇌ Pd(OH) ₂ (aq) + 2 H ⁺	-3.110 ± 0.310	69
Pd ²⁺ + 3 H ₂ O(l) ⇌ Pd(OH) ₃ ⁻ + 3 H ⁺	-15.400 ± 0.390	69
Pd ²⁺ + Cl ⁻ ⇌ PdCl ⁺	5.031 ± 0.200	70
Pd ²⁺ + 2 Cl ⁻ ⇌ PdCl ₂ (aq)	8.471 ± 0.283	70
Pd ²⁺ + 3 Cl ⁻ ⇌ PdCl ₃ ⁻	10.582 ± 0.346	70
Pd ²⁺ + 4 Cl ⁻ ⇌ PdCl ₄ ²⁻	11.464 ± 0.400	70
Pd ²⁺ + NO ₃ ⁻ ⇌ PdNO ₃ ⁺	0.167 ± 0.024 *	73
Pd ²⁺ + 2 NO ₃ ⁻ ⇌ Pd(NO ₃) ₂ (aq)	-0.762 ± 0.039 *	73
Pd ²⁺ + 2 NO ₃ ⁻ + H ₂ O(l) ⇌ PdOHNO ₃ (aq) + H ⁺	-0.650 ± 0.036 *	73

*tentative value

Table 14 Additionally and tentatively selected thermodynamic data for selenium compounds for JAEA-TDB ⁷⁶⁾

Compound	Reaction	$\log_{10} K^\circ$ *1
FeSe ₂ (cr)	Fe ²⁺ + 2 HSe ⁻ ⇌ FeSe ₂ (cr) + 2 H ⁺ + 2 e ⁻	17.220 ± 2.754*
β -Fe _{1.04} Se	1.04 Fe ²⁺ + HSe ⁻ + 0.08 e ⁻ ⇌ β -Fe _{1.04} Se + H ⁺	3.503 ± 0.870*
γ -Fe ₃ Se ₄ #	3 Fe ²⁺ + 4 HSe ⁻ ⇌ γ -Fe ₃ Se ₄ + 4 H ⁺ + 2 e ⁻	25.908 ± 5.547*
α -Fe ₇ Se ₈	7 Fe ²⁺ + 8 HSe ⁻ ⇌ α -Fe ₇ Se ₈ + 8 H ⁺ + 2 e ⁻	36.274 ± 5.175*

*1 Selected values in this table should be treated as tentative values.

Table 15 Additionally selected or modified thermodynamic data for lead for JAEA-TDB

Reaction	$\log_{10} K^\circ$	
	JAEA-TDB ⁸⁰⁾	Lothenbach <i>et al.</i> ⁶⁾
Pb ²⁺ + H ₂ O(l) ⇌ PbOH ⁺ + H ⁺	-7.07 ± 0.43	-7.51
Pb ²⁺ + 2 H ₂ O(l) ⇌ Pb(OH) ₂ (aq) + 2 H ⁺	-16.24 ± 0.84	-16.95
Pb ²⁺ + 3 H ₂ O(l) ⇌ Pb(OH) ₃ ⁻ + 3 H ⁺	-27.06 ± 1.20	-28.02
Pb ⁴⁺ + 4 H ₂ O(l) ⇌ Pb(OH) ₄ ²⁻ + 4 H ⁺	-38.78 ± 0.39	—
Pb ²⁺ + Cl ⁻ ⇌ #PbCl ⁺	1.50 ± 0.17	1.55
Pb ²⁺ + 2 Cl ⁻ ⇌ #PbCl ₂ (aq)	2.01 ± 0.19	2.00
Pb ²⁺ + 3 Cl ⁻ ⇌ #PbCl ₃ ⁻	1.98 ± 0.30	2.01

Table 16 Additionally selected or modified thermodynamic data for bismuth for JAEA-TDB

Reaction	$\log_{10} K^\circ$	
	JAEA-TDB ⁸¹⁾	Lothenbach <i>et al.</i> ⁶⁾
Bi(OH) ₃ (am) + OH ⁻ ⇌ Bi(OH) ₄ ⁻	-4.16 ± 0.32	
0.5 α-Bi ₂ O ₃ + 1.5 H ₂ O + OH ⁻ ⇌ Bi(OH) ₄ ⁻	-4.16 ± 0.32	
BiPO ₄ (cr) ⇌ Bi ³⁺ + PO ₄ ³⁻	-30.35 ± 0.54	
Bi ³⁺ + 2 H ₂ O ⇌ Bi(OH) ₂ ⁺ + 2 H ⁺	-2.56 ± 1.00	-2.56
Bi ³⁺ + 3 H ₂ O ⇌ Bi(OH) ₃ (aq) + 3 H ⁺	-8.94 ± 0.50	-5.31
Bi ³⁺ + 4 H ₂ O ⇌ Bi(OH) ₄ ⁻ + 4 H ⁺	-21.66 ± 0.87	-18.71
Bi ³⁺ + Cl ⁻ ⇌ BiCl ²⁺	3.61 ± 0.18	3.65
Bi ³⁺ + 2 Cl ⁻ ⇌ BiCl ₂ ⁺	5.56 ± 0.24	5.85
Bi ³⁺ + 3 Cl ⁻ ⇌ BiCl ₃ (aq)	6.98 ± 0.37	7.62
Bi ³⁺ + 4 Cl ⁻ ⇌ BiCl ₄ ⁻	8.04 ± 0.20	9.06
Bi ³⁺ + 5 Cl ⁻ ⇌ BiCl ₅ ²⁻	7.36 ± 0.37	8.33
Bi ³⁺ + PO ₄ ³⁻ ⇌ BiPO ₄ (aq)	≤ 21.85	

Table 17 Tentatively selected formation constants of interested elements with oxalic (ox), citric (cit), ethylendiaminetetraacetic (edta) and isosaccharic (isa) ligands

Species	Reaction	$\log_{10} K^\circ$	Ref.
$\text{Na}(\text{ox})^-$	$\text{Na}^+ + (\text{ox})^{2-} \rightleftharpoons \text{Na}(\text{ox})^-$	1.00	89
$\text{K}(\text{ox})^-$	$\text{K}^+ + (\text{ox})^{2-} \rightleftharpoons \text{K}(\text{ox})^-$	0.90	89
$\text{Sr}(\text{ox})$	$\text{Sr}^{2+} + (\text{ox})^{2-} \rightleftharpoons \text{Sr}(\text{ox})$	2.33	88
$\text{Sr}(\text{ox})_2^{2-}$	$\text{Sr}^{2+} + 2 (\text{ox})^{2-} \rightleftharpoons \text{Sr}(\text{ox})_2^{2-}$	2.98	88
$\text{Ra}(\text{ox})$	$\text{Ra}^{2+} + (\text{ox})^{2-} \rightleftharpoons \text{Ra}(\text{ox})$	2.78	90
$\text{Ra}(\text{ox})_2^{2-}$	$\text{Ra}^{2+} + 2 (\text{ox})^{2-} \rightleftharpoons \text{Ra}(\text{ox})_2^{2-}$	3.44	90
$\text{Fe}(\text{ox})$	$\text{Fe}^{2+} + (\text{ox})^{2-} \rightleftharpoons \text{Fe}(\text{ox})$	4.13	88
$\text{Fe}(\text{ox})_2^{2-}$	$\text{Fe}^{2+} + 2 (\text{ox})^{2-} \rightleftharpoons \text{Fe}(\text{ox})_2^{2-}$	6.23	88
$\text{Co}(\text{ox})$	$\text{Co}^{2+} + (\text{ox})^{2-} \rightleftharpoons \text{Co}(\text{ox})$	4.72	88
$\text{Co}(\text{ox})_2^{2-}$	$\text{Co}^{2+} + 2 (\text{ox})^{2-} \rightleftharpoons \text{Co}(\text{ox})_2^{2-}$	7.00	88
$\text{Pb}(\text{ox})$	$\text{Pb}^+ + 2 (\text{ox})^{2-} \rightleftharpoons \text{Pb}(\text{ox})$	4.91	88
$\text{Pb}(\text{ox})_2^{2-}$	$\text{Pb}^+ + 2 (\text{ox})^{2-} \rightleftharpoons \text{Pb}(\text{ox})_2^{2-}$	6.76	88
$\text{Al}(\text{ox})^+$	$\text{Al}^{3+} + (\text{ox})^{2-} \rightleftharpoons \text{Al}(\text{ox})^+$	7.72	88
$\text{Al}(\text{ox})_2^-$	$\text{Al}^{3+} + 2 (\text{ox})^{2-} \rightleftharpoons \text{Al}(\text{ox})_2^-$	13.20	88
$\text{Al}(\text{ox})_3^{3-}$	$\text{Al}^{3+} + 3 (\text{ox})^{2-} \rightleftharpoons \text{Al}(\text{ox})_3^{3-}$	16.74	88
$\text{Zr}(\text{ox})^{2+}$	$\text{Zr}^{4+} + (\text{ox})^{2-} \rightleftharpoons \text{Zr}(\text{ox})^{2+}$	10.52	90
$\text{Zr}(\text{ox})_2$	$\text{Zr}^{4+} + 2 (\text{ox})^{2-} \rightleftharpoons \text{Zr}(\text{ox})_2$	18.15	90
$\text{TcO}(\text{ox})$	$\text{TcO}^{2+} + (\text{ox})^{2-} \rightleftharpoons \text{TcO}(\text{ox})$	9.50	90
$\text{TcO}(\text{ox})_2^{2-}$	$\text{TcO}^{2+} + 2 (\text{ox})^{2-} \rightleftharpoons \text{TcO}(\text{ox})_2^{2-}$	16.21	90
$\text{Sm}(\text{ox})^+$	$\text{Sm}^{3+} + (\text{ox})^{2-} \rightleftharpoons \text{Sm}(\text{ox})^+$	6.30	90
$\text{Sm}(\text{ox})_2^-$	$\text{Sm}^{3+} + 2 (\text{ox})^{2-} \rightleftharpoons \text{Sm}(\text{ox})_2^-$	10.13	90
$\text{Ac}(\text{ox})^+$	$\text{Ac}^{3+} + (\text{ox})^{2-} \rightleftharpoons \text{Ac}(\text{ox})^+$	5.65	88
$\text{Ac}(\text{ox})_2^-$	$\text{Ac}^{3+} + 2 (\text{ox})^{2-} \rightleftharpoons \text{Ac}(\text{ox})_2^-$	8.80	88
$\text{Cm}(\text{ox})^+$	$\text{Cm}^{3+} + (\text{ox})^{2-} \rightleftharpoons \text{Cm}(\text{ox})^+$	6.54	88
$\text{Cm}(\text{ox})_2^-$	$\text{Cm}^{3+} + 2 (\text{ox})^{2-} \rightleftharpoons \text{Cm}(\text{ox})_2^-$	10.57	88
$\text{Th}(\text{ox})^{2+}$	$\text{Th}^{4+} + (\text{ox})^{2-} \rightleftharpoons \text{Th}(\text{ox})^{2+}$	10.60	88
$\text{Th}(\text{ox})_2$	$\text{Th}^{4+} + 2 (\text{ox})^{2-} \rightleftharpoons \text{Th}(\text{ox})_2$	20.20	88
$\text{Th}(\text{ox})_3^{2+}$	$\text{Th}^{4+} + 3 (\text{ox})^{2-} \rightleftharpoons \text{Th}(\text{ox})_3^{2+}$	26.40	88
$\text{Pu}(\text{ox})^{2+}$	$\text{Pu}^{4+} + (\text{ox})^{2-} \rightleftharpoons \text{Pu}(\text{ox})^{2+}$	10.34	90
$\text{Pu}(\text{ox})_2$	$\text{Pu}^{4+} + 2 (\text{ox})^{2-} \rightleftharpoons \text{Pu}(\text{ox})_2$	17.80	90
$\text{U}(\text{ox})^{2+}$	$\text{U}^{4+} + (\text{ox})^{2-} \rightleftharpoons \text{U}(\text{ox})^{2+}$	10.18	90
$\text{U}(\text{ox})_2$	$\text{U}^{4+} + 2 (\text{ox})^{2-} \rightleftharpoons \text{U}(\text{ox})_2$	17.50	90
$\text{Np}(\text{ox})^{2+}$	$\text{Np}^{4+} + (\text{ox})^{2-} \rightleftharpoons \text{Np}(\text{ox})^{2+}$	10.29	90
$\text{Np}(\text{ox})_2$	$\text{Np}^{4+} + 2 (\text{ox})^{2-} \rightleftharpoons \text{Np}(\text{ox})_2$	17.71	90

Species	Reaction	$\log_{10} K^\circ$	Ref.
$\text{PuO}_2(\text{ox})$	$\text{PuO}_2^{2+} + (\text{ox})^{2-} \rightleftharpoons \text{PuO}_2(\text{ox})$	7.25	90
$\text{PuO}_2(\text{ox})_2^{2-}$	$\text{PuO}_2^{2+} + 2(\text{ox})^{2-} \rightleftharpoons \text{PuO}_2(\text{ox})_2^{2-}$	11.94	90
$\text{Na}(\text{cit})^{2-}$	$\text{Na}^+ + (\text{cit})^{3-} \rightleftharpoons \text{Na}(\text{cit})^{2-}$	1.34	88
$\text{K}(\text{cit})^{2-}$	$\text{K}^+ + (\text{cit})^{3-} \rightleftharpoons \text{K}(\text{cit})^{2-}$	1.23	88
$\text{Sr}(\text{cit})^-$	$\text{Sr}^{2+} + (\text{cit})^{3-} \rightleftharpoons \text{Sr}(\text{cit})^-$	4.11	88
$\text{SrH}(\text{cit})^-$	$\text{Sr}^{2+} + \text{H}(\text{cit})^{2-} \rightleftharpoons \text{SrH}(\text{cit})(\text{aq})$	2.72	90
$\text{Ra}(\text{cit})^-$	$\text{Ra}^{2+} + (\text{cit})^{3-} \rightleftharpoons \text{Ra}(\text{cit})^-$	3.59	90
$\text{RaH}(\text{cit})^-$	$\text{Ra}^{2+} + \text{H}(\text{cit})^{2-} \rightleftharpoons \text{Ra H}(\text{cit})(\text{aq})$	2.64	90
$\text{Fe}(\text{cit})^-$	$\text{Fe}^{2+} + (\text{cit})^{3-} \rightleftharpoons \text{Fe}(\text{cit})^-$	5.69	88
$\text{FeH}(\text{cit})(\text{aq})$	$\text{Fe}^{2+} + \text{H}(\text{cit})^{2-} \rightleftharpoons \text{FeH}(\text{cit})(\text{aq})$	3.51	88
$\text{Co}(\text{cit})^-$	$\text{Co}^{2+} + (\text{cit})^{3-} \rightleftharpoons \text{Co}(\text{cit})^-$	6.29	88
$\text{CoH}(\text{cit})(\text{aq})$	$\text{Co}^{2+} + \text{H}(\text{cit})^{2-} \rightleftharpoons \text{CoH}(\text{cit})(\text{aq})$	3.88	88
$\text{Pb}(\text{cit})^-$	$\text{Pb}^{2+} + (\text{cit})^{3-} \rightleftharpoons \text{Pb}(\text{cit})^-$	5.70	88
$\text{Pb}(\text{cit})_2^{4-}$	$\text{Pb}^{2+} + 2(\text{cit})^{3-} \rightleftharpoons \text{Pb}(\text{cit})_2^{4-}$	6.91	88
$\text{Pb}(\text{cit})_3^{7-}$	$\text{Pb}^{2+} + 3(\text{cit})^{3-} \rightleftharpoons \text{Pb}(\text{cit})_3^{7-}$	4.55	88
$\text{PbH}(\text{cit})^-$	$\text{Pb}^{2+} + \text{H}(\text{cit})^{2-} \rightleftharpoons \text{PbH}(\text{cit})^-$	4.05	88
$\text{Al}(\text{cit})$	$\text{Al}^{3+} + (\text{cit})^{3-} \rightleftharpoons \text{Al}(\text{cit})$	9.91	89
$\text{Al}(\text{cit})_2^{3-}$	$\text{Al}^{3+} + 2(\text{cit})^{3-} \rightleftharpoons \text{Al}(\text{cit})_2^{3-}$	14.12	89
$\text{AlH}(\text{cit})^+$	$\text{Al}^{3+} + \text{H}(\text{cit})^{2-} \rightleftharpoons \text{AlH}(\text{cit})^+$	6.50	89
$\text{Zr}(\text{cit})^+$	$\text{Zr}^{4+} + (\text{cit})^{3-} \rightleftharpoons \text{Zr}(\text{cit})^+$	13.27	90
$\text{ZrH}(\text{cit})^{2+}$	$\text{Zr}^{4+} + \text{H}(\text{cit})^{2-} \rightleftharpoons \text{ZrH}(\text{cit})^{2+}$	8.52	90
$\text{TcO}(\text{cit})^-$	$\text{TcO}^{2+} + (\text{cit})^{3-} \rightleftharpoons \text{TcO}(\text{cit})^-$	11.99	90
$\text{TcOH}(\text{cit})$	$\text{TcO}^{2+} + \text{H}(\text{cit})^{2-} \rightleftharpoons \text{TcOH}(\text{cit})(\text{aq})$	7.75	90
$\text{Sm}(\text{cit})(\text{aq})$	$\text{Sm}^{3+} + (\text{cit})^{3-} \rightleftharpoons \text{Sm}(\text{cit})(\text{aq})$	7.99	90
$\text{SmH}(\text{cit})^+$	$\text{Sm}^{3+} + \text{H}(\text{cit})^{2-} \rightleftharpoons \text{SmH}(\text{cit})^+$	5.31	90
$\text{Ac}(\text{cit})(\text{aq})$	$\text{Ac}^{3+} + (\text{cit})^{3-} \rightleftharpoons \text{Ac}(\text{cit})(\text{aq})$	7.99	90
$\text{AcH}(\text{cit})^+$	$\text{Ac}^{3+} + \text{H}(\text{cit})^{2-} \rightleftharpoons \text{AcH}(\text{cit})^+$	5.31	90
$\text{Am}(\text{cit})(\text{aq})$	$\text{Am}^{3+} + (\text{cit})^{3-} \rightleftharpoons \text{Am}(\text{cit})(\text{aq})$	7.99	90
$\text{AmH}(\text{cit})^+$	$\text{Am}^{3+} + \text{H}(\text{cit})^{2-} \rightleftharpoons \text{AmH}(\text{cit})^+$	5.31	90
$\text{Cm}(\text{cit})(\text{aq})$	$\text{Cm}^{3+} + (\text{cit})^{3-} \rightleftharpoons \text{Cm}(\text{cit})(\text{aq})$	7.99	90
$\text{CmH}(\text{cit})^+$	$\text{Cm}^{3+} + \text{H}(\text{cit})^{2-} \rightleftharpoons \text{CmH}(\text{cit})^+$	5.31	90
$\text{Pu}(\text{cit})(\text{aq})$	$\text{Pu}^{3+} + (\text{cit})^{3-} \rightleftharpoons \text{Pu}(\text{cit})(\text{aq})$	7.99	90
$\text{PuH}(\text{cit})^+$	$\text{Pu}^{3+} + \text{H}(\text{cit})^{2-} \rightleftharpoons \text{PuH}(\text{cit})^+$	5.31	90
$\text{Th}(\text{cit})^+$	$\text{Th}^{4+} + (\text{cit})^{3-} \rightleftharpoons \text{Th}(\text{cit})^+$	11.29	90
$\text{ThH}(\text{cit})^{2+}$	$\text{Th}^{4+} + \text{H}(\text{cit})^{2-} \rightleftharpoons \text{ThH}(\text{cit})^{2+}$	7.32	90
$\text{Pu}(\text{cit})^+$	$\text{Pu}^{4+} + (\text{cit})^{3-} \rightleftharpoons \text{Pu}(\text{cit})^+$	13.04	90
$\text{PuH}(\text{cit})^{2+}$	$\text{Pu}^{4+} + \text{H}(\text{cit})^{2-} \rightleftharpoons \text{PuH}(\text{cit})^{2+}$	8.39	90
$\text{U}(\text{cit})^+$	$\text{U}^{4+} + (\text{cit})^{3-} \rightleftharpoons \text{U}(\text{cit})^+$	12.84	90

Species	Reaction	$\log_{10} K^\circ$	Ref.
UH(cit)^{2+}	$\text{U}^{4+} + \text{H(cit)}^{2-} \rightleftharpoons \text{UH(cit)}^{2+}$	8.26	90
Np(cit)^+	$\text{Np}^{4+} + (\text{cit})^{3-} \rightleftharpoons \text{Np(cit)}^+$	12.98	90
NpH(cit)^{2+}	$\text{Np}^{4+} + \text{H(cit)}^{2-} \rightleftharpoons \text{NpH(cit)}^{2+}$	8.35	90
$\text{NpO}_2\text{H(cit)}^-$	$\text{NpO}_2^+ + \text{H(cit)}^{2-} \rightleftharpoons \text{NpH(cit)}^-$	3.56	90
$\text{PuO}_2(\text{cit})^-$	$\text{PuO}_2^{2+} + (\text{cit})^{3-} \rightleftharpoons \text{PuO}_2(\text{cit})^-$	9.18	90
$\text{PuO}_2\text{H(cit)(aq)}$	$\text{PuO}_2^{2+} + \text{H(cit)}^{2-} \rightleftharpoons \text{PuO}_2\text{H(cit)(aq)}$	6.04	90
Sr(edta)^{2-}	$\text{Sr}^{2+} + (\text{edta})^{4-} \rightleftharpoons \text{Sr(edta)}^{2-}$	10.46	89
SrH(edta)^-	$\text{Sr}^{2+} + \text{H(edta)}^{3-} \rightleftharpoons \text{SrH(edta)}^-$	3.58	89
Fe(edta)^{2-}	$\text{Fe}^{2+} + (\text{edta})^{4-} \rightleftharpoons \text{Fe(edta)}^{2-}$	16.02	89
FeH(edta)^-	$\text{Fe}^{2+} + \text{H(edta)}^{3-} \rightleftharpoons \text{FeH(edta)}^-$	8.01	89
Co(edta)^{2-}	$\text{Co}^{2+} + (\text{edta})^{4-} \rightleftharpoons \text{Co(edta)}^{2-}$	18.17	89
CoH(edta)^-	$\text{Co}^{2+} + \text{H(edta)}^{3-} \rightleftharpoons \text{CoH(edta)}^-$	10.36	89
$\text{CoH}_2(\text{edta})(\text{aq})$	$\text{Co}^{2+} + \text{H}_2(\text{edta})^{2-} \rightleftharpoons \text{CoH}_2(\text{edta})(\text{aq})$	5.53	89
Pb(edta)^{2-}	$\text{Pb}^{2+} + (\text{edta})^{4-} \rightleftharpoons \text{Pb(edta)}^{2-}$	19.68	89
PbH(edta)^-	$\text{Pb}^{2+} + \text{H(edta)}^{3-} \rightleftharpoons \text{PbH(edta)}^-$	11.37	89
$\text{PbH}_2(\text{edta})$	$\text{Pb}^{2+} + \text{H}_2(\text{edta})^{3-} \rightleftharpoons \text{PbH}_2(\text{edta})$	6.53	89
$\text{PbH}_3(\text{edta})$	$\text{Pb}^{2+} + \text{H}_3(\text{edta})^{3-} \rightleftharpoons \text{PbH}_3(\text{edta})$	4.58	89
Th(edta)(aq)	$\text{Th}^{4+} + (\text{edta})^{4-} \rightleftharpoons \text{Th(edta)(aq)}$	26.63	89
ThH(edta)^+	$\text{Th}^{4+} + \text{H(edta)}^{3-} \rightleftharpoons \text{ThH(edta)}^+$	17.37	89
PuOH(edta)^-	$\text{Pu}^{4+} + (\text{edta})^{4-} + \text{OH}^- \rightleftharpoons \text{PuOH(edta)}^-$	38.20	93
$\text{Pu(OH)}_2(\text{edta})^{2-}$	$\text{Pu}^{4+} + (\text{edta})^{4-} + 2 \text{OH}^- \rightleftharpoons \text{Pu(OH)}_2(\text{edta})^{2-}$	47.22	93
$\text{Pu(OH)}_3(\text{edta})^{3-}$	$\text{Pu}^{4+} + (\text{edta})^{4-} + 3 \text{OH}^- \rightleftharpoons \text{Pu(OH)}_3(\text{edta})^{3-}$	51.71	93
Mg(isa)^+	$\text{Mg}^{2+} + (\text{isa})^- \rightleftharpoons \text{Mg(isa)}^+$	0.60	90
Sr(isa)^+	$\text{Sr}^{2+} + (\text{isa})^- \rightleftharpoons \text{Sr(isa)}^+$	0.91	90
Fe(isa)^+	$\text{Fe}^{2+} + (\text{isa})^- \rightleftharpoons \text{Fe(isa)}^+$	0.94	90
Ni(isa)^+	$\text{Ni}^{2+} + (\text{isa})^- \rightleftharpoons \text{Ni(isa)}^+$	2.20	94
Pb(isa)^+	$\text{Pb}^{2+} + (\text{isa})^- \rightleftharpoons \text{Pb(isa)}^+$	2.44	90
$\text{Am(OH)}_3(\text{isa})^-$	$\text{Am(OH)}_3 + (\text{isa})^- \rightleftharpoons \text{Am(OH)}_3(\text{isa})^-$	-21.50	94
$\text{Pu(OH)}_4(\text{isa})^-$	$\text{Pu(OH)}_4 + (\text{isa})^- \rightleftharpoons \text{Pu(OH)}_4(\text{isa})^-$	-3.80	94
$\text{Pu(OH)}_4(\text{isa})_2^{2-}$	$\text{Pu(OH)}_4 + 2 (\text{isa})^- \rightleftharpoons \text{Pu(OH)}_4(\text{isa})_2^{2-}$	0.40	94
$\text{Np(OH)}_4(\text{isa})^-$	$\text{Np(OH)}_4 + (\text{isa})^- \rightleftharpoons \text{Np(OH)}_4(\text{isa})^-$	-4.06	94
$\text{Np(OH)}_4(\text{isa})_2^{2-}$	$\text{Np(OH)}_4 + 2 (\text{isa})^- \rightleftharpoons \text{Np(OH)}_4(\text{isa})_2^{2-}$	-2.20	94
$\text{U(OH)}_4(\text{isa})^-$	$\text{U(OH)}_4 + (\text{isa})^- \rightleftharpoons \text{U(OH)}_4(\text{isa})^-$	-6.80	94
$\text{U(OH)}_4(\text{isa})_2^{2-}$	$\text{U(OH)}_4 + 2 (\text{isa})^- \rightleftharpoons \text{U(OH)}_4(\text{isa})_2^{2-}$	-4.90	94
ThOH(isa)^{2+}	$\text{Th}^{4+} + \text{OH}^- + (\text{isa})^- \rightleftharpoons \text{ThOH(isa)}^{2+}$	7.80	95
$\text{Th(OH)}_3(\text{isa})_2^-$	$\text{Th}^{4+} + 3 \text{OH}^- + 2 (\text{isa})^- \rightleftharpoons \text{Th(OH)}_3(\text{isa})_2^-$	-28.30	95
$\text{Th(OH)}_4(\text{isa})_2^{2-}$	$\text{Th}^{4+} + 4 \text{OH}^- + 2 (\text{isa})^- \rightleftharpoons \text{Th(OH)}_4(\text{isa})_2^{2-}$	-49.90	95

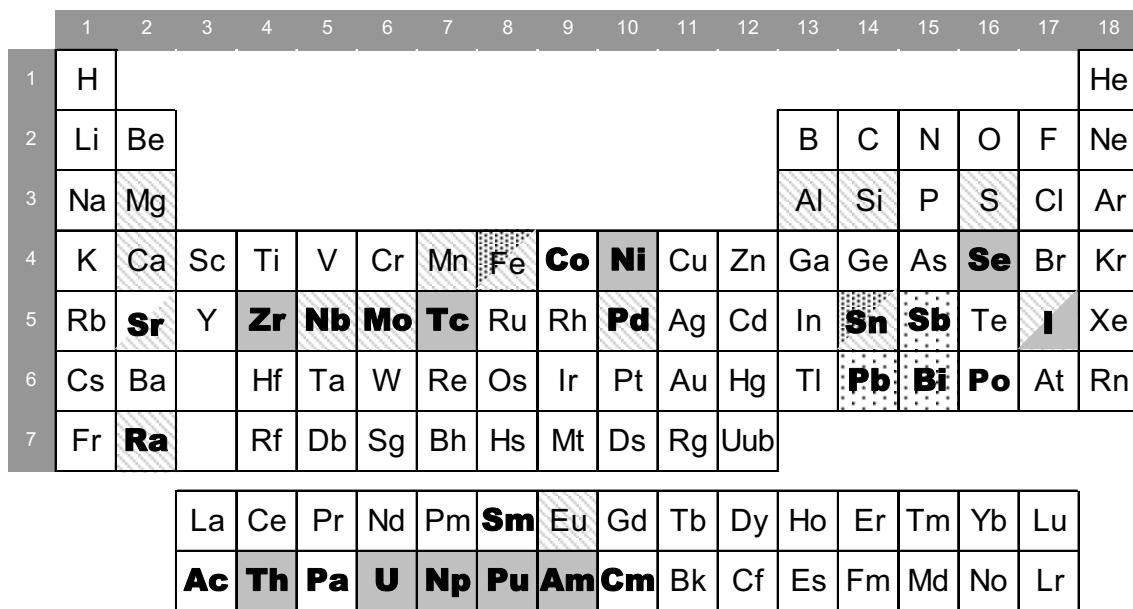


Figure 1 Elements of interest in JAEA-TDB and other TDBs viewed on periodic table

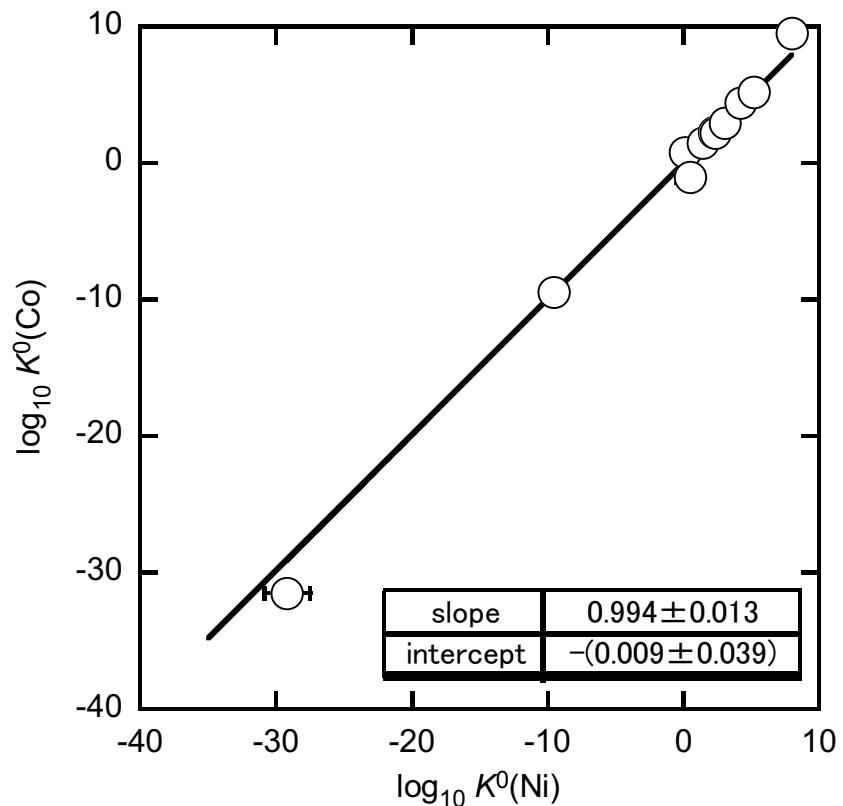


Figure 2 Correlation between equilibrium constant ($\log_{10} K^\circ$) of nickel and cobalt⁵¹⁾

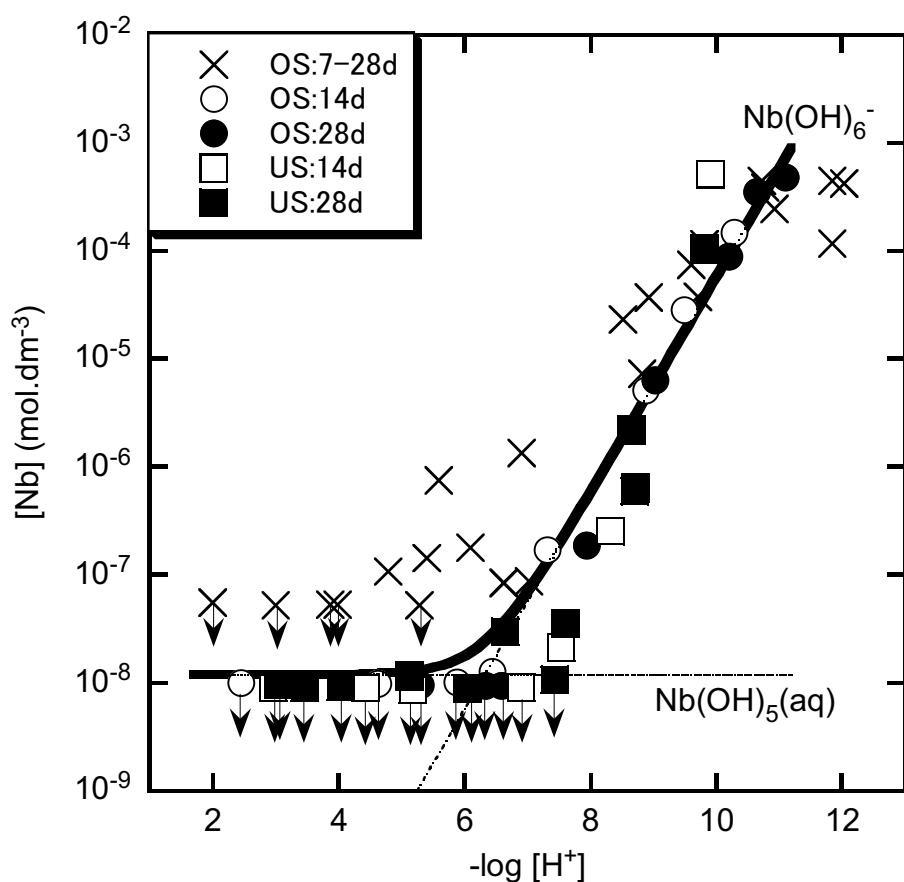


Figure 3 Solubility of niobium(V) under anaerobic conditions performed by Yajima *et al.*

Plots with mark “ \times ” were taken from the first run ⁵⁷⁾ (analyzed by ICP-OES) and others were taken from the second run ⁵⁸⁾ (analyzed by ICP-MS).

Solid line shows a least-square regress assuming aqueous species of $\text{Nb}(\text{OH})_5(\text{aq})$ and $\text{Nb}(\text{OH})_6^-$ with solubility limiting solid of $\text{Nb}_2\text{O}_5(\text{s})$ and dashed lines show contribution of each aqueous species. See text for detail.

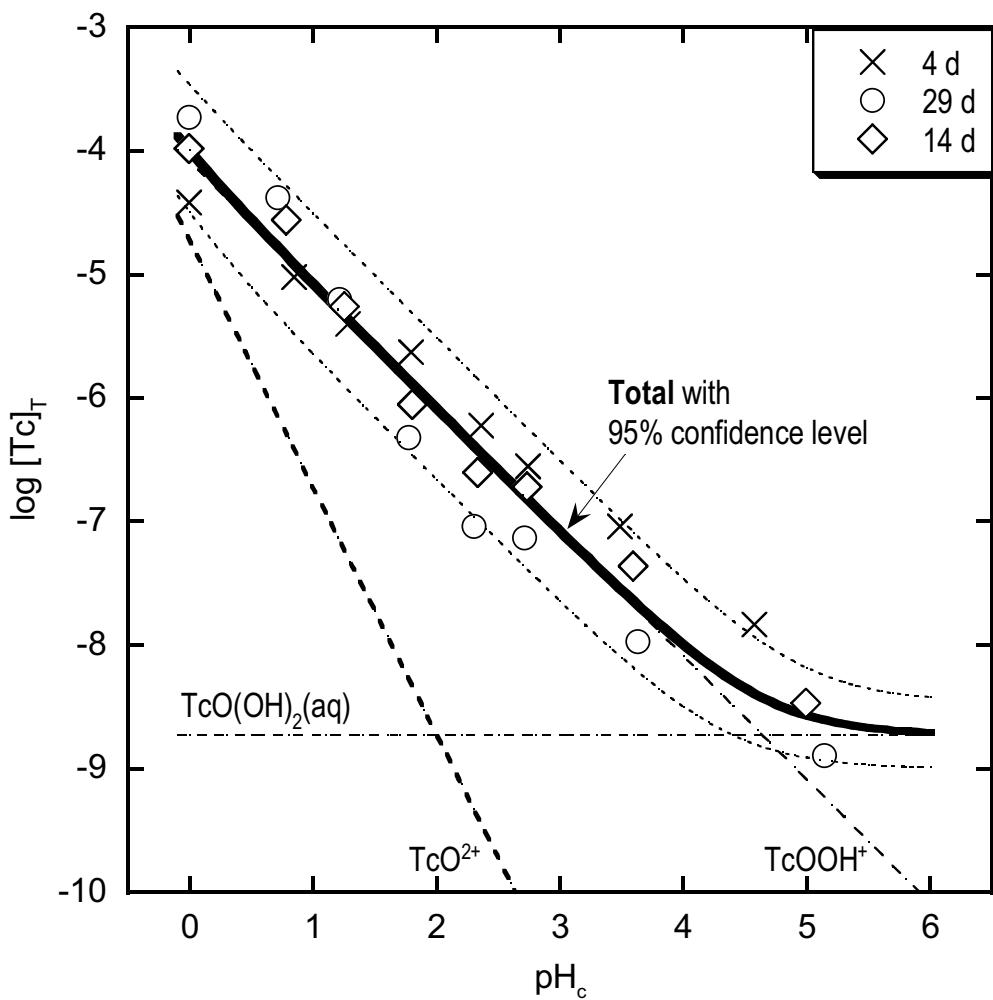


Figure 4 Reinterpretation of solubility data of technetium(IV) in 0.8 M NaCl using the SIT

Marks are experimental data by Hess *et al.*⁶⁵⁾ Solid, dotted and dashed lines are result of the least-squares regression, 95 % confidence level of the result and contribution of each aqueous species, respectively.

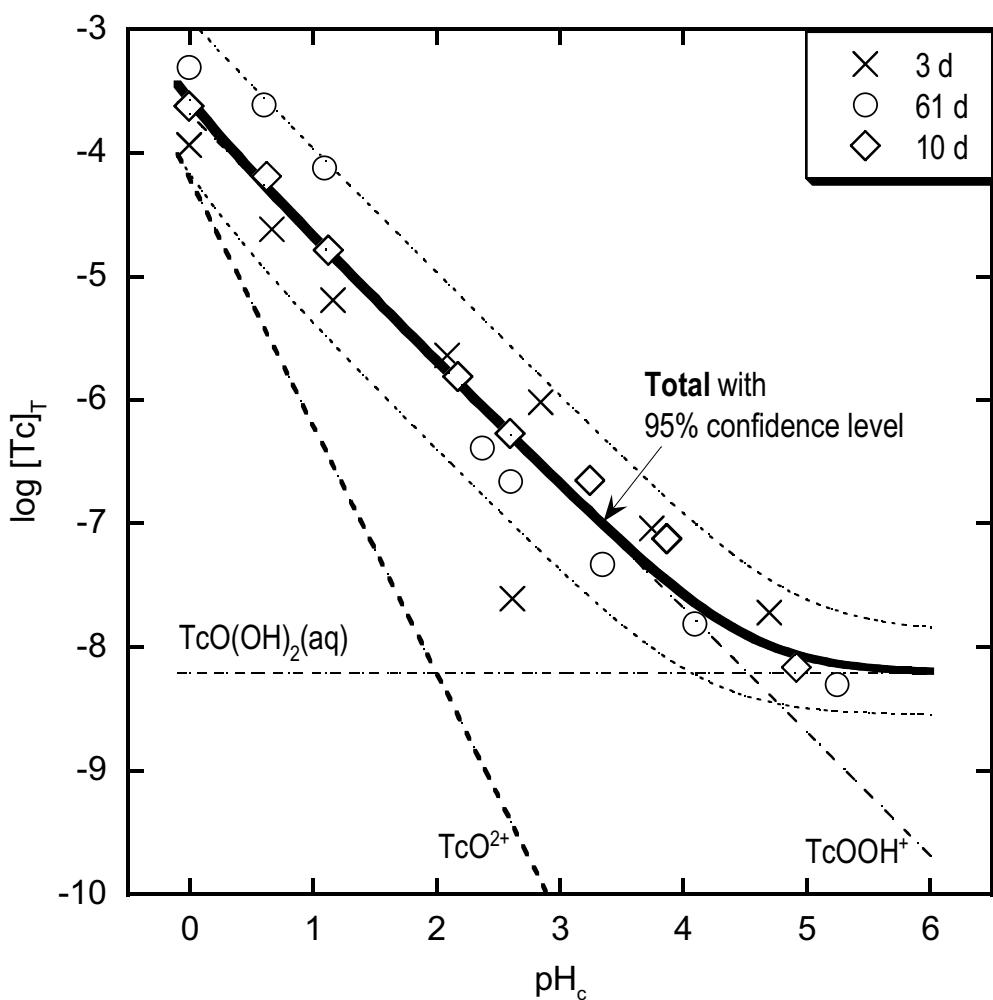


Figure 5 Reinterpretation of solubility data of technetium(IV) in 2.5 M NaCl using the SIT

Marks are experimental data by Hess *et al.*⁶⁵⁾ Solid, dotted and dashed lines are result of the least-squares regression, 95 % confidence level of the result and contribution of each aqueous species, respectively.

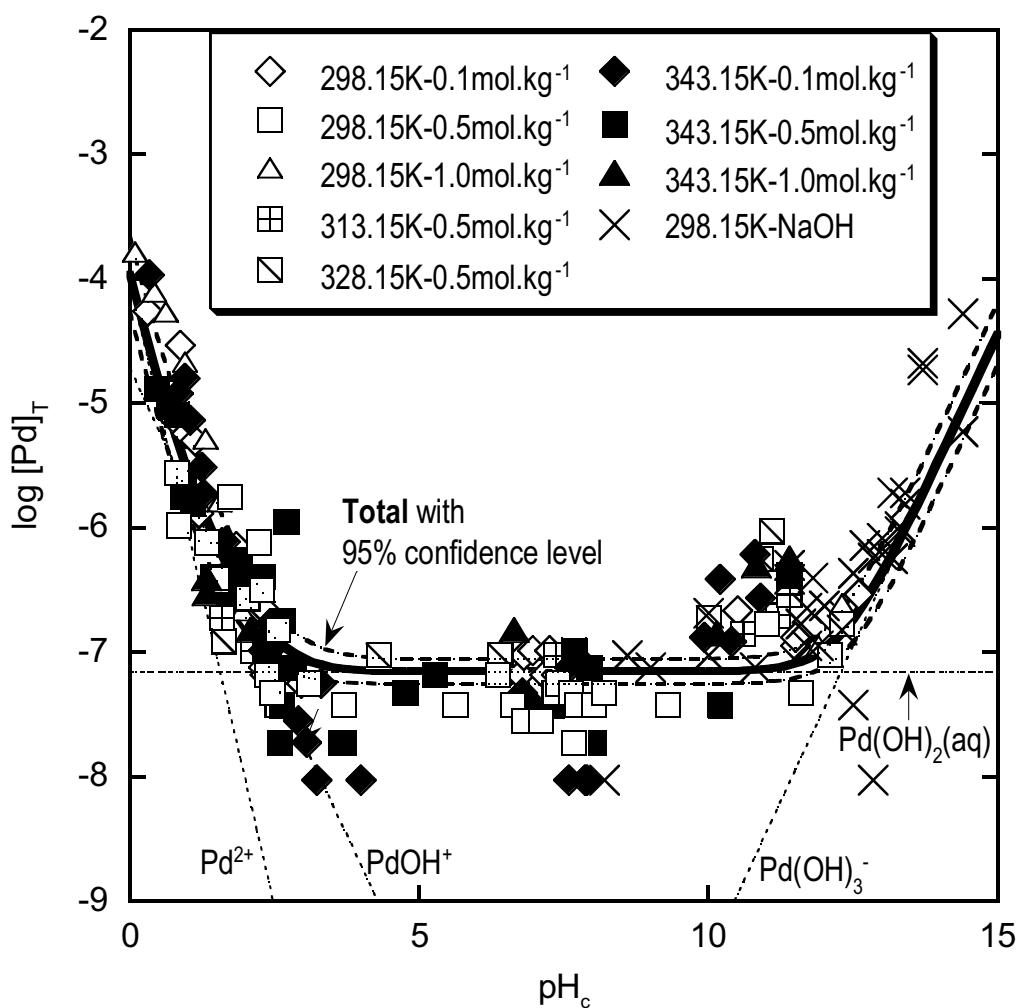


Figure 6 Solubility of Pd(II) in $0.1 - 1.0 \text{ mol}\cdot\text{kg}^{-1}$ NaClO_4 or NaOH media used for determination of equilibrium constants

Marks are experimental data by van Middlesworth and Wood ⁶⁸⁾ and Wood ⁶⁷⁾. Solid, dashed and dotted lines show result of a least-squares regression, uncertainty of the regression and contribution of each species, respectively, by us. See text for detail.

Appendix 1. Thermodynamic Data Compiled for JAEA-TDB

Table 18 Selected equilibrium constants of aqueous species for JAEA-TDB ready to use for the geochemical calculation programs

Reaction	$\log_{10} K^\circ$	ref.	t.v.*†
$2 \text{H}^+ + 2 \text{e}^- \rightleftharpoons \text{H}_2(\text{aq})$	-3.150	2	
$\text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{H}^+ + \text{OH}^-$	-14.001 ± 0.015	12	
$2 \text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{O}_2(\text{aq}) + 4 \text{H}^+ + 4 \text{e}^-$	-86.080	2	
$\text{Li}^+ + \text{SO}_4^{2-} \rightleftharpoons \text{LiSO}_4^-$	0.640	2	
$\text{B(OH)}_3(\text{aq}) \rightleftharpoons \text{H}_2\text{BO}_3^- + \text{H}^+$	-9.240	2	
$\text{B(OH)}_3(\text{aq}) + \text{F}^- \rightleftharpoons \text{BF(OH)}_3^-$	-0.400	2	
$\text{B(OH)}_3(\text{aq}) + 2 \text{F}^- + \text{H}^+ \rightleftharpoons \text{BF}_2(\text{OH})_2^- + \text{H}_2\text{O}(\text{l})$	7.628	2	
$\text{B(OH)}_3(\text{aq}) + 2 \text{H}^+ + 3 \text{F}^- \rightleftharpoons \text{BF}_3\text{OH}^- + 2 \text{H}_2\text{O}(\text{l})$	13.666	2	
$\text{B(OH)}_3(\text{aq}) + 3 \text{H}^+ + 4 \text{F}^- \rightleftharpoons \text{BF}_4^- + 3 \text{H}_2\text{O}(\text{l})$	20.274	2	
$\text{CO}_3^{2-} + \text{H}^+ \rightleftharpoons \text{HCO}_3^-$	10.329 ± 0.020	12	
$\text{CO}_3^{2-} + 2 \text{H}^+ \rightleftharpoons \text{CO}_2(\text{aq}) + \text{H}_2\text{O}(\text{l})$	16.683 ± 0.028	12	
$\text{CO}_3^{2-} + 10 \text{H}^+ + 8 \text{e}^- \rightleftharpoons \text{CH}_4(\text{aq}) + 3 \text{H}_2\text{O}(\text{l})$	41.071	2	
$\text{CO}_3^{2-} + \text{NO}_3^- + 12 \text{H}^+ + 10 \text{e}^- \rightleftharpoons \text{CN}^- + 6 \text{H}_2\text{O}(\text{l})$	108.129 ± 0.455	12	
$\text{NO}_3^- + 10 \text{H}^+ + 8 \text{e}^- \rightleftharpoons \text{NH}_4^+ + 3 \text{H}_2\text{O}(\text{l})$	119.134 ± 0.089	12	
$\text{NO}_3^- + 2 \text{H}^+ + 2 \text{e}^- \rightleftharpoons \text{NO}_2^- + \text{H}_2\text{O}(\text{l})$	27.776 ± 0.075	12, 26	
$3 \text{NO}_3^- + 18 \text{H}^+ + 16 \text{e}^- \rightleftharpoons \text{N}_3^- + 9 \text{H}_2\text{O}(\text{l})$	254.672 ± 0.418	12	
$3 \text{NO}_3^- + 19 \text{H}^+ + 16 \text{e}^- \rightleftharpoons \text{HN}_3(\text{aq}) + 9 \text{H}_2\text{O}(\text{l})$	259.372 ± 0.382	12	
$\text{NH}_4^+ \rightleftharpoons \text{H}^+ + \text{NH}_3(\text{aq})$	-9.237 ± 0.022	12	
$\text{NH}_4^+ + \text{SO}_4^{2-} \rightleftharpoons \text{NH}_4\text{SO}_4^-$	1.052	2	
$\text{F}^- + \text{H}^+ \rightleftharpoons \text{HF}(\text{aq})$	3.180 ± 0.020	12	
$2 \text{F}^- + \text{H}^+ \rightleftharpoons \text{HF}_2^-$	3.620 ± 0.122	12	
$\text{Na}^+ + \text{CO}_3^{2-} \rightleftharpoons \text{NaCO}_3^-$	1.268	2	
$\text{Na}^+ + \text{CO}_3^{2-} + \text{H}^+ \rightleftharpoons \text{NaHCO}_3(\text{aq})$	10.080	2	
$\text{Na}^+ + \text{SO}_4^{2-} \rightleftharpoons \text{NaSO}_4^-$	0.700 ± 0.050	2, 99	
$\text{Na}^+ + \text{H}^+ + \text{PO}_4^{3-} \rightleftharpoons \text{NaHPO}_4^-$	12.636	2	
$\text{Mg}^{2+} + \text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{MgOH}^+ + \text{H}^+$	-11.794	2	
$\text{Mg}^{2+} + \text{CO}_3^{2-} \rightleftharpoons \text{MgCO}_3(\text{aq})$	2.981 ± 0.030	2, 99	
$\text{Mg}^{2+} + \text{SO}_4^{2-} \rightleftharpoons \text{MgSO}_4(\text{aq})$	2.250	2	
$\text{Mg}^{2+} + \text{PO}_4^{3-} \rightleftharpoons \text{MgPO}_4^-$	6.589	2	
$\text{Mg}^{2+} + \text{H}^+ + \text{PO}_4^{3-} \rightleftharpoons \text{MgHPO}_4(\text{aq})$	15.216	2	
$\text{Mg}^{2+} + 2 \text{H}^+ + \text{PO}_4^{3-} \rightleftharpoons \text{MgH}_2\text{PO}_4^+$	21.066	2	
$\text{Mg}^{2+} + \text{F}^- \rightleftharpoons \text{MgF}^+$	1.820	2	
$\text{Al}^{3+} + \text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{AlOH}^{2+} + \text{H}^+$	-4.990 ± 0.020	2, 99	
$\text{Al}^{3+} + 2 \text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{Al(OH)}_2^+ + 2 \text{H}^+$	-10.100 ± 0.200	2, 99	
$\text{Al}^{3+} + 3 \text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{Al(OH)}_3(\text{aq}) + 3 \text{H}^+$	-16.000	2	
$\text{Al}^{3+} + 4 \text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{Al(OH)}_4^- + 4 \text{H}^+$	-23.000	2	
$\text{Al}^{3+} + \text{F}^- \rightleftharpoons \text{AlF}^{2+}$	7.010	2	
$\text{Al}^{3+} + 2 \text{F}^- \rightleftharpoons \text{AlF}_2^+$	12.750	2	
$\text{Al}^{3+} + 3 \text{F}^- \rightleftharpoons \text{AlF}_3(\text{aq})$	17.020	2	
$\text{Al}^{3+} + 4 \text{F}^- \rightleftharpoons \text{AlF}_4^-$	19.720	2	
$\text{Al}^{3+} + \text{SO}_4^{2-} \rightleftharpoons \text{AlSO}_4^+$	3.020	2	
$\text{Al}^{3+} + 2 \text{SO}_4^{2-} \rightleftharpoons \text{Al(SO}_4)_2^-$	4.920	2	
$\text{H}_4\text{SiO}_4(\text{aq}) \rightleftharpoons \text{H}_2\text{SiO}_4^{2-} + 2 \text{H}^+$	-23.140 ± 0.090	12	

Reaction	$\log_{10} K^\circ$	ref.	t.v. ^{*1}
$\text{H}_4\text{SiO}_4(\text{aq}) \rightleftharpoons \text{H}_3\text{SiO}_4^- + \text{H}^+$	-9.810 ± 0.020	12	
$2 \text{H}_4\text{SiO}_4(\text{aq}) \rightleftharpoons \text{H}_4\text{Si}_2\text{O}_7^{2-} + \text{H}_2\text{O}(\text{l}) + 2 \text{H}^+$	-19.000 ± 0.300	12	
$2 \text{H}_4\text{SiO}_4(\text{aq}) \rightleftharpoons \text{H}_5\text{Si}_2\text{O}_7^- + \text{H}_2\text{O}(\text{l}) + \text{H}^+$	-8.100 ± 0.300	12	
$3 \text{H}_4\text{SiO}_4(\text{aq}) \rightleftharpoons \text{H}_3\text{Si}_3\text{O}_9^{3-} + 3 \text{H}_2\text{O}(\text{l}) + 3 \text{H}^+$	-28.600 ± 0.300	12	
$3 \text{H}_4\text{SiO}_4(\text{aq}) \rightleftharpoons \text{H}_5\text{Si}_3\text{O}_{10}^{3-} + 2 \text{H}_2\text{O}(\text{l}) + 3 \text{H}^+$	-27.500 ± 0.300	12	
$4 \text{H}_4\text{SiO}_4(\text{aq}) \rightleftharpoons \text{H}_4\text{Si}_4\text{O}_{12}^{4-} + 4 \text{H}_2\text{O}(\text{l}) + 4 \text{H}^+$	-36.300 ± 0.500	12	
$4 \text{H}_4\text{SiO}_4(\text{aq}) \rightleftharpoons \text{H}_5\text{Si}_4\text{O}_{12}^{3-} + 4 \text{H}_2\text{O}(\text{l}) + 3 \text{H}^+$	-25.500 ± 0.300	12	
$4 \text{H}_4\text{SiO}_4(\text{aq}) \rightleftharpoons \text{H}_{13}\text{Si}_4\text{O}_{16}^{3-} + 3 \text{H}^+$	-34.901	2	
$\text{H}_4\text{SiO}_4(\text{aq}) + 4 \text{H}^+ + 6 \text{F}^- \rightleftharpoons \text{F}_6\text{Si}^{2-} + 4 \text{H}_2\text{O}(\text{l})$	30.180	2	
$2 \text{PO}_4^{3-} + 2 \text{H}^+ \rightleftharpoons \text{P}_2\text{O}_7^{4-} + \text{H}_2\text{O}(\text{l})$	21.314 ± 0.890	12	
$\text{PO}_4^{3-} + \text{H}^+ \rightleftharpoons \text{HPO}_4^{2-}$	12.350 ± 0.030	12	
$\text{PO}_4^{3-} + 2 \text{H}^+ \rightleftharpoons \text{H}_2\text{PO}_4^-$	19.562 ± 0.033	12	
$\text{PO}_4^{3-} + 3 \text{H}^+ \rightleftharpoons \text{H}_3\text{PO}_4(\text{aq})$	21.702 ± 0.176	12	
$2 \text{PO}_4^{3-} + 3 \text{H}^+ \rightleftharpoons \text{HP}_2\text{O}_7^{3-} + \text{H}_2\text{O}(\text{l})$	30.714 ± 0.660	12	
$2 \text{PO}_4^{3-} + 4 \text{H}^+ \rightleftharpoons \text{H}_2\text{P}_2\text{O}_7^{2-} + \text{H}_2\text{O}(\text{l})$	37.364 ± 0.652	12	
$2 \text{PO}_4^{3-} + 5 \text{H}^+ \rightleftharpoons \text{H}_3\text{P}_2\text{O}_7^- + \text{H}_2\text{O}(\text{l})$	39.614 ± 0.635	12	
$2 \text{PO}_4^{3-} + 6 \text{H}^+ \rightleftharpoons \text{H}_4\text{P}_2\text{O}_7(\text{aq}) + \text{H}_2\text{O}(\text{l})$	40.614 ± 0.391	12	
$\text{HS}^- \rightleftharpoons \text{S}^{2-} + \text{H}^+$	-19.000 ± 2.000	12	
$\text{SO}_4^{2-} + 2 \text{H}^+ + 2 \text{e}^- \rightleftharpoons \text{HSO}_3^- + \text{H}_2\text{O}(\text{l})$	-3.397 ± 0.701	12	
$2 \text{SO}_4^{2-} + 10 \text{H}^+ + 8 \text{e}^- \rightleftharpoons \text{S}_2\text{O}_3^{2-} + 5 \text{H}_2\text{O}(\text{l})$	38.013 ± 1.985	12	
$\text{SO}_4^{2-} + 9 \text{H}^+ + 8 \text{e}^- \rightleftharpoons \text{HS}^- + 4 \text{H}_2\text{O}(\text{l})$	33.692 ± 0.378	12	
$\text{HS}^- + \text{H}^+ \rightleftharpoons \text{H}_2\text{S}(\text{aq})$	6.990 ± 0.170	12	
$\text{SO}_3^{2-} + \text{H}^+ \rightleftharpoons \text{HSO}_3^-$	7.220 ± 0.080	12	
$\text{S}_2\text{O}_3^{2-} + \text{H}^+ \rightleftharpoons \text{HS}_2\text{O}_3^-$	1.590 ± 0.150	12	
$0.5 \text{S}_2\text{O}_3^{2-} + 1.5 \text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{HSO}_3^- + \text{H}^+ + 2 \text{e}^-$	-13.344 ± 0.710	12	
$\text{SO}_4^{2-} + \text{H}^+ \rightleftharpoons \text{HSO}_4^-$	1.980 ± 0.050	12	
$\text{SO}_4^{2-} + \text{CO}_3^{2-} + \text{NO}_3^- + 20 \text{H}^+ + 16 \text{e}^- \rightleftharpoons \text{SCN}^- + 10 \text{H}_2\text{O}(\text{l})$	156.972 ± 0.715	12	
$\text{Cl}^- + \text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{ClO}^- + 2 \text{H}^+ + 2 \text{e}^-$	-57.933 ± 0.170	12	
$\text{Cl}^- + 2 \text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{ClO}_2^- + 4 \text{H}^+ + 4 \text{e}^-$	-107.874 ± 0.709	12	
$\text{Cl}^- + 3 \text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{ClO}_3^- + 6 \text{H}^+ + 6 \text{e}^-$	-146.238 ± 0.236	12	
$\text{Cl}^- + 4 \text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{ClO}_4^- + 8 \text{H}^+ + 8 \text{e}^-$	-187.785 ± 0.108	12	
$\text{Cl}^- + \text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{HClO}(\text{aq}) + \text{H}^+ + 2 \text{e}^-$	-50.513 ± 0.109	12	
$\text{Cl}^- + 2 \text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{HClO}_2(\text{aq}) + 3 \text{H}^+ + 4 \text{e}^-$	-105.913 ± 0.708	12	
$\text{K}^+ + \text{SO}_4^{2-} \rightleftharpoons \text{KSO}_4^-$	0.850 ± 0.050	2, 99	
$\text{K}^+ + \text{H}^+ + \text{PO}_4^{3-} \rightleftharpoons \text{KHPO}_4^-$	12.636	2	
$\text{Ca}^{2+} + \text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{CaOH}^+ + \text{H}^+$	-12.850 ± 0.500	49	
$\text{Ca}^{2+} + \text{SO}_4^{2-} \rightleftharpoons \text{CaSO}_4(\text{aq})$	2.309	2	
$\text{Ca}^{2+} + \text{PO}_4^{3-} \rightleftharpoons \text{CaPO}_4^-$	6.459	2	
$\text{Ca}^{2+} + \text{H}^+ + \text{PO}_4^{3-} \rightleftharpoons \text{CaHPO}_4(\text{aq})$	15.085	2	
$\text{Ca}^{2+} + 2 \text{H}^+ + \text{PO}_4^{3-} \rightleftharpoons \text{CaH}_2\text{PO}_4^+$	20.961	2	
$\text{Ca}^{2+} + \text{F}^- \rightleftharpoons \text{CaF}^+$	0.940	2	
$\text{Mn}^{2+} + \text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{MnOH}^+ + \text{H}^+$	-10.590 ± 0.040	2, 99	
$\text{Mn}^{2+} + 3 \text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{Mn}(\text{OH})_3^- + 3\#\text{H}^+$	-34.800	2	
$\text{Mn}^{2+} \rightleftharpoons \text{Mn}^{3+} + \text{e}^-$	-25.507	2	
$\text{Mn}^{2+} + 4 \text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{MnO}_4^{2-} + 8 \text{H}^+ + 4 \text{e}^-$	-118.440	2	
$\text{Mn}^{2+} + 4 \text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{MnO}_4^- + 8 \text{H}^+ + 5 \text{e}^-$	-127.824	2	
$\text{Mn}^{2+} + \text{F}^- \rightleftharpoons \text{MnF}^+$	0.850	2	
$\text{Mn}^{2+} + \text{Cl}^- \rightleftharpoons \text{MnCl}^+$	0.607	2	
$\text{Mn}^{2+} + 2 \text{Cl}^- \rightleftharpoons \text{MnCl}_2(\text{aq})$	0.041	2	
$\text{Mn}^{2+} + 3 \text{Cl}^- \rightleftharpoons \text{MnCl}_3^-$	-0.305	2	

Reaction	$\log_{10} K^\circ$	ref.	t.v. ^{*1}
Mn ²⁺ + 2 NO ₃ ⁻ ⇌ #Mn(NO ₃) ₂ (aq)	0.600	2	
Mn ²⁺ + SO ₄ ²⁻ ⇌ MnSO ₄ (aq)	2.260	2	
Mn ²⁺ + CO ₃ ²⁻ + H ⁺ ⇌ MnHCO ₃ ⁺	11.600	2	
Fe ²⁺ + H ₂ O(l) ⇌ FeOH ⁺ + H ⁺	-9.500 ± 0.100	2, 99	
Fe ²⁺ + 2 H ₂ O(l) ⇌ Fe(OH) ₂ (aq) + 2#H ⁺	-20.570 ± 1.000	2, 99	
Fe ²⁺ + 3 H ₂ O(l) ⇌ Fe(OH) ₃ ⁻ + 3#H ⁺	-31.000 ± 1.500	2, 99	
Fe ²⁺ + SO ₄ ²⁻ ⇌ FeSO ₄ (aq)	2.250	2	
Fe ²⁺ + 2 HS ⁻ ⇌ Fe(HS) ₂ (aq)	8.864	2	
Fe ²⁺ + 3 HS ⁻ ⇌ Fe(HS) ₃ ⁻	10.858	2	
Fe ²⁺ + H ⁺ + PO ₄ ³⁻ ⇌ FeHPO ₄ (aq)	15.946	2	
Fe ²⁺ + 2 H ⁺ + PO ₄ ³⁻ ⇌ FeH ₂ PO ₄ ⁺	22.253	2	
Fe ²⁺ ⇌ Fe ³⁺ + e ⁻	-13.032 ± 0.010	2, 99	
Fe ³⁺ + H ₂ O(l) ⇌ FeOH ²⁺ + H ⁺	-2.188 ± 0.020	2, 99	
Fe ³⁺ + 2 H ₂ O(l) ⇌ Fe(OH) ₂ ⁺ + 2#H ⁺	-5.668 ± 0.100	2, 99	
Fe ³⁺ + 3 H ₂ O(l) ⇌ Fe(OH) ₃ (aq) + 3#H ⁺	-13.598	2	
Fe ³⁺ + 4 H ₂ O(l) ⇌ Fe(OH) ₄ ⁻ + 4#H ⁺	-21.598 ± 0.200	2, 99	
2 Fe ³⁺ + 2 H ₂ O(l) ⇌ Fe ₂ (OH) ₂ ⁴⁺ + 2#H ⁺	-2.946 ± 0.050	2, 99	
3 Fe ³⁺ + 4 H ₂ O(l) ⇌ Fe ₃ (OH) ₄ ⁵⁺ + 4#H ⁺	-6.304 ± 0.100	2, 99	
Fe ³⁺ + Cl ⁻ ⇌ FeCl ²⁺	1.482	2	
Fe ³⁺ + 2 Cl ⁻ ⇌ FeCl ₂ ⁺	2.132	2	
Fe ³⁺ + 3 Cl ⁻ ⇌ FeCl ₃ (aq)	1.132	2	
Fe ³⁺ + SO ₄ ²⁻ ⇌ FeSO ₄ ⁺	3.922	2	
Fe ³⁺ + 2 SO ₄ ²⁻ ⇌ Fe(SO ₄) ₂ ⁻	5.422	2	
Fe ³⁺ + H ⁺ + PO ₄ ³⁻ ⇌ FeHPO ₄ ⁺	17.772	2	
Fe ³⁺ + 2 H ⁺ + PO ₄ ³⁻ ⇌ FeH ₂ PO ₄ ²⁺	24.982	2	
Fe ³⁺ + F ⁻ ⇌ FeF ²⁺	6.232	2	
Fe ³⁺ + 2 F ⁻ ⇌ FeF ₂ ⁺	10.832	2	
Fe ³⁺ + 3 F ⁻ ⇌ FeF ₃ (aq)	14.002	2	
Co ²⁺ + H ₂ O(l) ⇌ #H ⁺ + CoOH ⁺	-9.470 ± 0.020	51	
Co ²⁺ + 2 H ₂ O(l) ⇌ #2 H ⁺ + #Co(OH) ₂ (aq)	-18.000 ± 1.100	51	
Co ²⁺ + 3 H ₂ O(l) ⇌ #3 H ⁺ + Co(OH) ₃ ⁻	-31.500 ± 0.500	51	
2 Co ²⁺ + H ₂ O(l) ⇌ #H ⁺ + Co ₂ OH ³⁺	-10.548 ± 0.861	51	*
4 Co ²⁺ + 4 H ₂ O(l) ⇌ #4 H ⁺ + Co ₄ (OH) ₄ ⁴⁺	-27.371 ± 0.211	51	*
Co ²⁺ + F ⁻ ⇌ #CoF ⁺	1.470 ± 0.040	51	
Co ²⁺ + Cl ⁻ ⇌ #CoCl ⁺	0.810 ± 0.070	51	
Co ²⁺ + HS ²⁻ ⇌ #CoS(aq) + H ⁺	0.600 ± 2.062	51	
Co ²⁺ + HS ⁻ ⇌ #CoHS ⁺	5.141 ± 0.277	51	*
Co ²⁺ + SO ₄ ²⁻ ⇌ #CoSO ₄ (aq)	2.200 ± 0.050	51	
Co ²⁺ + 2 SO ₄ ²⁻ ⇌ #Co(SO ₄) ₂ ²⁻	2.870 ± 0.050	51	
Co ²⁺ + NO ₃ ⁻ ⇌ #CoNO ₃ ⁺	-1.020 ± 0.060	51	
Co ²⁺ + NH ₄ ⁺ ⇌ #CoNH ₃ ²⁺ + H ⁺	-7.037 ± 0.102	51, 12	
Co ²⁺ + 2 NH ₄ ⁺ ⇌ #Co(NH ₃) ₂ ²⁺ + 2 H ⁺	-14.574 ± 0.205	51, 12	
Co ²⁺ + 3 NH ₄ ⁺ ⇌ #Co(NH ₃) ₃ ²⁺ + 3 H ⁺	-22.311 ± 0.405	51, 12	
Co ²⁺ + 4 NH ₄ ⁺ ⇌ #Co(NH ₃) ₄ ²⁺ + 4 H ⁺	-30.548 ± 0.410	51, 12	
Co ²⁺ + 5 NH ₄ ⁺ ⇌ #Co(NH ₃) ₅ ²⁺ + 5 H ⁺	-39.485 ± 0.415	51, 12	
Co ²⁺ + 6 NH ₄ ⁺ ⇌ #Co(NH ₃) ₆ ²⁺ + 6 H ⁺	-49.522 ± 0.421	51, 12	
Co ²⁺ + H ⁺ + PO ₄ ³⁻ ⇌ #CoHPO ₄ (aq)	15.300 ± 0.143	51, 12	
Co ²⁺ + 2 H ⁺ + 2 PO ₄ ³⁻ ⇌ #CoP ₂ O ₇ ²⁻ + H ₂ O(l)	29.985 ± 0.966	51, 12	*
Co ²⁺ + 3 H ⁺ + 2 PO ₄ ³⁻ ⇌ #CoP ₂ O ₇ ⁻ + H ₂ O(l)	35.815 ± 0.737	51, 12	*
Co ²⁺ + H ⁺ + AsO ₄ ³⁻ ⇌ #CoHAsO ₄ (aq)	14.477 ± 1.052	51, 12	*

Reaction	$\log_{10} K^\circ$	ref.	t.v. ^{*1}
$\text{Co}^{2+} + \text{CO}_3^{2-} \rightleftharpoons \text{CoCO}_3(\text{aq})$	4.400 ± 0.100	51	
$\text{Co}^{2+} + \text{H}^+ + \text{CO}_3^{2-} \rightleftharpoons \text{CoHCO}_3^+$	11.729 ± 0.201	51, 12	
$\text{Co}^{2+} + 4 \text{CO}_3^{2-} + 4 \text{NO}_3^- + 48 \text{H}^+ + 40 \text{e}^- \rightleftharpoons \text{Co}(\text{CN})_4^{2-} + 24 \text{H}_2\text{O}(\text{l})$	462.533 ± 1.896	51, 12	*
$\text{Co}^{2+} + 5 \text{CO}_3^{2-} + 5 \text{NO}_3^- + 60 \text{H}^+ + 50 \text{e}^- \rightleftharpoons \text{Co}(\text{CN})_5^{3-} + 30 \text{H}_2\text{O}(\text{l})$	568.972 ± 2.442	51, 12	*
$\text{Co}^{2+} + \text{SO}_4^{2-} + \text{CO}_3^{2-} + \text{NO}_3^- + 20 \text{H}^+ + 16 \text{e}^- \rightleftharpoons \text{CoSCN}^+ + 10 \text{H}_2\text{O}(\text{l})$	158.762 ± 0.719	51, 12	*
$\text{Co}^{2+} + 2 \text{SO}_4^{2-} + 2 \text{CO}_3^{2-} + 2 \text{NO}_3^- + 40 \text{H}^+ + 32 \text{e}^- \rightleftharpoons \text{Co}(\text{SCN})_2(\text{aq}) + 20 \text{H}_2\text{O}(\text{l})$	316.609 ± 1.435	51, 12	*
$\text{Co}^{2+} + 3 \text{SO}_4^{2-} + 3 \text{CO}_3^{2-} + 3 \text{NO}_3^- + 60 \text{H}^+ + 48 \text{e}^- \rightleftharpoons \text{Co}(\text{SCN})_3^- + 30 \text{H}_2\text{O}(\text{l})$	473.909 ± 2.157	51, 12	*
$\text{Ni}^{2+} + \text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{H}^+ + \text{NiOH}^+$	-9.540 ± 0.140	8	
$\text{Ni}^{2+} + 2 \text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{H}^+ + \text{Ni(OH)}_2(\text{aq})$	< -18.029	51	
$\text{Ni}^{2+} + 3 \text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{H}^+ + \text{Ni(OH)}_3^-$	-29.200 ± 1.700	8	
$2 \text{Ni}^{2+} + \text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{H}^+ + \text{Ni}_2\text{OH}^{3+}$	-10.600 ± 1.000	8	
$4 \text{Ni}^{2+} + 4 \text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{H}^+ + \text{Ni}_4(\text{OH})_4^{4+}$	-27.520 ± 0.150	8	
$\text{Ni}^{2+} + \text{F}^- \rightleftharpoons \text{NiF}^+$	1.430 ± 0.080	8	
$\text{Ni}^{2+} + \text{Cl}^- \rightleftharpoons \text{NiCl}^+$	0.080 ± 0.600	8	
$\text{Ni}^{2+} + \text{HS}^{2-} \rightleftharpoons \text{NiS}(\text{aq}) + \text{H}^+$	0.723 ± 2.013	51, 12	*
$\text{Ni}^{2+} + \text{HS}^- \rightleftharpoons \text{NiHS}^+$	5.180 ± 0.200	8	
$\text{Ni}^{2+} + \text{SO}_4^{2-} \rightleftharpoons \text{NiSO}_4(\text{aq})$	2.350 ± 0.030	8	
$\text{Ni}^{2+} + 2 \text{SO}_4^{2-} \rightleftharpoons \text{Ni}(\text{SO}_4)_2^{2-}$	2.896 ± 0.002	51	*
$\text{Ni}^{2+} + \text{NO}_3^- \rightleftharpoons \text{NiNO}_3^+$	0.500 ± 1.000	8	
$\text{Ni}^{2+} + \text{NH}_4^+ \rightleftharpoons \text{NiNH}_3^{2+} + \text{H}^+$	-7.015 ± 0.065	51, 12	*
$\text{Ni}^{2+} + 2 \text{NH}_4^+ \rightleftharpoons \text{Ni}(\text{NH}_3)_2^{2+} + 2 \text{H}^+$	-14.542 ± 0.146	51, 12	*
$\text{Ni}^{2+} + 3 \text{NH}_4^+ \rightleftharpoons \text{Ni}(\text{NH}_3)_3^{2+} + 3 \text{H}^+$	-22.271 ± 0.327	51, 12	*
$\text{Ni}^{2+} + 4 \text{NH}_4^+ \rightleftharpoons \text{Ni}(\text{NH}_3)_4^{2+} + 4 \text{H}^+$	-30.502 ± 0.318	51, 12	*
$\text{Ni}^{2+} + 5 \text{NH}_4^+ \rightleftharpoons \text{Ni}(\text{NH}_3)_5^{2+} + 5 \text{H}^+$	-39.437 ± 0.321	51, 12	*
$\text{Ni}^{2+} + 6 \text{NH}_4^+ \rightleftharpoons \text{Ni}(\text{NH}_3)_6^{2+} + 6 \text{H}^+$	-49.479 ± 0.340	51, 12	*
$\text{Ni}^{2+} + \text{H}^+ + \text{PO}_4^{3-} \rightleftharpoons \text{NiHPO}_4(\text{aq})$	15.400 ± 0.095	8, 12	
$\text{Ni}^{2+} + 2 \text{H}^+ + 2 \text{PO}_4^{3-} \rightleftharpoons \text{NiP}_2\text{O}_7^{2-} + \text{H}_2\text{O}(\text{l})$	30.044 ± 0.924	8, 12	
$\text{Ni}^{2+} + 3 \text{H}^+ + 2 \text{PO}_4^{3-} \rightleftharpoons \text{HNI}_2\text{P}_2\text{O}_7^- + \text{H}_2\text{O}(\text{l})$	35.854 ± 0.706	8, 12	
$\text{Ni}^{2+} + \text{H}^+ + \text{AsO}_4^{3-} \rightleftharpoons \text{NiHAsO}_4(\text{aq})$	14.503 ± 1.037	8, 12	
$\text{Ni}^{2+} + \text{CO}_3^{2-} \rightleftharpoons \text{NiCO}_3(\text{aq})$	4.200 ± 0.400	8	
$\text{Ni}^{2+} + \text{H}^+ + \text{CO}_3^{2-} \rightleftharpoons \text{NiHCO}_3^+$	11.746 ± 0.174	51, 12	*
$\text{Ni}^{2+} + 4 \text{NO}_3^- + 4 \text{CO}_3^{2-} + 48 \text{H}^+ + 40 \text{e}^- \rightleftharpoons \text{Ni}(\text{CN})_4^{2-} + 24 \text{H}_2\text{O}(\text{l})$	462.716 ± 1.824	8, 12	
$\text{Ni}^{2+} + 5 \text{NO}_3^- + 5 \text{CO}_3^{2-} + 60 \text{H}^+ + 50 \text{e}^- \rightleftharpoons \text{Ni}(\text{CN})_5^{3-} + 30 \text{H}_2\text{O}(\text{l})$	569.145 ± 2.329	8, 12	
$\text{Ni}^{2+} + \text{NO}_3^- + \text{CO}_3^{2-} + \text{SO}_4^{2-} + 20 \text{H}^+ + 16 \text{e}^- \rightleftharpoons \text{NiSCN}^+ + 10 \text{H}_2\text{O}(\text{l})$	158.782 ± 0.716	8, 12	
$\text{Ni}^{2+} + 2 \text{NO}_3^- + 2 \text{CO}_3^{2-} + 2 \text{SO}_4^{2-} + 40 \text{H}^+ + 32 \text{e}^- \rightleftharpoons \text{Ni}(\text{SCN})_2(\text{aq}) + 20 \text{H}_2\text{O}(\text{l})$	316.634 ± 1.432	8, 12	
$\text{Ni}^{2+} + 3 \text{NO}_3^- + 3 \text{CO}_3^{2-} + 3 \text{SO}_4^{2-} + 60 \text{H}^+ + 48 \text{e}^- \rightleftharpoons \text{Ni}(\text{SCN})_3^- + 30 \text{H}_2\text{O}(\text{l})$	473.936 ± 2.153	8, 12	
$\text{AsO}_4^{3-} + 4 \text{H}^+ + 2 \text{e}^- \rightleftharpoons \text{AsO}_2^- + 2 \text{H}_2\text{O}(\text{l})$	30.859 ± 0.993	12	
$\text{AsO}_4^{3-} + 5 \text{H}^+ + 2 \text{e}^- \rightleftharpoons \text{HAsO}_2(\text{aq}) + 2 \text{H}_2\text{O}(\text{l})$	40.092 ± 0.993	12	
$\text{AsO}_4^{3-} + 4 \text{H}^+ + 2 \text{e}^- \rightleftharpoons \text{H}_2\text{AsO}_3^- + \text{H}_2\text{O}(\text{l})$	30.809 ± 0.993	12	
$\text{AsO}_4^{3-} + 5 \text{H}^+ + 2 \text{e}^- \rightleftharpoons \text{H}_3\text{AsO}_3(\text{aq}) + \text{H}_2\text{O}(\text{l})$	40.024 ± 0.994	12	
$\text{AsO}_4^{3-} + \text{H}^+ \rightleftharpoons \text{HAsO}_4^{2-}$	11.603 ± 0.993	12	
$\text{AsO}_4^{3-} + 2 \text{H}^+ \rightleftharpoons \text{H}_2\text{AsO}_4^-$	18.368 ± 0.994	12	
$\text{AsO}_4^{3-} + 3 \text{H}^+ \rightleftharpoons \text{H}_3\text{AsO}_4(\text{aq})$	20.630 ± 0.994	12	
$\text{SeO}_4^{2-} + 8 \text{H}^+ + 8 \text{e}^- \rightleftharpoons \text{Se}^{2-} + 4 \text{H}_2\text{O}(\text{l})$	66.656 ± 0.583	9	
$2 \text{SeO}_4^{2-} + 16 \text{H}^+ + 14 \text{e}^- \rightleftharpoons \text{Se}_2^{2-} + 8 \text{H}_2\text{O}(\text{l})$	158.632 ± 1.213	9	
$3 \text{SeO}_4^{2-} + 24 \text{H}^+ + 20 \text{e}^- \rightleftharpoons \text{Se}_3^{2-} + 12 \text{H}_2\text{O}(\text{l})$	249.934 ± 1.780	9	
$4 \text{SeO}_4^{2-} + 32 \text{H}^+ + 26 \text{e}^- \rightleftharpoons \text{Se}_4^{2-} + 16 \text{H}_2\text{O}(\text{l})$	339.647 ± 2.356	9	
$\text{SeO}_4^{2-} + 2 \text{H}^+ + 2 \text{e}^- \rightleftharpoons \text{SeO}_3^{2-} + \text{H}_2\text{O}(\text{l})$	28.039 ± 0.397	9	
$\text{SeO}_4^{2-} + 9 \text{H}^+ + 8 \text{e}^- \rightleftharpoons \text{HSe}^- + 4 \text{H}_2\text{O}(\text{l})$	81.570 ± 0.435	9	
$\text{HSe}^- + \text{H}^+ \rightleftharpoons \text{H}_2\text{Se}(\text{aq})$	3.850 ± 0.050	9	

Reaction	$\log_{10} K^\circ$	ref.	t.v. ^{*1}
$\text{SeO}_3^{2-} + \text{H}^+ \rightleftharpoons \text{HSeO}_3^-$	8.360 ± 0.230	9	
$\text{SeO}_4^{2-} + \text{H}^+ \rightleftharpoons \text{HSeO}_4^-$	1.750 ± 0.100	9	
$\text{SeO}_3^{2-} + 2 \text{H}^+ \rightleftharpoons \text{H}_2\text{SeO}_3(\text{aq})$	11.000 ± 0.269	9	
$2 \text{SeO}_4^{2-} + 16 \text{H}^+ + 10 \text{e}^- + 2 \text{Cl}^- \rightleftharpoons \text{Se}_2\text{Cl}_2(\text{aq}) + 8 \text{H}_2\text{O}(\text{l})$	140.427 ± 0.904	9	
$\text{SeO}_4^{2-} + 20 \text{H}^+ + 16 \text{e}^- + \text{CO}_3^{2-} + \text{NO}_3^- \rightleftharpoons \text{SeCN}^- + 10 \text{H}_2\text{O}(\text{l})$	202.726 ± 0.722	9	
$\text{SeO}_4^{2-} + 20 \text{H}^+ + 16 \text{e}^- + \text{CO}_3^{2-} + \text{NO}_3^- + \text{Tl}^+ \rightleftharpoons \text{TlSeCN}(\text{aq}) + 10 \text{H}_2\text{O}(\text{l})$	204.476 ± 0.778	9	
$\text{SeO}_4^{2-} + \text{Zn}^{2+} \rightleftharpoons \text{ZnSeO}_4(\text{aq})$	2.160 ± 0.060	9	
$\text{SeO}_4^{2-} + 20 \text{H}^+ + 16 \text{e}^- + \text{CO}_3^{2-} + \text{NO}_3^- + \text{Zn}^{2+} \rightleftharpoons \text{ZnSeCN}^+ + 10 \text{H}_2\text{O}(\text{l})$	203.936 ± 0.724	9	
$2 \text{SeO}_4^{2-} + 40 \text{H}^+ + 32 \text{e}^- + 2 \text{CO}_3^{2-} + 2 \text{NO}_3^- + \text{Zn}^{2+} \rightleftharpoons \text{Zn}(\text{SeCN})_2(\text{aq}) + 20 \text{H}_2\text{O}(\text{l})$	407.133 ± 1.448	9	
$\text{Cd}^{2+} + \text{SeO}_4^{2-} \rightleftharpoons \text{CdSeO}_4(\text{aq})$	2.270 ± 0.060	9	
$\text{SeO}_4^{2-} + 20 \text{H}^+ + 16 \text{e}^- + \text{CO}_3^{2-} + \text{NO}_3^- + \text{Cd}^{2+} \rightleftharpoons \text{CdSeCN}^+ + 10 \text{H}_2\text{O}(\text{l})$	204.966 ± 0.724	9	
$2 \text{SeO}_4^{2-} + 40 \text{H}^+ + 32 \text{e}^- + 2 \text{CO}_3^{2-} + 2 \text{NO}_3^- + \text{Cd}^{2+} \rightleftharpoons \text{Cd}(\text{SeCN})_2(\text{aq}) + 20 \text{H}_2\text{O}(\text{l})$	408.793 ± 1.449	9	
$3 \text{SeO}_4^{2-} + 60 \text{H}^+ + 48 \text{e}^- + 3 \text{CO}_3^{2-} + 3 \text{NO}_3^- + \text{Cd}^{2+} \rightleftharpoons \text{Cd}(\text{SeCN})_3^- + 30 \text{H}_2\text{O}(\text{l})$	611.989 ± 2.176	9	
$4 \text{SeO}_4^{2-} + 80 \text{H}^+ + 64 \text{e}^- + 4 \text{CO}_3^{2-} + 4 \text{NO}_3^- + \text{Cd}^{2+} \rightleftharpoons \text{Cd}(\text{SeCN})_4^{2-} + 40 \text{H}_2\text{O}(\text{l})$	815.505 ± 2.890	9	
$2 \text{SeO}_4^{2-} + 16 \text{H}^+ + 16 \text{e}^- + \text{Hg}^{2+} \rightleftharpoons \text{HgSe}_2^{2-} + 8 \text{H}_2\text{O}(\text{l})$	195.773 ± 1.111	9	
$2 \text{SeO}_3^{2-} + \text{Hg}^{2+} \rightleftharpoons \text{H}(\text{SeO}_3)_2^{2-}$	14.850 ± 1.011	9	
$2 \text{SeO}_4^{2-} + 40 \text{H}^+ + 32 \text{e}^- + 2 \text{CO}_3^{2-} + 2 \text{NO}_3^- + \text{Hg}^{2+} \rightleftharpoons \text{Hg}(\text{SeCN})_2(\text{aq}) + 20 \text{H}_2\text{O}(\text{l})$	427.753 ± 1.756	9	
$3 \text{SeO}_4^{2-} + 60 \text{H}^+ + 48 \text{e}^- + 3 \text{CO}_3^{2-} + 3 \text{NO}_3^- + \text{Hg}^{2+} \rightleftharpoons \text{Hg}(\text{SeCN})_3^- + 30 \text{H}_2\text{O}(\text{l})$	634.979 ± 2.386	9	
$4 \text{SeO}_4^{2-} + 80 \text{H}^+ + 64 \text{e}^- + 4 \text{CO}_3^{2-} + 4 \text{NO}_3^- + \text{Hg}^{2+} \rightleftharpoons \text{Hg}(\text{SeCN})_4^{2-} + 40 \text{H}_2\text{O}(\text{l})$	840.205 ± 2.931	9	
$3 \text{SeO}_4^{2-} + 60 \text{H}^+ + 48 \text{e}^- + 3 \text{CO}_3^{2-} + 3 \text{NO}_3^- + \text{Ag}^+ \rightleftharpoons \text{Ag}(\text{SeCN})_3^{2-} + 30 \text{H}_2\text{O}(\text{l})$	622.029 ± 2.187	9	
$\text{SeO}_4^{2-} + \text{Ni}^{2+} \rightleftharpoons \text{NiSeO}_4(\text{aq})$	2.670 ± 0.050	9	
$\text{SeO}_4^{2-} + 20 \text{H}^+ + 16 \text{e}^- + \text{CO}_3^{2-} + \text{NO}_3^- + \text{Ni}^{2+} \rightleftharpoons \text{NiSeCN}^+ + 10 \text{H}_2\text{O}(\text{l})$	204.496 ± 0.724	9	
$2 \text{SeO}_4^{2-} + 40 \text{H}^+ + 32 \text{e}^- + 2 \text{CO}_3^{2-} + 2 \text{NO}_3^- + \text{Ni}^{2+} \rightleftharpoons \text{Ni}(\text{SeCN})_2(\text{aq}) + 20 \text{H}_2\text{O}(\text{l})$	407.693 ± 1.451	9	
$\text{SeO}_4^{2-} + \text{UO}_2^{2+} \rightleftharpoons \text{UO}_2\text{SeO}_4(\text{aq})$	2.740 ± 0.250	9	
$\text{SeO}_4^{2-} + \text{Mg}^{2+} \rightleftharpoons \text{MgSeO}_4(\text{aq})$	2.200 ± 0.200	9	
$\text{SeO}_4^{2-} + \text{Ca}^{2+} \rightleftharpoons \text{CaSeO}_4(\text{aq})$	2.000 ± 0.100	9	
$2 \text{Br}^- \rightleftharpoons \text{Br}_2(\text{aq}) + 2 \text{e}^-$	-37.246 ± 0.180	12	
$\text{Br}^- + \text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{BrO}^- + 2 \text{H}^+ + 2 \text{e}^-$	-54.116 ± 0.271	12	
$\text{Br}^- + 3 \text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{BrO}_3^- + 6 \text{H}^+ + 6 \text{e}^-$	-146.169 ± 0.116	12	
$\text{Br}^- + \text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{HBrO}(\text{aq}) + \text{H}^+ + 2 \text{e}^-$	-45.486 ± 0.269	12	
$\text{Sr}^{2+} + \text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{SrOH}^+ + \text{H}^+$	-13.290 ± 0.500	49	
$\text{Sr}^{2+} + \text{SO}_4^{2-} \rightleftharpoons \text{SrSO}_4(\text{aq})$	1.860 ± 0.030	49	
$\text{Sr}^{2+} + \text{NO}_3^- \rightleftharpoons \text{SrNO}_3^+$	0.800	2	
$\text{Sr}^{2+} + \text{PO}_4^{3-} \rightleftharpoons \text{SrPO}_4^-$	4.200	2	
$\text{Zr}^{4+} + \text{H}_2\text{O}(\text{l}) \rightleftharpoons \# \text{ZrOH}^{3+} + \text{H}^+$	0.320 ± 0.220	10	
$\text{Zr}^{4+} + 2 \text{H}_2\text{O}(\text{l}) \rightleftharpoons \# \text{ZrOH}_2^{2+} + 2 \text{H}^+$	0.980 ± 1.060	10	
$\text{Zr}^{4+} + 4 \text{H}_2\text{O}(\text{l}) \rightleftharpoons \# \text{Zr(OH)}_4(\text{aq}) + 4 \text{H}^+$	-2.190 ± 1.700	10	
$\text{Zr}^{4+} + 6 \text{H}_2\text{O}(\text{l}) \rightleftharpoons \# \text{Zr(OH)}_6^{2-} + 6 \text{H}^+$	-29.000 ± 0.700	10	
$3 \text{Zr}^{4+} + 4 \text{H}_2\text{O}(\text{l}) \rightleftharpoons \# \text{Zr}_3(\text{OH})_4^{8+} + 4 \text{H}^+$	0.400 ± 0.300	10	
$3 \text{Zr}^{4+} + 9 \text{H}_2\text{O}(\text{l}) \rightleftharpoons \# \text{Zr}_3(\text{OH})_9^{3+} + 9 \text{H}^+$	12.190 ± 0.080	10	
$4 \text{Zr}^{4+} + 8 \text{H}_2\text{O}(\text{l}) \rightleftharpoons \# \text{Zr}_4(\text{OH})_8^{8+} + 8 \text{H}^+$	6.520 ± 0.650	10	
$4 \text{Zr}^{4+} + 15 \text{H}_2\text{O}(\text{l}) \rightleftharpoons \# \text{Zr}_4(\text{OH})_{15}^+ + 15 \text{H}^+$	12.580 ± 0.240	10	
$4 \text{Zr}^{4+} + 16 \text{H}_2\text{O}(\text{l}) \rightleftharpoons \# \text{Zr}_4(\text{OH})_{16}(\text{aq}) + 16 \text{H}^+$	8.390 ± 0.800	10	
$\text{Zr}^{4+} + \text{F}^- \rightleftharpoons \# \text{ZrF}^{3+}$	10.120 ± 0.070	10	
$\text{Zr}^{4+} + 2 \text{F}^- \rightleftharpoons \# \text{ZrF}_2^{2+}$	18.550 ± 0.310	10	
$\text{Zr}^{4+} + 3 \text{F}^- \rightleftharpoons \# \text{ZrF}_3^+$	24.720 ± 0.380	10	
$\text{Zr}^{4+} + 4 \text{F}^- \rightleftharpoons \# \text{ZrF}_4(\text{aq})$	30.110 ± 0.400	10	
$\text{Zr}^{4+} + 5 \text{F}^- \rightleftharpoons \# \text{ZrF}_5^-$	34.600 ± 0.420	10	
$\text{Zr}^{4+} + 6 \text{F}^- \rightleftharpoons \# \text{ZrF}_6^{2-}$	38.110 ± 0.430	10	
$\text{Zr}^{4+} + \text{Cl}^- \rightleftharpoons \# \text{ZrCl}^{3+}$	1.590 ± 0.060	10	
$\text{Zr}^{4+} + 2 \text{Cl}^- \rightleftharpoons \# \text{ZrCl}_2^{2+}$	2.170 ± 0.240	10	
$\text{Zr}^{4+} + 3 \text{Cl}^- \rightleftharpoons \# \text{ZrCl}_3^+$	3.000 ± 0.450	56	

Reaction	$\log_{10} K^\circ$	ref.	t.v. ^{*1}
Zr ⁴⁺ + 4 Cl ⁻ ⇌ #ZrCl ₄	-1.230 ± 0.500	56	
Zr ⁴⁺ + SO ₄ ²⁻ ⇌ #ZrSO ₄ ²⁺	7.040 ± 0.090	10	
Zr ⁴⁺ + 2 SO ₄ ²⁻ ⇌ #Zr(SO ₄) ₂ (aq)	11.540 ± 0.210	10	
Zr ⁴⁺ + 3 SO ₄ ²⁻ ⇌ #Zr(SO ₄) ₃ ²⁻	14.300 ± 0.500	10	
Zr ⁴⁺ + NO ₃ ⁻ ⇌ #ZrNO ₃ ³⁺	1.590 ± 0.080	10	
Zr ⁴⁺ + 2 NO ₃ ⁻ ⇌ #Zr(NO ₃) ₂ ²⁺	2.640 ± 0.170	10	
Zr ⁴⁺ + 3 NO ₃ ⁻ ⇌ #Zr(NO ₃) ₃ ⁺	1.040 ± 1.500	56	*
Zr ⁴⁺ + 4 CO ₃ ²⁻ ⇌ #Zr(CO ₃) ₄ ⁴⁻	42.900 ± 1.000	10	
Zr ⁴⁺ + 2 Ca ²⁺ + 6 H ₂ O(l) ⇌ #Ca ₂ [Zr(OH) ₆] ²⁺ + 6 H ⁺	-22.606 ± 0.313	28	
Zr ⁴⁺ + 3 Ca ²⁺ + 6 H ₂ O(l) ⇌ #Ca ₃ [Zr(OH) ₆] ⁴⁺ + 6 H ⁺	-23.206 ± 0.313	28	
Nb(OH) ₅ (aq) + H ₂ O(l) ⇌ Nb(OH) ₆ ⁻ + H ⁺	> -6.758	present	
MoO ₄ ²⁻ + 8 H ⁺ + 3 e ⁻ ⇌ Mo ³⁺ + 4 H ₂ O(l)	29.390	96	
MoO ₄ ²⁻ + H ⁺ ⇌ HMoO ₄ ⁻	4.100 ± 0.100	64	
MoO ₄ ²⁻ + 2 H ⁺ ⇌ H ₂ MoO ₄ (aq)	6.700 ± 0.200	64	
7 MoO ₄ ²⁻ + 8 H ⁺ ⇌ Mo ₇ O ₂₄ ⁶⁻ + 4 H ₂ O(l)	53.000 ± 0.200	64	
7 MoO ₄ ²⁻ + 9 H ⁺ ⇌ HM ₇ O ₂₄ ⁵⁻ + 4 H ₂ O(l)	59.800 ± 0.500	64	
Sm ³⁺ + 2 MoO ₄ ²⁻ ⇌ Sm(MoO ₄) ₂ ⁴⁻	11.200 ± 0.300	97	
TcO ₄ ⁻ + e ⁻ ⇌ #TcO ₄ ²⁻	-10.800 ± 0.500	11	
TcO ²⁺ + 3 H ₂ O(l) ⇌ #TcO ₄ ²⁻ + 6 H ⁺ + 2 e ⁻	> -44.214	11	
TcO ²⁺ + 3 H ₂ O(l) ⇌ #TcO ₄ ⁻ + 6 H ⁺ + 3 e ⁻	> -33.414	11	
TcO ²⁺ + H ₂ O(l) ⇌ #TcO(OH) ⁺ + H ⁺	> 0.563	present	
TcO ²⁺ + 2 H ₂ O(l) ⇌ #TcO(OH) ₂ (aq) + 2 H ⁺	> -4.000	11	
TcO ²⁺ + 3 H ₂ O(l) ⇌ #TcO(OH) ₃ ⁻ + 3 H ⁺	> -14.900	present	
TcO ²⁺ + H ₂ O(l) + CO ₃ ²⁻ ⇌ #TcCO ₃ (OH) ₂ (aq)	> 15.267	present	
TcO ²⁺ + 2 H ₂ O(l) + CO ₃ ²⁻ ⇌ #TcCO ₃ (OH) ₃ ⁻ + H ⁺	> 6.967	present	
Pd ²⁺ + H ₂ O(l) ⇌ PdOH ⁺ + H ⁺	-0.680 ± 0.450	69	
Pd ²⁺ + 2 H ₂ O(l) ⇌ Pd(OH) ₂ (aq) + 2 H ⁺	-3.110 ± 0.310	69	
Pd ²⁺ + 3 H ₂ O(l) ⇌ Pd(OH) ₃ ⁻ + 3 H ⁺	-15.400 ± 0.390	69	
Pd ²⁺ + Cl ⁻ ⇌ PdCl ⁺	5.031 ± 0.200	present	
Pd ²⁺ + 2 Cl ⁻ ⇌ PdCl ₂ (aq)	8.471 ± 0.283	present	
Pd ²⁺ + 3 Cl ⁻ ⇌ PdCl ₃ ⁻	10.582 ± 0.346	present	
Pd ²⁺ + 4 Cl ⁻ ⇌ PdCl ₄ ²⁻	11.464 ± 0.400	present	
Pd ²⁺ + NO ₃ ⁻ ⇌ PdNO ₃ ⁺	0.167 ± 0.024	present	*
Pd ²⁺ + 2 NO ₃ ⁻ ⇌ Pd(NO ₃) ₂ (aq)	-0.762 ± 0.039	present	*
Pd ²⁺ + 2 NO ₃ ⁻ + H ₂ O(l) ⇌ PdOHNO ₃ (aq) + H ⁺	-0.650 ± 0.036	present	*
Pd ⁺² + 3 Cl ⁻ + H ₂ O(l) ⇌ PdCl ₃ OH ²⁻ + H ⁺	2.500	6	
Pd ⁺² + 2 Cl ⁻ + 2 H ₂ O(l) ⇌ PdCl ₂ (OH) ₂ ²⁻ + 2 H ⁺	-7.000	6	
Pd ⁺² + NH ₄ ⁺ ⇌ PdNH ₃ ²⁺ + H ⁺	0.363	6	
Pd ⁺² + 2 NH ₄ ⁺ ⇌ Pd(NH ₃) ₂ ²⁺ + 2 H ⁺	0.026	6	
Pd ⁺² + 3 NH ₄ ⁺ ⇌ Pd(NH ₃) ₃ ²⁺ + 3 H ⁺	-1.711	6	
Pd ⁺² + 4 NH ₄ ⁺ ⇌ Pd(NH ₃) ₄ ²⁺ + 4 H ⁺	-4.148	6	
Sn ²⁺ + H ₂ O(l) ⇌ SnOH ⁺ + H ⁺	-3.750	6	
Sn ²⁺ + 2 H ₂ O(l) ⇌ Sn(OH) ₂ (aq) + 2 H ⁺	-7.710	6	
Sn ²⁺ + 3 H ₂ O(l) ⇌ Sn(OH) ₃ ⁻ + 3 H ⁺	-17.540	6	
3 Sn ²⁺ + 4 H ₂ O(l) ⇌ Sn ₃ (OH) ₄ ²⁺ + 4 H ⁺	-6.510	6	
Sn ²⁺ + Cl ⁻ ⇌ SnCl ⁺	1.650	6	
Sn ²⁺ + 2 Cl ⁻ ⇌ SnCl ₂ (aq)	2.310	6	
Sn ²⁺ + 3 Cl ⁻ ⇌ SnCl ₃ ⁻	2.090	6	
Sn ²⁺ + H ₂ O(l) + Cl ⁻ ⇌ SnClOH(aq) + H ⁺	-2.270	6	
Sn ²⁺ + F ⁻ ⇌ SnF ⁺	4.460	6	
Sn ²⁺ + 2 F ⁻ ⇌ SnF ₂ (aq)	7.740	6	
Sn ²⁺ + 3 F ⁻ ⇌ SnF ₃ ⁻	9.610	6	

Reaction	$\log_{10} K^\circ$	ref.	t.v. ^{*1}
$\text{Sn}^{2+} + \text{NO}_3^- \rightleftharpoons \text{SnNO}_3^+$	1.250	6	
$\text{Sn}^{2+} + 2 \text{NO}_3^- \rightleftharpoons \text{Sn}(\text{NO}_3)_2(\text{aq})$	1.740	6	
$\text{Sn}^{2+} + 3 \text{NO}_3^- \rightleftharpoons \text{Sn}(\text{NO}_3)_3^-$	1.370	6	
$\text{Sn}^{2+} + 4 \text{NO}_3^- \rightleftharpoons \text{Sn}(\text{NO}_3)_4^{2-}$	0.300	6	
$\text{Sn}^{2+} + \text{SO}_4^{2-} \rightleftharpoons \text{SnSO}_4(\text{aq})$	2.910	6	
$\text{Sn}^{2+} + 2 \text{SO}_4^{2-} \rightleftharpoons \text{Sn}(\text{SO}_4)_2^{2-}$	2.830	6	
$\text{Sn}(\text{OH})_4(\text{aq}) + 4 \text{H}^+ + 2 \text{e}^- \rightleftharpoons \text{Sn}^{2+} + 4 \text{H}_2\text{O}(\text{l})$	5.400	6	
$\text{Sn}(\text{OH})_4(\text{aq}) + \text{H}_2\text{O}(\text{l}) - \text{H}^+ \rightleftharpoons \text{Sn}(\text{OH})_5^-$	-7.970	6	
$\text{Sn}(\text{OH})_4(\text{aq}) + 2 \text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{Sn}(\text{OH})_6^{2-} + 2 \text{H}^+$	-18.400	6	
$\text{Sn}(\text{OH})_4(\text{aq}) + 4 \text{H}^+ \rightleftharpoons \text{Sn}^{4+} + 4 \text{H}_2\text{O}(\text{l})$	0.400	6	
$\text{Sb}(\text{OH})_3(\text{aq}) + 3 \text{H}^+ \rightleftharpoons \text{Sb}^{3+} + 3 \text{H}_2\text{O}(\text{l})$	-0.730	6	
$\text{Sb}(\text{OH})_3(\text{aq}) + 2 \text{H}^+ \rightleftharpoons \text{SbOH}^{2+} + 2 \text{H}_2\text{O}(\text{l})$	0.830	6	
$\text{Sb}(\text{OH})_3(\text{aq}) + \text{H}^+ \rightleftharpoons \text{Sb}(\text{OH})_2^+ + \text{H}_2\text{O}(\text{l})$	1.300	6	
$\text{Sb}(\text{OH})_3(\text{aq}) + \text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{Sb}(\text{OH})_4^- + \text{H}^+$	-11.930	6	
$2 \text{Sb}(\text{OH})_3(\text{aq}) + 2 \text{H}^+ + 4 \text{HS}^- \rightleftharpoons \text{Sb}_2\text{S}_4^{2-} + 6 \text{H}_2\text{O}(\text{l})$	42.530	6	
$2 \text{Sb}(\text{OH})_3(\text{aq}) + 3 \text{H}^+ + 4 \text{HS}^- \rightleftharpoons \text{HSb}_2\text{S}_4^- + 6 \text{H}_2\text{O}(\text{l})$	52.180	6	
$2 \text{Sb}(\text{OH})_3(\text{aq}) + 4 \text{H}^+ + 4 \text{HS}^- \rightleftharpoons \text{H}_2\text{Sb}_2\text{S}_4(\text{aq}) + 6 \text{H}_2\text{O}(\text{l})$	57.000	6	
$2 \text{Sb}(\text{OH})_3(\text{aq}) \rightleftharpoons \text{Sb}_2(\text{OH})_6(\text{aq})$	0.080	6	
$\text{Sb}(\text{OH})_3(\text{aq}) + 3 \text{H}^+ + \text{Cl}^- \rightleftharpoons \text{SbCl}^{2+} + 3 \text{H}_2\text{O}(\text{l})$	2.780	6	
$\text{Sb}(\text{OH})_3(\text{aq}) + 3 \text{H}^+ + 2 \text{Cl}^- \rightleftharpoons \text{SbCl}_2^+ + 3 \text{H}_2\text{O}(\text{l})$	3.270	6	
$\text{Sb}(\text{OH})_3(\text{aq}) + 3 \text{H}^+ + \text{F}^- \rightleftharpoons \text{SbF}^{2+} + 3 \text{H}_2\text{O}(\text{l})$	6.480	6	
$\text{Sb}(\text{OH})_3(\text{aq}) + 3 \text{H}^+ + 2 \text{F}^- \rightleftharpoons \text{SbF}_2^+ + 3 \text{H}_2\text{O}(\text{l})$	12.650	6	
$\text{Sb}(\text{OH})_3(\text{aq}) + 3 \text{H}^+ + 3 \text{F}^- \rightleftharpoons \text{SbF}_3(\text{aq}) + 3 \text{H}_2\text{O}(\text{l})$	18.360	6	
$\text{Sb}(\text{OH})_3(\text{aq}) + 2 \text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{Sb}(\text{OH})_5(\text{aq}) + 2 \text{H}^+ + 2 \text{e}^-$	-21.840	6	
$\text{Sb}(\text{OH})_5(\text{aq}) + \text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{Sb}(\text{OH})_6^- + \text{H}^+$	-2.720	6	
$12 \text{Sb}(\text{OH})_5(\text{aq}) + 4 \text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{Sb}_{12}(\text{OH})_{64}^{4-} + 4 \text{H}^+$	20.340	6	
$12 \text{Sb}(\text{OH})_5(\text{aq}) + 5 \text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{Sb}_{12}(\text{OH})_{65}^{5-} + 5 \text{H}^+$	16.720	6	
$12 \text{Sb}(\text{OH})_5(\text{aq}) + 6 \text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{Sb}_{12}(\text{OH})_{66}^{6-} + 6 \text{H}^+$	11.890	6	
$12 \text{Sb}(\text{OH})_5(\text{aq}) + 7 \text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{Sb}_{12}(\text{OH})_{67}^{7-} + 7 \text{H}^+$	6.070	6	
$\Gamma + 3 \text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{IO}_3^- + 6 \text{H}^+ + 6 \text{e}^-$	-111.563 ± 0.138	12	
$\Gamma + 3 \text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{HIO}_3(\text{aq}) + 5 \text{H}^+ + 6 \text{e}^-$	-110.775 ± 0.141	12	
$3 \text{I}^- \rightleftharpoons \text{I}_3^- + 2 \text{e}^-$	-18.300	2	
$\Gamma + \text{H}^+ \rightleftharpoons \text{HI}(\text{aq})$	-0.051	2	
$\Gamma + \text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{IO}^- + 2 \text{H}^+ + 2 \text{e}^-$	-44.000	2	
$\Gamma + 4 \text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{IO}_4^- + 8 \text{H}^+ + 8 \text{e}^-$	-165.000	2	
$2 \text{I}^- + \text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{I}_2\text{O}^{2-} + 2 \text{H}^+ + 2 \text{e}^-$	-45.300	2	
$\Gamma + \text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{HIO}(\text{aq}) + \text{H}^+ + 2 \text{e}^-$	-33.300	2	
$\Gamma + \text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{H}_2\text{IO}^-$	-32.100	2	
$2 \text{I}^- + \text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{HI}_2\text{O}^- + \text{H}^+ + 2 \text{e}^-$	-19.400	2	
$2 \text{I}^- + \text{Cl}^- \rightleftharpoons \text{I}_2\text{Cl}^- + 2 \text{e}^-$	-20.800	2	
$\Gamma + \text{Cl}^- \rightleftharpoons \text{ICl}^- + \text{e}^-$	-29.000	2	
$\Gamma + 2 \text{Cl}^- \rightleftharpoons \text{ICl}_2^- + 2 \text{e}^-$	-26.900	2	
$2 \text{I}^- \rightleftharpoons \text{I}_2(\text{aq}) + 2 \text{e}^-$	-18.180	2	
$\text{Ba}^{2+} + \text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{BaOH}^+ + \# \text{H}^+$	-13.470 ± 0.500	49	
$\text{Ba}^{2+} + \text{SO}_4^{2-} \rightleftharpoons \text{BaSO}_4(\text{aq})$	2.720 ± 0.090	49	
$\text{Sm}^{3+} + \text{H}_2\text{O}(\text{l}) \rightleftharpoons \#\text{SmOH}^{2+} + \text{H}^+$	-7.200 ± 0.500	26	
$\text{Sm}^{3+} + 2 \text{H}_2\text{O}(\text{l}) \rightleftharpoons \#\text{Sm}(\text{OH})_2^+ + 2 \text{H}^+$	-15.100 ± 0.700	26	
$\text{Sm}^{3+} + 3 \text{H}_2\text{O}(\text{l}) \rightleftharpoons \#\text{Sm}(\text{OH})_3(\text{aq}) + 3 \text{H}^+$	-26.200 ± 0.500	26	
$\text{Sm}^{3+} + \text{F}^- \rightleftharpoons \#\text{SmF}^{2+}$	3.400 ± 0.400	26	
$\text{Sm}^{3+} + 2 \text{F}^- \rightleftharpoons \#\text{SmF}_2^+$	5.800 ± 0.200	26	

Reaction	$\log_{10} K^\circ$	ref.	t.v. ^{*1}
$\text{Sm}^{3+} + \text{Cl}^- \rightleftharpoons \text{SmCl}^{2+}$	0.240 ± 0.030	26	
$\text{Sm}^{3+} + 2 \text{Cl}^- \rightleftharpoons \text{SmCl}_2^{+}$	-0.740 ± 0.050	26	
$\text{Sm}^{3+} + \text{SO}_4^{2-} \rightleftharpoons \text{SmSO}_4^{+}$	3.300 ± 0.150	26	
$\text{Sm}^{3+} + 2 \text{SO}_4^{2-} \rightleftharpoons \text{Sm}(\text{SO}_4)_2^{-}$	3.700 ± 0.150	26	
$\text{Sm}^{3+} + 3 \text{NO}_3^- + 18 \text{H}^+ + 16 \text{e}^- \rightleftharpoons \text{SmN}_3^{2+} + 9 \text{H}_2\text{O(l)}$	256.342 ± 0.430	26, 12	
$\text{Sm}^{3+} + \text{NO}_2^- \rightleftharpoons \text{SmNO}_2^{2+}$	2.100 ± 0.200	26	
$\text{Sm}^{3+} + \text{NO}_3^- \rightleftharpoons \text{SmNO}_3^{2+}$	1.330 ± 0.200	26	
$\text{Sm}^{3+} + 2 \text{H}^+ + \text{PO}_4^{3-} \rightleftharpoons \text{SmH}_2\text{PO}_4^{2+}$	22.562 ± 0.501	26, 12	
$\text{Sm}^{3+} + \text{CO}_3^{2-} \rightleftharpoons \text{SmCO}_3^{+}$	8.000 ± 0.400	26	
$\text{Sm}^{3+} + 2 \text{CO}_3^{2-} \rightleftharpoons \text{Sm}(\text{CO}_3)_2^{-}$	12.900 ± 0.600	26	
$\text{Sm}^{3+} + 3 \text{CO}_3^{2-} \rightleftharpoons \text{Sm}(\text{CO}_3)_3^{3-}$	15.000 ± 1.000	26	
$\text{Sm}^{3+} + \text{H}^+ + \text{CO}_3^{2-} \rightleftharpoons \text{SmHCO}_3^{2+}$	13.429 ± 0.301	26, 12	
$\text{Sm}^{3+} + \text{H}_4\text{SiO}_4(\text{aq}) \rightleftharpoons \text{SmSiO(OH)}_3^{2+} + \text{H}^+$	-1.680 ± 0.180	26	
$\text{Sm}^{3+} + \text{NO}_3^- + \text{CO}_3^{2-} + \text{SO}_4^{2-} + 20 \text{H}^+ + 16 \text{e}^- \rightleftharpoons \text{SmSCN}^{2+} + 10 \text{H}_2\text{O(l)}$	158.272 ± 0.775	26, 12	
$2 \text{Hg}^{2+} + 2 \text{e}^- \rightleftharpoons \text{Hg}_2^{2+}$	3.889 ± 0.224	12	
$\text{Pb}^{2+} + \text{H}_2\text{O(l)} \rightleftharpoons \text{PbOH}^+ + \text{H}^+$	-6.910 ± 0.360	80	
$\text{Pb}^{2+} + 2 \text{H}_2\text{O(l)} \rightleftharpoons \text{Pb(OH)}_2(\text{aq}) + 2 \text{H}^+$	-16.110 ± 0.710	80	
$\text{Pb}^{2+} + 3 \text{H}_2\text{O(l)} \rightleftharpoons \text{Pb(OH)}_3^- + 3 \text{H}^+$	-26.270 ± 1.180	80	
$\text{Pb}^{2+} + 4 \text{H}_2\text{O(l)} \rightleftharpoons \text{Pb(OH)}_4^{2-} + 4 \text{H}^+$	-38.780 ± 0.390	80	
$2 \text{Pb}^{2+} + \text{H}_2\text{O(l)} \rightleftharpoons \text{Pb}_2\text{OH}^{3+} + \text{H}^+$	-7.180	6	
$4 \text{Pb}^{2+} + 4 \text{H}_2\text{O(l)} \rightleftharpoons \text{Pb}_4\text{OH}_4^{4+} + 4 \text{H}^+$	-20.630	6	
$3 \text{Pb}^{2+} + 4 \text{H}_2\text{O(l)} \rightleftharpoons \text{Pb}_3\text{OH}_4^{2+} + 4 \text{H}^+$	-22.480	6	
$3 \text{Pb}^{2+} + 5 \text{H}_2\text{O(l)} \rightleftharpoons \text{Pb}_3\text{OH}_5^{+} + 5 \text{H}^+$	-30.720	6	
$6 \text{Pb}^{2+} + 8 \text{H}_2\text{O(l)} \rightleftharpoons \text{Pb}_6\text{OH}_8^{4+} + 8 \text{H}^+$	-42.680	6	
$\text{Pb}^{2+} + \text{CO}_3^{2-} \rightleftharpoons \text{PbCO}_3(\text{aq})$	7.300	6	
$\text{Pb}^{2+} + 2 \text{CO}_3^{2-} \rightleftharpoons \text{Pb}(\text{CO}_3)_2^{-2}$	10.130	6	
$\text{Pb}^{2+} + \text{NO}_3^- \rightleftharpoons \text{PbNO}_3^{+}$	1.060	6	
$\text{Pb}^{2+} + 2 \text{NO}_3^- \rightleftharpoons \text{Pb}(\text{NO}_3)_2(\text{aq})$	1.480	6	
$\text{Pb}^{2+} + 3 \text{NO}_3^- \rightleftharpoons \text{Pb}(\text{NO}_3)_3^-$	0.760	6	
$\text{Pb}^{2+} + \text{PO}_4^{3-} + \text{H}^+ \rightleftharpoons \text{PbHPO}_4(\text{aq})$	15.450	6	
$\text{Pb}^{2+} + \text{PO}_4^{3-} + 2 \text{H}^+ \rightleftharpoons \text{PbH}_2\text{PO}_4^{+}$	21.050	6	
$\text{Pb}^{2+} + \text{SO}_4^{2-} \rightleftharpoons \text{PbSO}_4(\text{aq})$	2.820	6	
$\text{Pb}^{2+} + 2 \text{SO}_4^{2-} \rightleftharpoons \text{Pb}(\text{SO}_4)_2^{2-}$	2.370	6	
$\text{Pb}^{2+} + 2 \text{HS}^- \rightleftharpoons \text{Pb}(\text{HS})_2(\text{aq})$	12.340	6	
$\text{Pb}^{2+} + 3 \text{HS}^- \rightleftharpoons \text{Pb}(\text{HS})_3^-$	13.590	6	
$\text{Pb}^{2+} + \text{Cl}^- \rightleftharpoons \text{PbCl}^+$	1.480 ± 0.100	80	
$\text{Pb}^{2+} + 2 \text{Cl}^- \rightleftharpoons \text{PbCl}_2(\text{aq})$	2.070 ± 0.170	80	
$\text{Pb}^{2+} + 3 \text{Cl}^- \rightleftharpoons \text{PbCl}_3^-$	1.800 ± 0.320	80	
$\text{Pb}^{2+} + 4 \text{Cl}^- \rightleftharpoons \text{PbCl}_4^{2-}$	1.330 ± 0.830	6	*
$\text{Pb}^{2+} + \text{F}^- \rightleftharpoons \text{PbF}^+$	2.270	6	
$\text{Pb}^{2+} + 2 \text{F}^- \rightleftharpoons \text{PbF}_2(\text{aq})$	3.010	6	
$\text{Pb}^{2+} + \text{F}^- + \text{Cl}^- \rightleftharpoons \text{PbFCl}(\text{aq})$	3.550	6	
$\text{Bi}^{3+} + \text{H}_2\text{O} \rightleftharpoons \text{BiOH}^{2+} + \text{H}^+$	-0.920	6	
$\text{Bi}^{3+} + 2 \text{H}_2\text{O} \rightleftharpoons \text{Bi}(\text{OH})_2^+ + 2 \text{H}^+$	-2.560 ± 1.000	6	
$\text{Bi}^{3+} + 3 \text{H}_2\text{O} \rightleftharpoons \text{Bi}(\text{OH})_3(\text{aq}) + 3 \text{H}^+$	-8.940 ± 0.500	81	
$\text{Bi}^{3+} + 4 \text{H}_2\text{O} \rightleftharpoons \text{Bi}(\text{OH})_4^- + 4 \text{H}^+$	-21.660 ± 0.870	81	
$6 \text{Bi}^{3+} + 12 \text{H}_2\text{O} \rightleftharpoons \text{Bi}_6(\text{OH})_{12}^{6+} + 12 \text{H}^+$	1.340	6	
$9 \text{Bi}^{3+} + 20 \text{H}_2\text{O} \rightleftharpoons \text{Bi}_9(\text{OH})_{20}^{7+} + 20 \text{H}^+$	-1.360	6	
$9 \text{Bi}^{3+} + 21 \text{H}_2\text{O} \rightleftharpoons \text{Bi}_9(\text{OH})_{21}^{6+} + 21 \text{H}^+$	-3.250	6	
$9 \text{Bi}^{3+} + 22 \text{H}_2\text{O} \rightleftharpoons \text{Bi}_9(\text{OH})_{22}^{5+} + 22 \text{H}^+$	-4.860	6	

Reaction	$\log_{10} K^\circ$	ref.	t.v. ^{*1}
$3 \text{Bi}^{3+} + 4 \text{H}_2\text{O} \rightleftharpoons \text{Bi}_3(\text{OH})_4^{5+} + 4 \text{H}^+$	-0.800	6	
$\text{Bi}^{3+} + \text{Cl}^- \rightleftharpoons \text{BiCl}^{2+}$	3.610 ± 0.180	81	
$\text{Bi}^{3+} + 2 \text{Cl}^- \rightleftharpoons \text{BiCl}_2^{+}$	5.560 ± 0.240	81	
$\text{Bi}^{3+} + 3 \text{Cl}^- \rightleftharpoons \text{BiCl}_3(\text{aq})$	6.980 ± 0.370	81	
$\text{Bi}^{3+} + 4 \text{Cl}^- \rightleftharpoons \text{BiCl}_4^-$	8.040 ± 0.200	81	
$\text{Bi}^{3+} + 5 \text{Cl}^- \rightleftharpoons \text{BiCl}_5^{2-}$	7.360 ± 0.370	81	
$\text{Bi}^{3+} + \text{PO}_4^{3-} \rightleftharpoons \text{BiPO}_4(\text{aq})$	≤ 21.850	81	
$\text{Bi}^{3+} + \text{NO}_3^- \rightleftharpoons \text{BiNO}_3^{2+}$	1.970	6	
$\text{Bi}^{3+} + 2 \text{NO}_3^- \rightleftharpoons \text{Bi}(\text{NO}_3)_2^+$	2.950	6	
$\text{Bi}^{3+} + 3 \text{NO}_3^- \rightleftharpoons \text{Bi}(\text{NO}_3)_3(\text{aq})$	3.620	6	
$\text{Bi}^{3+} + 4 \text{NO}_3^- \rightleftharpoons \text{Bi}(\text{NO}_3)_4^-$	3.090	6	
$\text{Bi}^{3+} + \text{Cl}^- + \text{NO}_3^- \rightleftharpoons \text{BiClNO}_3^+$	5.160	6	
$\text{Bi}^{3+} + \text{Cl}^- + 2 \text{NO}_3^- \rightleftharpoons \text{BiCl}(\text{NO}_3)_2(\text{aq})$	5.280	6	
$\text{Bi}^{3+} + 2 \text{Cl}^- + \text{NO}_3^- \rightleftharpoons \text{BiCl}_2\text{NO}_3(\text{aq})$	6.860	6	
$\text{Bi}^{3+} + 2 \text{Cl}^- + 2 \text{NO}_3^- \rightleftharpoons \text{BiCl}_2(\text{NO}_3)_2^-$	5.750	6	
$\text{Bi}^{3+} + 3 \text{Cl}^- + \text{NO}_3^- \rightleftharpoons \text{BiCl}_3\text{NO}_3^-$	8.090	6	
$\text{Ra}^{2+} + \text{H}_2\text{O} \rightleftharpoons \text{RaOH}^+ + \text{H}^+$	-13.470 ± 0.500	49	
$\text{Ra}^{2+} + \text{SO}_4^{2-} \rightleftharpoons \text{RaSO}_4(\text{aq})$	2.720 ± 0.090	49	
$\text{Ac}^{3+} + \text{H}_2\text{O(l)} \rightleftharpoons \text{AcOH}^{2+} + \text{H}^+$	-7.200 ± 0.700	26	*
$\text{Ac}^{3+} + 2 \text{H}_2\text{O(l)} \rightleftharpoons \text{Ac OH}_2^+ + 2 \text{H}^+$	-15.100 ± 0.900	26	*
$\text{Ac}^{3+} + 3 \text{H}_2\text{O(l)} \rightleftharpoons \text{Ac(OH)}_3(\text{aq}) + 3 \text{H}^+$	-26.200 ± 0.700	26	*
$\text{Ac}^{3+} + \text{F}^- \rightleftharpoons \text{AcF}^{2+}$	3.400 ± 0.600	26	*
$\text{Ac}^{3+} + 2 \text{F}^- \rightleftharpoons \text{AcF}_2^+$	5.800 ± 0.400	26	*
$\text{Ac}^{3+} + \text{Cl}^- \rightleftharpoons \text{AcCl}^{2+}$	0.240 ± 0.230	26	*
$\text{Ac}^{3+} + 2 \text{Cl}^- \rightleftharpoons \#\text{AcCl}_2^+$	-0.740 ± 0.250	26	*
$\text{Ac}^{3+} + \text{SO}_4^{2-} \rightleftharpoons \text{AcSO}_4^+$	3.300 ± 0.350	26	*
$\text{Ac}^{3+} + 2 \text{SO}_4^{2-} \rightleftharpoons \text{Ac}(\text{SO}_4)_2^-$	3.700 ± 0.350	26	*
$\text{Ac}^{3+} + 3 \text{NO}_3^- + 18 \text{H}^+ + 16 \text{e}^- \rightleftharpoons \text{AcN}_3^{2+} + 9 \text{H}_2\text{O(l)}$	256.342 ± 0.515	26, 12	*
$\text{Ac}^{3+} + \text{NO}_2^- \rightleftharpoons \text{AcNO}_2^{2+}$	2.100 ± 0.400	26	*
$\text{Ac}^{3+} + \text{NO}_3^- \rightleftharpoons \#\text{AcNO}_3^{2+}$	1.330 ± 0.400	26	*
$\text{Ac}^{3+} + 2 \text{H}^+ + \text{PO}_4^{3-} \rightleftharpoons \text{AcH}_2\text{PO}_4^{2+}$	22.562 ± 0.701	26, 12	*
$\text{Ac}^{3+} + \text{CO}_3^{2-} \rightleftharpoons \text{AcCO}_3^+$	8.000 ± 0.600	26	*
$\text{Ac}^{3+} + 2 \text{CO}_3^{2-} \rightleftharpoons \text{Ac}(\text{CO}_3)_2^-$	12.900 ± 0.800	26	*
$\text{Ac}^{3+} + 3 \text{CO}_3^{2-} \rightleftharpoons \#\text{Ac}(\text{CO}_3)_3^{3-}$	15.000 ± 1.200	26	*
$\text{Ac}^{3+} + \text{H}^+ + \text{CO}_3^{2-} \rightleftharpoons \text{AcHCO}_3^{2+}$	13.429 ± 0.500	26, 12	*
$\text{Ac}^{3+} + \text{H}_4\text{SiO}_4(\text{aq}) \rightleftharpoons \text{AcSiO}(\text{OH})_3^{2+} + \text{H}^+$	-1.680 ± 0.380	26	*
$\text{Ac}^{3+} + \text{NO}_3^- + \text{CO}_3^{2-} + \text{SO}_4^{2-} + 20 \text{H}^+ + 16 \text{e}^- \rightleftharpoons \text{AcSCN}^{2+} + 10 \text{H}_2\text{O(l)}$	158.272 ± 0.872	26, 12	*
$\text{Th}^{4+} + \text{H}_2\text{O(l)} \rightleftharpoons \#\text{ThOH}^{3+} + \text{H}^+$	-2.500 ± 0.500	12	
$\text{Th}^{4+} + 2 \text{H}_2\text{O(l)} \rightleftharpoons \#\text{Th}(\text{OH})_2^{2+} + 2 \text{H}^+$	-6.200 ± 0.500	12	
$\text{Th}^{4+} + 4 \text{H}_2\text{O(l)} \rightleftharpoons \#\text{Th}(\text{OH})_4(\text{aq}) + 4 \text{H}^+$	-17.400 ± 0.700	12	
$2 \text{Th}^{4+} + 2 \text{H}_2\text{O(l)} \rightleftharpoons \#\text{Th}_2(\text{OH})_2^{6+} + 2 \text{H}^+$	-5.900 ± 0.500	12	
$2 \text{Th}^{4+} + 3 \text{H}_2\text{O(l)} \rightleftharpoons \#\text{Th}_2(\text{OH})_3^{5+} + 3 \text{H}^+$	-6.800 ± 0.200	12	
$4 \text{Th}^{4+} + 8 \text{H}_2\text{O(l)} \rightleftharpoons \#\text{Th}_4(\text{OH})_8^{8+} + 8 \text{H}^+$	-20.400 ± 0.400	12	
$4 \text{Th}^{4+} + 12 \text{H}_2\text{O(l)} \rightleftharpoons \#\text{Th}_4(\text{OH})_{12}^{4+} + 12 \text{H}^+$	-26.600 ± 0.200	12	
$6 \text{Th}^{4+} + 14 \text{H}_2\text{O(l)} \rightleftharpoons \#\text{Th}_6(\text{OH})_{14}^{10+} + 14 \text{H}^+$	-36.800 ± 1.200	12	
$6 \text{Th}^{4+} + 15 \text{H}_2\text{O(l)} \rightleftharpoons \#\text{Th}_6(\text{OH})_{15}^{9+} + 15 \text{H}^+$	-36.800 ± 1.500	12	
$\text{Th}^{4+} + \text{F}^- \rightleftharpoons \#\text{ThF}^{3+}$	8.870 ± 0.150	12	
$\text{Th}^{4+} + 2 \text{F}^- \rightleftharpoons \#\text{ThF}_2^{2+}$	15.630 ± 0.230	12	
$\text{Th}^{4+} + 3 \text{F}^- \rightleftharpoons \#\text{ThF}_3^+$	20.670 ± 0.160	12	
$\text{Th}^{4+} + 4 \text{F}^- \rightleftharpoons \#\text{ThF}_4(\text{aq})$	25.580 ± 0.180	12	

Reaction	$\log_{10} K^\circ$	ref.	t.v. ^{*1}
$\text{Th}^{4+} + \text{Cl}^- \rightleftharpoons \#\text{ThCl}^{3+}$	1.700 ± 0.100	12	
$\text{Th}^{4+} + \text{SO}_4^{2-} \rightleftharpoons \#\text{ThSO}_4^{2+}$	6.170 ± 0.320	12	
$\text{Th}^{4+} + 2 \text{SO}_4^{2-} \rightleftharpoons \#\text{Th}(\text{SO}_4)_2(\text{aq})$	9.690 ± 0.270	12	
$\text{Th}^{4+} + 3 \text{SO}_4^{2-} \rightleftharpoons \#\text{Th}(\text{SO}_4)_3^{2-}$	10.748 ± 0.076	12	
$\text{Th}^{4+} + \text{NO}_3^- \rightleftharpoons \#\text{ThNO}_3^{3+}$	1.300 ± 0.200	12	
$\text{Th}^{4+} + 2 \text{NO}_3^- \rightleftharpoons \#\text{Th}(\text{NO}_3)_2^{2+}$	2.300 ± 0.400	12	
$\text{Th}^{4+} + 2 \text{H}^+ + \text{PO}_4^{3-} \rightleftharpoons \#\text{ThH}_2\text{PO}_4^{3+}$	25.152 ± 0.365	12	
$\text{Th}^{4+} + 3 \text{H}^+ + \text{PO}_4^{3-} \rightleftharpoons \#\text{ThH}_3\text{PO}_4^{4+}$	23.592 ± 0.356	12	
$\text{Th}^{4+} + 4 \text{H}^+ + 2 \text{PO}_4^{3-} \rightleftharpoons \#\text{Th}(\text{H}_2\text{PO}_4)_2^{2+}$	49.604 ± 0.476	12	
$\text{Th}^{4+} + 5 \text{H}^+ + 2 \text{PO}_4^{3-} \rightleftharpoons \#\text{Th}(\text{H}_3\text{PO}_4)(\text{H}_2\text{PO}_4)^{3+}$	48.824 ± 0.476	12	
$\text{Th}^{4+} + 5 \text{CO}_3^{2-} \rightleftharpoons \#\text{Th}(\text{CO}_3)_5^{6-}$	31.000 ± 0.700	12	
$\text{Th}^{4+} + 2 \text{CO}_3^{2-} + 2 \text{H}_2\text{O(l)} \rightleftharpoons \#\text{Th}(\text{CO}_3)_2(\text{OH})_2^{2-} + 2 \text{H}^+$	8.798 ± 0.501	12	
$\text{Th}^{4+} + 4 \text{CO}_3^{2-} + \text{H}_2\text{O(l)} \rightleftharpoons \#\text{Th}(\text{CO}_3)_4\text{OH}^{5-} + \text{H}^+$	21.599 ± 0.500	12	
$\text{Th}^{4+} + \text{CO}_3^{2-} + 4 \text{H}_2\text{O(l)} \rightleftharpoons \#\text{ThCO}_3(\text{OH})_4^{2-} + 4 \text{H}^+$	-15.605 ± 0.603	12	
$\text{Th}^{4+} + 3 \text{H}_4\text{SiO}_4(\text{aq}) + 3 \text{H}_2\text{O(l)} \rightleftharpoons \#\text{Th}(\text{OH})_3(\text{H}_3\text{SiO}_4)_3^{2-} + 6 \text{H}^+$	-27.800 ± 0.700	28	
$\text{Th}^{4+} + 8 \text{H}_2\text{O(l)} + 4 \text{Ca}^{2+} \rightleftharpoons \text{Ca}_4[\text{Th}(\text{OH})_8]^{4+} + 8 \text{H}^+$	-62.708 ± 0.908	29	
$\text{Pa}^{4+} + \text{H}_2\text{O(l)} \rightleftharpoons \text{PaOH}^{3+} + \text{H}^+$	0.840	31	
$\text{Pa}^{4+} + 2 \text{H}_2\text{O(l)} \rightleftharpoons \text{Pa(OH)}_2^{2+} + 2 \text{H}^+$	-0.020	31	
$\text{Pa}^{4+} + 3 \text{H}_2\text{O(l)} \rightleftharpoons \text{Pa(OH)}_3^{+} + 3 \text{H}^+$	-1.500	31	
$\text{PaOOH}^{2+} + 2 \text{H}_2\text{O(l)} \rightleftharpoons \text{PaO(OH)}_3(\text{aq}) + 2 \text{H}^+$	-5.460	31	
$\text{PaOOH}^{2+} + \text{H}_2\text{O(l)} \rightleftharpoons \text{PaO(OH)}_2^{+} + \text{H}^+$	-1.240 ± 0.020	32, 33	
$\text{PaOOH}^{2+} + 3 \text{H}_2\text{O(l)} \rightleftharpoons \#\text{Pa(OH)}_5(\text{aq}) + 2 \text{H}^+$	-8.270 ± 0.151	32, 33	
$\text{PaOOH}^{2+} + \text{Cl}^- \rightleftharpoons \text{PaOOHCl}^+$	1.922 ± 0.020	present	
$\text{PaOOH}^{2+} + \text{SO}_4^{2-} + \text{H}^+ \rightleftharpoons \#\text{PaOSO}_4^{+} + \text{H}_2\text{O(l)}$	3.890 ± 0.180	35	
$\text{PaOOH}^{2+} + 2 \text{SO}_4^{2-} + \text{H}^+ \rightleftharpoons \#\text{PaO(SO}_4)_2^{-} + \text{H}_2\text{O(l)}$	7.000 ± 0.200	35	
$\text{PaOOH}^{2+} + 3 \text{SO}_4^{2-} + \text{H}^+ \rightleftharpoons \#\text{PaO(SO}_4)_3^{3-} + \text{H}_2\text{O(l)}$	8.590 ± 0.230	35	
$\text{Pa}^{4+} + 2 \text{H}_2\text{O(l)} \rightleftharpoons \text{PaOOH}^{2+} + \text{e}^- + 3 \text{H}^+$	1.860	31	
$\text{U}^{4+} + \text{e}^- \rightleftharpoons \#\text{U}^{3+}$	-9.353 ± 0.070	11	
$\text{U}^{4+} + \text{H}_2\text{O(l)} \rightleftharpoons \#\text{UOH}^{3+} + \text{H}^+$	-0.290 ± 0.310	30	
$\text{U}^{4+} + 2 \text{H}_2\text{O(l)} \rightleftharpoons \#\text{U(OH)}_2^{2+} + 2 \text{H}^+$	-1.780 ± 0.210	30	
$\text{U}^{4+} + 3 \text{H}_2\text{O(l)} \rightleftharpoons \#\text{U(OH)}_3^{+} + 3 \text{H}^+$	-5.150 ± 0.210	30	
$\text{U}^{4+} + 4 \text{H}_2\text{O(l)} \rightleftharpoons \#\text{U(OH)}_4(\text{aq}) + 4 \text{H}^+$	-10.800 ± 1.400	30	
$\text{U}^{4+} + \text{F}^- \rightleftharpoons \#\text{UF}^{3+}$	9.420 ± 0.510	11	
$\text{U}^{4+} + 2 \text{F}^- \rightleftharpoons \#\text{UF}_2^{2+}$	16.560 ± 0.710	11	
$\text{U}^{4+} + 3 \text{F}^- \rightleftharpoons \#\text{UF}_3^{+}$	21.890 ± 0.830	11	
$\text{U}^{4+} + 4 \text{F}^- \rightleftharpoons \#\text{UF}_4$	26.340 ± 0.960	11	
$\text{U}^{4+} + 5 \text{F}^- \rightleftharpoons \#\text{UF}_5^{-}$	27.730 ± 0.740	11	
$\text{U}^{4+} + 6 \text{F}^- \rightleftharpoons \#\text{UF}_6^{2-}$	29.800 ± 0.700	11	
$\text{U}^{4+} + \text{Cl}^- \rightleftharpoons \#\text{UCl}^{3+}$	1.720 ± 0.130	11	
$\text{U}^{4+} + \text{Br}^- \rightleftharpoons \#\text{UBr}^{3+}$	1.460 ± 0.200	11	
$\text{U}^{4+} + \text{I}^- \rightleftharpoons \#\text{UI}^{3+}$	1.250 ± 0.300	11	
$\text{U}^{4+} + \text{SO}_4^{2-} \rightleftharpoons \#\text{USO}_4^{2+}$	6.580 ± 0.190	11	
$\text{U}^{4+} + 2 \text{SO}_4^{2-} \rightleftharpoons \#\text{U}(\text{SO}_4)_2(\text{aq})$	10.510 ± 0.200	11	
$\text{U}^{4+} + \text{NO}_3^- \rightleftharpoons \#\text{UNO}_3^{3+}$	1.470 ± 0.130	11	
$\text{U}^{4+} + 2 \text{NO}_3^- \rightleftharpoons \#\text{U}(\text{NO}_3)_2^{2+}$	2.300 ± 0.350	11	
$\text{U}^{4+} + 4 \text{CO}_3^{2-} \rightleftharpoons \#\text{U}(\text{CO}_3)_4^{4-}$	35.120 ± 0.934	11	
$\text{U}^{4+} + 5 \text{CO}_3^{2-} \rightleftharpoons \#\text{U}(\text{CO}_3)_5^{6-}$	31.500 ± 1.000	11	
$\text{U}^{4+} + 2 \text{CO}_3^{2-} + 2 \text{H}_2\text{O(l)} \rightleftharpoons \#\text{U}(\text{CO}_3)_2(\text{OH})_2^{2-} + 2 \text{H}^+$	13.557 ± 1.000	30	
$\text{U}^{4+} + \text{SO}_4^{2-} + \text{CO}_3^{2-} + \text{NO}_3^- + 20 \text{H}^+ + 16 \text{e}^- \rightleftharpoons \#\text{USCN}^{3+} + 10 \text{H}_2\text{O(l)}$	159.942 ± 0.718	11	
$\text{U}^{4+} + 2 \text{SO}_4^{2-} + 2 \text{CO}_3^{2-} + 2 \text{NO}_3^- + 40 \text{H}^+ + 32 \text{e}^- \rightleftharpoons \#\text{U}(\text{SCN})_2^{2+} + 20 \text{H}_2\text{O(l)}$	318.204 ± 1.441	11	

Reaction	$\log_{10} K^\circ$	ref.	t.v. ^{*1}
$\text{U}^{4+} + 2 \text{H}_2\text{O(l)} \rightleftharpoons \text{UO}_2^{+} + 4 \text{H}^+ + \text{e}^-$	-7.554 ± 0.047	11	
$\text{UO}_2^{+} + 3 \text{CO}_3^{2-} \rightleftharpoons \# \text{UO}_2(\text{CO}_3)_3^{5-}$	6.950 ± 0.360	11	
$\text{U}^{4+} + 2 \text{H}_2\text{O(l)} \rightleftharpoons \text{UO}_2^{2+} + 4 \text{H}^+ + 2 \text{e}^-$	-9.038 ± 0.041	11	
$\text{UO}_2^{2+} + \text{H}_2\text{O(l)} \rightleftharpoons \# \text{UO}_2\text{OH}^+ + \text{H}^+$	-5.250 ± 0.240	11	
$\text{UO}_2^{2+} + 2 \text{H}_2\text{O(l)} \rightleftharpoons \# \text{UO}_2(\text{OH})_2(\text{aq}) + 2 \text{H}^+$	-12.150 ± 0.070	11	
$\text{UO}_2^{2+} + 3 \text{H}_2\text{O(l)} \rightleftharpoons \# \text{UO}_2(\text{OH})_3^- + 3 \text{H}^+$	-20.250 ± 0.420	11	
$\text{UO}_2^{2+} + 4 \text{H}_2\text{O(l)} \rightleftharpoons \# \text{UO}_2(\text{OH})_4^{2-} + 4 \text{H}^+$	-32.400 ± 0.680	11	
$2 \text{UO}_2^{2+} + \text{H}_2\text{O(l)} \rightleftharpoons \# (\text{UO}_2)_2\text{OH}^{3+} + \text{H}^+$	-2.700 ± 1.000	11	
$2 \text{UO}_2^{2+} + 2 \text{H}_2\text{O(l)} \rightleftharpoons \# (\text{UO}_2)_2\text{OH}_2^{2+} + 2 \text{H}^+$	-5.620 ± 0.040	11	
$3 \text{UO}_2^{2+} + 4 \text{H}_2\text{O(l)} \rightleftharpoons \# (\text{UO}_2)_3(\text{OH})_4^{2+} + 4 \text{H}^+$	-11.900 ± 0.300	11	
$3 \text{UO}_2^{2+} + 5 \text{H}_2\text{O(l)} \rightleftharpoons \# (\text{UO}_2)_3(\text{OH})_5^+ + 5 \text{H}^+$	-15.550 ± 0.120	11	
$3 \text{UO}_2^{2+} + 7 \text{H}_2\text{O(l)} \rightleftharpoons \# (\text{UO}_2)_3(\text{OH})_7^- + 7 \text{H}^+$	-32.200 ± 0.800	11	
$4 \text{UO}_2^{2+} + 7 \text{H}_2\text{O(l)} \rightleftharpoons \# (\text{UO}_2)_4(\text{OH})_7^+ + 7 \text{H}^+$	-21.900 ± 1.000	11	
$\text{UO}_2^{2+} + \text{F}^- \rightleftharpoons \# \text{UO}_2\text{F}^+$	5.160 ± 0.060	11	
$\text{UO}_2^{2+} + 2 \text{F}^- \rightleftharpoons \# \text{UO}_2\text{F}_2(\text{aq})$	8.830 ± 0.080	11	
$\text{UO}_2^{2+} + 3 \text{F}^- \rightleftharpoons \# \text{UO}_2\text{F}_3^-$	10.900 ± 0.100	11	
$\text{UO}_2^{2+} + 4 \text{F}^- \rightleftharpoons \# \text{UO}_2\text{F}_4^{2-}$	11.840 ± 0.110	11	
$\text{UO}_2^{2+} + \text{Cl}^- \rightleftharpoons \# \text{UO}_2\text{Cl}^+$	0.170 ± 0.020	11	
$\text{UO}_2^{2+} + 2 \text{Cl}^- \rightleftharpoons \# \text{UO}_2\text{Cl}_2(\text{aq})$	-1.100 ± 0.400	11	
$\text{UO}_2^{2+} + \text{Cl}^- + 3 \text{H}_2\text{O(l)} \rightleftharpoons \# \text{UO}_2\text{ClO}_3^+ + 6 \text{H}^+ + 6 \text{e}^-$	-145.738 ± 0.246	11	
$\text{UO}_2^{2+} + \text{Br}^- \rightleftharpoons \# \text{UO}_2\text{Br}^+$	0.220 ± 0.020	11	
$\text{UO}_2^{2+} + \text{Br}^- + 3 \text{H}_2\text{O(l)} \rightleftharpoons \# \text{UO}_2\text{BrO}_3^+ + 6 \text{H}^+ + 6 \text{e}^-$	-145.539 ± 0.141	11	
$\text{UO}_2^{2+} + \text{I}^- + 3 \text{H}_2\text{O(l)} \rightleftharpoons \# \text{UO}_2\text{IO}_3^+ + 6 \text{H}^+ + 6 \text{e}^-$	-109.563 ± 0.139	11	
$\text{UO}_2^{2+} + 2 \text{I}^- + 6 \text{H}_2\text{O(l)} \rightleftharpoons \# \text{UO}_2(\text{IO}_3)_2(\text{aq}) + 12 \text{H}^+ + 12 \text{e}^-$	-219.536 ± 0.314	11	
$\text{UO}_2^{2+} + \text{SO}_3^{2-} \rightleftharpoons \# \text{UO}_2\text{SO}_3(\text{aq})$	6.600 ± 0.600	11	
$\text{UO}_2^{2+} + \text{S}_2\text{O}_3^{2-} \rightleftharpoons \# \text{UO}_2\text{S}_2\text{O}_3(\text{aq})$	2.800 ± 0.300	11	
$\text{UO}_2^{2+} + \text{SO}_4^{2-} \rightleftharpoons \# \text{UO}_2\text{SO}_4(\text{aq})$	3.150 ± 0.020	11	
$\text{UO}_2^{2+} + 2 \text{SO}_4^{2-} \rightleftharpoons \# \text{UO}_2(\text{SO}_4)_2^{2-}$	4.140 ± 0.070	11	
$\text{UO}_2^{2+} + 3 \text{SO}_4^{2-} \rightleftharpoons \# \text{UO}_2(\text{SO}_4)_3^{4-}$	3.020 ± 0.380	11	
$\text{UO}_2^{2+} + 3 \text{NO}_3^- + 18 \text{H}^+ + 16 \text{e}^- \rightleftharpoons \# \text{UO}_2\text{N}_3^+ + 9 \text{H}_2\text{O(l)}$	257.252 ± 0.428	11	
$\text{UO}_2^{2+} + 6 \text{NO}_3^- + 36 \text{H}^+ + 32 \text{e}^- \rightleftharpoons \# \text{UO}_2(\text{N}_3)_2(\text{aq}) + 18 \text{H}_2\text{O(l)}$	513.674 ± 0.867	11	
$\text{UO}_2^{2+} + 9 \text{NO}_3^- + 54 \text{H}^+ + 48 \text{e}^- \rightleftharpoons \# \text{UO}_2(\text{N}_3)_3^- + 27 \text{H}_2\text{O(l)}$	769.756 ± 1.273	11	
$\text{UO}_2^{2+} + 12 \text{NO}_3^- + 72 \text{H}^+ + 64 \text{e}^- \rightleftharpoons \# \text{UO}_2(\text{N}_3)_4^{2-} + 36 \text{H}_2\text{O(l)}$	1023.608 ± 1.689	11	
$\text{UO}_2^{2+} + \text{NO}_3^- \rightleftharpoons \# \text{UO}_2\text{NO}_3^+$	0.300 ± 0.150	11	
$\text{UO}_2^{2+} + \text{PO}_4^{3-} \rightleftharpoons \# \text{UO}_2\text{PO}_4^-$	13.230 ± 0.150	11	
$\text{UO}_2^{2+} + \text{H}^+ + \text{PO}_4^{3-} \rightleftharpoons \# \text{UO}_2\text{HPO}_4(\text{aq})$	19.590 ± 0.262	11	
$\text{UO}_2^{2+} + 2 \text{H}^+ + \text{PO}_4^{3-} \rightleftharpoons \# \text{UO}_2\text{H}_2\text{PO}_4^+$	20.682 ± 0.068	11	
$\text{UO}_2^{2+} + 3 \text{H}^+ + \text{PO}_4^{3-} \rightleftharpoons \# \text{UO}_2\text{H}_3\text{PO}_4^{2+}$	22.462 ± 0.231	11	
$\text{UO}_2^{2+} + 4 \text{H}^+ + 2 \text{PO}_4^{3-} \rightleftharpoons \# \text{UO}_2(\text{H}_2\text{PO}_4)_2(\text{aq})$	44.044 ± 0.369	11	
$\text{UO}_2^{2+} + 5 \text{H}^+ + 2 \text{PO}_4^{3-} \rightleftharpoons \# \text{UO}_2(\text{H}_2\text{PO}_4)(\text{H}_3\text{PO}_4)^+$	45.054 ± 0.369	11	
$\text{UO}_2^{2+} + \text{AsO}_4^{3-} + \text{H}^+ \rightleftharpoons \# \text{UO}_2\text{HAsO}_4(\text{aq})$	18.760 ± 0.310	11	
$\text{UO}_2^{2+} + \text{AsO}_4^{3-} + 2 \text{H}^+ \rightleftharpoons \# \text{UO}_2\text{H}_2\text{AsO}_4^+$	21.960 ± 0.240	11	
$\text{UO}_2^{2+} + 2 \text{AsO}_4^{3-} + 4 \text{H}^+ \rightleftharpoons \# \text{UO}_2(\text{H}_2\text{AsO}_4)_2(\text{aq})$	41.530 ± 0.200	11	
$\text{UO}_2^{2+} + \text{CO}_3^{2-} \rightleftharpoons \# \text{UO}_2\text{CO}_3(\text{aq})$	9.940 ± 0.030	11	
$\text{UO}_2^{2+} + 2 \text{CO}_3^{2-} \rightleftharpoons \# \text{UO}_2(\text{CO}_3)_2^{2-}$	16.610 ± 0.090	11	
$\text{UO}_2^{2+} + 3 \text{CO}_3^{2-} \rightleftharpoons \# \text{UO}_2(\text{CO}_3)_3^{4-}$	21.840 ± 0.040	11	
$3 \text{UO}_2^{2+} + 6 \text{CO}_3^{2-} \rightleftharpoons \# (\text{UO}_2)_3(\text{CO}_3)_6^{6-}$	54.000 ± 1.000	11	
$2 \text{UO}_2^{2+} + \text{CO}_3^{2-} + 3 \text{H}_2\text{O(l)} \rightleftharpoons \# (\text{UO}_2)_2\text{CO}_3(\text{OH})_3^- + 3 \text{H}^+$	-0.855 ± 0.501	11	
$3 \text{UO}_2^{2+} + \text{CO}_3^{2-} + 3 \text{H}_2\text{O(l)} \rightleftharpoons \# (\text{UO}_2)_3\text{O}(\text{OH})_2(\text{HCO}_3)^+ + 3 \text{H}^+$	0.655 ± 0.501	11	
$11 \text{UO}_2^{2+} + 6 \text{CO}_3^{2-} + 12 \text{H}_2\text{O(l)} \rightleftharpoons \# (\text{UO}_2)_{11}(\text{CO}_3)_6(\text{OH})_{12}^{2-} + 12 \text{H}^+$	36.430 ± 2.011	11	

Reaction	$\log_{10} K^\circ$	ref.	t.v. ^{*1}
$\text{UO}_2^{2+} + \text{CO}_3^{2-} + \text{F}^- \rightleftharpoons \# \text{UO}_2\text{CO}_3\text{F}^-$	13.750 ± 0.090	11	
$\text{UO}_2^{2+} + \text{CO}_3^{2-} + 2 \text{F}^- \rightleftharpoons \# \text{UO}_2\text{CO}_3\text{F}_2^{2-}$	15.570 ± 0.140	11	
$\text{UO}_2^{2+} + \text{CO}_3^{2-} + 3 \text{F}^- \rightleftharpoons \# \text{UO}_2\text{CO}_3\text{F}_3^{3-}$	16.380 ± 0.110	11	
$\text{UO}_2^{2+} + \text{SO}_4^{2-} + \text{CO}_3^{2-} + \text{NO}_3^- + 20 \text{H}^+ + 16 \text{e}^- \rightleftharpoons \# \text{UO}_2\text{SCN}^+ + 10 \text{H}_2\text{O(l)}$	158.372 ± 0.751	11	
$\text{UO}_2^{2+} + 2 \text{SO}_4^{2-} + 2 \text{CO}_3^{2-} + 2 \text{NO}_3^- + 40 \text{H}^+ + 32 \text{e}^- \rightleftharpoons \# \text{UO}_2(\text{SCN})_2(\text{aq}) + 20 \text{H}_2\text{O(l)}$	315.184 ± 1.532	11	
$\text{UO}_2^{2+} + 3 \text{SO}_4^{2-} + 3 \text{CO}_3^{2-} + 3 \text{NO}_3^- + 60 \text{H}^+ + 48 \text{e}^- \rightleftharpoons \# \text{UO}_2(\text{SCN})_3^- + 30 \text{H}_2\text{O(l)}$	473.016 ± 2.203	11	
$\text{UO}_2^{2+} + \text{H}_4\text{SiO}_4(\text{aq}) \rightleftharpoons \# \text{UO}_2\text{SiO(OH)}_3^+ + \text{H}^+$	-1.840 ± 0.100	11	
$\text{UO}_2^{2+} + \text{PuO}_2^{2+} + 6 \text{CO}_3^{2-} \rightleftharpoons \# (\text{UO}_2)_2\text{PuO}_2(\text{CO}_3)_6^{6-}$	53.480 ± 1.395	11	
$\text{UO}_2^{2+} + \text{NpO}_2^{2+} + 6 \text{CO}_3^{2-} \rightleftharpoons \# (\text{UO}_2)_2\text{NpO}_2(\text{CO}_3)_6^{6-}$	54.053 ± 3.336	11	
$\text{Np}^{4+} + \text{e}^- \rightleftharpoons \text{Np}^{3+}$	3.695 ± 0.169	11	
$\text{Np}^{4+} + 3 \text{CO}_3^{2-} + \text{e}^- \rightleftharpoons \# \text{Np}(\text{CO}_3)_3^{3-}$	20.279 ± 2.385	30, 11	
$\text{Np}^{3+} + \text{H}_2\text{O(l)} \rightleftharpoons \# \text{NpOH}^{3+} + \text{H}^+$	-6.800 ± 0.300	11	
$\text{Np}^{4+} + \text{H}_2\text{O(l)} \rightleftharpoons \# \text{Np}(\text{OH})_2^{2+} + 2 \text{H}^+$	-0.090 ± 0.300	30	
$\text{Np}^{4+} + 2 \text{H}_2\text{O(l)} \rightleftharpoons \# \text{Np}(\text{OH})_3^+ + 3 \text{H}^+$	4.300 ± 0.300	30	
$\text{Np}^{4+} + 4 \text{H}_2\text{O(l)} \rightleftharpoons \# \text{Np}(\text{OH})_4(\text{aq}) + 4 \text{H}^+$	-9.600 ± 1.100	30	
$\text{Np}^{4+} + \text{F}^- \rightleftharpoons \# \text{NpF}^{3+}$	8.960 ± 0.140	11	
$\text{Np}^{4+} + 2 \text{F}^- \rightleftharpoons \# \text{NpF}_2^{2+}$	15.700 ± 0.300	11	
$\text{Np}^{4+} + \text{Cl}^- \rightleftharpoons \# \text{NpCl}^{3+}$	1.500 ± 0.300	11	
$\text{Np}^{4+} + \text{I}^- \rightleftharpoons \# \text{NpI}^{3+}$	1.500 ± 0.400	11	
$\text{Np}^{4+} + \text{SO}_4^{2-} \rightleftharpoons \# \text{NpSO}_4^{2+}$	6.850 ± 0.158	11	
$\text{Np}^{4+} + 2 \text{SO}_4^{2-} \rightleftharpoons \# \text{Np}(\text{SO}_4)_2(\text{aq})$	11.050 ± 0.269	11	
$\text{Np}^{4+} + \text{NO}_3^- \rightleftharpoons \# \text{NpNO}_3^{3+}$	1.900 ± 0.150	11	
$\text{Np}^{4+} + 4 \text{CO}_3^{2-} \rightleftharpoons \# \text{Np}(\text{CO}_3)_4^{4-}$	37.610 ± 0.686	30, 11	
$\text{Np}^{4+} + 5 \text{CO}_3^{2-} \rightleftharpoons \# \text{Np}(\text{CO}_3)_5^{6-}$	36.540 ± 0.748	30, 11	
$\text{Np}^{4+} + 2 \text{CO}_3^{2-} + 2 \text{H}_2\text{O(l)} \rightleftharpoons \# \text{Np}(\text{CO}_3)_2(\text{OH})_2^{2-} + \text{H}^+$	16.387 ± 1.210	30	
$\text{Np}^{4+} + \text{SO}_4^{2-} + \text{CO}_3^{2-} + \text{NO}_3^- + 20 \text{H}^+ + 16 \text{e}^- \rightleftharpoons \# \text{NpSCN}^{3+} + 10 \text{H}_2\text{O(l)}$	159.972 ± 0.775	11	
$\text{Np}^{4+} + 2 \text{SO}_4^{2-} + 2 \text{CO}_3^{2-} + 2 \text{NO}_3^- + 40 \text{H}^+ + 32 \text{e}^- \rightleftharpoons \# \text{Np}(\text{SCN})_2^{2+} + 20 \text{H}_2\text{O(l)}$	318.044 ± 1.515	11	
$\text{Np}^{4+} + 3 \text{SO}_4^{2-} + 3 \text{CO}_3^{2-} + 3 \text{NO}_3^- + 60 \text{H}^+ + 48 \text{e}^- \rightleftharpoons \# \text{Np}(\text{SCN})_3^+ + 30 \text{H}_2\text{O(l)}$	475.716 ± 2.203	11	
$\text{Np}^{4+} + 2 \text{H}_2\text{O(l)} \rightleftharpoons \text{NpO}_2^+ + 4 \text{H}^+ + \text{e}^-$	-10.212 ± 1.389	11	
$\text{NpO}_2^+ + \text{H}_2\text{O(l)} \rightleftharpoons \# \text{NpO}_2\text{OH}(\text{aq}) + \text{H}^+$	-11.300 ± 0.700	11	
$\text{NpO}_2^+ + 2 \text{H}_2\text{O(l)} \rightleftharpoons \# \text{NpO}_2(\text{OH})_2^- + 2 \text{H}^+$	-23.600 ± 0.500	11	
$\text{NpO}_2^+ + \text{F}^- \rightleftharpoons \# \text{NpO}_2\text{F}(\text{aq})$	1.200 ± 0.300	11	
$\text{NpO}_2^+ + \text{I}^- + 3 \text{H}_2\text{O(l)} \rightleftharpoons \# \text{NpO}_2\text{IO}_3(\text{aq}) + 6 \text{H}^+ + 6 \text{e}^-$	-111.063 ± 0.330	11	
$\text{NpO}_2^+ + \text{SO}_4^{2-} \rightleftharpoons \# \text{NpO}_2\text{SO}_4^-$	0.440 ± 0.270	11	
$\text{NpO}_2^+ + \text{H}^+ + \text{PO}_4^{3-} \rightleftharpoons \# \text{NpO}_2\text{HPO}_4^-$	15.300 ± 0.104	11	
$\text{NpO}_2^+ + \text{CO}_3^{2-} \rightleftharpoons \# \text{NpO}_2\text{CO}_3^-$	4.962 ± 0.061	11	
$\text{NpO}_2^+ + 2 \text{CO}_3^{2-} \rightleftharpoons \# \text{NpO}_2(\text{CO}_3)_2^{3-}$	6.534 ± 0.103	11	
$\text{NpO}_2^+ + 3 \text{CO}_3^{2-} \rightleftharpoons \# \text{NpO}_2(\text{CO}_3)_3^{5-}$	5.500 ± 0.151	11	
$3 \text{NpO}_2^+ + 6 \text{CO}_3^{2-} \rightleftharpoons \# (\text{NpO}_2)_3(\text{CO}_3)_6^{6-} + 3 \text{e}^-$	-8.492 ± 1.458	11	
$2 \text{NpO}_2^+ + 2 \text{CO}_3^{2-} + \text{H}_2\text{O(l)} \rightleftharpoons \# \text{NpO}_2(\text{CO}_3)_2\text{OH}^{4-} + \text{H}^+$	5.306 ± 1.174	11	
$\text{Np}^{4+} + 2 \text{H}_2\text{O(l)} \rightleftharpoons \text{NpO}_2^{2+} + 4 \text{H}^+ + 2 \text{e}^-$	-29.803 ± 1.388	11	
$\text{NpO}_2^{2+} + \text{H}_2\text{O(l)} \rightleftharpoons \# \text{NpO}_2\text{OH}^+ + \text{H}^+$	-5.100 ± 0.400	11	
$2 \text{NpO}_2^{2+} + 2 \text{H}_2\text{O(l)} \rightleftharpoons \# (\text{NpO}_2)_2(\text{OH})_2^{2+} + 2 \text{H}^+$	-6.270 ± 0.210	11	
$3 \text{NpO}_2^{2+} + 5 \text{H}_2\text{O(l)} \rightleftharpoons \# (\text{NpO}_2)_3(\text{OH})_5^+ + 5 \text{H}^+$	-17.120 ± 0.220	11	
$\text{NpO}_2^{2+} + \text{F}^- \rightleftharpoons \# \text{NpO}_2\text{F}^+$	4.570 ± 0.070	11	
$\text{NpO}_2^{2+} + 2 \text{F}^- \rightleftharpoons \# \text{NpO}_2\text{F}_2(\text{aq})$	7.600 ± 0.080	11	
$\text{NpO}_2^{2+} + \text{Cl}^- \rightleftharpoons \# \text{NpO}_2\text{Cl}^+$	0.400 ± 0.170	11	
$\text{NpO}_2^{2+} + \text{I}^- + 3 \text{H}_2\text{O(l)} \rightleftharpoons \# \text{NpO}_2\text{IO}_3^+ + 6 \text{H}^+ + 6 \text{e}^-$	-110.363 ± 0.330	11	
$\text{NpO}_2^{2+} + \text{SO}_4^{2-} \rightleftharpoons \# \text{NpO}_2\text{SO}_4(\text{aq})$	3.280 ± 0.060	11	

Reaction	$\log_{10} K^\circ$	ref.	t.v. ^{*1}
$\text{NpO}_2^{2+} + 2 \text{SO}_4^{2-} \rightleftharpoons \text{#NpO}_2(\text{SO}_4)_2^{2-}$	4.700 ± 0.100	11	
$\text{NpO}_2^{2+} + \text{H}^+ + \text{PO}_4^{3-} \rightleftharpoons \text{#NpO}_2\text{HPO}_4(\text{aq})$	18.550 ± 0.701	11	
$\text{NpO}_2^{2+} + 2 \text{H}^+ + \text{PO}_4^{3-} \rightleftharpoons \text{#NpO}_2\text{H}_2\text{PO}_4^+$	22.882 ± 0.501	11	
$\text{NpO}_2^{2+} + 2 \text{H}^+ + 2 \text{PO}_4^{3-} \rightleftharpoons \text{#NpO}_2(\text{HPO}_4)_2^{2-}$	34.200 ± 1.001	11	
$\text{NpO}_2^{2+} + \text{CO}_3^{2-} \rightleftharpoons \text{#NpO}_2\text{CO}_3(\text{aq})$	9.320 ± 0.610	11	
$\text{NpO}_2^{2+} + 2 \text{CO}_3^{2-} \rightleftharpoons \text{#NpO}_2(\text{CO}_3)_2^{2-}$	16.516 ± 0.729	11	
$\text{NpO}_2^{2+} + 3 \text{CO}_3^{2-} \rightleftharpoons \text{#NpO}_2(\text{CO}_3)_3^{4-}$	19.371 ± 1.972	11	
$\text{NpO}_2^{2+} + \text{CO}_3^{2-} + 3 \text{H}_2\text{O(l)} \rightleftharpoons \text{#NpO}_2)_2 \text{CO}_3 (\text{OH})_3^-$	4.493 ± 4.253	11	
$\text{Pu}^{4+} + \text{e}^- \rightleftharpoons \text{#Pu}^{3+}$	17.694 ± 0.668	11	
$\text{Pu}^{3+} + \text{H}_2\text{O(l)} \rightleftharpoons \text{#PuOH}^{2+} + \text{H}^+$	-7.200 ± 0.500	26	
$\text{Pu}^{3+} + 2 \text{H}_2\text{O(l)} \rightleftharpoons \text{#Pu(OH)}_2^+ + 2 \text{H}^+$	-15.100 ± 0.700	26	
$\text{Pu}^{3+} + 3 \text{H}_2\text{O(l)} \rightleftharpoons \text{#Pu(OH)}_3(\text{aq}) + 3 \text{H}^+$	-26.200 ± 0.500	26	
$\text{Pu}^{3+} + \text{F}^- \rightleftharpoons \text{#PuF}^{2+}$	3.400 ± 0.400	26	
$\text{Pu}^{3+} + 2 \text{F}^- \rightleftharpoons \text{#PuF}_2^+$	5.800 ± 0.200	26	
$\text{Pu}^{3+} + \text{Cl}^- \rightleftharpoons \text{#PuCl}^{2+}$	0.240 ± 0.030	26	
$\text{Pu}^{3+} + 2 \text{Cl}^- \rightleftharpoons \text{#PuCl}_2^+$	-0.740 ± 0.050	26	
$\text{Pu}^{3+} + \text{SO}_4^{2-} \rightleftharpoons \text{#PuSO}_4^+$	3.300 ± 0.150	26	
$\text{Pu}^{3+} + 2 \text{SO}_4^{2-} \rightleftharpoons \text{#Pu}(\text{SO}_4)_2^-$	3.700 ± 0.150	26	
$\text{Pu}^{3+} + 3 \text{NO}_3^- + 18 \text{H}^+ + 16 \text{e}^- \rightleftharpoons \text{#PuN}_3^{2+} + 9 \text{H}_2\text{O(l)}$	256.342 ± 0.430	26, 12	
$\text{Pu}^{3+} + \text{NO}_2^- \rightleftharpoons \text{#PuNO}_2^{2+}$	2.100 ± 0.200	26	
$\text{Pu}^{3+} + \text{NO}_3^- \rightleftharpoons \text{#PuNO}_3^{2+}$	1.330 ± 0.200	26	
$\text{Pu}^{3+} + 2 \text{H}^+ + \text{PO}_4^{3-} \rightleftharpoons \text{#PuH}_2\text{PO}_4^{2+}$	22.562 ± 0.501	26, 12	
$\text{Pu}^{3+} + \text{CO}_3^{2-} \rightleftharpoons \text{#PuCO}_3^+$	8.000 ± 0.400	26	
$\text{Pu}^{3+} + 2 \text{CO}_3^{2-} \rightleftharpoons \text{#Pu}(\text{CO}_3)_2^-$	12.900 ± 0.600	26	
$\text{Pu}^{3+} + 3 \text{CO}_3^{2-} \rightleftharpoons \text{#Pu}(\text{CO}_3)_3^{3-}$	15.000 ± 1.000	26	
$\text{Pu}^{3+} + \text{H}^+ + \text{CO}_3^{2-} \rightleftharpoons \text{#PuHCO}_3^{2+}$	13.429 ± 0.301	26, 12	
$\text{Pu}^{3+} + \text{H}_4\text{SiO}_4(\text{aq}) \rightleftharpoons \text{#PuSiO}(\text{OH})_3^{2+} + \text{H}^+$	-1.680 ± 0.180	26	
$\text{Pu}^{3+} + \text{NO}_3^- + \text{CO}_3^{2-} + \text{SO}_4^{2-} + 20 \text{H}^+ + 16 \text{e}^- \rightleftharpoons \text{#PuSCN}^{2+} + 10 \text{H}_2\text{O(l)}$	158.272 ± 0.775	26, 12	
$\text{Pu}^{4+} + \text{H}_2\text{O(l)} \rightleftharpoons \text{PuOH}^{3+} + \text{H}^+$	0.000 ± 0.200	30	
$\text{Pu}^{4+} + 2 \text{H}_2\text{O(l)} \rightleftharpoons \text{Pu(OH)}_2^{2+} + 2 \text{H}^+$	-1.200 ± 0.600	30	
$\text{Pu}^{4+} + 3 \text{H}_2\text{O(l)} \rightleftharpoons \text{Pu(OH)}_3^+ + 3 \text{H}^+$	-3.100 ± 0.900	30	
$\text{Pu}^{4+} + 4 \text{H}_2\text{O(l)} \rightleftharpoons \text{Pu(OH)}_4(\text{aq}) + 4 \text{H}^+$	-8.500 ± 0.500	30	
$\text{Pu}^{4+} + \text{F}^- \rightleftharpoons \text{#PuF}^{3+}$	8.840 ± 0.100	11	
$\text{Pu}^{4+} + 2 \text{F}^- \rightleftharpoons \text{#PuF}_2^{2+}$	15.700 ± 0.200	11	
$\text{Pu}^{4+} + \text{Cl}^- \rightleftharpoons \text{#PuCl}^{3+}$	1.800 ± 0.300	11	
$\text{Pu}^{4+} + \text{Br}^- \rightleftharpoons \text{#PuBr}^{3+}$	1.600 ± 0.300	11	
$\text{Pu}^{4+} + \text{SO}_4^{2-} \rightleftharpoons \text{#PuSO}_4^{2+}$	6.890 ± 0.226	11	
$\text{Pu}^{4+} + 2 \text{SO}_4^{2-} \rightleftharpoons \text{#Pu}(\text{SO}_4)_2(\text{aq})$	11.140 ± 0.335	11	
$\text{Pu}^{4+} + \text{NO}_3^- \rightleftharpoons \text{#PuNO}_3^{3+}$	1.950 ± 0.150	11	
$\text{Pu}^{4+} + 3 \text{H}^+ + \text{PO}_4^{3-} \rightleftharpoons \text{#PuH}_3\text{PO}_4^{4+}$	24.102 ± 0.348	11	
$\text{Pu}^{4+} + 4 \text{CO}_3^{2-} \rightleftharpoons \text{#Pu}(\text{CO}_3)_4^{4-}$	37.000 ± 1.100	11	
$\text{Pu}^{4+} + 5 \text{CO}_3^{2-} \rightleftharpoons \text{#Pu}(\text{CO}_3)_5^{6-}$	35.650 ± 1.130	11	
$\text{Pu}^{4+} + 2 \text{CO}_3^{2-} + 2 \text{H}_2\text{O(l)} \rightleftharpoons \text{#Pu}(\text{CO}_3)_2(\text{OH})_2^{2-} + 2 \text{H}^+$	19.177 ± 1.250	30	
$\text{Pu}^{4+} + 2 \text{H}_2\text{O(l)} \rightleftharpoons \text{PuO}_2^+ + 4 \text{H}^+ + \text{e}^-$	-17.453 ± 0.691	11	
$\text{PuO}_2^+ + \text{H}_2\text{O(l)} \rightleftharpoons \text{#PuO}_2\text{OH}(\text{aq}) + \text{H}^+$	≤ -9.730	11	
$\text{PuO}_2^+ + \text{CO}_3^{2-} \rightleftharpoons \text{#PuO}_2\text{CO}_3^-$	5.120 ± 0.140	11	
$\text{PuO}_2^+ + 3 \text{CO}_3^{2-} \rightleftharpoons \text{#PuO}_2(\text{CO}_3)_3^{5-}$	5.025 ± 0.920	11	
$\text{Pu}^{4+} + 2 \text{H}_2\text{O(l)} \rightleftharpoons \text{#PuO}_2^{2+} + 4 \text{H}^+ + 2 \text{e}^-$	-33.272 ± 0.697	11	
$\text{PuO}_2^{2+} + \text{H}_2\text{O(l)} \rightleftharpoons \text{#PuO}_2\text{OH}^+ + \text{H}^+$	-5.500 ± 0.500	11	
$\text{PuO}_2^{2+} + 2 \text{H}_2\text{O(l)} \rightleftharpoons \text{#PuO}_2\text{OH}_2(\text{aq}) + 2 \text{H}^+$	-13.200 ± 1.500	11	

Reaction	$\log_{10} K^\circ$	ref.	t.v. ^{*1}
$2 \text{PuO}_2^{2+} + 2 \text{H}_2\text{O(l)} \rightleftharpoons \#(\text{PuO}_2)_2(\text{OH})_2^{2+} + 2 \text{H}^+$	-7.500 ± 1.000	11	
$\text{PuO}_2^{2+} + \text{F}^- \rightleftharpoons \#\text{PuO}_2\text{F}^+$	4.560 ± 0.200	11	
$\text{PuO}_2^{2+} + 2 \text{F}^- \rightleftharpoons \#\text{PuO}_2\text{F}_2(\text{aq})$	7.250 ± 0.450	11	
$\text{PuO}_2^{2+} + \text{Cl}^- \rightleftharpoons \#\text{PuO}_2\text{Cl}^+$	0.230 ± 0.030	11	
$\text{PuO}_2^{2+} + 2 \text{Cl}^- \rightleftharpoons \text{PuO}_2\text{Cl}_2(\text{aq})$	-1.150 ± 0.300	11	
$\text{PuO}_2^{2+} + \text{SO}_4^{2-} \rightleftharpoons \text{PuO}_2\text{SO}_4(\text{aq})$	3.380 ± 0.200	11	
$\text{PuO}_2^{2+} + 2 \text{SO}_4^{2-} \rightleftharpoons \text{PuO}_2(\text{SO}_4)_2^{2-}$	4.400 ± 0.200	11	
$\text{PuO}_2^{2+} + \text{CO}_3^{2-} \rightleftharpoons \#\text{PuO}_2\text{CO}_3(\text{aq})$	9.500 ± 0.500	11	
$\text{PuO}_2^{2+} + 2 \text{CO}_3^{2-} \rightleftharpoons \#\text{PuO}_2(\text{CO}_3)_2^{2-}$	14.700 ± 0.500	11	
$\text{PuO}_2^{2+} + 3 \text{CO}_3^{2-} \rightleftharpoons \#\text{PuO}_2(\text{CO}_3)_3^{4-}$	18.000 ± 0.500	11	
$\text{Am}^{3+} + \text{H}_2\text{O(l)} \rightleftharpoons \#\text{AmOH}^{2+} + \text{H}^+$	-7.200 ± 0.500	11	
$\text{Am}^{3+} + 2 \text{H}_2\text{O(l)} \rightleftharpoons \#\text{Am(OH)}_2^+ + 2 \text{H}^+$	-15.100 ± 0.700	11	
$\text{Am}^{3+} + 3 \text{H}_2\text{O(l)} \rightleftharpoons \#\text{Am(OH)}_3(\text{aq}) + 3 \text{H}^+$	-26.200 ± 0.500	11	
$\text{Am}^{3+} + \text{F}^- \rightleftharpoons \#\text{AmF}^{2+}$	3.400 ± 0.400	11	
$\text{Am}^{3+} + 2 \text{F}^- \rightleftharpoons \#\text{AmF}_2^+$	5.800 ± 0.200	11	
$\text{Am}^{3+} + \text{Cl}^- \rightleftharpoons \#\text{AmCl}^{2+}$	0.240 ± 0.030	11	
$\text{Am}^{3+} + 2 \text{Cl}^- \rightleftharpoons \#\text{AmCl}_2^+$	-0.740 ± 0.050	11	
$\text{Am}^{3+} + \text{SO}_4^{2-} \rightleftharpoons \#\text{AmSO}_4^+$	3.300 ± 0.150	11	
$\text{Am}^{3+} + 2 \text{SO}_4^{2-} \rightleftharpoons \#\text{Am}(\text{SO}_4)_2^-$	3.700 ± 0.150	11	
$\text{Am}^{3+} + 3 \text{NO}_3^- + 18 \text{H}^+ + 16 \text{e}^- \rightleftharpoons \#\text{AmN}_3^{2+} + 9 \text{H}_2\text{O(l)}$	256.342 ± 0.430	11	
$\text{Am}^{3+} + \text{NO}_2^- \rightleftharpoons \#\text{AmNO}_2^{2+}$	2.100 ± 0.200	11	
$\text{Am}^{3+} + \text{NO}_3^- \rightleftharpoons \#\text{AmNO}_3^{2+}$	1.330 ± 0.200	11	
$\text{Am}^{3+} + 2 \text{H}^+ + \text{PO}_4^{3-} \rightleftharpoons \#\text{AmH}_2\text{PO}_4^{2+}$	22.562 ± 0.501	11	
$\text{Am}^{3+} + \text{CO}_3^{2-} \rightleftharpoons \#\text{AmCO}_3^+$	8.000 ± 0.400	11	
$\text{Am}^{3+} + 2 \text{CO}_3^{2-} \rightleftharpoons \#\text{Am}(\text{CO}_3)_2^-$	12.900 ± 0.600	11	
$\text{Am}^{3+} + 3 \text{CO}_3^{2-} \rightleftharpoons \#\text{Am}(\text{CO}_3)_3^{3-}$	15.000 ± 1.000	11	
$\text{Am}^{3+} + \text{H}^+ + \text{CO}_3^{2-} \rightleftharpoons \#\text{AmHCO}_3^{2+}$	13.429 ± 0.301	11	
$\text{Am}^{3+} + \text{H}_4\text{SiO}_4(\text{aq}) \rightleftharpoons \#\text{AmSiO}(\text{OH})_3^{2+} + \text{H}^+$	-1.680 ± 0.180	11	
$\text{Am}^{3+} + \text{NO}_3^- + \text{CO}_3^{2-} + \text{SO}_4^{2-} + 20 \text{H}^+ + 16 \text{e}^- \rightleftharpoons \#\text{AmSCN}^{2+} + 10 \text{H}_2\text{O(l)}$	158.272 ± 0.775	11	
$\text{Cm}^{3+} + \text{H}_2\text{O(l)} \rightleftharpoons \#\text{CmOH}^{2+} + \text{H}^+$	-7.200 ± 0.500	26	
$\text{Cm}^{3+} + 2 \text{H}_2\text{O(l)} \rightleftharpoons \#\text{Cm(OH)}_2^+ + 2 \text{H}^+$	-15.100 ± 0.700	26	
$\text{Cm}^{3+} + 3 \text{H}_2\text{O(l)} \rightleftharpoons \#\text{Cm(OH)}_3(\text{aq}) + 3 \text{H}^+$	-26.200 ± 0.500	26	
$\text{Cm}^{3+} + \text{F}^- \rightleftharpoons \#\text{CmF}^{2+}$	3.400 ± 0.400	26	
$\text{Cm}^{3+} + 2 \text{F}^- \rightleftharpoons \#\text{CmF}_2^+$	5.800 ± 0.200	26	
$\text{Cm}^{3+} + \text{Cl}^- \rightleftharpoons \#\text{CmCl}^{2+}$	0.240 ± 0.030	26	
$\text{Cm}^{3+} + 2 \text{Cl}^- \rightleftharpoons \#\text{CmCl}_2^+$	-0.740 ± 0.050	26	
$\text{Cm}^{3+} + \text{SO}_4^{2-} \rightleftharpoons \#\text{CmSO}_4^+$	3.300 ± 0.150	26	
$\text{Cm}^{3+} + 2 \text{SO}_4^{2-} \rightleftharpoons \#\text{Cm}(\text{SO}_4)_2^-$	3.700 ± 0.150	26	
$\text{Cm}^{3+} + 3 \text{NO}_3^- + 18 \text{H}^+ + 16 \text{e}^- \rightleftharpoons \#\text{CmN}_3^{2+} + 9 \text{H}_2\text{O(l)}$	256.342 ± 0.430	26, 12	
$\text{Cm}^{3+} + \text{NO}_2^- \rightleftharpoons \#\text{CmNO}_2^{2+}$	2.100 ± 0.200	26	
$\text{Cm}^{3+} + \text{NO}_3^- \rightleftharpoons \#\text{CmNO}_3^{2+}$	1.330 ± 0.200	26	
$\text{Cm}^{3+} + 2 \text{H}^+ + \text{PO}_4^{3-} \rightleftharpoons \#\text{CmH}_2\text{PO}_4^{2+}$	22.562 ± 0.501	26, 12	
$\text{Cm}^{3+} + \text{CO}_3^{2-} \rightleftharpoons \#\text{CmCO}_3^+$	8.000 ± 0.400	26	
$\text{Cm}^{3+} + 2 \text{CO}_3^{2-} \rightleftharpoons \#\text{Cm}(\text{CO}_3)_2^-$	12.900 ± 0.600	26	
$\text{Cm}^{3+} + 3 \text{CO}_3^{2-} \rightleftharpoons \#\text{Cm}(\text{CO}_3)_3^{3-}$	15.000 ± 1.000	26	
$\text{Cm}^{3+} + \text{H}^+ + \text{CO}_3^{2-} \rightleftharpoons \#\text{CmHCO}_3^{2+}$	13.429 ± 0.301	26, 12	
$\text{Cm}^{3+} + \text{H}_4\text{SiO}_4(\text{aq}) \rightleftharpoons \#\text{CmSiO}(\text{OH})_3^{2+} + \text{H}^+$	-1.680 ± 0.180	26	
$\text{Cm}^{3+} + \text{NO}_3^- + \text{CO}_3^{2-} + \text{SO}_4^{2-} + 20 \text{H}^+ + 16 \text{e}^- \rightleftharpoons \#\text{CmSCN}^{2+} + 10 \text{H}_2\text{O(l)}$	158.272 ± 0.775	26, 12	
$\text{H}^+ + \text{ox}^{2-} \rightleftharpoons \text{Hox}^- \#$	4.250 ± 0.010	22	
$9\#\text{H}^+ + \text{ox}^{2-} \rightleftharpoons \#\text{H}_2\text{ox}(\text{aq})$	5.650 ± 0.032	22	

Reaction	$\log_{10} K^\circ$	ref.	t.v. ^{*1}
$\text{Ni}^{2+} + \text{ox}^{2-} \rightleftharpoons \text{Ni}(\text{ox})(\text{aq})$	5.190 ± 0.040	22	
$\text{Ni}^{2+} + 2 \text{ox}^{2-} \rightleftharpoons \text{Ni}(\text{ox})_2^{2-}$	7.640 ± 0.070	22	
$\text{Am}^{3+} + \text{ox}^{2-} \rightleftharpoons \text{Am}(\text{ox})^+$	6.510 ± 0.150	22	
$\text{Am}^{3+} + 2 \text{ox}^{2-} \rightleftharpoons \text{Am}(\text{ox})_2^-$	10.710 ± 0.200	22	
$\text{Am}^{3+} + 3 \text{ox}^{2-} \rightleftharpoons \text{Am}(\text{ox})_3^{3-}$	13.000 ± 1.000	22	
$\text{NpO}_2^+ + \text{ox}^{2-} \rightleftharpoons \text{NpO}_2\text{ox}^-$	3.900 ± 0.100	22	
$\text{NpO}_2^+ + 2 \text{ox}^{2-} \rightleftharpoons \text{NpO}_2(\text{ox})_2^{3-}$	5.800 ± 0.200	22	
$\text{UO}_2^{2+} + \text{ox}^{2-} \rightleftharpoons \text{UO}_2\text{ox}(\text{aq})$	7.130 ± 0.160	22	
$\text{UO}_2^{2+} + 2 \text{ox}^{2-} \rightleftharpoons \text{UO}_2(\text{ox})_2^{2-}$	11.650 ± 0.150	22	
$\text{UO}_2^{2+} + 3 \text{ox}^{2-} \rightleftharpoons \text{UO}_2(\text{ox})_3^{4-}$	13.800 ± 1.500	22	
$\text{Mg}^{2+} + \text{ox}^{2-} \rightleftharpoons \text{Mg}(\text{ox})(\text{aq})$	3.560 ± 0.040	22	
$\text{Mg}^{2+} + 2 \text{ox}^{2-} \rightleftharpoons \text{Mg}(\text{ox})_2^{2-}$	5.170 ± 0.080	22	
$\text{Ca}^{2+} + \text{ox}^{2-} \rightleftharpoons \text{Ca}(\text{ox})(\text{aq})$	3.190 ± 0.060	22	
$\text{Ca}^{2+} + 2 \text{ox}^{2-} \rightleftharpoons \text{Ca}(\text{ox})_2^{2-}$	4.020 ± 0.199	22	
$\text{cit}^{3-} + \text{H}^+ \rightleftharpoons \text{Hcit}^{2-}$	6.360 ± 0.020	22	
$\text{cit}^{3-} + 2 \text{H}^+ \rightleftharpoons \text{H}_2\text{cit}^-$	11.140 ± 0.022	22	
$\text{cit}^{3-} + 3 \text{H}^+ \rightleftharpoons \text{H}_3\text{cit}(\text{aq})$	14.270 ± 0.024	22	
$\text{Ni}^{2+} + \text{cit}^{3-} \rightleftharpoons \text{Ni}(\text{cit})^-$	6.760 ± 0.080	22	
$\text{Ni}^{2+} + 2 \text{cit}^{3-} \rightleftharpoons \text{Ni}(\text{cit})_2^{4-}$	8.500 ± 0.400	22	
$\text{Ni}^{2+} + \text{H}^+ + \text{cit}^{3-} \rightleftharpoons \text{Ni}(\text{Hcit})(\text{aq})$	10.520 ± 0.102	22	
$\text{Ni}^{2+} + 2 \text{H}^+ + \text{cit}^{3-} \rightleftharpoons \text{Ni}(\text{H}_2\text{cit})^+$	13.190 ± 0.251	22	
$\text{Am}^{3+} + \text{cit}^{3-} \rightleftharpoons \text{Am}(\text{cit})(\text{aq})$	8.550 ± 0.200	22	
$\text{Am}^{3+} + 2 \text{cit}^{3-} \rightleftharpoons \text{Am}(\text{cit})_2^{3-}$	13.900 ± 1.000	22	
$\text{Am}^{3+} + \text{H}^+ + \text{cit}^{3-} \rightleftharpoons \text{Am}(\text{Hcit})^+$	12.860 ± 1.000	22	
$\text{Am}^{3+} + 2 \text{H}^+ + 2 \text{cit}^{3-} \rightleftharpoons \text{Am}(\text{Hcit})_2^-$	23.520 ± 1.001	22	
$\text{NpO}_2^+ + \text{cit}^{3-} \rightleftharpoons \text{NpO}_2\text{cit}^{2-}$	3.680 ± 0.050	22	
$\text{UO}_2^{2+} + \text{cit}^{3-} \rightleftharpoons \text{UO}_2\text{cit}^-$	8.960 ± 0.170	22	
$2 \text{UO}_2^{2+} + 2 \text{cit}^{3-} \rightleftharpoons \text{UO}_2(\text{cit})_2^{2-}$	21.300 ± 0.500	22	
$\text{UO}_2^{2+} + \text{H}^+ + \text{cit}^{3-} \rightleftharpoons \text{UO}_2(\text{Hcit})(\text{aq})$	11.360 ± 1.000	22	
$\text{Mg}^{2+} + \text{cit}^{3-} \rightleftharpoons \text{Mg}(\text{cit})^-$	4.810 ± 0.030	22	
$\text{Mg}^{2+} + \text{H}^+ + \text{cit}^{3-} \rightleftharpoons \text{Mg}(\text{Hcit})(\text{aq})$	8.960 ± 0.073	22	
$\text{Mg}^{2+} + 2 \text{H}^+ + \text{cit}^{3-} \rightleftharpoons \text{Mg}(\text{H}_2\text{cit})^+$	12.450 ± 0.162	22	
$\text{Ca}^{2+} + \text{cit}^{3-} \rightleftharpoons \text{Ca}(\text{cit})^-$	4.800 ± 0.030	22	
$\text{Ca}^{2+} + \text{H}^+ + \text{cit}^{3-} \rightleftharpoons \text{Ca}(\text{Hcit})(\text{aq})$	9.280 ± 0.073	22	
$\text{Ca}^{2+} + 2 \text{H}^+ + \text{cit}^{3-} \rightleftharpoons \text{Ca}(\text{H}_2\text{cit})^+$	12.670 ± 0.162	22	
$\text{edta}^{4-} + \text{H}^+ \rightleftharpoons \text{Hedta}^{3-}$	11.240 ± 0.030	22	
$\text{edta}^{4-} + 2 \text{H}^+ \rightleftharpoons \text{H}_2\text{edta}^{2-}$	18.040 ± 0.036	22	
$\text{edta}^{4-} + 3 \text{H}^+ \rightleftharpoons \text{H}_3\text{edta}^-$	21.190 ± 0.041	22	
$\text{edta}^{4-} + 4 \text{H}^+ \rightleftharpoons \text{H}_4\text{edta}(\text{aq})$	23.420 ± 0.065	22	
$\text{edta}^{4-} + 5 \text{H}^+ \rightleftharpoons \text{H}_5\text{edta}^+$	24.720 ± 0.119	22	
$\text{edta}^{4-} + 6 \text{H}^+ \rightleftharpoons \text{H}_6\text{edta}^{2+}$	24.220 ± 0.233	22	
$\text{Ni}^{2+} + \text{edta}^{4-} \rightleftharpoons \text{Ni}(\text{edta})^{2-}$	20.540 ± 0.130	22	
$\text{Ni}^{2+} + \text{edta}^{4-} + \text{H}^+ \rightleftharpoons \text{Ni}(\text{Hedta})^-$	24.200 ± 0.206	22	
$\text{Am}^{3+} + \text{edta}^{4-} \rightleftharpoons \text{Am}(\text{edta})^-$	19.670 ± 0.110	22	
$\text{Am}^{3+} + \text{edta}^{4-} + \text{H}^+ \rightleftharpoons \text{Am}(\text{Hedta})(\text{aq})$	21.840 ± 0.273	22	
$\text{Pu}^{3+} + \text{edta}^{4-} \rightleftharpoons \text{Pu}(\text{edta})^-$	20.180 ± 0.370	22	
$\text{Pu}^{3+} + \text{edta}^{4-} + \text{H}^+ \rightleftharpoons \text{Pu}(\text{Hedta})(\text{aq})$	22.020 ± 0.454	22	
$\text{Np}^{4+} + \text{edta}^{4-} \rightleftharpoons \text{Np}(\text{edta})(\text{aq})$	31.200 ± 0.600	22	
$\text{NpO}_2^+ + \text{edta}^{4-} \rightleftharpoons \text{NpO}_2\text{edta}^{3-}$	9.230 ± 0.130	22	
$\text{NpO}_2^+ + \text{edta}^{4-} + \text{H}^+ \rightleftharpoons \text{NpO}_2(\text{Hedta})^{2-}$	17.060 ± 0.114	22	

Reaction	$\log_{10} K^\circ$	ref.	t.v. ^{*1}
$\text{NpO}_2^+ + \text{edta}^{4-} + 2 \text{H}^+ \rightleftharpoons \text{#NpO}_2(\text{H}_2\text{edta})^-$	22.510 ± 0.145	22	
$\text{U}^{4+} + \text{edta}^{4-} \rightleftharpoons \text{#Uedta(aq)}$	29.500 ± 0.200	22	
$\text{UO}_2^{2+} + \text{edta}^{4-} \rightleftharpoons \text{#UO}_2\text{edta}^{2-}$	13.700 ± 0.200	22	
$2 \text{UO}_2^{2+} + \text{edta}^{4-} \rightleftharpoons \text{#(UO}_2)_2\text{edta(aq)}$	20.600 ± 0.400	22	
$\text{UO}_2^{2+} + \text{edta}^{4-} + \text{H}^+ \rightleftharpoons \text{#UO}_2(\text{Hdta})^-$	19.610 ± 0.104	22	
$\text{Mg}^{2+} + \text{edta}^{4-} \rightleftharpoons \text{#Mg(edta)}^{2-}$	10.900 ± 0.100	22	
$\text{Mg}^{2+} + \text{edta}^{4-} + \text{H}^+ \rightleftharpoons \text{#Mg(Hdta)}^-$	15.400 ± 0.224	22	
$\text{Ca}^{2+} + \text{edta}^{4-} \rightleftharpoons \text{#Ca(edta)}^{2-}$	12.690 ± 0.060	22	
$\text{Ca}^{2+} + \text{edta}^{4-} + \text{H}^+ \rightleftharpoons \text{#Ca(Hdta)}^-$	16.230 ± 0.108	22	
$\text{Na}^+ + \text{edta}^{4-} \rightleftharpoons \text{#Na(edta)}^{3-}$	2.800 ± 0.200	22	
$\text{K}^+ + \text{edta}^{4-} \rightleftharpoons \text{#Na(edta)}^{3-}$	1.800 ± 0.300	22	
$\text{H}^+ + \text{isa}^- \rightleftharpoons \text{#His(aq)}$	4.000 ± 0.500	22	
$\text{Ca}^{2+} + \text{isa}^- \rightleftharpoons \text{#Ca(isa)}^+$	1.700 ± 0.300	22	
$\text{Na}^+ + (\text{ox})^{2-} \rightleftharpoons \text{Na}(\text{ox})^-$	1.000	89	*
$\text{K}^+ + (\text{ox})^{2-} \rightleftharpoons \text{K}(\text{ox})^-$	0.900	89	*
$\text{Sr}^{2+} + (\text{ox})^{2-} \rightleftharpoons \text{Sr}(\text{ox})$	2.330	88	*
$\text{Sr}^{2+} + 2 (\text{ox})^{2-} \rightleftharpoons \text{Sr}(\text{ox})_2^{2-}$	2.980	88	*
$\text{Ra}^{2+} + (\text{ox})^{2-} \rightleftharpoons \text{Ra}(\text{ox})$	2.780	90	*
$\text{Ra}^{2+} + 2 (\text{ox})^{2-} \rightleftharpoons \text{Ra}(\text{ox})_2^{2-}$	3.440	90	*
$\text{Fe}^{2+} + (\text{ox})^{2-} \rightleftharpoons \text{Fe}(\text{ox})$	4.130	88	*
$\text{Fe}^{2+} + 2 (\text{ox})^{2-} \rightleftharpoons \text{Fe}(\text{ox})_2^{2-}$	6.230	88	*
$\text{Co}^{2+} + (\text{ox})^{2-} \rightleftharpoons \text{Co}(\text{ox})$	4.720	88	*
$\text{Co}^{2+} + 2 (\text{ox})^{2-} \rightleftharpoons \text{Co}(\text{ox})_2^{2-}$	7.000	88	*
$\text{Pb}^+ + 2 (\text{ox})^{2-} \rightleftharpoons \text{Pb}(\text{ox})$	4.910	88	*
$\text{Pb} + 2 (\text{ox})^{2-} \rightleftharpoons \text{Pb}(\text{ox})_2^{2-}$	6.760	88	*
$\text{Al}^{3+} + (\text{ox})^{2-} \rightleftharpoons \text{Al}(\text{ox})^+$	7.720	88	*
$\text{Al}^{3+} + 2 (\text{ox})^{2-} \rightleftharpoons \text{Al}(\text{ox})_2^-$	13.200	88	*
$\text{Al}^{3+} + 3 (\text{ox})^{2-} \rightleftharpoons \text{Al}(\text{ox})_3^{3-}$	16.740	88	*
$\text{Zr}^{4+} + (\text{ox})^{2-} \rightleftharpoons \text{Zr}(\text{ox})^{2+}$	10.520	90	*
$\text{Zr}^{4+} + 2 (\text{ox})^{2-} \rightleftharpoons \text{Zr}(\text{ox})_2$	18.150	90	*
$\text{TcO}^{2+} + (\text{ox})^{2-} \rightleftharpoons \text{TcO}(\text{ox})$	9.500	90	*
$\text{TcO}^{2+} + 2 (\text{ox})^{2-} \rightleftharpoons \text{TcO}(\text{ox})_2^{2-}$	16.210	90	*
$\text{Sm}^{3+} + (\text{ox})^{2-} \rightleftharpoons \text{Sm}(\text{ox})^+$	6.300	90	*
$\text{Sm}^{3+} + 2 (\text{ox})^{2-} \rightleftharpoons \text{Sm}(\text{ox})_2^-$	10.130	90	*
$\text{Ac}^{3+} + (\text{ox})^{2-} \rightleftharpoons \text{Ac}(\text{ox})^+$	5.650	88	*
$\text{Ac}^{3+} + 2 (\text{ox})^{2-} \rightleftharpoons \text{Ac}(\text{ox})_2^-$	8.800	88	*
$\text{Cm}^{3+} + (\text{ox})^{2-} \rightleftharpoons \text{Cm}(\text{ox})^+$	6.540	88	*
$\text{Cm}^{3+} + 2 (\text{ox})^{2-} \rightleftharpoons \text{Cm}(\text{ox})_2^-$	10.570	88	*
$\text{Th}^{4+} + (\text{ox})^{2-} \rightleftharpoons \text{Th}(\text{ox})^{2+}$	10.600	88	*
$\text{Th}^{4+} + 2 (\text{ox})^{2-} \rightleftharpoons \text{Th}(\text{ox})_2(\text{aq})$	20.200	88	*
$\text{Th}^{4+} + 3 (\text{ox})^{2-} \rightleftharpoons \text{Th}(\text{ox})_3^{2-}$	26.400	88	*
$\text{Pu}^{4+} + (\text{ox})^{2-} \rightleftharpoons \text{Pu}(\text{ox})^{2+}$	10.340	90	*
$\text{Pu}^{4+} + 2 (\text{ox})^{2-} \rightleftharpoons \text{Pu}(\text{ox})_2(\text{aq})$	17.800	90	*
$\text{U}^{4+} + (\text{ox})^{2-} \rightleftharpoons \text{U}(\text{ox})^{2+}$	10.180	90	*
$\text{U}^{4+} + 2 (\text{ox})^{2-} \rightleftharpoons \text{U}(\text{ox})_2(\text{aq})$	17.500	90	*
$\text{Np}^{4+} + (\text{ox})^{2-} \rightleftharpoons \text{Np}(\text{ox})^{2+}$	10.290	90	*
$\text{Np}^{4+} + 2 (\text{ox})^{2-} \rightleftharpoons \text{Np}(\text{ox})_2(\text{aq})$	17.710	90	*
$\text{PuO}_2^{2+} + (\text{ox})^{2-} \rightleftharpoons \text{PuO}_2(\text{ox})(\text{aq})$	7.250	90	*
$\text{PuO}_2^{2+} + 2 (\text{ox})^{2-} \rightleftharpoons \text{PuO}_2(\text{ox})_2^{2-}$	11.940	90	*
$\text{Na}^+ + (\text{cit})^{3-} \rightleftharpoons \text{Na}(\text{cit})^{2-}$	1.340	88	*

Reaction	$\log_{10} K^\circ$	ref.	t.v.*
$K^+ + (\text{cit})^{3-} \rightleftharpoons K(\text{cit})^{2-}$	1.230	88	*
$\text{Sr}^{2+} + (\text{cit})^{3-} \rightleftharpoons \text{Sr}(\text{cit})^-$	4.110	88	*
$\text{Sr}^{2+} + \text{H}^+ + (\text{cit})^{3-} \rightleftharpoons \text{SrH}(\text{cit})(\text{aq})$	9.080	90	*
$\text{Ra}^{2+} + (\text{cit})^{3-} \rightleftharpoons \text{Ra}(\text{cit})^-$	3.590	90	*
$\text{Ra}^{2+} + \text{H}^+ + (\text{cit})^{3-} \rightleftharpoons \text{RaH}(\text{cit})(\text{aq})$	9.000	90	*
$\text{Fe}^{2+} + (\text{cit})^{3-} \rightleftharpoons \text{Fe}(\text{cit})^-$	5.690	88	*
$\text{Fe}^{2+} + \text{H}^+ + (\text{cit})^{3-} \rightleftharpoons \text{FeH}(\text{cit})(\text{aq})$	9.870	88	*
$\text{Co}^{2+} + (\text{cit})^{3-} \rightleftharpoons \text{Co}(\text{cit})^-$	6.290	88	*
$\text{Co}^{2+} + \text{H}^+ + (\text{cit})^{3-} \rightleftharpoons \text{CoH}(\text{cit})(\text{aq})$	10.270	88	*
$\text{Pb}^{2+} + (\text{cit})^{3-} \rightleftharpoons \text{Pb}(\text{cit})^-$	5.700	88	*
$\text{Pb}^{2+} + 2 (\text{cit})^{3-} \rightleftharpoons \text{Pb}(\text{cit})_2^{4-}$	9.910	88	*
$\text{Pb}^{2+} + 3 (\text{cit})^{3-} \rightleftharpoons \text{Pb}(\text{cit})_3^{7-}$	4.550	88	*
$\text{Pb}^{2+} + \text{H}^+ + (\text{cit})^{3-} \rightleftharpoons \text{PbH}(\text{cit})(\text{aq})$	10.410	88	*
$\text{Al}^{3+} + (\text{cit})^{3-} \rightleftharpoons \text{Al}(\text{cit})$	9.910	89	*
$\text{Al}^{3+} + 2 (\text{cit})^{3-} \rightleftharpoons \text{Al}(\text{cit})_2^{3-}$	14.120	89	*
$\text{Al}^{3+} + \text{H}^+ + (\text{cit})^{3-} \rightleftharpoons \text{AlH}(\text{cit})^+$	12.860	89	*
$\text{Zr}^{4+} + (\text{cit})^{3-} \rightleftharpoons \text{Zr}(\text{cit})^+$	13.270	90	*
$\text{Zr}^{4+} + \text{H}^+ + (\text{cit})^{3-} \rightleftharpoons \text{ZrH}(\text{cit})^{2+}$	14.880	90	*
$\text{TcO}^{2+} + (\text{cit})^{3-} \rightleftharpoons \text{TcO}(\text{cit})^-$	11.990	90	*
$\text{TcO}^{2+} + \text{H}^+ + (\text{cit})^{3-} \rightleftharpoons \text{TcOH}(\text{cit})(\text{aq})$	14.110	90	*
$\text{Sm}^{3+} + (\text{cit})^{3-} \rightleftharpoons \text{Sm}(\text{cit})(\text{aq})$	7.990	90	*
$\text{Sm}^{3+} + \text{H}^+ + (\text{cit})^{3-} \rightleftharpoons \text{SmH}(\text{cit})^+$	11.670	90	*
$\text{Ac}^{3+} + (\text{cit})^{3-} \rightleftharpoons \text{Ac}(\text{cit})(\text{aq})$	7.990	90	*
$\text{Ac}^{3+} + \text{H}^+ + (\text{cit})^{3-} \rightleftharpoons \text{AcH}(\text{cit})^+$	11.670	90	*
$\text{Am}^{3+} + (\text{cit})^{3-} \rightleftharpoons \text{Am}(\text{cit})(\text{aq})$	7.990	90	*
$\text{Am}^{3+} + \text{H}^+ + (\text{cit})^{3-} \rightleftharpoons \text{AmH}(\text{cit})^+$	11.670	90	*
$\text{Cm}^{3+} + (\text{cit})^{3-} \rightleftharpoons \text{Cm}(\text{cit})(\text{aq})$	7.990	90	*
$\text{Cm}^{3+} + \text{H}^+ + (\text{cit})^{3-} \rightleftharpoons \text{CmH}(\text{cit})^+$	11.670	90	*
$\text{Pu}^{3+} + (\text{cit})^{3-} \rightleftharpoons \text{Pu}(\text{cit})(\text{aq})$	7.990	90	*
$\text{Pu}^{3+} + \text{H}^+ + (\text{cit})^{3-} \rightleftharpoons \text{PuH}(\text{cit})^+$	11.670	90	*
$\text{Th}^{4+} + (\text{cit})^{3-} \rightleftharpoons \text{Th}(\text{cit})^+$	11.290	90	*
$\text{Th}^{4+} + \text{H}^+ + (\text{cit})^{3-} \rightleftharpoons \text{ThH}(\text{cit})^{2+}$	13.680	90	*
$\text{Pu}^{4+} + (\text{cit})^{3-} \rightleftharpoons \text{Pu}(\text{cit})^+$	13.040	90	*
$\text{Pu}^{4+} + \text{H}^+ + (\text{cit})^{3-} \rightleftharpoons \text{PuH}(\text{cit})^{2+}$	14.750	90	*
$\text{U}^{4+} + (\text{cit})^{3-} \rightleftharpoons \text{U}(\text{cit})^+$	12.840	90	*
$\text{U}^{4+} + \text{H}^+ + (\text{cit})^{3-} \rightleftharpoons \text{UH}(\text{cit})^{2+}$	14.620	90	*
$\text{Np}^{4+} + (\text{cit})^{3-} \rightleftharpoons \text{Np}(\text{cit})^+$	12.980	90	*
$\text{Np}^{4+} + \text{H}^+ + (\text{cit})^{3-} \rightleftharpoons \text{NpH}(\text{cit})^{2+}$	14.710	90	*
$\text{NpO}_2^{+} + \text{H}^+ + (\text{cit})^{3-} \rightleftharpoons \text{NpH}(\text{cit})^-$	9.920	90	*
$\text{PuO}_2^{2+} + (\text{cit})^{3-} \rightleftharpoons \text{PuO}_2(\text{cit})^-$	9.180	90	*
$\text{PuO}_2^{2+} + \text{H}^+ + (\text{cit})^{3-} \rightleftharpoons \text{PuO}_2\text{H}(\text{cit})(\text{aq})$	12.400	90	*
$\text{Sr}^{2+} + (\text{edta})^{4-} \rightleftharpoons \text{Sr}(\text{edta})^{2-}$	10.460	89	*
$\text{Sr}^{2+} + \text{H}^+ + (\text{edta})^{4-} \rightleftharpoons \text{SrH}(\text{edta})^-$	14.820	89	*
$\text{Fe}^{2+} + (\text{edta})^{4-} \rightleftharpoons \text{Fe}(\text{edta})^{2-}$	16.020	89	*
$\text{Fe}^{2+} + \text{H}^+ + (\text{edta})^{4-} \rightleftharpoons \text{FeH}(\text{edta})^-$	19.250	89	*
$\text{Co}^{2+} + (\text{edta})^{4-} \rightleftharpoons \text{Co}(\text{edta})^{2-}$	18.170	89	*
$\text{Co}^{2+} + \text{H}^+ + (\text{edta})^{4-} \rightleftharpoons \text{CoH}(\text{edta})^-$	21.600	89	*
$\text{Co}^{2+} + 2 \text{H}^+ + (\text{edta})^{4-} \rightleftharpoons \text{CoH}_2(\text{edta})(\text{aq})$	23.570	89	*
$\text{Pb}^{2+} + (\text{edta})^{4-} \rightleftharpoons \text{Pb}(\text{edta})^{2-}$	19.680	89	*
$\text{Pb}^{2+} + \text{H}^+ + (\text{edta})^{4-} \rightleftharpoons \text{PbH}(\text{edta})^-$	22.610	89	*

Reaction	$\log_{10} K^\circ$	ref.	t.v. ^{*1}
Pb ²⁺ + 2 H ⁺ + (edta) ⁴⁻ ⇋ PbH ₂ (edta)(aq)	24.570	89	*
Pb ²⁺ + 3 H ⁺ + (edta) ⁴⁻ ⇋ PbH ₃ (edta) ⁺	25.770	89	*
Th ⁴⁺ + (edta) ⁴⁻ ⇋ Th(edta)(aq)	26.630	89	*
Th ⁴⁺ + H ⁺ + (edta) ⁴⁻ ⇋ ThH(edta) ⁺	28.610	89	*
Pu ⁴⁺ + (edta) ⁴⁻ + H ₂ O ⇋ PuOH(edta) ⁻ + H ⁺	24.200	93	*
Pu ⁴⁺ + (edta) ⁴⁻ + 2 H ₂ O ⇋ Pu(OH) ₂ (edta) ²⁻ + 2 H ⁺	19.220	93	*
Pu ⁴⁺ + (edta) ⁴⁻ + 3 H ₂ O ⇋ Pu(OH) ₃ (edta) ³⁻ + 3 H ⁺	9.710	93	*
Mg ²⁺ + (isa) ⁻ ⇋ Mg(isa) ⁺	0.600	90	*
Sr ²⁺ + (isa) ⁻ ⇋ Sr(isa) ⁺	0.910	90	*
Fe ²⁺ + (isa) ⁻ ⇋ Fe(isa) ⁺	0.940	90	*
Ni ²⁺ + (isa) ⁻ ⇋ Ni(isa) ⁺	2.200	94	*
Pb ²⁺ + (isa) ⁻ ⇋ Pb(isa) ⁺	2.440	90	*
Am ³⁺ + 3 H ₂ O(l) + (isa) ⁻ ⇋ Am(OH) ₃ (isa) ⁻ + 3 H ⁺	-47.700	94	*
Pu ⁴⁺ + 4 H ₂ O(l) + (isa) ⁻ ⇋ Pu(OH) ₄ (isa) ⁻ + 4 H ⁺	-12.300	94	*
Pu ⁴⁺ + 4 H ₂ O(l) + 2 (isa) ⁻ ⇋ Pu(OH) ₄ (isa) ₂ ²⁻ + 4 H ⁺	-8.100	94	*
Np ⁴⁺ + 4 H ₂ O(l) + (isa) ⁻ ⇋ Np(OH) ₄ (isa) ⁻ + 4 H ⁺	-13.660	94	*
Np ⁴⁺ + 4 H ₂ O(l) + 2 (isa) ⁻ ⇋ Np(OH) ₄ (isa) ₂ ²⁻ + 4 H ⁺	-11.800	94	*
U ⁴⁺ + 4 H ₂ O(l) + (isa) ⁻ ⇋ U(OH) ₄ (isa) ⁻ + 4 H ⁺	-17.600	94	*
U ⁴⁺ + 4 H ₂ O(l) + 2(isa) ⁻ ⇋ U(OH) ₄ (isa) ₂ ²⁻ + 4 H ⁺	-15.700	94	*
Th ⁴⁺ + H ₂ O(l) + (isa) ⁻ ⇋ ThOH(isa) ²⁺ + H ⁺	-6.200	95	*
Th ⁴⁺ + 3 H ₂ O(l) + 2 (isa) ⁻ ⇋ Th(OH) ₃ (isa) ₂ ⁻ + 3 H ⁺	-70.300	95	*
Th ⁴⁺ + 4 H ₂ O(l) + 2 (isa) ⁻ ⇋ Th(OH) ₄ (isa) ₂ ²⁻ + 4 H ⁺	-105.900	95	*

^{*1} Tentative values.

Table 19 Selected equilibrium constants of solid phases for JAEA-TDB ready to use for the geochemical calculation programs

Reaction	$\log_{10} K^\circ$	ref.	t.v. ^{*1}
$H(g) \rightleftharpoons H^+ + e^-$	35.612 ± 0.001	12	
$H_2(g) \rightleftharpoons 2 H^+ + 2 e^-$	0.000	2, 12	
$H_2O(g) \rightleftharpoons H_2O(l)$	1.499 ± 0.010	12	
$B(cr) + 3 H_2O(l) \rightleftharpoons B(OH)_3(aq) + 3 H^+ + 3 e^-$	45.173 ± 0.145	12	
$B(g) + 3 H_2O(l) \rightleftharpoons B(OH)_3(aq) + 3 H^+ + 3 e^-$	136.450 ± 0.888	12	
$B_2O_3(cr) + 3 H_2O(l) \rightleftharpoons 2 B(OH)_3(aq)$	5.745 ± 0.379	12	
$B(OH)_3(cr) \rightleftharpoons B(OH)_3(aq)$	-0.070 ± 0.203	12	
$BF_3(g) + 3 H_2O(l) \rightleftharpoons B(OH)_3(aq) + 3 F^- + 3 H^+$	-2.976 ± 0.416	12	
$C(cr) + 3 H_2O(l) \rightleftharpoons CO_3^{2-} + 6 H^+ + 4 e^-$	-32.151 ± 0.069	12	
$C(g) + 3 H_2O(l) \rightleftharpoons CO_3^{2-} + 6 H^+ + 4 e^-$	85.447 ± 0.105	12	
$CO(g) + 2 H_2O(l) \rightleftharpoons CO_3^{2-} + 4 H^+ + 2 e^-$	-14.637 ± 0.075	12	
$CO_2(g) + H_2O(l) \rightleftharpoons CO_3^{2-} + 2 H^+$	-18.155 ± 0.035	12	
$CH_4(g) + 3 H_2O(l) \rightleftharpoons CO_3^{2-} + 10 H^+ + 8 e^-$	-43.931	2	
$N(g) + 3 H_2O(l) \rightleftharpoons NO_3^- + 6 H^+ + 5 e^-$	-25.418 ± 0.102	12	
$N_2(g) + 6 H_2O(l) \rightleftharpoons 2 NO_3^- + 12 H^+ + 10 e^-$	-210.449 ± 0.105	12	
$NH_3(g) + 3 H_2O(l) \rightleftharpoons NO_3^- + 9 H^+ + 8 e^-$	-108.099 ± 0.096	12	
$O(g) + 2 H^+ + 2 e^- \rightleftharpoons H_2O(l)$	82.144 ± 0.019	12	
$O_2(g) + 4 H^+ + 4 e^- \rightleftharpoons 2 H_2O(l)$	83.090 ± 0.010	12	
$F(g) + e^- \rightleftharpoons F^-$	60.231 ± 0.132	12	
$F_2(g) + 2 e^- \rightleftharpoons 2 F^-$	98.641 ± 0.171	12	
$HF(g) \rightleftharpoons F^- + H^+$	1.073 ± 0.172	12	
$Na(cr) \rightleftharpoons Na^+ + e^-$	45.892 ± 0.017	12	
$Na(g) \rightleftharpoons Na^+ + e^-$	59.375 ± 0.124	12	
$Na_2Al_{14}Si_{22}O_{60}(OH)_{12}(montmorillonite,Na) + 16 H_2O(l) + 44 H^+ \rightleftharpoons 2 Na^+ + 14 Al^{3+} + 22 H_4SiO_4(aq)$	58.540	2	
$NaAl_3Si_3O_{10}(OH)_2(plagioclase) + 10 H^+ \rightleftharpoons Na^+ + 3 Al^{3+} + 3 H_4SiO_4(aq)$	18.870	2	
$NaAlSi_3O_8(albite) + 4 H_2O(l) + 4 H^+ \rightleftharpoons Na^+ + Al^{3+} + 3 H_4SiO_4(aq)$	3.540	2	
$Mg_{26}Fe_8Al_{20}Si_{24}O_{80}(OH)_{64}(clinochlore) + 128 H^+ \rightleftharpoons 26 Mg^{2+} + 20 Al^{3+} + 24 H_4SiO_4(aq) + 8 Fe^{2+} + 48 H_2O(l)$	447.610	2	
$Mg_2Si_2O_6(s) + 2 H_2O(l) + 4 H^+ \rightleftharpoons 2 Mg^{2+} + 2 H_4SiO_4(aq)$	23.260	2	
$Mg_3Si_4O_{10}(OH)_2(talc) + 4 H_2O(l) + 6 H^+ \rightleftharpoons 3 Mg^{2+} + 4 H_4SiO_4(aq)$	20.600 ± 2.000	2, 99	
$Mg_{40}Al_{16}Si_{24}O_{80}(OH)_{64}(clinochlore,Mg-rich) + 128 H^+ \rightleftharpoons 40 Mg^{2+} + 16 Al^{3+} + 24 H_4SiO_4(aq) + 48 H_2O(l)$	546.830	2	
$Mg_4Si_6O_9(OH)_{14}(sepiolite) + H_2O(l) + 8 H^+ \rightleftharpoons 4 Mg^{2+} + 6 H_4SiO_4(aq)$	32.830	2	
$Mg_8Fe_{26}Al_{25}Si_{20}O_{80}(OH)_{64}(clinochlore,Fe-rich) + 144 H^+ + e^- \rightleftharpoons 8 Mg^{2+} + 25 Al^{3+} + 20 H_4SiO_4(aq) + 26 Fe^{2+} + 64 H_2O(l)$	178.370	2	
$MgAl_{14}Si_{22}O_{60}(OH)_{12}(montmorillonite,Mg) + 16 H_2O(l) + 44 H^+ \rightleftharpoons Mg^{2+} + 14 Al^{3+} + 22 H_4SiO_4(aq)$	57.040	2	
$MgFe_2O_4(magnesio-ferrite) + 8 H^+ + 2 e^- \rightleftharpoons Mg^{2+} + 2 Fe^{2+} + 4 H_2O(l)$	42.820	2	
$MgO(periclase) + 2 H^+ \rightleftharpoons Mg^{2+} + H_2O(l)$	21.580	2	
$Al(OH)_3(gibbsite) + 3 H^+ \rightleftharpoons Al^{3+} + 3 H_2O(l)$	8.770	2	
$Al_2SiO_4(OH)_2(topaz,O) + 6 H^+ \rightleftharpoons 2 Al^{3+} + H_4SiO_4(aq) + 2 H_2O(l)$	12.810	2	
$Al_2Si_2O_5(OH)_4(kaolinite) + 6 H^+ \rightleftharpoons 2 H_4SiO_4(aq) + 2 Al^{3+} + H_2O(l)$	9.080	2	
$SiO_2(chalcedony) + 2 H_2O(l) \rightleftharpoons H_4SiO_4(aq)$	-3.490	2	
$SiO_2(quartz) + 2 H_2O(l) \rightleftharpoons H_4SiO_4(aq)$	-3.780	2	
$SiO_2 \cdot 0.5H_2O(am) + 2 H_2O(l) \rightleftharpoons H_4SiO_4(aq) + H^+ + e^-$	-2.470	2	
$SiO_2(silica-gel) + 2 H_2O(l) \rightleftharpoons H_4SiO_4(aq)$	-2.700	2	
$SiO_2 \cdot H_2O(silica-glass) + H_2O(l) \rightleftharpoons H_4SiO_4(aq)$	-3.020	2	

Reaction	$\log_{10} K^\circ$	ref.	t.v. ^{*1}
$\text{SiO}_2(\text{am}) + 2 \text{H}_2\text{O(l)} \rightleftharpoons \text{H}_4\text{SiO}_4(\text{aq})$	-2.710	2	
$\text{Si(cr)} + 4 \text{H}_2\text{O(l)} \rightleftharpoons \text{H}_4\text{SiO}_4(\text{aq}) + 4 \text{H}^+ + 4 \text{e}^-$	62.924 ± 0.205	12	
$\text{Si(g)} + 4 \text{H}_2\text{O(l)} \rightleftharpoons \text{H}_4\text{SiO}_4(\text{aq}) + 4 \text{H}^+ + 4 \text{e}^-$	133.969 ± 1.416	12	
$\text{SiO}_2(\alpha\text{-quartz}) + 2 \text{H}_2\text{O(l)} \rightleftharpoons \text{H}_4\text{SiO}_4(\text{aq})$	-4.000 ± 0.268	12	
$\text{SiF}_4(\text{g}) + 4 \text{H}_2\text{O(l)} \rightleftharpoons \text{H}_4\text{SiO}_4(\text{aq}) + 4 \text{F}^- + 4 \text{H}^+$	-15.330 ± 0.545	12	
$\text{P(am)} + 4 \text{H}_2\text{O(l)} \rightleftharpoons \text{PO}_4^{3-} + 8 \text{H}^+ + 5 \text{e}^-$	13.478 ± 0.276	12	
$\text{P(cr)} + 4 \text{H}_2\text{O(l)} \rightleftharpoons \text{PO}_4^{3-} + 8 \text{H}^+ + 5 \text{e}^-$	13.478 ± 0.276	12	
$\text{P(g)} + 4 \text{H}_2\text{O(l)} \rightleftharpoons \text{PO}_4^{3-} + 8 \text{H}^+ + 5 \text{e}^-$	62.548 ± 0.328	12	
$\text{P}_2(\text{g}) + 8 \text{H}_2\text{O(l)} \rightleftharpoons 2 \text{PO}_4^{3-} + 16 \text{H}^+ + 10 \text{e}^-$	45.082 ± 0.526	12	
$\text{P}_4(\text{g}) + 16 \text{H}_2\text{O(l)} \rightleftharpoons 4 \text{PO}_4^{3-} + 32 \text{H}^+ + 20 \text{e}^-$	58.189 ± 0.558	12	
$\text{S(cr)} + 4 \text{H}_2\text{O(l)} \rightleftharpoons \text{SO}_4^{2-} + 8 \text{H}^+ + 6 \text{e}^-$	-35.836 ± 0.075	12	
$\text{S(g)} + 4 \text{H}_2\text{O(l)} \rightleftharpoons \text{SO}_4^{2-} + 8 \text{H}^+ + 6 \text{e}^-$	5.629 ± 0.079	12	
$\text{S}_2(\text{g}) + 8 \text{H}_2\text{O(l)} \rightleftharpoons 2 \text{SO}_4^{2-} + 16 \text{H}^+ + 12 \text{e}^-$	-57.713 ± 0.118	12	
$\text{SO}_2(\text{g}) + 2 \text{H}_2\text{O(l)} \rightleftharpoons \text{SO}_4^{2-} + 4 \text{H}^+ + 2 \text{e}^-$	-5.321 ± 0.082	12	
$\text{H}_2\text{S(g)} + 4 \text{H}_2\text{O(l)} \rightleftharpoons \text{SO}_4^{2-} + 10 \text{H}^+ + 8 \text{e}^-$	-41.695 ± 0.115	12	
$\text{Cl(g)} + \text{e}^- \rightleftharpoons \text{Cl}^-$	41.437 ± 0.021	12	
$\text{Cl}_2(\text{g}) + 2 \text{e}^- \rightleftharpoons 2 \text{Cl}^-$	45.976 ± 0.029	12	
$\text{HCl(g)} \rightleftharpoons \text{Cl}^- + \text{H}^+$	6.293 ± 0.027	12	
$\text{K(cr)} \rightleftharpoons \text{K}^+ + \text{e}^-$	49.493 ± 0.020	12	
$\text{K(g)} \rightleftharpoons \text{K}^+ + \text{e}^-$	60.089 ± 0.142	12	
$\text{KAl}_2(\text{AlSi}_3\text{O}_{10})(\text{OH})_2(\text{muscovite}) + \text{H}^+ \rightleftharpoons 3 \text{Al}^{3+} + 3 \text{H}_4\text{SiO}_4(\text{aq}) + \text{K}^+$	14.600	2	
$\text{K}_2\text{Al}_{10}\text{Si}_{14}\text{O}_{40}(\text{OH})_8(\text{illite,idealized2}) + 8 \text{H}_2\text{O(l)} + 32 \text{H}^+ \rightleftharpoons 10 \text{Al}^{3+} + 14 \text{H}_4\text{SiO}_4(\text{aq}) + 2 \text{K}^+$	28.540	2	
$\text{K}_2\text{Al}_{14}\text{Si}_{22}\text{O}_{60}(\text{OH})_{12}(\text{montmorillonite,K}) + 16 \text{H}_2\text{O(l)} + 44 \text{H}^+ \rightleftharpoons 14 \text{Al}^{3+} + 22 \text{H}_4\text{SiO}_4(\text{aq}) + 2 \text{K}^+$	57.510	2	
$\text{KAl}_3(\text{SO}_4)_2(\text{OH})_6(\text{alunite}) + 6 \text{H}^+ \rightleftharpoons 3 \text{Al}^{3+} + 2 \text{SO}_4^{2-} + \text{K}^+ + 6 \text{H}_2\text{O(l)}$	1.610	2	
$\text{KAlSi}_3\text{O}_8(\text{microcline}) + 4 \text{H}_2\text{O(l)} + 4 \text{H}^+ \rightleftharpoons \text{Al}^{3+} + 3 \text{H}_4\text{SiO}_4(\text{aq}) + \text{K}^+$	1.780	2	
$\text{KAlSi}_3\text{O}_8(\text{orthoclase}) + 4 \text{H}_2\text{O(l)} + 4 \text{H}^+ \rightleftharpoons \text{Al}^{3+} + 3 \text{H}_4\text{SiO}_4(\text{aq}) + \text{K}^+$	0.860	2	
$\text{KFe}_3\text{AlSi}_3\text{O}_{10}(\text{OH})_2(\text{annite}) + 10 \text{H}^+ \rightleftharpoons \text{Al}^{3+} + 3 \text{H}_4\text{SiO}_4(\text{aq}) + \text{K}^+ + 3 \text{Fe}^{2+}$	22.330	2	
$\text{K}_3\text{MgAl}_9\text{Si}_{14}\text{O}_{40}(\text{OH})_8(\text{illite,idealized}) + 8 \text{H}_2\text{O(l)} + 32 \text{H}^+ \rightleftharpoons \text{Mg}^{2+} + 9 \text{Al}^{3+} + 14 \text{H}_4\text{SiO}_4(\text{aq}) + 3 \text{K}^+$	67.150	2	
$\text{KMg}_3\text{AlSi}_3\text{O}_{10}(\text{OH})_2(\text{phlogopite}) + 10 \text{H}^+ \rightleftharpoons 3 \text{Mg}^{2+} + \text{Al}^{3+} + 3 \text{H}_4\text{SiO}_4(\text{aq}) + \text{K}^+$	36.330	2	
$\text{KAlSi}_3\text{O}_8(\text{feldspar,K}) + 4 \text{H}_2\text{O(l)} + 4 \text{H}^+ \rightleftharpoons 3 \text{H}_4\text{SiO}_4(\text{aq}) + \text{K}^+ + \text{Al}^{3+}$	0.0832	2	
$\text{Ca(cr)} \rightleftharpoons \text{Ca}^{2+} + 2 \text{e}^-$	96.847 ± 0.184	12	
$\text{Ca(g)} \rightleftharpoons \text{Ca}^{2+} + 2 \text{e}^-$	122.078 ± 0.232	12	
$\text{CaO(cr)} + 2 \text{H}^+ \rightleftharpoons \text{Ca}^{2+} + \text{H}_2\text{O(l)}$	32.699 ± 0.244	12	
$\text{CaCO}_3(\text{calcite}) \rightleftharpoons \text{Ca}^{2+} + \text{CO}_3^{2-}$	-8.460 ± 0.010	49	
$\text{CaCO}_3(\text{aronite}) \rightleftharpoons \text{Ca}^{2+} + \text{CO}_3^{2-}$	-8.340 ± 0.020	2, 99	
$\text{CaMg}(\text{CO}_3)_2(\text{dolomite}) \rightleftharpoons \text{Ca}^{2+} + \text{Mg}^{2+} + 2 \text{CO}_3^{2-}$	-17.090	2	
$\text{CaSO}_4 \cdot 2\text{H}_2\text{O}(\text{gypsum}) \rightleftharpoons \text{Ca}^{2+} + \text{SO}_4^{2-} + 2 \text{H}_2\text{O(l)}$	-4.600 ± 0.020	2, 99	
$\text{CaSO}_4(\text{anhidrite}) \rightleftharpoons \text{Ca}^{2+} + \text{SO}_4^{2-}$	-4.380	2	
$\text{Ca}_5(\text{PO}_4)_3(\text{OH})(\text{hydroxyapatite}) + \text{H}^+ \rightleftharpoons \text{H}_2\text{O(l)} + 3 \text{PO}_4^{3-} + 5 \text{Ca}^{2+}$	-40.470	2	
$\text{CaF}_2(\text{fluorite}) \rightleftharpoons \text{Ca}^{2+} + 2 \text{F}^-$	-10.960	2	
$\text{Ca}_2\text{Al}_3(\text{SiO}_4)_3\text{OH}(\text{clinzozoisite}) + 13 \text{H}^+ \rightleftharpoons 3 \text{Al}^{3+} + 3 \text{H}_4\text{SiO}_4(\text{aq}) + 2 \text{Ca}^{2+} \text{H}_2\text{O(l)}$	43.610	2	
$\text{Ca}_2\text{Al}_2\text{Fe}(\text{SiO}_4)(\text{Si}_2\text{O}_7)\text{OOH}(\text{epidote}) + 13 \text{H}^+ + \text{e}^- \rightleftharpoons \#2 \text{Al}^{3+} + 3 \text{H}_4\text{SiO}_4(\text{aq}) + 2 \text{Ca}^{2+} + \text{Fe}^{2+} + \text{H}_2\text{O(l)}$	45.430	2	
$\text{Ca}_2\text{Mg}_5\text{Si}_8\text{O}_{22}(\text{OH})_2(\text{tremolite}) + 8 \text{H}_2\text{O(l)} + 14 \text{H}^+ \rightleftharpoons 5 \text{Mg}^{2+} + 8 \text{H}_4\text{SiO}_4(\text{aq}) + 2 \text{Ca}^{2+}$	57.700	2	
$\text{Ca}_3\text{Fe}_2(\text{SiO}_4)_3(\text{andradite}) + 12 \text{H}^+ + 2 \text{e}^- \rightleftharpoons 3 \text{H}_4\text{SiO}_4(\text{aq}) + 3 \text{Ca}^{2+} + 2 \text{Fe}^{2+}$	55.100	2	
$\text{CaAl}_{14}\text{Si}_{22}\text{O}_{60}(\text{OH})_{12} (\text{montmorillonite,Ca}) + 16 \text{H}_2\text{O(l)} + 44 \text{H}^+ \rightleftharpoons 14 \text{Al}^{3+} + 22 \text{H}_4\text{SiO}_4(\text{aq}) + \text{Ca}^{2+}$	41.880	2	
$\text{CaAl}_2\text{Si}_2\text{O}_8(\text{anorthite,hexagonal}) + 8 \text{H}^+ \rightleftharpoons 2 \text{Al}^{3+} + 2 \text{H}_4\text{SiO}_4(\text{aq}) + \text{Ca}^{2+}$	26.700	2	

Reaction	$\log_{10} K^\circ$	ref.	t.v. ^{*1}
$\text{CaAl}_2\text{Si}_2\text{O}_8(\text{anorthite,triclinic}) + 8 \text{H}^+ \rightleftharpoons 2 \text{Al}^{3+} + 2 \text{H}_4\text{SiO}_4(\text{aq}) + \text{Ca}^{2+}$	26.370	2	
$\text{CaO}(\text{s}) + 2 \text{H}^+ \rightleftharpoons \text{Ca}^{2+} + \text{H}_2\text{O}(\text{l})$	32.700	2	
$\text{MnO}_2(\text{birnessite-type}) + 2 \text{e}^- + 4 \text{H}^+ \rightleftharpoons \text{Mn}^{2+} + 2 \text{H}_2\text{O}(\text{l})$	43.597	2	
$\text{MnOOH}(\text{manganite}) + \text{e}^- + 3 \text{H}^+ \rightleftharpoons \text{Mn}^{2+} + 2 \text{H}_2\text{O}(\text{l})$	25.267	2	
$\text{MnCO}_3(\text{rhodochrosite}) \rightleftharpoons \text{CO}_3^{2-} + \text{Mn}^{2+}$	-10.540	2	
$\text{MnO}_2(\text{pyrolusite}) + 4 \text{H}^+ + 2 \text{e}^- \rightleftharpoons \text{Mn}^{2+} + 2 \text{H}_2\text{O}(\text{l})$	41.550	2	
$\text{MnS}(\text{alabandite}) + 4 \text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{SO}_4^{2-} + \text{Mn}^{2+} + 8 \text{H}^+ + 8 \text{e}^-$	-34.110	2	
$\text{Fe(OH)}_3(\text{s}) + 3 \text{H}^+ \rightleftharpoons \text{Fe}^{3+} + 3 \text{H}_2\text{O}(\text{l})$	4.890	2	
$\text{FeCO}_3(\text{siderite}) \rightleftharpoons \text{Fe}^{2+} + \text{CO}_3^{2-}$	-10.570	2	
$\text{Fe}_2\text{O}_3(\text{hematite}) + 6 \text{H}^+ + 2 \text{e}^- \rightleftharpoons 2 \text{Fe}^{2+} + 3 \text{H}_2\text{O}(\text{l})$	22.400	2	
$\text{FeS}(\text{mackinawite}) + 4 \text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{Fe}^{2+} + \text{SO}_4^{2-} + \text{H}^+ + 8 \text{e}^-$	-38.323	2	
$\text{FeS}(\text{s}) + 4 \text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{Fe}^{2+} + \text{SO}_4^{2-} + 8 \text{H}^+ + 8 \text{e}^-$	-37.603	2	
$\text{Fe}_3(\text{PO}_4)_2 \cdot 8\text{H}_2\text{O}(\text{l}) (\text{vivianite}) \rightleftharpoons 3 \text{Fe}^{2+} + 2 \text{PO}_4^{3-} + 8 \text{H}_2\text{O}(\text{l})$	-36.000	2, 99	
$\text{Fe}_2\text{Si}_2\text{O}_6(\text{s}) + 2 \text{H}_2\text{O}(\text{l}) + 4 \text{H}^+ \rightleftharpoons 2 \text{H}_4\text{SiO}_4(\text{aq}) + 2 \text{Fe}^{2+}$	10.600	2	
$\text{Fe}_3\text{Al}_2(\text{SiO}_4)_3(\text{almandine}) + 12 \text{H}^+ \rightleftharpoons 2 \text{Al}^{3+} + 3 \text{H}_4\text{SiO}_4(\text{aq}) + 3 \text{Fe}^{2+}$	33.410	2	
$\text{Fe}_3\text{O}_4(\text{magnetite}) + 8 \text{H}^+ + 2 \text{e}^- \rightleftharpoons 3 \text{Fe}^{2+} + 4 \text{H}_2\text{O}(\text{l})$	30.650	2	
$\text{Fe}_7\text{S}_8(\text{pyrrhotite}) + 32 \text{H}_2\text{O}(\text{l}) \rightleftharpoons 8 \text{SO}_4^{2-} + 7 \text{Fe}^{2+} + 64 \text{H}^+ + 62 \text{e}^-$	-321.280	2	
$\text{FeCl}_2(\text{lawrencite}) \rightleftharpoons 2 \text{Cl}^- + \text{Fe}^{2+}$	6.820	2	
$\text{FeCl}_3(\text{molyosite}) + \text{e}^- \rightleftharpoons 3 \text{Cl}^- + \text{Fe}^{2+}$	24.560	2	
$\text{FeOOH}(\text{goethite}) + 3 \text{H}^+ + \text{e}^- \rightleftharpoons \text{Fe}^{2+} + 2 \text{H}_2\text{O}(\text{l})$	11.290	2	
$\text{FeS}_2(\text{pyrite}) + 8 \text{H}_2\text{O}(\text{l}) \rightleftharpoons 2 \text{SO}_4^{2-} + \text{Fe}^{2+} + 16 \text{H}^+ + 14 \text{e}^-$	-85.950	2	
$\text{FeSiO}_3(\text{ferrosilite}) + \text{H}_2\text{O}(\text{l}) + 2 \text{H}^+ \rightleftharpoons \text{Fe}^{2+} + \text{H}_4\text{SiO}_4(\text{aq})$	7.420	2	
$\text{Fe}_3\text{Si}_2\text{O}_5(\text{OH})_4(\text{greenalite}) + 6 \text{H}^+ \rightleftharpoons 3 \text{Fe}^{2+} + 2 \text{H}_4\text{SiO}_4(\text{aq}) + \text{H}_2\text{O}(\text{l})$	22.590	2	
$\text{Fe}_2\text{SiO}_4(\text{fayalite}) + 4 \text{H}^+ \rightleftharpoons 2 \text{Fe}^{2+} + \text{H}_4\text{SiO}_4(\text{aq})$	19.050	2	
$\text{Co(cr)} \rightleftharpoons \# \text{Co}^{2+} + 2 \text{e}^-$	9.530 ± 0.175	51	
$\text{CoO(cr)} + \# \text{H}^+ \rightleftharpoons \# \text{Co}^{2+} + \text{H}_2\text{O}(\text{l})$	12.399 ± 0.326	51	*
$\beta\text{-Co(OH)}_2 + 2 \text{H}^+ \rightleftharpoons \# \text{Co}^{2+} + 2 \text{H}_2\text{O}(\text{l})$	12.430 ± 0.170	51	
$\text{CoCl}_2 \cdot 6\text{H}_2\text{O(cr)} + \# \text{Co}^{2+} + 2 \text{Cl}^- + 6 \text{H}_2\text{O}(\text{l})$	3.037 ± 0.018	51	*
$\beta\text{-Co(IO}_3)_2 + 12 \text{H}^+ + 12 \text{e}^- \rightleftharpoons \# \text{Co}^{2+} + 2 \text{I}^- + 6 \text{H}_2\text{O}(\text{l})$	218.731 ± 0.293	51	*
$\text{Co(IO}_3)_2 \cdot 2\text{H}_2\text{O(cr)} + 12 \text{H}^+ + 12 \text{e}^- \rightleftharpoons \# \text{Co}^{2+} + 8 \text{H}_2\text{O}(\text{l}) + 2 \text{I}^-$	218.025 ± 0.328	51	*
$\alpha\text{-CoS} + \text{H}^+ \rightleftharpoons \# \text{Co}^{2+} + \text{HS}^-$	-7.440 ± 0.120	51	
$\beta\text{-CoS} + \text{H}^+ \rightleftharpoons \# \text{Co}^{2+} + \text{HS}^-$	-11.100 ± 1.700	51	
$\alpha\text{-CoSO}_4 \cdot 6\text{H}_2\text{O} \rightleftharpoons \# \text{Co}^{2+} + 6 \text{H}_2\text{O}(\text{l}) + \text{SO}_4^{2-}$	-2.229 ± 0.279	51	*
$\beta\text{-CoSO}_4 \cdot 6\text{H}_2\text{O} \rightleftharpoons \# \text{Co}^{2+} + 6 \text{H}_2\text{O}(\text{l}) + \text{SO}_4^{2-}$	-2.124 ± 0.467	51	*
$\text{CoSO}_4 \cdot 7\text{H}_2\text{O(cr)} \rightleftharpoons \# \text{Co}^{2+} + 7 \text{H}_2\text{O}(\text{l}) + \text{SO}_4^{2-}$	-2.245 ± 0.058	51	
$\text{Co}_3(\text{AsO}_3)_2(\text{cr,hyd}) + 2 \text{H}_2\text{O}(\text{l}) + 4 \text{e}^- \rightleftharpoons \# \text{Co}^{2+} + 4 \text{H}^+ + 2 \text{AsO}_4^{3-}$	-51.640 ± 2.012	51	*
$\text{Co}_3(\text{AsO}_4)_2 \cdot 8\text{H}_2\text{O(cr)} \rightleftharpoons \# \text{Co}^{2+} + 2 \text{AsO}_4^{3-} + 8 \text{H}_2\text{O}(\text{l})$	-27.929 ± 0.883	51	*
$\text{CoCO}_3(\text{cr}) \rightleftharpoons \# \text{Co}^{2+} + \text{CO}_3^{2-}$	-11.027 ± 0.098	51	*
$\text{CoCO}_3 \cdot 5.5\text{H}_2\text{O(cr)} \rightleftharpoons \# \text{Co}^{2+} + \text{CO}_3^{2-} + 5.5 \text{H}_2\text{O}(\text{l})$	-7.577 ± 0.049	51	*
$\text{Ni(cr)} \rightleftharpoons \# \text{Ni}^{2+} + 2 \text{e}^-$	8.019 ± 0.135	8	
$\text{NiO(cr)} + \# \text{H}^+ \rightleftharpoons \# \text{Ni}^{2+} + \text{H}_2\text{O}(\text{l})$	12.483 ± 0.154	51	*
$\beta\text{-Ni(OH)}_2 + 2 \text{H}^+ \rightleftharpoons \# \text{Ni}^{2+} + 2 \text{H}_2\text{O}(\text{l})$	11.029 ± 0.280	51	*
$\text{NiCl}_2 \cdot 6\text{H}_2\text{O(cr)} \rightleftharpoons \# \text{Ni}^{2+} + 2 \text{Cl}^- + 6 \text{H}_2\text{O}(\text{l})$	3.045 ± 0.014	8	
$\beta\text{-Ni(IO}_3)_2 + 12 \text{H}^+ + 12 \text{e}^- \rightleftharpoons \# \text{Ni}^{2+} + 2 \text{I}^- + 6 \text{H}_2\text{O}(\text{l})$	218.696 ± 0.277	8	
$\text{Ni(IO}_3)_2 \cdot 2\text{H}_2\text{O(cr)} + 12 \text{H}^+ + 12 \text{e}^- \rightleftharpoons \# \text{Ni}^{2+} + 8 \text{H}_2\text{O}(\text{l}) + 2 \text{I}^-$	217.986 ± 0.294	8	
$\alpha\text{-NiS} + \text{H}^+ \rightleftharpoons \# \text{Ni}^{2+} + \text{HS}^-$	-9.508 ± 0.464	51	*
$\beta\text{-NiS} + \text{H}^+ \rightleftharpoons \# \text{Ni}^{2+} + \text{HS}^-$	-10.128 ± 0.464	51	*
$\text{NiSO}_4 \cdot 7\text{H}_2\text{O(cr)} \rightleftharpoons \# \text{Ni}^{2+} + 7 \text{H}_2\text{O}(\text{l}) + \text{SO}_4^{2-}$	-2.267 ± 0.019	8	
$\text{Ni}_3(\text{AsO}_3)_2(\text{cr,hyd}) + 2 \text{H}_2\text{O}(\text{l}) + 4 \text{e}^- \rightleftharpoons \# \text{Ni}^{2+} + 4 \text{H}^+ + 2 \text{HAsO}_4^{3-}$	-51.484 ± 2.106	8	
$\text{Ni}_3(\text{AsO}_4)_2 \cdot 8\text{H}_2\text{O(cr)} \rightleftharpoons \# \text{Ni}^{2+} + 2 \text{AsO}_4^{3-} + 8 \text{H}_2\text{O}(\text{l})$	-28.100 ± 0.500	8	

Reaction	$\log_{10} K^\circ$	ref.	t.v. ^{*1}
$\text{NiCO}_3(\text{cr}) \rightleftharpoons \text{Ni}^{2+} + \text{CO}_3^{2-}$	-10.995 ± 0.183	8	
$\text{NiCO}_3 \cdot 5\text{H}_2\text{O}(\text{cr}) \rightleftharpoons \text{Ni}^{2+} + \text{CO}_3^{2-} + 5.5 \text{H}_2\text{O}(\text{l})$	-7.525 ± 0.106	8	
$\text{As}(\text{cr}) + 4 \text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{AsO}_4^{3-} + 8 \text{H}^+ + 5 \text{e}^-$	-52.592 ± 0.703	12	
$\text{As}_2\text{O}_5(\text{cr}) + 3 \text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{#AsO}_4^{3-} + 6 \text{H}^+$	-34.539 ± 1.986	12	
$\text{As}_4\text{O}_6(\text{cubic}) + 10 \text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{#AsO}_4^{3-} + 8 \text{H}^+ + 5 \text{e}^-$	-162.999 ± 3.973	12	
$\text{As}_4\text{O}_6(\text{monoclinic}) + 10 \text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{#AsO}_4^{3-} + 8 \text{H}^+ + 5 \text{e}^-$	-163.273 ± 3.974	12	
$\text{Se}(\text{cr,trigonal}) + \text{H}^+ + 2 \text{e}^- \rightleftharpoons \text{HSe}^-$	-7.616 ± 0.355	9	
$\text{PbSeO}_3(\text{cr}) \rightleftharpoons \text{Pb}^{2+} + \text{SeO}_3^{2-}$	-12.500 ± 1.000	9	
$\text{PbSeO}_4(\text{cr}) \rightleftharpoons \text{Pb}^{2+} + \text{SeO}_4^{2-}$	-6.900 ± 0.250	9	
$\text{Tl}_2\text{SeO}_4(\text{cr}) \rightleftharpoons 2 \text{Tl}^+ + \text{SeO}_4^{2-}$	-3.900 ± 0.150	9	
$\text{ZnSeO}_4 \cdot 6\text{H}_2\text{O}(\text{cr}) \rightleftharpoons \text{Zn}^{2+} + 6\text{H}_2\text{O}(\text{l}) + \text{SeO}_4^{2-}$	-1.538 ± 0.068	9	
$\text{Cd}(\text{SeCN})_2(\text{cr}) + 20 \text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{Cd}^{2+} + 2 \text{SeO}_4^{2-} + 40 \text{H}^+ + 32 \text{e}^- + 2 \text{CO}_3^{2-} + 2 \text{NO}_3^-$	-411.153 ± 1.528	9	
$\text{Ag}_2\text{SeO}_3(\text{cr}) \rightleftharpoons 2 \text{Ag}^+ + \text{SeO}_3^{2-}$	-15.800 ± 0.300	9	
$\text{Ag}_2\text{SeO}_4(\text{cr}) \rightleftharpoons 2 \text{Ag}^+ + \text{SeO}_4^{2-}$	-7.860 ± 0.500	9	
$\text{AgSeCN}(\text{cr}) + 10 \text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{SeO}_4^{2-} + 20 \text{H}^+ + 16 \text{e}^- + \text{CO}_3^{2-} + \text{NO}_3^- + \text{Ag}^+$	-216.724 ± 0.883	9	
$\text{NiSeO}_3 \cdot 2\text{H}_2\text{O}(\text{cr}) \rightleftharpoons \text{Ni}^{2+} + 2 \text{H}_2\text{O}(\text{l}) + \text{SeO}_3^{2-}$	-5.800 ± 1.000	9	
$\text{NiSeO}_4 \cdot 6\text{H}_2\text{O}(\text{cr}) \rightleftharpoons \text{Ni}^{2+} + 6 \text{H}_2\text{O}(\text{l}) + \text{SeO}_4^{2-}$	-1.381 ± 0.045	9	
$\text{CuSeO}_4 \cdot 5\text{H}_2\text{O}(\text{cr}) \rightleftharpoons \text{Cu}^{2+} + 5 \text{H}_2\text{O}(\text{l}) + \text{SeO}_4^{2-}$	-2.440 ± 0.200	9	
$\text{MgSeO}_3 \cdot 6\text{H}_2\text{O}(\text{cr}) \rightleftharpoons \text{Mg}^{2+} + 6 \text{H}_2\text{O}(\text{l}) + \text{SeO}_3^{2-}$	-5.820 ± 0.250	9	
$\text{MgSeO}_4 \cdot 6\text{H}_2\text{O}(\text{cr}) \rightleftharpoons \text{Mg}^{2+} + 6 \text{H}_2\text{O}(\text{l}) + \text{SeO}_4^{2-}$	-1.133 ± 0.044	9	
$\text{CaSeO}_3 \cdot \text{H}_2\text{O}(\text{cr}) \rightleftharpoons \text{Ca}^{2+} + \text{H}_2\text{O}(\text{l}) + \text{SeO}_3^{2-}$	-6.400 ± 0.250	9	
$\text{CaSeO}_4 \cdot 2\text{H}_2\text{O}(\text{cr}) \rightleftharpoons \text{Ca}^{2+} + 2 \text{H}_2\text{O}(\text{l}) + \text{SeO}_4^{2-}$	-2.680 ± 0.250	9	
$\text{SrSeO}_3(\text{cr}) \rightleftharpoons \text{Sr}^{2+} + \text{SeO}_3^{2-}$	-6.300 ± 0.500	9	
$\text{BaSeO}_3(\text{cr}) \rightleftharpoons \text{Ba}^{2+} + \text{SeO}_3^{2-}$	-6.500 ± 0.250	9	
$\text{BaSeO}_4(\text{cr}) \rightleftharpoons \text{Ba}^{2+} + \text{SeO}_4^{2-}$	-7.560 ± 0.100	9	
$\text{NH}_4\text{HSe}(\text{cr}) + 7 \text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{SeO}_4^{2-} + \text{NO}_3^- + 19 \text{H}^+ + 16 \text{e}^-$	-198.643 ± 0.973	9	
$(\text{NH}_4)_2\text{SeO}_4(\text{cr}) \rightleftharpoons 2 \text{NH}_4^+ + \text{SeO}_4^{2-}$	0.911 ± 0.065	9	
$\text{Li}_2\text{SeO}_4 \cdot \text{H}_2\text{O}(\text{cr}) \rightleftharpoons 2 \text{Li}^+ + \text{H}_2\text{O}(\text{l}) + \text{SeO}_4^{2-}$	1.762 ± 0.065	9	
$\text{Na}_2\text{SeO}_4 \cdot 10\text{H}_2\text{O}(\text{cr}) \rightleftharpoons 2 \text{Na}^+ + 10\text{H}_2\text{O}(\text{l}) + \text{SeO}_4^{2-}$	-0.681 ± 0.087	9	
$\text{K}_2\text{SeO}_4(\text{cr}) \rightleftharpoons 2 \text{K}^+ + \text{SeO}_4^{2-}$	0.904 ± 0.065	9	
$\text{Cs}_2\text{SeO}_4(\text{cr}) \rightleftharpoons 2 \text{Cs}^+ + \text{SeO}_4^{2-}$	0.636 ± 0.065	9	
$\text{FeSe}_2(\text{cr}) + 2 \text{H}^+ + 2 \text{e}^- \rightleftharpoons \text{Fe}^{2+} + 2 \text{HSe}^-$	-17.220 ± 2.754	76	*
$\beta\text{-Fe}_{1.04}\text{Se} + \text{H}^+ \rightleftharpoons \#0.04 \text{Fe}^{2+} + \text{HSe}^- + 0.08 \text{e}^-$	-3.503 ± 0.870	76	*
$\gamma\text{-Fe}_3\text{Se}_4 + 4 \text{H}^+ + 2 \text{e}^- \rightleftharpoons \# \text{Fe}^{2+} + 4 \text{HSe}^-$	-25.908 ± 5.547	76	*
$\alpha\text{-Fe}_7\text{Se}_8 + 8 \text{H}^+ + 2 \text{e}^- \rightleftharpoons \# \text{Fe}^{2+} + 8 \text{HSe}^-$	-36.274 ± 5.175	76	*
$\text{HgSeO}_3(\text{cr}) \rightleftharpoons \text{Hg}^{2+} + \text{SeO}_3^{2-}$	-16.200 ± 1.000	9	
$\text{Hg}_2\text{SeO}_3(\text{cr}) \rightleftharpoons \text{Hg}^{2+} + \text{SeO}_3^{2-}$	-15.200 ± 1.000	9	
$\text{Br(g)} + \text{e}^- \rightleftharpoons \text{Br}^-$	32.626 ± 0.037	12	
$\text{Br}_2(\text{g}) + 2 \text{e}^- \rightleftharpoons 2 \text{Br}^-$	36.931 ± 0.048	12	
$\text{HBr(g)} \rightleftharpoons \text{Br}^- + \text{H}^+$	8.845 ± 0.041	12	
$\text{Sr(cr)} \rightleftharpoons \text{Sr}^{2+} + 2 \text{e}^-$	98.784 ± 0.137	12	
$\text{SrO(cr)} + 2 \text{H}^+ \rightleftharpoons \text{Sr}^{2+} + \text{H}_2\text{O(l)}$	42.233 ± 0.211	12	
$\text{SrCO}_3(\text{strontianite}) \rightleftharpoons \text{Sr}^{2+} + \text{CO}_3^{2-}$	-9.250 ± 0.010	49	
$\text{SrSO}_4(\text{celestite}) \rightleftharpoons \text{Sr}^{2+} + \text{SO}_4^{2-}$	-6.620 ± 0.020	49	
$\text{Sr}_3(\text{PO}_4)_2(\text{s}) \rightleftharpoons 3 \text{Sr}^{2+} + 2 \text{PO}_4^{3-}$	-27.800	2	
$\text{SrHPO}_4(\text{s}) \rightleftharpoons \text{Sr}^{2+} + \text{P O}_4^{3-} + \text{H}^+$	-19.310	2	
$\text{Sr(OH)}_2(\text{s}) \rightleftharpoons \text{Sr}^{2+} + 2 \text{H}_2\text{O(l)} - 2 \text{H}^+$	24.980	2	
$\text{Sr(NO}_3)_2(\text{cr}) \rightleftharpoons \text{Sr}^{2+} + 2 \text{NO}_3^-$	0.404 ± 0.268	12	
$\text{ZrO}_2(\text{mono}) + 4 \text{H}^+ \rightleftharpoons \# \text{Zr}^{4+} + 2 \text{H}_2\text{O(l)}$	-7.000 ± 1.600	10	
$\text{Zr(OH)}_4(\text{am,fresh}) + 4 \text{H}^+ \rightleftharpoons \# \text{Zr}^{4+} + 4 \text{H}_2\text{O(l)}$	-3.240 ± 0.100	10	

Reaction	$\log_{10} K^\circ$	ref.	t.v. ^{*1}
$\beta\text{-ZrF}_4 \rightleftharpoons \text{Zr}^{4+} + 4 \text{F}^-$	-31.830 ± 0.408	10	
$\text{Zr}(\text{SO}_4)_2 \cdot 9\text{H}_2\text{O}(\text{cr}) \rightleftharpoons \text{Zr}^{4+} + 9 \text{H}_2\text{O}(\text{l}) \rightleftharpoons 2 \text{SO}_4^{2-}$	-11.250 ± 0.096	10	
$\text{ZrSiO}_4(\text{cr}) + 4 \text{H}^+ \rightleftharpoons \text{Zr}^{4+} + \text{H}_4\text{SiO}_4(\text{aq})$	-14.623 ± 1.718	10	
$\text{Nb}_2\text{O}_5(\text{s}) + 7 \text{H}_2\text{O} \rightleftharpoons 2 \text{Nb}(\text{OH})_6^- + 2 \text{H}^+$	-28.913 ± 0.507	present	
$\text{Mo}(\text{metal}) + 4 \text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{MoO}_4^{2-} + 8 \text{H}^+ + 6 \text{e}^-$	-19.280	96	
$\text{MoO}_2(\text{cr}) + 2 \text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{MoO}_4^{2-} + 4 \text{H}^+ + 2 \text{e}^-$	-29.570	96	
$\text{PbMoO}_4(\text{cr}) \rightleftharpoons \text{MoO}_4^{2-} + \text{Pb}^{2+}$	-12.980 ± 0.050	98	
$\text{CaMoO}_4(\text{cr}) \rightleftharpoons \text{MoO}_4^{2-} + \text{Ca}^{2+}$	-7.950 ± 0.050	96	
$\text{Sm}_2(\text{MoO}_4)_3 \cdot x\text{H}_2\text{O}(\text{cr}) \rightleftharpoons 3 \text{MoO}_4^{2-} + 2 \text{Sm}^{3+}$	-26.100 ± 0.300	97	
$\text{NH}_4\text{TcO}_4(\text{cr}) \rightleftharpoons \text{TcO}_4^- + \text{NH}_4^+$	-0.910 ± 0.070	11	
$\text{TlTcO}_4(\text{cr}) \rightleftharpoons \text{TcO}_4^- + \text{Tl}^+$	-5.320 ± 0.120	11	
$\text{AgTcO}_4(\text{cr}) \rightleftharpoons \text{TcO}_4^- + \text{Ag}^+$	-3.270 ± 0.130	11	
$\text{NaTcO}_4 \cdot 4\text{H}_2\text{O}(\text{s}) \rightleftharpoons \text{TcO}_4^- + 4 \text{H}_2\text{O}(\text{l}) + \text{Na}^+$	0.790 ± 0.040	11	
$\text{KTcO}_4(\text{cr}) \rightleftharpoons \text{TcO}_4^- + \text{K}^+$	-2.288 ± 0.026	11	
$\text{TcO}_2 \cdot 1.6\text{H}_2\text{O}(\text{s}) + 2 \text{H}^+ \rightleftharpoons \text{TcO}^{2+} + 2.6 \text{H}_2\text{O}(\text{l})$	< -4.415	present	
$\text{TcO}_2 \cdot 1.6\text{H}_2\text{O}(\text{s}) + 0.4 \text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{TcO}_4^- + 4 \text{H}^+ + 3 \text{e}^-$	-37.829 ± 0.609	11	
$\text{Pd}(\text{cr}) \rightleftharpoons \text{Pd}^{2+} + 2 \text{e}^-$	-32.900	6	
$\text{Pd}(\text{OH})_2(\text{s}) + 2 \text{H}^+ \rightleftharpoons \text{Pd}^{2+} + 2 \text{H}_2\text{O}(\text{l})$	-4.040 ± 0.290	69	
$\text{Sn}(\text{cr}) + 4 \text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{Sn}(\text{OH})_4(\text{aq}) + 4 \text{H}^+ + 4 \text{e}^-$	-0.770	6	
$\text{Sn}(\text{OH})_2(\text{s}) + 2 \text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{Sn}(\text{OH})_4(\text{aq}) + 2 \text{H}^+ + 2 \text{e}^-$	-2.580	6	
$\text{SnO}(\text{cr}) + 3 \text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{Sn}(\text{OH})_4(\text{aq}) + 2 \text{H}^+ + 2 \text{e}^-$	-2.990	6	
$\text{SnClOH}(\text{s}) + 3 \text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{Sn}(\text{OH})_4(\text{aq}) + 3 \text{H}^+ + \text{Cl}^- + 2 \text{e}^-$	-7.820	6	
$\text{SnO}_2(\text{am}) + 2 \text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{Sn}(\text{OH})_4(\text{aq})$	-7.460	6	
$\text{SnO}_2(\text{cassiterite}) + 2 \text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{Sn}(\text{OH})_4(\text{aq})$	-8.000	6	
$\text{I(g)} + \text{e}^- \rightleftharpoons \text{I}^-$	21.355 ± 0.022	12	
$\text{I}_2(\text{cr}) + 2 \text{e}^- \rightleftharpoons 2 \text{I}^-$	18.123 ± 0.028	12	
$\text{I}_2(\text{g}) + 2 \text{e}^- \rightleftharpoons 2 \text{I}^-$	21.508 ± 0.035	12	
$\text{HI(g)} \rightleftharpoons \text{I}^- + \text{H}^+$	9.359 ± 0.028	12	
$\text{Sb}(\text{cr}) + 3 \text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{Sb}(\text{OH})_3(\text{aq}) + 3 \text{H}^+ + 3 \text{e}^-$	-11.990	6	
$\text{Sb}_2\text{O}_3(\text{valentinite}) + 3 \text{H}_2\text{O}(\text{l}) \rightleftharpoons 2 \text{Sb}(\text{OH})_3(\text{aq})$	-8.720	6	
$\text{Sb}_2\text{S}_3(\text{stibnite}) + 18 \text{H}_2\text{O}(\text{l}) \rightleftharpoons 2 \text{Sb}(\text{OH})_3(\text{aq}) + 3 \text{SO}_4^{2-} + 30 \text{H}^+ + 24 \text{e}^-$	-156.219	6	
$\text{Sb}_2\text{O}_5(\text{am}) + 5 \text{H}_2\text{O}(\text{l}) \rightleftharpoons 2 \text{Sb}(\text{OH})_5(\text{aq})$	-7.400	6	
$\text{Cs}(\text{cr}) \rightleftharpoons \text{Cs}^+ + \text{e}^-$	51.061 ± 0.094	12	
$\text{Cs}(\text{g}) \rightleftharpoons \text{Cs}^+ + \text{e}^-$	59.742 ± 0.200	12	
$\text{CsNO}_3(\text{s}) \rightleftharpoons \text{Cs}^+ + \text{NO}_3^-$	-0.410	2	
$\text{Cs}_2\text{O}(\text{s}) + 2 \text{H}^+ \rightleftharpoons 2 \text{Cs}^+ + \text{H}_2\text{O}(\text{l})$	89.890	2	
$\text{CsOH}(\text{s}) + \text{H}^+ \rightleftharpoons \text{Cs}^+ + \text{H}_2\text{O}(\text{l})$	27.420	2	
$\text{Cs}_2\text{SO}_4(\text{s}) \rightleftharpoons 2 \text{Cs}^+ + \text{SO}_4^{2-}$	0.870	2	
$\text{Cs}_2\text{CO}_3(\text{s}) \rightleftharpoons 2 \text{Cs}^+ + \text{CO}_3^{2-}$	10.070	2	
$\text{Ba}(\text{cr}) \rightleftharpoons \text{Ba}^{2+} + 2 \text{e}^-$	97.697 ± 0.452	12	
$\text{BaO}(\text{cr}) + 2 \text{H}^+ \rightleftharpoons \text{Ba}^{2+} + \text{H}_2\text{O}(\text{l})$	48.073 ± 0.632	12	
$\text{BaCO}_3(\text{witherite}) \rightleftharpoons \text{Ba}^{2+} + \text{CO}_3^{2-}$	-8.540 ± 0.030	49	
$\text{BaSO}_4(\text{barite}) \rightleftharpoons \text{Ba}^{2+} + \text{SO}_4^{2-}$	-10.050 ± 0.050	49	
$\text{Sm(OH)}_3(\text{am}) + 3 \text{H}^+ \rightleftharpoons \text{Sm}^{3+} + 3 \text{H}_2\text{O}(\text{l})$	16.900 ± 0.800	26	
$\text{Sm(OH)}_3(\text{cr}) + 3 \text{H}^+ \rightleftharpoons \text{Sm}^{3+} + 3 \text{H}_2\text{O}(\text{l})$	15.600 ± 0.600	26	
$\text{Sm}_2(\text{CO}_3)_3(\text{am}) \rightleftharpoons 2 \text{Sm}^{3+} + 3 \text{CO}_3^{2-}$	-16.700 ± 1.100	26	
$\text{SmCO}_3\text{OH}(\text{am}) + \text{H}^+ \rightleftharpoons \text{Sm}^{3+} + \text{CO}_3^{2-} + \text{H}_2\text{O}(\text{l})$	-6.199 ± 1.000	26	
$\text{SmCO}_3\text{OH} \cdot 0.5\text{H}_2\text{O}(\text{cr}) + \text{H}^+ \rightleftharpoons \text{Sm}^{3+} + \text{CO}_3^{2-} + 1.5 \text{H}_2\text{O}(\text{l})$	-8.399 ± 0.500	26	
$\text{NaSm}(\text{CO}_3)_2 \cdot 5\text{H}_2\text{O}(\text{cr}) \rightleftharpoons \text{Sm}^{3+} + 2 \text{CO}_3^{2-} + 5 \text{H}_2\text{O}(\text{l}) + \text{Na}^+$	-21.000 ± 0.500	26	
$\text{SmPO}_4(\text{am,hydr}) \rightleftharpoons \text{Sm}^{3+} + \text{PO}_4^{3-}$	-24.790 ± 0.600	26	

Reaction	$\log_{10} K^\circ$	ref.	t.v. ^{*1}
Pb(cr) \diamond Pb ²⁺ + 2 e ⁻	4.250	6	
PbO(red,litharge) + 2 H ⁺ \diamond Pb ²⁺ + H ₂ O(l)	12.680	6	
PbO(yellow,massicot) + 2 H ⁺ \diamond Pb ²⁺ + H ₂ O(l)	12.960	6	
Pb(OH) ₂ (am) + 2 H ⁺ \diamond Pb ²⁺ + 2 H ₂ O(l)	13.050	6	
PbSO ₄ (anglesite) \diamond Pb ²⁺ + SO ₄ ²⁻	-7.810	6	
PbCl ₂ (s) \diamond Pb ²⁺ + 2 Cl ⁻	-4.810	6	
PbClOH(cr) + H ⁺ \diamond Pb ²⁺ + Cl ⁻ + H ₂ O(l)	0.620	6	
PbF ₂ (s) \diamond Pb ²⁺ + 2 F ⁻	-7.520	6	
PbFCI(matlockite) \diamond Pb ²⁺ + F ⁻ + Cl ⁻	-8.820	6	
PbCO ₃ (cerrusite) \diamond Pb ²⁺ + CO ₃ ²⁻	-13.230	6	
Pb ₃ (CO ₃) ₂ (OH) ₂ (hydrocerrusite) + 2 H ⁺ \diamond 3 Pb ²⁺ + 2 CO ₃ ²⁻ + 2 H ₂ O(l)	-17.640	6	
Pb ₁₀ (CO ₃) ₆ (OH) ₆ (plumbonacrite) + 8 H ⁺ \diamond 10 Pb ²⁺ + 6 CO ₃ ²⁻ + 7 H ₂ O(l)	-41.210	6	
PbOHNO ₃ (cr) + H ⁺ \diamond Pb ²⁺ + NO ₃ ⁻ + H ₂ O(l)	2.940	6	
PbHPO ₄ (s) \diamond Pb ²⁺ + PO ₄ ³⁻ + H ⁺	-23.780	6	
Pb(H ₂ PO ₄) ₂ (s) \diamond Pb ²⁺ + 2 PO ₄ ³⁻ + 4 H ⁺	-48.940	6	
Pb ₃ (PO ₄) ₄ (s) \diamond 3 Pb ²⁺ + 2 PO ₄ ³⁻	-44.400	6	
Pb ₄ (PO ₄) ₂ O(s) + 2 H ⁺ \diamond 4 Pb ²⁺ + 2 PO ₄ ³⁻ + H ₂ O(l)	-37.090	6	
Pb ₅ (PO ₄) ₃ OH(hydroxyl pyromorphite) + H ⁺ \diamond 5 Pb ²⁺ + 3 PO ₄ ³⁻ + H ₂ O(l)	-62.800	6	
Pb ₅ (PO ₄) ₃ Cl(chloro pyromorphite) \diamond 5 Pb ²⁺ + 3 PO ₄ ³⁻ + Cl ⁻	-84.400	6	
Pb ₅ (PO ₄) ₃ F(fluoro pyromorphite) \diamond 5 Pb ²⁺ + 3 PO ₄ ³⁻ + F ⁻	-71.600	6	
PbS(galena) + 4 H ₂ O(l) \diamond Pb ²⁺ + SO ₄ ²⁻ + 8 H ⁺ + 8 e ⁻	-45.863	6	
PbO ₂ (s) + 4 H ⁺ + 2 e ⁻ \diamond Pb ²⁺ + 2 H ₂ O(l)	48.980	6	
Pb ₃ O ₄ (s) + 8 H ⁺ + 2 e ⁻ \diamond 3 Pb ²⁺ + 4 H ₂ O(l)	70.980	6	
Bi(OH) ₃ (am) + 3 H ⁺ \diamond Bi ³⁺ + 3 H ₂ O(l)	31.501 ± 0.927	81	
0.5 α-Bi ₂ O ₃ (c) + 3 H ⁺ \diamond Bi ³⁺ + 1.5 H ₂ O(l)	31.501 ± 0.927	81	
BiPO ₄ (c) \diamond Bi ³⁺ + PO ₄ ³⁻	-30.350 ± 0.540	81	
Bi(cr) \diamond Bi ³⁺ + 3 e ⁻	-16.740	6	
BiOCl(s) + 2 H ⁺ \diamond Bi ³⁺ + H ₂ O + Cl ⁻	-8.470	6	
(BiO) ₂ CO ₃ (cr) + 4 H ⁺ \diamond 2 Bi ³⁺ + 2 H ₂ O + CO ₃ ²⁻	-14.270	6	
(BiO) ₄ (OH) ₂ CO ₃ (cr) + 10 H ⁺ \diamond 4 Bi ³⁺ + 6 H ₂ O + CO ₃ ²⁻	-8.680	6	
BiONO ₃ (s) + 2 H ⁺ \diamond Bi ³⁺ + H ₂ O + NO ₃ ⁻	-2.750	6	
Po(OH) ₄ (s) + 4 H ⁺ \diamond Po ⁴⁺ + 4 H ₂ O(l)	19.520	2	
RaSO ₄ (cr) \diamond Ra ²⁺ + SO ₄ ²⁻	-10.050 ± 0.390	49	
RaCO ₃ (cr) \diamond Ra ²⁺ + CO ₃ ²⁻	-8.540 ± 0.200	49	
Ac(OH) ₃ (am) + 3 H ⁺ \diamond Ac ³⁺ + 3 H ₂ O(l)	16.900 ± 4.800	26	*
Ac ₂ (CO ₃) ₃ (am) \diamond 2 Ac ³⁺ + 3 CO ₃ ²⁻	-16.700 ± 5.100	26	*
AcCO ₃ OH(am) + H ⁺ \diamond #Ac ³⁺ + CO ₃ ²⁻ + H ₂ O(l)	-6.199 ± 5.000	26	*
AcPO ₄ (am,hydr) \diamond Ac ³⁺ + PO ₄ ³⁻	-24.790 ± 4.600	26	*
ThO ₂ (am,fresh) + 4 H ⁺ \diamond Th ⁴⁺ + 2 H ₂ O(l)	9.304 ± 0.900	12	
ThO ₂ (am,aged) + 4 H ⁺ \diamond Th ⁴⁺ + 2 H ₂ O(l)	8.504 ± 0.900	12	
ThO ₂ (cr) + 4 H ⁺ \diamond Th ⁴⁺ + 2 H ₂ O(l)	1.765 ± 1.113	12	
ThF ₄ (cr, hyd) + 4 H ⁺ \diamond #Th ⁴⁺ + 4 HF(aq)	-19.110 ± 0.400	12	
Th(SO ₄) ₂ •9H ₂ O(cr) \diamond #Th ⁴⁺ + 9 H ₂ O(l) #2#2 SO ₄ ²⁻	-11.250 ± 0.096	12	
Na ₆ Th(CO ₃) ₅ •12H ₂ O(cr) \diamond #Th ⁴⁺ + 5 CO ₃ ²⁻ + 12 H ₂ O(l) #2#6 Na ⁺	-42.200 ± 0.800	12	
PaO ₂ (cr) + 4 H ⁺ \diamond Pa ⁴⁺ + 2 H ₂ O(l)	0.600	92	
PaCl ₄ (s) \diamond Pa ⁴⁺ + 4 Cl ⁻	24.010	31	
Pa ₂ O ₅ (cr) + 2 e ⁻ + 10 H ⁺ \diamond 2 Pa ⁴⁺ + 5 H ₂ O(l)	-8.720	31	
PaCl ₅ (cr) - e ⁻ \diamond Pa ⁴⁺ + 5 Cl ⁻	32.850	31	
UO ₂ (am) + 4 H ⁺ \diamond U ⁴⁺ + 2 H ₂ O(l)	2.304 ± 1.000	30	
UO ₂ (cr) + 4 H ⁺ \diamond U ⁴⁺ + 2 H ₂ O(l)	-4.852 ± 0.365	11	

Reaction	$\log_{10} K^\circ$	ref.	t.v. ^{*1}
$\alpha\text{-UO}_3 + 2 \text{H}^+ \rightleftharpoons \text{UO}_2^{2+} + \text{H}_2\text{O(l)}$	9.524 ± 0.401	11	
$\beta\text{-UO}_3 + 2 \text{H}^+ \rightleftharpoons \text{UO}_2^{2+} + \text{H}_2\text{O(l)}$	8.302 ± 0.382	11	
$\gamma\text{-UO}_3 + 2 \text{H}^+ \rightleftharpoons \text{UO}_2^{2+} + \text{H}_2\text{O(l)}$	7.700 ± 0.372	11	
$\alpha\text{-UO}_3\cdot0.9\text{H}_2\text{O(cr)} + 2 \text{H}^+ \rightleftharpoons \text{UO}_2^{2+} + 1.9 \text{H}_2\text{O(l)}$	5.003 ± 0.529	11	
$\text{UO}_3\cdot2\text{H}_2\text{O(cr)} + 2 \text{H}^+ \rightleftharpoons \text{UO}_2^{2+} + 3 \text{H}_2\text{O(l)}$	4.812 ± 0.428	11	
$\beta\text{-UO}_2(\text{OH})_2 + 4 \text{H}^+ \rightleftharpoons \text{UO}_2^{2+} + 2 \text{H}_2\text{O(l)}$	4.931 ± 0.435	11	
$\text{U(OH)}_2\text{SO}_4(\text{cr}) + 2 \text{H}^+ \rightleftharpoons \text{U}^{4+} + 2 \text{H}_2\text{O(l)} + \text{SO}_4^{2-}$	-3.168 ± 0.500	11	
$\text{U(HPO}_4)_2\bullet4\text{H}_2\text{O(cr)} \rightleftharpoons \text{U}^{4+} + 2 \text{PO}_4^{3-} + 2 \text{H}^+ + 4 \text{H}_2\text{O(l)}$	-55.194 ± 0.383	11	
$\text{UF}_6(\text{cr}) + 2 \text{H}_2\text{O(l)} \rightleftharpoons \#\text{UO}_2^{2+} + 6 \text{F}^- + 4 \text{H}^+$	17.204 ± 0.853	11	
$\text{UO}_2(\text{IO}_3)_2(\text{cr}) + 12 \text{H}^+ + 12 \text{e}^- \rightleftharpoons \#\text{UO}_2^{2+} + 2 \text{I}^- + 6 \text{H}_2\text{O(l)}$	215.246 ± 0.294	11	
$\text{UO}_2\text{SO}_4(\text{cr}) \rightleftharpoons \text{UO}_2^{2+} + \text{SO}_4^{2-}$	1.889 ± 0.560	11	
$\text{UO}_2\text{SO}_4\bullet2.5\text{H}_2\text{O(cr)} \rightleftharpoons \text{UO}_2^{2+} + \text{SO}_4^{2-} + 2.5 \text{H}_2\text{O(l)}$	-1.589 ± 0.019	11	
$\text{UO}_2\text{SO}_4\bullet3.5\text{H}_2\text{O(cr)} \rightleftharpoons \text{UO}_2^{2+} + \text{SO}_4^{2-} + 3.5 \text{H}_2\text{O(l)}$	-1.585 ± 0.019	11	
$\text{UO}_2\text{HPO}_4\bullet4\text{H}_2\text{O(cr)} + 2 \text{H}^+ \rightleftharpoons \text{UO}_2^{2+} + \text{PO}_4^{3-} + \text{H}^+ + 4 \text{H}_2\text{O(l)}$	-24.202 ± 0.198	11	
$(\text{UO}_2)_3(\text{PO}_4)_2\bullet4\text{H}_2\text{O(cr)} \rightleftharpoons 3 \text{UO}_2^{2+} + 2 \text{PO}_4^{3-} + 4 \text{H}_2\text{O(l)}$	-48.364 ± 0.462	11	
$\text{UO}_2\text{CO}_3(\text{cr}) \rightleftharpoons \#\text{UO}_2^{2+} + \text{CO}_3^{2-}$	-14.760 ± 0.020	11	
$\text{CaU}_6\text{O}_{19}\cdot11\text{H}_2\text{O(cr)} + 14 \text{H}^+ \rightleftharpoons \#\text{UO}_2^{2+} + \text{Ca}^{2+} + 18 \text{H}_2\text{O(l)}$	-40.500 ± 1.600	11	
$\text{Na}_4\text{UO}_2(\text{CO}_3)_3(\text{cr}) \rightleftharpoons \#\text{UO}_2^{2+} + 3 \text{CO}_3^{2-} + 4 \text{Na}^+$	-27.180 ± 0.165	11	
$\text{K}_2\text{U}_6\text{O}_{19}\cdot11\text{H}_2\text{O(cr)} + 14 \text{H}^+ \rightleftharpoons \#\text{UO}_2^{2+} + 2 \text{K}^+ + 18 \text{H}_2\text{O(l)}$	-37.100 ± 0.540	11	
$\text{NpO}_2(\text{am}) + 4 \text{H}^+ \rightleftharpoons \text{Np}^{4+} + 2 \text{H}_2\text{O(l)}$	0.604 ± 1.000	30	
$\text{NpO}_2\text{OH(am, aged)} + \text{H}^+ \rightleftharpoons \#\text{NpO}_2^{+} + \text{H}_2\text{O(l)}$	-4.700 ± 0.500	11	
$\text{NpO}_2\text{OH(am, fresh)} + \text{H}^+ \rightleftharpoons \#\text{NpO}_2^{+} + \text{H}_2\text{O(l)}$	-5.300 ± 0.200	11	
$\text{Na}_3\text{NpO}_2(\text{CO}_3)_2(\text{cr}) \rightleftharpoons \#\text{NpO}_2^{+} + 2 \text{CO}_3^{2-} + 3 \text{Na}^+$	-14.220 ± 0.500	11	
$\text{NaNpO}_2\text{CO}_3\bullet3.5\text{H}_2\text{O(cr)} \rightleftharpoons \#\text{NpO}_2^{+} + \text{CO}_3^{2-} + 3.5 \text{H}_2\text{O} + \text{Na}^+$	-11.000 ± 0.240	11	
$\text{KNpO}_2\text{CO}_3(\text{s}) \rightleftharpoons \#\text{NpO}_2^{+} + \text{CO}_3^{2-} + \text{K}^+$	-13.150 ± 0.190	11	
$\text{K}_3\text{NpO}_2(\text{CO}_3)_2(\text{s}) \rightleftharpoons \#\text{NpO}_2^{+} + 2 \text{CO}_3^{2-} + 3 \text{K}^+$	-15.460 ± 0.160	11	
$\text{NpO}_3\bullet\text{H}_2\text{O(cr)} + 2 \text{H}^+ \rightleftharpoons \#\text{NpO}_2^{2+} + 2 \text{H}_2\text{O(l)}$	5.470 ± 0.400	11	
$\text{NpO}_2\text{CO}_3(\text{s}) \rightleftharpoons \#\text{NpO}_2^{2+} + \text{CO}_3^{2-}$	-14.596 ± 0.469	11	
$(\text{NH}_4)_4\text{NpO}_2(\text{CO}_3)_3(\text{s}) + \text{e}^- \rightleftharpoons \#\text{NpO}_2^{+} + 3 \text{CO}_3^{2-} + 4 \text{NH}_4^+$	-7.223 ± 0.346	11	
$\text{K}_4\text{NpO}_2(\text{CO}_3)_3(\text{s}) + \text{e}^- \rightleftharpoons \#\text{NpO}_2^{+} + 3 \text{CO}_3^{2-} + 4 \text{K}^+$	-6.813 ± 0.894	11	
$\text{Pu(OH)}_3(\text{am}) + 3 \text{H}^+ \rightleftharpoons \#\text{Pu}^{3+} + 3 \text{H}_2\text{O(l)}$	16.900 ± 0.800	26	
$\text{PuCO}_3\text{OH(am)} + \text{H}^+ \rightleftharpoons \#\text{Pu}^{3+} + \text{CO}_3^{2-} + \text{H}_2\text{O(l)}$	-6.199 ± 1.000	26	
$\text{PuCO}_3\text{OH}\bullet0.5\text{H}_2\text{O(cr)} + \text{H}^+ \rightleftharpoons \#\text{Pu}^{3+} + \text{CO}_3^{2-} + 1.5 \text{H}_2\text{O(l)}$	-8.399 ± 0.500	26	
$\text{Pu(OH)}_3(\text{cr}) + 3 \text{H}^+ \rightleftharpoons \#\text{Pu}^{3+} + 3 \text{H}_2\text{O(l)}$	15.600 ± 0.600	26	
$\text{Pu}_2(\text{CO}_3)_3(\text{am}) \rightleftharpoons \#\text{Pu}^{3+} + 3 \text{CO}_3^{2-}$	-16.700 ± 1.100	26	
$\text{PuPO}_4(\text{am,hydr}) \rightleftharpoons \#\text{Pu}^{3+} + \text{PO}_4^{3-}$	-24.790 ± 0.600	26	
$\text{PuO}_2(\text{am})\#2 4 \text{H}^+ \rightleftharpoons \text{Pu}^{4+} + 2 \text{H}_2\text{O(l)}$	-2.326 ± 0.520	11	
$\text{PuO}_2\text{OH(am)} + \text{H}^+ \rightleftharpoons \text{PuO}_2^{+} + \text{H}_2\text{O(l)}$	5.000 ± 0.500	11	
$\text{PuO}_2(\text{OH})_2\cdot\text{H}_2\text{O(cr)} + 2 \text{H}^+ \rightleftharpoons \#\text{PuO}_2^{2+} + 3 \text{H}_2\text{O(l)}$	5.500 ± 1.000	11	
$\text{Pu(HPO}_4)_2(\text{am}) \rightleftharpoons \#\text{Pu}^{4+} + 2 \text{H}^+ + 2 \text{PO}_4^{3-}$	5.750 ± 0.514	11	
$\text{PuO}_2\text{CO}_3(\text{s}) \rightleftharpoons \#\text{PuO}_2^{2+} + \text{CO}_3^{2-}$	-14.650 ± 0.470	11	
$\text{Am(OH)}_3(\text{am}) + 3 \text{H}^+ \rightleftharpoons \#\text{Am}^{3+} + 3 \text{H}_2\text{O(l)}$	16.900 ± 0.800	11	
$\text{Am(OH)}_3(\text{cr}) + 3 \text{H}^+ \rightleftharpoons \#\text{Am}^{3+} + 3 \text{H}_2\text{O(l)}$	15.600 ± 0.600	11	
$\text{Am}_2(\text{CO}_3)_3(\text{am}) \rightleftharpoons \#\text{Am}^{3+} + 3 \text{CO}_3^{2-}$	-16.700 ± 1.100	11	
$\text{AmCO}_3\text{OH(am)} + \text{H}^+ \rightleftharpoons \#\text{Am}^{3+} + \text{CO}_3^{2-} + \text{H}_2\text{O(l)}$	-6.199 ± 1.000	11	
$\text{AmCO}_3\text{OH}\bullet0.5\text{H}_2\text{O(cr)} + \text{H}^+ \rightleftharpoons \#\text{Am}^{3+} + \text{CO}_3^{2-} + 1.5 \text{H}_2\text{O(l)}$	-8.399 ± 0.500	11	
$\text{NaAm}(\text{CO}_3)_2\bullet5\text{H}_2\text{O(cr)} \rightleftharpoons \#\text{Am}^{3+} + 2 \text{CO}_3^{2-} + 5 \text{H}_2\text{O(l)} + \text{Na}^+$	-21.000 ± 0.500	11	
$\text{AmPO}_4(\text{am,hydr}) \rightleftharpoons \#\text{Am}^{3+} + \text{PO}_4^{3-}$	-24.790 ± 0.600	11	
$\text{Cm(OH)}_3(\text{am}) + 3 \text{H}^+ \rightleftharpoons \#\text{Cm}^{3+} + 3 \text{H}_2\text{O(l)}$	16.900 ± 0.800	26	
$\text{Cm(OH)}_3(\text{cr}) + 3 \text{H}^+ \rightleftharpoons \#\text{Cm}^{3+} + 3 \text{H}_2\text{O(l)}$	15.600 ± 0.600	26	

Reaction	$\log_{10} K^\circ$	ref.	t.v. ^{*1}
Cm ₂ (CO ₃) ₃ (am) ⇌ #Cm ³⁺ + 3 CO ₃ ²⁻	-16.700 ± 1.100	26	
CmCO ₃ OH(am) + H ⁺ ⇌ #Cm ³⁺ + CO ₃ ²⁻ + H ₂ O(l)	-6.199 ± 1.000	26	
CmCO ₃ OH•0.5H ₂ O(cr) + H ⁺ ⇌ #Cm ³⁺ + CO ₃ ²⁻ + 1.5 H ₂ O(l)	-8.399 ± 0.500	26	
NaCm(CO ₃) ₂ •5H ₂ O(cr) ⇌ #Cm ³⁺ + 2 CO ₃ ²⁻ + 5 H ₂ O(l) + Na ⁺	-21.000 ± 0.500	26	
CmPO ₄ (am,hydr) ⇌ #Cm ³⁺ + PO ₄ ³⁻	-24.790 ± 0.600	26	
UO ₂ ox•3H ₂ O(cr) ⇌ #UO ₂ ²⁺ + ox ²⁻ + 3 H ₂ O(l)##	-8.930 ± 0.314	22	
Ca(ox)•H ₂ O(cr) ⇌ #Ca ²⁺ + H ₂ O(l) + ox ²⁻	-8.730 ± 0.060	22	
Ca(ox)•2H ₂ O(cr) ⇌ #Ca ²⁺ + 2 H ₂ O(l) + ox ²⁻	-8.300 ± 0.060	22	
Ca(ox)•3H ₂ O(cr) ⇌ #Ca ²⁺ + 3 H ₂ O(l) + ox ²⁻	-8.190 ± 0.040	22	
H ₃ cit(cr) ⇌ #cit ³⁻ + 3 H ⁺	-13.041 ± 0.500	22	
H ₃ cit•H ₂ O(cr) ⇌ #cit ³⁻ + 3 H ⁺ + H ₂ O(l)	-12.950 ± 0.024	22	
Ca ₃ (cit) ₂ •4H ₂ O(cr) ⇌ #B Ca ²⁺ 4 H ₂ O(l) + 2 cit ³⁻	-17.900 ± 0.100	22	
H ₄ edta(cr) ⇌ #edta ⁴⁻ + 4 H ⁺	-27.220 ± 0.201	22	
Ca(isa) ₂ (cr) ⇌ #Ca ²⁺ + 2 isa ⁻	-6.400 ± 0.200	22	

^{*1} Tentative values.

Appendix 2. Additionally determined or used ion interact coefficients for JAEA-TDB

Many ion interaction coefficients of ion j against counter-electrolyte ion k ($\varepsilon(j,k)$) have been published in the NEA-TDB¹²⁾. We basically took these ion interaction coefficients. Additionally determined, modified or used some ion interaction coefficients for JAEA-TDB have been collected in the following table.

Table 20 Additionally determined, modified or used ion interact coefficients for JAEA-TDB

j	k	$\varepsilon(j,k)$	comment
$\text{Ca}_4[\text{Th}(\text{OH})_8]^{4+}$	ClO_4^-	0.21 ± 0.17	obtained in ref. 28
$\text{Ca}_4[\text{Th}(\text{OH})_8]^{4+}$	Cl^-	-0.01 ± 0.10	obtained in ref. 28
PaOOH^{2+}	ClO_4^-	-0.03 ± 0.02	obtained in refs. 32
$\text{PaO}(\text{OH})_2^+$	ClO_4^-	-0.23 ± 0.10	obtained in refs. 32
PaOOHCl^+	ClO_4^-	0.19 ± 0.64	average value among that for hydroxide and chloride complexes of metal ions with positive net charge of 1 listed in the NEA-TDB ¹²⁾ , i.e. CdCl^+ , HgCl^+ , NiCl^+ , PuO_2Cl^+ , NpO_2Cl^+ , UO_2Cl^+ , NiOH^+ , $\text{Am}(\text{OH})_2^+$, NpO_2OH^+ , UO_2OH^+ , $\text{Th}(\text{OH})_3^+$
PaOSO_4^+	ClO_4^-	0.80 ± 0.20	obtained in ref. 35
$\text{PaO}(\text{SO}_4)_2^-$	Na^+	0.40 ± 0.10	obtained in ref. 35
$\text{PaO}(\text{SO}_4)_3^{3-}$	Na^+	0.20 ± 0.10	obtained in ref. 35
U^{4+}	ClO_4^-	0.29 ± 0.17	obtained in ref. 37
UOH^{3+}	ClO_4^-	0.54 ± 0.34	obtained in ref. 37
$\text{U}(\text{OH})_2^{2+}$	ClO_4^-	0.52 ± 0.31	obtained in ref. 37
$\text{U}(\text{OH})_3^+$	ClO_4^-	0.23 ± 0.39	obtained in ref. 37
NpOH^{3+}	ClO_4^-	0.49 ± 0.15	obtained in ref. 41
$\text{Np}(\text{OH})_2^{2+}$	ClO_4^-	0.35 ± 0.11	obtained in ref. 41
$\text{Np}(\text{OH})_3^+$	ClO_4^-	0.29 ± 0.15	obtained in ref. 41
Pu^{4+}	Cl^-	0.40 ± 0.10	obtained in ref. 46
PuOH_3^+	Cl^-	0.20 ± 0.10	obtained in ref. 46

<i>j</i>	<i>k</i>	$\varepsilon(j,k)$	comment
$\text{Pu}(\text{OH})_2^{2+}$	Cl^-	0.10 ± 0.10	obtained in ref. 46
$\text{Pu}(\text{OH})_3^+$	Cl^-	0.05 ± 0.10	obtained in ref. 46
Co^{2+}	F^-	0.31 ± 0.04	obtained in ref. 51
$\text{Co}(\text{OH})^+$	ClO_4^-	0.14 ± 0.07	taken from $\varepsilon(\text{Ni}(\text{OH})^+, \text{ClO}_4^-)$ ⁵¹⁾
$\text{Co}(\text{OH})^+$	Cl^-	-0.01 ± 0.07	taken from $\varepsilon(\text{Ni}(\text{OH})^+, \text{Cl}^-)$ ⁵¹⁾
CoCl^+	ClO_4^-	0.41 ± 0.04	obtained in ref. 51
$\text{Co}(\text{SO}_4)_2^{2-}$	Na^+	-0.12 ± 0.06	taken from $\varepsilon(\text{UO}_2(\text{SO}_4)_2^{2-}, \text{Na}^+)$ ⁵¹⁾
CoNO_3^+	ClO_4^-	0.33 ± 0.04	taken from $\varepsilon(\text{UO}_2\text{NO}_3^+, \text{ClO}_4^-)$ ⁵¹⁾
CoHCO_3^+	ClO_4^-	0.2 ± 0.2	taken from $\varepsilon(\text{ZnHCO}_3^+, \text{ClO}_4^-)$ with uncertainties of ± 0.2 ⁵¹⁾
ZrCl_3^+	ClO_4^-	0.88 ± 0.45	obtained in ref. 56
$\text{Zr}(\text{NO}_3)_3^+$	ClO_4^-	0.22 ± 1.24	average value of $\varepsilon(\text{M}^+, \text{ClO}_4^-)$ in the NEA-TDB ¹²⁾
Pd^{2+}	ClO_4^-	0.34 ± 0.06	average value of $\varepsilon(\text{M}^{2+}, \text{ClO}_4^-)$ (M: Zn, Cu, Ni, Co) in the NEA-TDB ¹²⁾
PdOH^+	ClO_4^-	0.41 ± 0.72	obtained in ref. 69
$\text{Pd}(\text{OH})_3^-$	Na^+	-0.10 ± 0.28	obtained in ref. 69
$\text{Nb}(\text{OH})_6^-$	Na^+	-0.07 ± 0.11	average value among hydrolysis species with net charge of -1, i.e. $\varepsilon(\text{SiO}(\text{OH})_3^-, \text{Na}^+)$, $\varepsilon(\text{Si}_2\text{O}_2(\text{OH})_5^-, \text{Na}^+)$, $\varepsilon(\text{B}(\text{OH})_4^-, \text{Na}^+)$, $\varepsilon(\text{NpO}_2(\text{OH})_2^-, \text{Na}^+)$ and $\varepsilon(\text{UO}_2(\text{OH})_3^-, \text{Na}^+)$ in the NEA-TDB ¹²⁾
TcOOH^+	Cl^-	0.11 ± 0.01	obtained in this report
PbOH^+	ClO_4^-	0.13 ± 0.25	obtained in ref. 80
$\text{Pb}(\text{OH})_3^-$	Na^+	0.42 ± 0.80	obtained in ref. 80
PbCl^+	ClO_4^-	0.04 ± 0.14	obtained in ref. 80
PbCl_3^-	Li^+	-0.07 ± 0.61	obtained in ref. 80
PbCl_3^-	Na^+	-0.22 ± 0.22	obtained in ref. 80
Bi^{3+}	ClO_4^-	0.30	obtained in ref. 81
$\text{Bi}(\text{OH})_4^-$	Na^+	0.07	obtained in ref. 81
BiCl_4^-	H^+	-0.09	obtained in ref. 81
BiCl_4^-	Na^+	0.03	obtained in ref. 81
BiCl_4^-	Li^+	0.15	obtained in ref. 81

<i>j</i>	<i>k</i>	$\varepsilon(j,k)$	comment
BiCl^{2+}	ClO_4^-	0.34	obtained in ref. 81
BiCl_2^+	ClO_4^-	0.13	obtained in ref. 81
BiCl_5^{2-}	H^+	-0.10	obtained in ref. 81
BiCl_5^{2-}	Na^+	-0.10	obtained in ref. 81
BiCl_5^{2-}	Li^+	-0.10	obtained in ref. 81

国際単位系 (SI)

表1. SI 基本単位		
基本量	SI 基本単位	
	名称	記号
長さ	メートル	m
質量	キログラム	kg
時間	秒	s
電流	アンペア	A
熱力学温度	ケルビン	K
物質量	モル	mol
光度	カンデラ	cd

組立量	SI 基本単位	
	名称	記号
面積	平方メートル	m^2
体積	立方メートル	m^3
速度, 加速度	メートル毎秒	m/s
波数	メートル毎秒	m/s^2
密度, 質量密度	メートル每立方メートル	m^{-1}
面積密度	キログラム每平方メートル	kg/m^2
比體積	立方メートル每キログラム	m^3/kg
電流密度	アンペア每平方メートル	A/m^2
磁界の強さ	アンペア每メートル	A/m
量濃度 ^(a) , 濃度	モル每立方メートル	mol/m^3
質量濃度	キログラム每立方メートル	kg/m^3
輝度	カンデラ每平方メートル	cd/m^2
屈折率 ^(b)	(数字の) 1	1
比透磁率 ^(b)	(数字の) 1	1

(a) 量濃度 (amount concentration) は臨床化学の分野では物質濃度 (substance concentration) ともよばれる。

(b) これらは無次元あるいは次元 1 をもつ量であるが、そのことを表す単位記号である数字の 1 は通常は表記しない。

表3. 固有の名称と記号で表されるSI組立単位

組立量	SI 組立単位		
	名称	記号	他のSI単位による表し方
平面角	ラジアン ^(b)	rad	$1(b)$
立体角	ステラジアン ^(b)	sr ^(c)	$1(b)$
周波数	ヘルツ ^(d)	Hz	m^2/m^2
力	ニュートン	N	s^{-1}
圧力, 応力	パスカル	Pa	N/m^2
エネルギー, 仕事, 熱量	ジュール	J	$m^2 kg s^{-2}$
仕事率, 工率, 放射束	ワット	W	J/s
電荷, 電気量	クーロン	C	$m^2 kg s^{-3}$
電位差(電圧), 起電力	ボルト	V	$m^2 kg s^{-3} A^{-1}$
静電容量	ファラード	F	$m^{-2} kg^{-1} s^4 A^2$
電気抵抗	オーム	Ω	$m^2 kg s^{-3} A^2$
コンダクタンス	ジーメンス	S	$m^{-2} kg^{-1} s^3 A^2$
磁束密度	ウェーバ	Wb	$m^2 kg s^{-2} A^{-1}$
磁束密度	テスラ	T	Wb/m^2
インダクタンス	ヘンリー	H	$kg s^{-2} A^{-1}$
セルシウス温度	セルシウス度 ^(e)	$^{\circ}C$	$m^2 kg s^{-2} A^2$
光束度	ルーメン	lm	$cd sr^{(f)}$
照度	ルクス	lx	lm/m^2
放射性核種の放射能 ⁽¹⁾	ベクレル ^(d)	Bq	s^{-1}
吸収線量, 比エネルギー一分率, カーマ	グレイ	Gy	J/kg
線量当量, 周辺線量当量, 方向性線量当量, 個人線量当量	シーベルト ^(g)	Sv	J/kg
酸素活性	カタール	kat	$s^{-1} mol$

(a) SI接頭語は固有の名称と記号を持つ組立単位と組み合わせても使用できる。しかし接頭語を付した単位はもはやヨーヒレントではない。

(b) ラジアンとステラジアンは数字の 1 に対する単位の特別な名称で、量についての情報をつたえるために使われる。実際には、使用する時には記号rad及びsrが用いられるが、習慣として組立単位としての記号である数字の 1 は明示されない。

(c) 測光学ではステラジアンという名称と記号srを単位の表し方に中に、そのまま維持している。

(d) ヘルツは周期現象についてのみ、ペクレルは放射性核種の統計的過程についてのみ使用される。

(e) セルシウス度はケルビンの特別な名称で、セルシウス温度を表すために使用される。セルシウス度とケルビンの単位の大きさは同一である。したがって、温度差や温度間隔を表す数値はどちらの単位で表しても同じである。

(f) 放射性核種の放射能 (activity referred to a radionuclide) は、しばしば誤った用語で“radioactivity”と記される。

(g) 単位シーベルト (PV,2002,70,205) については CIPM勧告2 (CI-2002) を参照。

表4. 単位の中に固有の名称と記号を含むSI組立単位の例

組立量	SI 組立単位		
	名称	記号	SI 基本単位による表し方
粘度	パスカル秒	Pa s	$m^{-1} kg s^{-1}$
力のモーメント	ニュートンメートル	N m	$m^2 kg s^{-2}$
表面張力	ニュートン每メートル	N/m	$kg s^{-2}$
角速度	ラジアン毎秒	rad/s	$m^{-1} s^{-1}=s^{-1}$
角加速度	ラジアン毎秒毎秒	rad/s ²	$m^{-1} s^{-2}=s^{-2}$
熱流密度, 放射照度	ワット每平方メートル	W/m ²	$kg s^{-3}$
熱容量, エントロピー	ジュール毎ケルビン	J/K	$m^2 kg s^{-2} K^{-1}$
比熱容量, 比エントロピー	ジュール每キログラム毎ケルビン	J/(kg K)	$m^2 s^{-2} K^{-1}$
比エネルギー	ジュール每キログラム	J/kg	$m^2 s^{-2}$
熱伝導率	ワット每メートル每ケルビン	W/(m K)	$m kg s^{-3} K^{-1}$
体積エネルギー	ジュール每立方メートル	J/m ³	$m^{-1} kg s^{-2}$
電界の強さ	ボルト每メートル	V/m	$kg s^{-3} A^{-1}$
電荷密度	クーロン每立方メートル	C/m ³	$m^{-3} sA$
電束密度, 電気変位	クーロン每平方メートル	C/m ²	$m^2 sA$
誘電率	ファラード每メートル	F/m	$m^{-3} kg^{-1} s^4 A^2$
透磁率	ヘンリー每メートル	H/m	$m kg s^{-2} A^2$
モルエネルギー	ジュール每モル	J/mol	$m^2 kg s^{-2} mol^{-1}$
モルエントロピー, モル熱容量	ジュール每モル毎ケルビン	J/(mol K)	$m^2 kg s^{-2} K^{-1} mol^{-1}$
照射線量(X線及びγ線)	クーロン每キログラム	C/kg	$kg^{-1} sA$
吸収線量	グレイ毎秒	Gy/s	$m^3 s^{-3}$
放射強度	ワット每ステラジアン	W/sr	$m^4 m^{-2} kg s^{-3}=m^2 kg s^{-3}$
放射輝度	ワット每平方メートル每ステラジアン	W/(m ² sr)	$m^2 m^{-2} kg s^{-3}=kg s^{-3}$
酵素活性濃度	カタール每立方メートル	kat/m ³	$m^3 s^{-1} mol$

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表5. SI接頭語					
乗数	接頭語	記号	乗数	接頭語	記号
10^{24}	ヨタ	Y	10^{-1}	デシ	d
10^{21}	ゼタ	Z	10^{-2}	センチ	c
10^{18}	エクサ	E	10^{-3}	ミリ	m
10^{15}	ペタ	P	10^{-6}	マイクロ	μ
10^{12}	テラ	T	10^{-9}	ナノ	n
10^9	ギガ	G	10^{-12}	ピコ	p
10^6	メガ	M	10^{-15}	フェムト	f
10^3	キロ	k	10^{-18}	アト	a
10^2	ヘクト	h	10^{-21}	ゼブト	z
10^1	デカ	da	10^{-24}	ヨクト	y

表6. SIに属さないが、SIと併用される単位

名称	記号	SI 単位による値
分	min	1 min=60s
時	h	1h=60 min=3600 s
日	d	1 d=24 h=86 400 s
度	°	$1^{\circ}=(n/180) rad$
分	'	$1'=(1/60)^{\circ}=(n/10800) rad$
秒	"	$1''=(1/60)'=(n/648000) rad$
ヘクタール	ha	$1ha=1hm^2=10^4 m^2$
リットル	L	$1L=1dm^3=10^3 cm^3=10^{-3} m^3$
トン	t	$1t=10^3 kg$

表7. SIに属さないが、SIと併用される単位で、SI単位で表される数値が実験的に得られるもの

名称	記号	SI 単位で表される数値
電子ボルト	eV	$1eV=1.602 176 53(14) \times 10^{-19} J$
ダルトン	Da	$1Da=1.660 538 86(28) \times 10^{-27} kg$
統一原子質量単位	u	$1u=1 Da$
天文単位	ua	$1ua=1.495 978 706 91(6) \times 10^{11} m$

表8. SIに属さないが、SIと併用されるその他の単位

名称	記号	SI 単位で表される数値
バル	bar	$1 bar=0.1 MPa=100 kPa=10^5 Pa$
水銀柱ミリメートル	mmHg	$1 mmHg=133.322 Pa$
オングストローム	Å	$1 Å=0.1 nm=10 pm=10^{-10} m$
海里	M	$1 M=1852 m$
バイン	b	$1 b=100 fm^2=(10^{-12} cm)^2=10^{-28} m^2$
ノット	kn	$1 kn=(1852/3600)m/s$
ネバ	Np	SI 単位との数値的な関係は、 対数量の定義に依存。
ベル	B	
デジベル	dB	

(c) 3 元系の CGS 単位系と SI では直接比較できないため、等号「▲」は対応関係を示すものである。

表10. SIに属さないその他の単位の例

名称	記号	SI 単位で表される数値
キュリ	Ci	$1 Ci=3.7 \times 10^{10} Bq$
レントゲン	R	$1 R=2.58 \times 10^{-4} C/kg$
ラド	rad	$1 rad=1 cGy=10^{-2} Gy$
レム	rem	$1 rem=1 cSv=10^{-2} Sv$
ガンマ	γ	$1 \gamma=1 nT=10^{-9} T$
フェルミ	fm	$1 fm=10^{-15} m$
メートル系カラット		$1 メートル系カラット=200 mg=2 \times 10^{-4} kg$
トル	Torr	$1 Torr=(101 325/760) Pa$
標準大気圧	atm	$1 atm=101 325 Pa$
力口リ	cal	$1 cal=4.1858 J (15^{\circ}C \text{カロリー}), 4.1868 J (IT \text{カロリー})$
ミクロ	μ	$1 \mu=1 \mu m=10^{-6} m$

