

Molybdenum Supplement to Technical Bulletin 134:
Selection of Standard Free Energies of Formation for
Use in Soil Chemistry

K.J. Reddy

W.L. Lindsay

L. Wang

1990
WWRC-90-29

In

Technical Bulletin LTB90-4
August 1990

K.J. Reddy
Wyoming Water Research Center
University of Wyoming
Laramie, Wyoming

L. Wang
Department of Plant, Soil and Insect Sciences
University of Wyoming
Laramie, Wyoming

W.L. Lindsay
Department of Agronomy
Colorado State University
Fort Collins, Colorado

Agricultural
Experiment
Station

Department of
Agronomy

August 1990

Molybdenum Supplement to Technical Bulletin 134: Selection of Standard Free Energies of Formation for Use In Soil Chemistry

K.J. Reddy, L. Wang, W.L. Lindsay

Colorado State University does not discriminate on the basis of race, color, religion, national origin, sex, age, veteran status, or handicap. The University complies with the Civil Rights Act of 1964, related Executive Orders 11246 and 11375, Title IX of the Education Amendments Act of 1972, Sections 503 and 504 of the Rehabilitation Act of 1973, Section 402 of the Vietnam Era Veteran's Readjustment Act of 1974, the Age Discrimination in Employment Act of 1967, as amended, and all civil rights laws of the State of Colorado. Accordingly, equal opportunity for employment and admission shall be extended to all persons and the University shall promote equal opportunity and treatment through a positive and continuing affirmative action program. The Office of Equal Opportunity is located in Room 314, Student Services Building. In order to assist Colorado State University in meeting its affirmative action responsibilities, ethnic minorities, women, and other protected class members are encouraged to apply and to so identify themselves.

INTRODUCTION

The most important references to thermodynamic data on Mo include Garrels and Christ (1965); Wagman et al. (1968, 1969, 1982); Smith and Martell (1976); Parker et al. (1971); Stull et al. (1971); Naumov et al. (1971); Karapet'yants and Karapet'yants (1970); and Wood and Garrels (1987). Typically, there are large differences among the free energy of formation (ΔG_f°) and the values of Mo species reported by these various compilers. Choosing the best values is difficult.

Selection criteria

The free energies of formation (ΔG_f°) values that deviate widely from those of most studies have been eliminated unless a reason was found for not doing so. In cases where the agreement of ΔG_f° values is poor, the original sources of the compilers were traced and compared to other available data to obtain the most reliable values. If solubility data were available, the ΔG_f° value for a species was calculated using selected ΔG_f° value of the products and reactants involved in the selected equilibrium reaction.

Calculating standard free energies of formation (ΔG_f°)

The standard free energies of formation of Mo species (solid phases, solution complexes, and ion pairs) compiled in this report were calculated from calorimetric, electrochemical, or solubility data. In cases where ΔG_f° was derived from calorimetric data, the standard enthalpy of reaction and entropy of reaction, ΔH_r° and ΔS_r° , were evaluated. The standard enthalpy of formation (ΔH_f°) and standard entropy (S°) were calculated from equations:

$$\Delta H_r^\circ = \sum \Delta H_f^\circ (\text{products}) - \sum \Delta H_f^\circ (\text{reactants}) \quad (1)$$

$$\Delta S_r^\circ = \sum \Delta S^\circ (\text{products}) - \sum \Delta S^\circ (\text{reactants}) \quad (2)$$

The Gibbs free energy of reaction (ΔG_r°) was calculated from the equations:

$$\Delta G_r^\circ = \Delta H_r^\circ - T\Delta S_r^\circ \quad (3)$$

$$\Delta G_r^\circ = \sum \Delta G_f^\circ (\text{products}) - \sum \Delta G_f^\circ (\text{reactants}) \quad (4)$$

where ΔG_f° is the standard free energy of formation at 298.15K (25°C) If electrochemical data were available, ΔG_r° was calculated from the equation:

$$\Delta G_r^\circ = -nFE^\circ \quad (5)$$

where

n = Number of moles of electrons participating in the reaction

F = Faraday constant (96.487 kJ volt⁻¹ or 23.061 kcal volt⁻¹)

E° = Standard cell potential

When ΔG_f° values were available, ΔG_r° was calculated using equation (4). Once ΔG_r° was known, the equilibrium constant (K°) was calculated from the equation:

$$\Delta G_r^\circ = -RT \ln K^\circ \quad (6)$$

where

K° = Activity equilibrium constant

R = Universal gas constant (0.00831 kJ mol⁻¹ or 0.01987 kcal mol⁻¹)

T = Absolute temperature in degrees kelvin

At standard conditions (25°C and 1 atm.) equation (6) becomes

$$\log K^\circ = - \frac{\Delta G_f^\circ}{1.364} \quad (7)$$

(ΔG_f° in kcal mol⁻¹), or

$$\log K^\circ = - \frac{\Delta G_r^\circ}{5.707} \quad (8)$$

(ΔG_f° in kJ mol⁻¹). Substituting eq. (4) into eqs. (7) and (8) gives

$$\log K^\circ = - \frac{1}{1.364} [\sum \Delta G_f^\circ (\text{products}) - \sum \Delta G_f^\circ (\text{reactants})] \quad (9)$$

(ΔG_f° in kcal mol⁻¹) or

$$\log K^{\circ} = - \frac{1}{5.707} [\sum \Delta G^{\circ}_f(\text{products}) - \sum \Delta G^{\circ}_f(\text{reactants})] \quad (10)$$

(ΔG°_f in kJ mol^{-1}).

Summary Standard Free Energies of Formation for Mo

The available literature on thermodynamic, electrochemical, and solubility data of various molybdenum (Mo) species was carefully searched. The standard free energies of formation for Mo species reported by major compilers are listed in Table 1.

Based on the selection criteria, standard free energies of formation (ΔG°_f , kJ mol^{-1}) values for Mo species were collected, and the values were adjusted for internal consistency with those of Sadiq and Lindsay (1979). The selected ΔG°_f values of various Mo species are listed in Table 2.

Equilibrium constants (K°) for various reactions involving Mo were computed from the data in Table 2, and the resulting $\log K^{\circ}$ values are listed in Table 3.

A discussion of each Mo species and the factors involved in selection of each ΔG°_f value is discussed in the text that follows.

Table 1. Collected free energies of formation (ΔG°_f) values for molybdenum species (kJ mol^{-1}).

No.	Species	Source*									
		1	2	3	4	5	6	7	8	9	10
1.	Mo^{3+}	-57.7	-----	-----	-----	-----	-----	-----	-57.70	-----	-----
2.	MoO_4^{2-}	-----	-836.30	-835.59	-836.13	-838.00	-838.0	-----	-----	-----	-----
3.	MoO_2^{2+}	-----	-----	-----	-----	-----	-----	-411.28	-----	-----	-----
4.	$\text{MoO}_2(\text{OH})^+$	-----	-----	-----	-645.75	-----	-----	-645.88	-----	-----	-----
5.	HMoO_4^-	-870.60	-----	-----	-860.31	-866.60	-866.60	-866.63	-----	-----	-----
6.	H_2MoO_4^0	-----	-----	-----	-883.15	-877.10	-----	-877.13	-----	-----	-883.28
7.	CaMoO_4^-	-----	-1389.90	-1407.68	-----	-----	-----	-----	-----	-----	-----
8.	NaMoO_4^-	-----	-----	-1106.94	-----	-----	-109.35	-----	-----	-----	-----
9.	KMoO_4^-	-----	-----	-1125.41	-----	-1127.82	-----	-----	-----	-----	-----
10.	MgMoO_4^0	-----	-----	-----	-----	-----	-----	-----	-----	-1313.52	-----
11.	$\text{MoO}_3(\text{c})$ (molybdate)	-----	-667.97	-----	-668.01	-667.80	-----	-----	-----	-----	-----
12.	$\text{H}_2\text{MoO}_4(\text{c})$	-----	-----	-----	-912.44	-----	-----	-----	-----	-----	-----
13.	$\text{MoS}_2(\text{c})$	-----	-225.90	-----	-266.47	-----	-----	-----	-----	-----	-----
14.	$\text{Ag}_2\text{MoO}_4(\text{c})$	-----	-----	-----	-747.89	-750.00	-----	-----	-748.01	-----	-----
15.	$\text{BaMoO}_4(\text{c})$	-----	-1439.60	-----	-----	-1435.1	-----	-----	-1439.60	-----	-----
16.	$\text{CaMoO}_4(\text{c})$	-----	-1434.60	-----	-1435.90	-1450.2	-----	-----	-1435.99	-----	-----
17.	$\text{CuMoO}_4(\text{c})$	-----	-----	-----	-----	-----	-----	-809.60	-809.60	-----	-----
18.	$\text{FeMoO}_4(\text{c})$	-----	-975.00	-----	-971.27	-----	-----	-974.28	-971.44	-----	-----
19.	$\text{MgMoO}_4(\text{c})$	-----	-1295.78	-----	-1295.78	-----	-----	-1295.78	-1295.68	-----	-----
20.	$\text{Li}_2\text{MoO}_4(\text{c})$	-----	-1409.50	-----	-----	-----	-----	-----	-1409.50	-----	-----
21.	$\text{MnMoO}_4(\text{c})$	-----	-----	-----	-1090.30	-----	-----	-1090.39	-1090.39	-----	-----
22.	$\text{Na}_2\text{MoO}_4(\text{c})$	-----	-135.34	-----	-----	-----	-----	-----	-1354.34	-----	-----
23.	$\text{Ag}_2\text{MoO}_4^0$	-----	-681.90	-----	-----	-----	-----	-----	-681.90	-----	-----
24.	$\text{Na}_2\text{MoO}_4^0$	-----	-1360.20	-----	-----	-----	-----	-----	-1360.20	-----	-----
25.	K_2MoO_4^0	-----	-1402.80	-----	-----	-----	-----	-----	-1402.80	-----	-----
26.	$\text{PbMoO}_4(\text{c})$	-----	-951.40	-----	-952.36	-----	-----	-----	-952.36	-----	-----
27.	$\text{ZnMoO}_4(\text{c})$	-----	-----	-----	-----	-----	-----	-1010.85	-1009.09	-----	-----
28.	$\text{SrMoO}_4(\text{c})$	-----	-----	-----	-----	-----	-----	-1454.36	-----	-----	-----

* Sources: 1. Yang and Pourbaix (1981), 2. Wagman et al. (1982), 3. Essington (1990), 4. Sadiq and Lindsay (1979), 5. Naumov et al. (1974), 6. Babushkin et al. (1985), 7. Naumov et al. (1971), 8. Pourbaix (1960), 9. Sposito and Mattigod (1980), 10. Rohwer and Cruywagen (1963)

Table 2. Selected ΔG_f° values for various molybdenum species.

No.	Species	ΔG_f° (kJ mol ⁻¹)	Source	Remarks
1.	Mo ³⁺	-57.70	Yang and Poubaix (1981)	ΔH_f° , S°
2.	MoO ₄ ²⁻	-836.30	Wagman et al. (1982)	ΔH_f° , S°
3.	MoO ₂ ²⁺	-411.28	Naumov et al. (1971)	K°
4.	MoO ₂ (OH) ⁺	-645.75	Sadiq and Lindsay (1979)	K°
5.	HMoO ₄ ⁻	-860.48	Smith and Martell (1976)	K°
6.	H ₂ MoO ₄ ^o	-883.28	Rohwer and Cruywagen (1963)	K°
7.	MoO ₃ (c) (molybdate)	-667.97	Wagman et al. (1982)	ΔH_f° , S°
8.	H ₂ MoO ₄ (c)	-912.44	Sadiq and Lindsay (1979)	ΔH_f° , S°
9.	MoS ₂ (c) (molybdenite)	-266.40	Sadiq and Lindsay (1979)	ΔH_f° , S°
10.	Ag ₂ MoO ₄ (c)	-748.01	Smith and Martell (1976)	K°
11.	BaMoO ₄ (c)	-1439.60	Wagman et al. (1982)	ΔH_f° , S°
12.	CaMoO ₄ (c)	-1440.31	Essington (1990)	K°
13.	CuMoO ₄ (c)	-809.60	Naumov et al. (1971)	K°
14.	FeMoO ₄ (c)	-971.44	Naumov et al. (1971)	K°
15.	Li ₂ MoO ₄ (c)	-1409.50	Wagman et al. (1982)	ΔH_f° , S°
16.	MgMoO ₄ (c)	-1295.68	Wagman et al. (1982)	ΔH_f° , S°
17.	MnMoO ₄ (c)	-1090.39	Naumov et al. (1971)	ΔH_f°
18.	Na ₂ MoO ₄ (c)	-1354.34	Wagman et al. (1982)	ΔH_f° , S°
19.	PbMoO ₄ (c)	-952.36	Sadiq and Lindsay (1979)	ΔH_f° , S°
20.	ZnMoO ₄ (c)	-1009.09	Naumov et al. (1971)	K°
21.	SrMoO ₄ (c)	-1454.36	Naumov et al. (1971)	K°
22.	CaMoO ₄ ^o	-1407.68	Essington (1990)	K°
23.	MgMoO ₄ ^o	-1313.52	Sposito & Mattigod (1980)	K°
24.	Ag ₂ MoO ₄ ^o	-681.90	Wagman et al. (1982)	ΔH_f° , S°
25.	Na ₂ MoO ₄ ^o	-1360.20	Wagman et al. (1982)	ΔH_f° , S°
26.	K ₂ MoO ₄ ^o	-1402.80	Wagman et al. (1982)	ΔH_f° , S°
27.	NaMoO ₄ ⁻	-1106.94	Essington (1990)	K°
28.	KMoO ₄ ⁻	-1125.41	Essington (1990)	K°

Table 3. Equilibrium reactions of molybdenum at 25°C and 1 atm.

No.	Reaction	log K°
I. SOLID PHASES		
1.	$\text{H}_2\text{MoO}_4(\text{c}) = 2\text{H}^+ + \text{MoO}_4^{2-}$	-13.34
2.	$\text{MoO}_3(\text{molybdite}) + \text{H}_2\text{O} = \text{MoO}_4^{2-} + 2\text{H}^+$	-12.05
3.	$\text{Ag}_2\text{MoO}_4(\text{c}) = 2\text{Ag}^+ + \text{MoO}_4^{2-}$	-11.54
4.	$\text{BaMoO}_4(\text{c}) = \text{Ba}^{2+} + \text{MoO}_4^{2-}$	-7.45
5.	$\text{CaMoO}_4(\text{c}) = \text{Ca}^{2+} + \text{MoO}_4^{2-}$	-8.05
6.	$\text{CuMoO}_4(\text{c}) = \text{Cu}^{2+} + \text{MoO}_4^{2-}$	-6.81
7.	$\text{FeMoO}_4(\text{c}) = \text{Fe}^{2+} + \text{MoO}_4^{2-}$	-7.70
8.	$\text{Li}_2\text{MoO}_4(\text{c}) = 2\text{Li}^+ + \text{MoO}_4^{2-}$	2.35
9.	$\text{MgMoO}_4(\text{c}) = \text{Mg}^{2+} + \text{MoO}_4^{2-}$	-0.57
10.	$\text{MnMoO}_4(\text{c}) = \text{Mn}^{2+} + \text{MoO}_4^{2-}$	-4.12
11.	$\text{Na}_2\text{MoO}_4(\text{c}) = 2\text{Na}^+ + \text{MoO}_4^{2-}$	1.00
12.	$\text{PbMoO}_4(\text{c}) = \text{Pb}^{2+} + \text{MoO}_4^{2-}$	-16.01
13.	$\text{ZnMoO}_4(\text{c}) = \text{Zn}^{2+} + \text{MoO}_4^{2-}$	-4.48
14.	$\text{SrMoO}_4(\text{c}) = \text{Sr}^{2+} + \text{MoO}_4^{2-}$	-9.53
15.	$\text{MoS}_2(\text{c}) + 4\text{H}_2\text{O} = \text{MoO}_4^{2-} + 2\text{S}^{2-} + 2\text{e}^- + 8\text{H}^+$	-96.43
16.	$\text{H}_2\text{MoO}_4(\text{c}) = \text{H}^+ + \text{HMoO}_4^-$	-3.99
II. SOLUTION SPECIES		
17.	$\text{HMoO}_4^- = \text{H}^+ + \text{MoO}_4^{2-}$	-4.23
18.	$\text{H}_2\text{MoO}_4^0 = 2\text{H}^+ + \text{MoO}_4^{2-}$	-8.23
19.	$\text{MoO}_2(\text{OH})^+ + \text{H}_2\text{O} = \text{MoO}_4^{2-} + 3\text{H}^+$	-8.17
20.	$\text{MoO}_2^{2+} + 2\text{H}_2\text{O} = \text{MoO}_4^{2-} + 4\text{H}^+$	-8.64
21.	$\text{Ag}_2\text{MoO}_4^0 = 2\text{Ag}^+ + \text{MoO}_4^{2-}$	0.05
22.	$\text{CaMoO}_4^0 = \text{Ca}^{2+} + \text{MoO}_4^{2-}$	3.09
23.	$\text{Na}_2\text{MoO}_4^0 = 2\text{Na}^+ + \text{MoO}_4^{2-}$	-0.02
24.	$\text{K}_2\text{MoO}_4^0 = 2\text{K}^+ + \text{MoO}_4^{2-}$	-0.27
25.	$\text{MgMoO}_4^0 = \text{Mg}^{2+} + \text{MoO}_4^{2-}$	3.7
26.	$\text{NaMoO}_4^- = \text{Na}^+ + \text{MoO}_4^{2-}$	1.66
27.	$\text{KMoO}_4^{2-} = \text{K}^+ + \text{MoO}_4^{2-}$	1.29

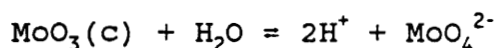
Selection of Individual Standard Free Energies of Formation

Mo^{3+}

Woods and Garrels (1987) recommended $\Delta G_f^\circ = -57.7 \text{ kJ mol}^{-1}$ ($-13.79 \text{ kcal mol}^{-1}$) from Pourbaix (1960) and Yang and Pourbaix (1981). No other information is available. Therefore, we adopted $\Delta G_f^\circ = -57.7 \text{ kJ mol}^{-1}$ for Mo^{3+} after Woods and Garrels (1987).

MoO_4^{2-}

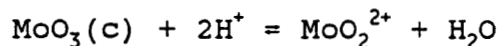
Wagman et al. (1982) reported $\Delta G_f^\circ = -836.30 \text{ kJ mol}^{-1}$ ($-199.88 \text{ kcal mol}^{-1}$) from $\Delta H_f^\circ = -997.70 \text{ kJ mol}^{-1}$ ($-238.45 \text{ kcal mol}^{-1}$) and $S^\circ = 27.20 \text{ J deg}^{-1} \text{ mol}^{-1}$ ($6.50 \text{ cal deg}^{-1} \text{ mol}^{-1}$). Sadiq and Lindsay (1979) critically evaluated ΔG_f° values for MoO_4^{2-} and recommended $\Delta G_f^\circ = -836.13 \text{ kJ mol}^{-1}$ ($-199.84 \text{ kcal mol}^{-1}$) from $\text{pK}^\circ = 12.10$ for the reaction:



after Smith and Martell (1976). Sadiq and Lindsay (1979) calculated ΔG_f° value for MoO_4^{2-} is in good agreement with Wagman et al. (1982). Therefore, we selected $\Delta G_f^\circ = -836.30 \text{ kJ mol}^{-1}$ ($-199.88 \text{ kcal mol}^{-1}$) for MoO_4^{2-} species after Wagman et al. (1982).

MoO_2^{2+}

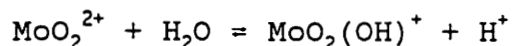
Naumov et al. (1971) recommended $\Delta G_f^\circ = -411.28 \text{ kJ mol}^{-1}$ ($-98.30 \text{ kcal mol}^{-1}$) from $\text{pK}^\circ = 3.45$ for the reaction:



No other information was available. Therefore, we adopted the available value after Naumov et al. (1971) for MoO_2^{2+} species.

$\text{MoO}_2(\text{OH})^+$

Naumov et al. (1971) reported $\Delta G_f^\circ = -645.88 \text{ kJ mol}^{-1}$ ($-154.37 \text{ kcal mol}^{-1}$). Authors based their calculation on $\text{pK}^\circ = 0.45$ for the reaction:

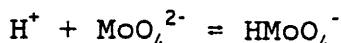


Sadiq and Lindsay (1979) calculated $\Delta G_f^\circ = -645.75 \text{ kJ mol}^{-1}$ ($-154.34 \text{ kcal mol}^{-1}$) from the above pK° value. No other information was available. We selected $\Delta G_f^\circ = -645.75 \text{ kJ mol}^{-1}$

(-154.34 kcal mol⁻¹) for MoO₂(OH)⁺ species after Sadiq and Lindsay (1979).



Naumov et al. (1971, 1974) reported $\Delta G_f^\circ = -886.63$ kJ mol⁻¹ (-211.91 kcal mol⁻¹) and $\Delta G_f^\circ = -886.60$ kJ mol⁻¹ (-211.90 kcal mol⁻¹) values for HMoO₄⁻. Garrels and Christ (1965) list $\Delta G_f^\circ = -893.70$ kJ mol⁻¹ (-213.60 kcal mol⁻¹) from ΔH_f° and S° values. Sadiq and Lindsay (1979) calculated $\Delta G_f^\circ = -860.31$ kJ mol⁻¹ (-205.62 kcal mol⁻¹) from $\text{pK}^\circ = -4.24$ for the reaction:



after Rohwer and Cruywagen (1963) and Smith and Martell (1976). Woods and Garrels (1987) listed $\Delta G_f^\circ = -870.60$ kJ mol⁻¹ (-208.00 kcal mol⁻¹) after Yang and Pourbaix (1981) and Babushin et al. (1985). No other information was available. We selected $\text{pK}^\circ = -4.24$ (Smith and Martell, 1976) and calculated $\Delta G_f^\circ = -860.48$ kJ mol⁻¹ (-205.66 kcal mol⁻¹) for HMoO₄⁻ species.



Latimer (1952) reported $\Delta G_f^\circ = -949.76$ kJ mol⁻¹ (-227.00 kcal mol⁻¹) from estimated $\Delta H_f^\circ = -1072.77$ kJ mol⁻¹ (-256.40 kcal mol⁻¹) and $S^\circ = 150.62$ J deg⁻¹ mol⁻¹ (36.00 cal deg⁻¹ mol⁻¹). Naumov et al. (1971) reported $\Delta G_f^\circ = -877.13$ kJ mol⁻¹ (-209.64 kcal mol⁻¹) from ΔH_f° and S° values.

Wagman et al. (1982) listed $\Delta H_f^\circ = -1007.50$ kJ mol⁻¹ (-240.80 kcal mol⁻¹). The author did not list any ΔG_f° or S° values for this species.

Sadiq and Lindsay (1979) calculated $\Delta G_f^\circ = -883.15$ kJ mol⁻¹ (-211.08 kcal mol⁻¹) from $\text{pK}^\circ = 4.0$ for the reaction:



after Rohwer and Cruywagen (1963). No other information was available. We calculated $\Delta G_f^\circ = -883.28$ kJ mol⁻¹ (-211.11 kcal mol⁻¹) using $\text{pK}^\circ = -4.0$ for the above equation.

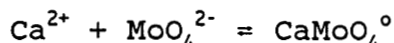


Wagman et al. (1982) listed $\Delta G_f^\circ = -681.90$ kJ mol⁻¹ (-162.97 kcal mol⁻¹) from $\Delta H_f^\circ = -786.60$ kJ mol⁻¹ (-188.00 kcal mol⁻¹) and

$S^\circ = 172.80 \text{ J deg}^{-1} \text{ mol}^{-1}$ ($41.30 \text{ cal deg}^{-1} \text{ mol}^{-1}$). No other information was available. We adopted the available ΔG_f° value for $\text{Ag}_2\text{MoO}_4^\circ$.

CaMoO_4°

Wagman et al. (1982) recommended $\Delta G_f^\circ = -1389.99 \text{ kJ mol}^{-1}$ ($-332.22 \text{ kcal mol}^{-1}$) from $\Delta H_f^\circ = -154.50 \text{ kJ mol}^{-1}$ ($-368.18 \text{ kcal mol}^{-1}$) and $S^\circ = 25.90 \text{ J deg}^{-1} \text{ mol}^{-1}$ ($6.19 \text{ cal deg}^{-1} \text{ mol}^{-1}$). Essington (1990) reported $\text{pK}^\circ = -3.09$ for the following reaction:



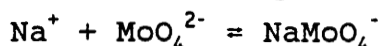
No other information was available. We calculated $\Delta G_f^\circ = -1407.68 \text{ kJ mol}^{-1}$ ($-336.44 \text{ kcal mol}^{-1}$) using $\text{pK}^\circ = -3.09$ for the above equation.

$\text{Na}_2\text{MoO}_4^\circ$

Wagman et al. (1982) recommended $\Delta G_f^\circ = -1360.20 \text{ kJ mol}^{-1}$ ($-325.09 \text{ kcal mol}^{-1}$) from $\Delta H_f^\circ = -1478.20 \text{ kJ mol}^{-1}$ ($-353.30 \text{ kcal mol}^{-1}$) and $S^\circ = 145.20 \text{ J deg}^{-1} \text{ mol}^{-1}$ ($34.70 \text{ cal deg}^{-1} \text{ mol}^{-1}$). No other information was available. We selected the available ΔG_f° value for $\text{Na}_2\text{MoO}_4^\circ$.

NaMoO_4^-

Essington (1990) reported $\text{pK}^\circ = -1.66$ for the reaction:



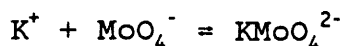
No other information was available. We adopted $\text{pK}^\circ = -1.66$ (Essington, 1990) for the above reaction and calculated $\Delta G_f^\circ = -1106.94 \text{ kJ mol}^{-1}$ ($-264.57 \text{ kcal mol}^{-1}$) for NaMoO_4^- .

$\text{K}_2\text{MoO}_4^\circ$

Wagman et al. (1982) listed $\Delta G_f^\circ = -1402.80 \text{ kJ mol}^{-1}$ ($-335.27 \text{ kcal mol}^{-1}$) from $\Delta H_f^\circ = -1502.50 \text{ kJ mol}^{-1}$ ($-359.11 \text{ kcal mol}^{-1}$) and $S^\circ = 232.30 \text{ J deg}^{-1} \text{ mol}^{-1}$ ($55.49 \text{ cal deg}^{-1} \text{ mol}^{-1}$). No other information was available. We adopted the available ΔG_f° value for $\text{K}_2\text{MoO}_4^\circ$.

KMoO_4^-

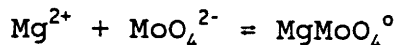
Essington (1990) reported $\text{pK}^\circ = -1.29$ for the reaction:



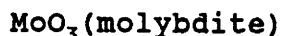
No other information was available. We adopted $\text{pK}^\circ = -1.29$ (Essington, 1990) for the above reaction and calculated $\Delta G_f^\circ = -1125.41 \text{ kJ mol}^{-1}$ ($-268.98 \text{ kcal mol}^{-1}$).



Sposito and Mattigod (1980) reported $\text{pK}^\circ = -3.7$ for the reaction:



No other information was available. We adopted $\text{pK}^\circ = -3.7$ (Sposito and Mattigod, 1980) for the above reaction and calculated $\Delta G_f^\circ = -1313.52 \text{ kJ mol}^{-1}$ ($-313.94 \text{ kcal mol}^{-1}$).



Wagman et al. (1982) listed $\Delta G_f^\circ = -667.97 \text{ kJ mol}^{-1}$ ($-159.65 \text{ kcal mol}^{-1}$) from $\Delta H_f^\circ = -745.09 \text{ kJ mol}^{-1}$ ($-178.08 \text{ kcal mol}^{-1}$) and $S^\circ = 77.74 \text{ J deg}^{-1} \text{ mol}^{-1}$ ($18.58 \text{ cal deg}^{-1} \text{ mol}^{-1}$). Stull et al. (1971) reported $\Delta G_f^\circ = -668.10 \text{ kJ mol}^{-1}$ ($-159.68 \text{ kcal mol}^{-1}$) from $\Delta H_f^\circ = -745.17 \text{ kJ mol}^{-1}$ ($-178.10 \text{ kcal mol}^{-1}$) and $S^\circ = 77.73 \text{ J deg}^{-1} \text{ mol}^{-1}$ ($18.58 \text{ cal deg}^{-1} \text{ mol}^{-1}$).

Sadiq and Lindsay (1979) calculated $\Delta G_f^\circ = -668.01 \text{ kJ mol}^{-1}$ ($-159.66 \text{ kcal mol}^{-1}$) from $\Delta H_f^\circ = -745.08 \text{ kJ mol}^{-1}$ ($-178.08 \text{ kcal mol}^{-1}$) after Mah (1957) and Staskiewicz et al. (1955) and $S^\circ = 77.73 \text{ J deg}^{-1} \text{ mol}^{-1}$ ($18.58 \text{ cal deg}^{-1} \text{ mol}^{-1}$) after Kelley and King (1961).

Listed ΔG_f° values for $\text{MoO}_3(\text{molybdite})$ by different investigators are in agreement. Therefore, we selected $\Delta G_f^\circ = -667.97$ ($-159.64 \text{ kcal mol}^{-1}$) after Wagman et al. (1982).



Wagman et al. (1982) reported $\Delta H_f^\circ = -1046.00 \text{ kJ mol}^{-1}$ ($-250.00 \text{ kcal mol}^{-1}$). The authors did not list any ΔG_f° or S° values for this species. Woods and Garrels (1987) listed $\Delta G_f^\circ = -1187.08 \text{ kJ mol}^{-1}$ ($-283.72 \text{ kcal mol}^{-1}$) from Yang and Pourbaix (1981). Sadiq and Lindsay (1979) calculated $\Delta G_f^\circ = -912.44 \text{ kJ mol}^{-1}$ ($-218.08 \text{ kcal mol}^{-1}$) from $\Delta H_f^\circ = -1046.00 \text{ kJ mol}^{-1}$ ($-250.00 \text{ kcal mol}^{-1}$) after Graham and Hepler (1956) and $S^\circ = 121.33 \text{ J deg}^{-1}$

mol⁻¹ (29.00 cal deg⁻¹ mol⁻¹) after Dellien et al. (1976).

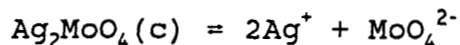
No other information was available. Therefore, we selected $\Delta G_f^\circ = -912.44$ kJ mol⁻¹ (-218.08 kcal mol⁻¹) after Sadiq and Lindsay (1979).

MoS₂(c) (molybdenite)

Latimer (1952) reported $\Delta G_f^\circ = -225.09$ kJ mol⁻¹ (-53.80 kcal mol⁻¹) from $\Delta H_f^\circ = -232.21$ kJ mol⁻¹ (-55.50 kcal mol⁻¹) and $S^\circ = 63.17$ J deg⁻¹ mol⁻¹ (15.10 cal deg⁻¹ mol⁻¹). Wagman et al. (1982) listed $\Delta G_f^\circ = -225.90$ kJ mol⁻¹ (-53.99 kcal mol⁻¹) from $\Delta H_f^\circ = -235.10$ kJ mol⁻¹ (-56.19 kcal mol⁻¹) and $S^\circ = 62.59$ J deg⁻¹ mol⁻¹ (14.96 cal deg⁻¹ mol⁻¹). Sadiq and Lindsay (1979) critically evaluated ΔH_f° and S° values for MoS₂(molybdenite) and calculated $S^\circ = 62.59$ J mol⁻¹ (14.96 cal mol⁻¹) after Westrum and McBride (1955). Recently, Chase et al. (1982) reported $\Delta G_f^\circ = -266.47$ kJ mol⁻¹ (-63.69 kcal mol⁻¹). The authors adopted $\Delta H_f^\circ = -275.30$ kJ mol⁻¹ (-65.80 kcal mol⁻¹) after O'Hare et al. (1970), which is similar to Sadiq and Lindsay (1979) selection. In this report we selected $\Delta G_f^\circ = -266.47$ kJ mol⁻¹ (-63.69 kcal mol⁻¹) for MoO₂ species after Sadiq and Lindsay (1979).

Ag₂MoO₄(c)

Naumov et al. (1974) reported $\Delta G_f^\circ = -750.00$ kJ mol⁻¹ (-179.26 kcal mol⁻¹) from $\Delta H_f^\circ = -837.8$ kJ mol⁻¹ (200.24 kcal mol⁻¹) and $S^\circ = 228.9$ J deg⁻¹ mol⁻¹ (54.71 cal deg⁻¹ mol⁻¹). Sadiq and Lindsay (1979) calculated $\Delta G_f^\circ = -747.89$ kJ mol⁻¹ (-178.75 kcal mol⁻¹) from $pK^\circ = 11.55$ for the reaction:



after Smith and Martell (1976). Similar pK° values for the above reaction were reported by Muldrow and Hepler (1956) and Pan (1954).

Latimer (1952) reported $\Delta G_f^\circ = -821.73$ kJ mol⁻¹ (196.40 kcal mol⁻¹). The author did not report any ΔH_f° or S° values.

The equilibrium constant (log K°) for the above reaction reported by various investigators are summarized below:

Investigators	log K°
Smith and Martell (1976)	-11.55
Muldrow and Hepler (1956)	-11.55
Pan (1954)	-11.55
Ricci and Link (1951)	-10.51
Lindsay (1979)	-11.55
WATEQFC (Runnells and Lindberg, 1980)	-11.55
GEOCHEM (Sposito and Mattigod, 1980)	-11.42

Reported log K° values are in good agreement except Ricci and Linke (1951). Therefore, we selected $\text{pK}^\circ = 11.55$ for the above reaction after Smith and Martell and calculated $\Delta G_f^\circ = -748.01 \text{ kJ mol}^{-1}$ ($-178.78 \text{ kcal mol}^{-1}$) for $\text{Ag}_2\text{MoO}_4(\text{c})$.

BaMoO₄(c)

Latimer (1952) reported $\Delta G_f^\circ = -1075.28 \text{ kJ mol}^{-1}$ ($-257.00 \text{ kcal mol}^{-1}$) from $\Delta H_f^\circ = -1179.88 \text{ kJ mol}^{-1}$ ($-282.00 \text{ kcal mol}^{-1}$) and estimated $S^\circ = 153.97 \text{ J deg}^{-1} \text{ mol}^{-1}$ ($36.80 \text{ cal deg}^{-1} \text{ mol}^{-1}$).

Similar ΔG_f° , ΔH_f° and S° values reported by Garrels and Christ (1965). Naumov et al. (1974) reported $\Delta G_f^\circ = -432.6 \text{ kJ mol}^{-1}$ ($-103.40 \text{ kcal mol}^{-1}$) from $\Delta H_f^\circ = -1537.00 \text{ kJ mol}^{-1}$ ($-367.37 \text{ kcal mol}^{-1}$) and $S^\circ = 149.00 \text{ J deg}^{-1} \text{ mol}^{-1}$ ($35.61 \text{ cal deg}^{-1} \text{ mol}^{-1}$).

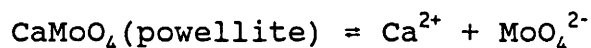
Babushkin et al. (1985) reported $\Delta G_f^\circ = -1435.1 \text{ kJ mol}^{-1}$ ($-343.02 \text{ kcal mol}^{-1}$) from $\Delta H_f^\circ = -1541.80 \text{ kJ mol}^{-1}$ ($-368.52 \text{ kcal mol}^{-1}$) and $S^\circ = 148.1 \text{ J deg}^{-1} \text{ mol}^{-1}$ ($35.40 \text{ cal deg}^{-1} \text{ mol}^{-1}$).

Wagman et al. (1982) reported $\Delta G_f^\circ = -1439.60 \text{ kJ mol}^{-1}$ ($-344.07 \text{ kcal mol}^{-1}$) from $\Delta H_f^\circ = -1548.00 \text{ kJ mol}^{-1}$ ($-369.98 \text{ kcal mol}^{-1}$) and $S^\circ = 138.00 \text{ J deg}^{-1} \text{ mol}^{-1}$ ($32.98 \text{ cal deg}^{-1} \text{ mol}^{-1}$). No other information was available. In this report, we selected $\Delta G_f^\circ = -1439.60 \text{ kJ mol}^{-1}$ ($-344.07 \text{ kcal mol}^{-1}$) for $\text{BaMoO}_4(\text{c})$ after Wagman et al. (1982).

CaMoO₄(c)

Wagman et al. (1982) listed $\Delta G_f^\circ = -1434.60 \text{ kJ mol}^{-1}$ ($-342.87 \text{ kcal mol}^{-1}$) from $\Delta H_f^\circ = -1541.40 \text{ kJ mol}^{-1}$ ($-368.40 \text{ kcal mol}^{-1}$) and $S_o = 122.60 \text{ J deg}^{-1} \text{ mol}^{-1}$ ($29.30 \text{ cal deg}^{-1} \text{ mol}^{-1}$). Sadiq and Lindsay (1979) reported $\Delta G_f^\circ = -1435.90 \text{ kJ mol}^{-1}$ ($-343.19 \text{ kcal mol}^{-1}$) from $\Delta H_f^\circ = -1545.59 \text{ kJ mol}^{-1}$ ($-369.50 \text{ kcal mol}^{-1}$) after Barany (1962) and $S^\circ = 122.59 \text{ J mol}^{-1}$ ($29.30 \text{ cal mol}^{-1}$) after Weller and King (1963).

The equilibrium constant ($\log K^\circ$) for the following reaction:



reported by various investigators and geochemical models are summarized below:

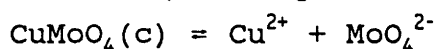
Investigator/Geochemical Model	$\log K^\circ$
Smith and Martell (1976)	-8.00
Lindsay (1979)	-7.94
GEOCHEM (Sposito and Mattigod, 1980)	-7.41
WATEQFC (Runnells and Lindberg, 1980)	-8.36
Essington (1990)	-8.05

The equilibrium constant reported by Lindsay (1979) calculated from selected ΔG_f° values of Sadiq and Lindsay (1979), and Essington (1990) are in good agreement with Smith and Martell (1979). Recently, Essington (1990) measured solubility of CaMoO₄(c) and reported $\log K^\circ$ of -8.05. In this study, author also made correction for solution species of Mo. We adopted $\log K^\circ = -8.05$ (Essington, 1990) for the above reaction and calculated $\Delta G_f^\circ = -1440.31 \text{ kJ mol}^{-1}$ ($-344.24 \text{ kcal mol}^{-1}$) for CaMoO₄(c).

CuMoO₄(c)

Latimer (1952) Listed $\Delta H_f^\circ = -948.09 \text{ kJ mol}^{-1}$ ($266.60 \text{ kcal mol}^{-1}$) and estimated $S^\circ = 141.41 \text{ J deg}^{-1} \text{ mol}^{-1}$ ($33.80 \text{ cal deg}^{-1} \text{ mol}^{-1}$) for CuMoO₄(c).

Naumov et al. (1971) recommended $\Delta G_f^\circ = -809.60 \text{ kJ mol}^{-1}$ ($-193.50 \text{ kcal mol}^{-1}$) from $\text{pK}^\circ = 6.48$ for the reaction:

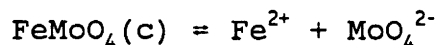


No other information was available for this compound. Therefore, we adopted $\Delta G_f^\circ = -809.60 \text{ kJ mol}^{-1}$ ($-193.50 \text{ kcal mol}^{-1}$) for $\text{CuMoO}_4(\text{c})$ after Naumov et al. (1971).

$\text{FeMoO}_4(\text{c})$

Latimer (1952) reported $\Delta G_f^\circ = -982.40 \text{ kJ mol}^{-1}$ ($-234.80 \text{ kcal mol}^{-1}$) from $\Delta H_f^\circ = -1077.38 \text{ kJ mol}^{-1}$ ($-257.50 \text{ kcal mol}^{-1}$) and estimated $S^\circ = 139.74 \text{ J deg}^{-1} \text{ mol}^{-1}$ ($33.40 \text{ cal deg}^{-1} \text{ mol}^{-1}$). Garrels and Christ (1965) listed similar ΔG_f° , ΔH_f° , and S° values from Latimer (1951).

Wagman et al. (1982) recommended $\Delta G_f^\circ = -975.00 \text{ kJ mol}^{-1}$ ($-233.03 \text{ kcal mol}^{-1}$) from $\Delta H_f^\circ = -1075.00 \text{ kJ mol}^{-1}$ ($-256.93 \text{ kcal mol}^{-1}$) and $S^\circ = 129.30 \text{ J deg}^{-1} \text{ mol}^{-1}$ ($30.90 \text{ cal deg}^{-1} \text{ mol}^{-1}$). Naumov et al. (1971) reported $\Delta G_f^\circ = -974.28 \text{ kJ mol}^{-1}$ ($-233.86 \text{ kcal mol}^{-1}$) from $\text{pK}^\circ = 7.7$ for the reaction:



O'Hare et al. (1970) reported $\text{pK}^\circ = 9.11$ for the same reaction, which determined $\Delta G_f^\circ = -979.38 \text{ kJ mol}^{-1}$ ($-234.07 \text{ kcal mol}^{-1}$) for $\text{FeMoO}_4(\text{c})$.

Sadiq and Lindsay (1979) critically evaluated ΔG_f° for $\text{FeMoO}_4(\text{c})$ and reported that calorimetric data of Wagman et al. (1982) and Latimer (1951) and solubility measurements of O'Hare et al. (1974) had higher uncertainties. Therefore, the authors selected $\text{pK}^\circ = 7.7$ for the above reaction after Naumov et al. (1971) and calculated $\Delta G_f^\circ = -971.27 \text{ kJ mol}^{-1}$ ($-232.14 \text{ kcal mol}^{-1}$) for $\text{FeMoO}_4(\text{c})$ to be internally consistent to their selection.

In this report, we selected $\text{pK}^\circ = 7.7$ (Naumov et al., 1971) for the above reaction and calculated $\Delta G_f^\circ = -971.44 \text{ kJ mol}^{-1}$ ($-232.18 \text{ kcal mol}^{-1}$) for $\text{FeMoO}_4(\text{c})$ to be internally consistent to our selection.

Li₂MoO₄(c)

Wagman et al. (1982) listed $\Delta G_f^\circ = -1409.50 \text{ kJ mol}^{-1}$ ($-336.87 \text{ kcal mol}^{-1}$) from $\Delta H_f^\circ = -1520.30 \text{ kJ mol}^{-1}$ ($-363.36 \text{ kcal mol}^{-1}$) and $S^\circ = 126.00 \text{ J deg}^{-1} \text{ mol}^{-1}$ ($-30.11 \text{ cal deg}^{-1} \text{ mol}^{-1}$). No other information was available. We selected the available ΔG_f° value for Li₂MoO₄(c).

MgMoO₄(c)

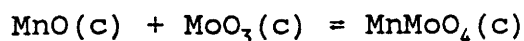
Wagman et al. (1982) recommended $\Delta G_f^\circ = -1295.68 \text{ kJ mol}^{-1}$ ($-309.67 \text{ kcal mol}^{-1}$) from $\Delta H_f^\circ = -1400.85 \text{ kJ mol}^{-1}$ ($-334.81 \text{ kcal mol}^{-1}$) and $S^\circ = 118.80 \text{ J deg}^{-1} \text{ mol}^{-1}$ ($28.39 \text{ cal deg}^{-1} \text{ mol}^{-1}$). Naumov et al. (1971) reported $\Delta G_f^\circ = -1295.78 \text{ kJ mol}^{-1}$ ($-309.70 \text{ kcal mol}^{-1}$) from $\Delta H_f^\circ = -1400.88 \text{ kJ mol}^{-1}$ ($-334.82 \text{ kcal mol}^{-1}$) after Barany (1962) and $S^\circ = 118.82 \text{ J deg}^{-1} \text{ mol}^{-1}$ ($28.40 \text{ cal deg}^{-1} \text{ mol}^{-1}$) after Weller and King (1963). Dellien et al (1976) reported similar values for MgMoO₄(c). Sadiq and Lindsay (1979) adopted Naumov et al. (1971) values.

Reported ΔG_f° values for MgMoO₄(c) are in good agreement. Therefore, we selected $\Delta G_f^\circ = -1295.68 \text{ kJ mol}^{-1}$ ($-309.67 \text{ kcal mol}^{-1}$) for MgMoO₄ after Wagman et al. (1982).

MnMoO₄ (c)

Sadiq and Lindsay (1979) recommended $\Delta G_f^\circ = -1090.30 \text{ kJ mol}^{-1}$ ($-260.59 \text{ kcal mol}^{-1}$) from $\Delta H_f^\circ = -1191.35 \text{ kJ mol}^{-1}$ ($-284.74 \text{ kcal mol}^{-1}$) after Barany (1965) and $S^\circ = 131.79 \text{ J deg}^{-1} \text{ mol}^{-1}$ ($31.50 \text{ cal deg}^{-1} \text{ mol}^{-1}$) after Naumov et al. (1971). Wagman et al. (1982) reported $\Delta H_f^\circ = -1191.31 \text{ kJ mol}^{-1}$ ($-284.73 \text{ kcal mol}^{-1}$), which is similar to Barany (1965). The authors did not list ΔG_f° or S° values for MnMoO₄(c).

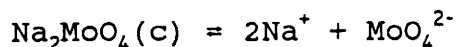
Naumov et al. (1971) reported $\Delta G_f^\circ = -1090.39 \text{ kJ mol}^{-1}$ ($-260.61 \text{ kcal mol}^{-1}$) from ΔH_f° for the reaction:



In this report, we selected $\Delta G_f^\circ = -1090.39 \text{ kJ mol}^{-1}$ ($-260.61 \text{ kcal mol}^{-1}$) for MnMoO₄(c) compound after Naumov et al. (1971).

Na₂MoO₄(c)

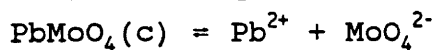
Wagman et al. (1982) reported $\Delta G_f^\circ = -1354.34 \text{ kJ mol}^{-1}$ ($-323.69 \text{ kcal mol}^{-1}$) from $\Delta H_f^\circ = -1468.12 \text{ kJ mol}^{-1}$ ($-350.89 \text{ kcal mol}^{-1}$) and $S^\circ = 159.70 \text{ J deg}^{-1} \text{ mol}^{-1}$ ($38.17 \text{ cal deg}^{-1} \text{ mol}^{-1}$). WATEQFC (Runnells and Lindberg, 1980) reported $\log K^\circ = 1.18$ for the reaction:



This equilibrium constant yields $\Delta G_f^\circ = -1353.31 \text{ kJ mol}^{-1}$ ($-323.45 \text{ kcal mol}^{-1}$) which is in good agreement with ΔG_f° value reported by Wagman et al. (1982). Therefore, we selected $\Delta G_f^\circ = -1354.34 \text{ kJ mol}^{-1}$ ($-323.69 \text{ kcal mol}^{-1}$) for Na₂MoO₄(c) after Wagman et al. (1982).

PbMoO₄(c)

Wagman et al. (1982) reported $\Delta G_f^\circ = -951.40 \text{ kJ mol}^{-1}$ ($-227.39 \text{ kcal mol}^{-1}$) from $\Delta H_f^\circ = -1051.90 \text{ kJ mol}^{-1}$ ($-251.41 \text{ kcal mol}^{-1}$) and $S^\circ = 166.10 \text{ J deg}^{-1} \text{ mol}^{-1}$ ($39.70 \text{ cal deg}^{-1} \text{ mol}^{-1}$). Latimer (1952) listed $\text{pK}^\circ = 5.39$ for the reaction:



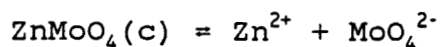
Smith and Martell (1976) reported $\text{pK}^\circ = 13.0$ for the same reaction from Muldrow and Hepler (1958). But the authors considered this pK° value to be questionable because of the difficulties associated with measuring the solubility of PbMoO₄(c). GEOCHEM (Runnell and Lindberg, 1980) and WATEQFC (Sposito and Mattigod, 1980) reported $\text{pK}^\circ = 13.0$ and 15.07 , respectively. Naumov et al. (1974) reported $\Delta G_f^\circ = -948.5 \text{ kJ mol}^{-1}$ ($-226.71 \text{ kcal mol}^{-1}$) from $\Delta H_f^\circ = -1049.00 \text{ kJ mol}^{-1}$ ($-250.72 \text{ kcal mol}^{-1}$) and $S^\circ = 166.1 \text{ J deg}^{-1} \text{ mol}^{-1}$ ($39.70 \text{ cal deg}^{-1} \text{ mol}^{-1}$).

Sadiq and Lindsay (1979) calculated $\Delta G_f^\circ = -952.36 \text{ kJ mol}^{-1}$ ($-227.62 \text{ kcal mol}^{-1}$) from $\Delta H_f^\circ = -1052.94 \text{ kJ mol}^{-1}$ ($-251.66 \text{ kcal mol}^{-1}$) after Dillien et al. (1976) and $S^\circ = 166.10 \text{ J deg}^{-1} \text{ mol}^{-1}$ ($39.70 \text{ cal deg}^{-1} \text{ mol}^{-1}$) after Weller and Kelley (1964). These values are similar to values reported by Wagman et al. (1982).

In this report, we selected $\Delta G_f^\circ = -952.36 \text{ kJ mol}^{-1}$ ($-227.62 \text{ kcal mol}^{-1}$) after Sadiq and Lindsay (1979).

ZnMoO₄(c)

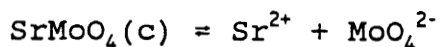
Naumov et al. (1971) recommended $\Delta G_f^\circ = -1010.85 \text{ kJ mol}^{-1}$ ($-241.60 \text{ kcal mol}^{-1}$) from $pK^\circ = 4.49$ for the reaction:



No other information was available. Therefore, we selected $pK^\circ = 4.49$ for the above reaction after Naumov et al. (1971) and calculated $\Delta G_f^\circ = -1009.09 \text{ kJ mol}^{-1}$ ($-241.18 \text{ kcal mol}^{-1}$) for $\text{ZnMoO}_4(\text{c})$ to be internally consistent to our selection.

SrMoO₄(c)

Naumov et al. (1971) listed $\Delta G_f^\circ = -1454.36 \text{ kJ mol}^{-1}$ ($-347.60 \text{ kcal mol}^{-1}$) from $\Delta H_f^\circ = 19.24 \text{ kJ mol}^{-1}$ ($-4.60 \text{ kcal mol}^{-1}$) and $pK^\circ = 7.89$ for the reaction:



Karapet'yants and Karapet'yants (1970) reported $\Delta G_f^\circ = -1448.50 \text{ kJ mol}^{-1}$ ($-346.20 \text{ kcal mol}^{-1}$) from ΔH_f° and S° values. No further information is available. Therefore, we adopted $\Delta G_f^\circ = -1454.36 \text{ kJ mol}^{-1}$ ($-347.60 \text{ kcal mol}^{-1}$) for $\text{SrMoO}_4(\text{c})$ after Naumov et al. (1971).

REFERENCES

- Babushkin, V. I., G. M. Matveyev and O. P. Mchedlov-Petrosyan. 1985. Thermodynamics of silicates. Springer-Verlag, Berlin, 459 p.
- Barany, R. 1962. Heats and free energy of formation of calcium tungstate, calcium molybdate, and magnesium molybdate. U. S. Bur. Mines Inv. Rept. 6143.
- Chase, M. W., J. L. Curnett, A. T. Hu, H. Prophet, A. N. Syverud, and L. C. Walker. JANAF Thermochemical Tables, 1974. Supp. Dow Chemical Company, Midland, MI
- Dellien, I., F. M. Hall, and L. G. Hepler. 1976. Chromium, molybdenum, and tungsten. Thermodynamic properties, chemical equilibria, and standard potentials. Chem. Rev. 76:283-310.
- Essington, M. E. 1990. Calcium molybdate solubility in spent oil shale and a preliminary evaluation of the association constants for the formation of $\text{CaMoO}_4^0(\text{aq})$, $\text{KMoO}_4^-(\text{aq})$ and $\text{NaMoO}_4^-(\text{aq})$. Environ. Sci. Technol. (In press).
- Garrels, R. M. and C. L. Christ. 1965. Solution, Minerals, and Equilibria. Harper and Row, New York.
- Graham, R. L. and L. G. Hepler. 1956. Heat of formation of sodium molybdate, molybdic acid, and aqueous molybdate ion. J. Am. Chem. Soc. 78:4846-4848.
- Karapet'yants, M. Kh., and M. L. Karapet'yants. 1970. Thermodynamic constants of inorganic and organic compounds. Humphrey Sci. Pub., Ann Arbor, London.
- Kelley, K. K., and E. G. King. 1961. Contribution to the data on theoretical metallurgy. XIV. Entropies of elements and inorganic compounds. U. S. Bur. Mines, Bull. 592.
- Latimer, W. M. 1952. The oxidation states of the elements and their potentials in aqueous solutions. Prentice-Hall, New York.
- Lindsay, W. L. 1979. Chemical equilibria in soils. Wiley-Interscience, New York.

- Mah, A. D. 1957. Heats of formation of alumina, molybdenum trioxide and molybdenum dioxide. *J. Phys. Chem.*, 61:1572-1573.
- Muldrow, C. N., and L. G. Hepler. 1958. Heats of precipitation and formation of lead and calcium molybdates. *J. Phys. Chem.*, 62:982-984.
- Muldrow, C. N. , and L. G. Hepler. 1956. The heat of precipitation and formation of silver molybdate. *J. Am. Chem. Soc.* 78:5989-5990.
- Naumov, G. B., B. N. Ryshenko, and I. L. Khodakovskii. 1971. Handbook of thermodynamic values. Atomizdat, Moscow. Russian Translation. U. S. Geol. Survey.
- Naumov, G. B., B. N. Ryzhenko and I. L. Khodakovskiy. 1974. Handbook of thermodynamic data, Nat. Tech. Inf. Service, Pb-226, 722/7 GA, U.S. Dept. of Commerce, 328 pp.
- O'Hare, P. A. G., E. Benn, F. Y. Cheng, and G. Kuzymycz. 1970. A fluorine bomb calorimetric study of molybdenum disulfide. The standard enthalpies of formation of di- and sesquesulfides of molybdenum. *J. Chem. Thermodyn.* 2:797-840.
- Pan, K. 1954. Cited by Sillen and Martell (1964). *J. Chinese Chem. Soc.* 1:16.
- Parker, V. B., D. D. Wagman, and W. H. Evans. 1971. Selected values of chemical thermodynamic properties. Nat. Bur. Std. Tech. Note. 270-6.
- Ricci, J. E., and W. F. Linke. 1951. The aqueous solubilities of silver molybdate and the ternary system $\text{Ag}_2\text{MoO}_4\text{-AgNO}_3\text{-H}_2\text{O}$ and $\text{Ag}_2\text{MoO}_4\text{-NaMoO}_4\text{-H}_2\text{O}$ at 25°C. *J. Am. Chem. Soc.* 73:3601-3603.
- Pourbaix, M. 1960. Standard free energies of formation at 25°C. CEBEICORT Ret. 684. Belgian center for the study of corrosion. Brussels.
- Rohwer, E. F. C., and J. J. Cruywagen. 1963. Cited by Sillen and Martell (1971). *J. S. African Chem. Inst.*, 16:26.
- Runnells, D. D. and R. D. Lindberg. 1981. Hydrogeochemical exploration for uranium ore deposits: Use of the computer model WATEQFC. *J. Geochem. Explor.* 15:37-50.

- Sadiq, M. and W. L. Lindsay. 1979. Selection of standard free energies of formation for use in soil chemistry. Colorado State Univ. Exp. Stn. Tech. Bull. 134.
- Smith, R. M. and A. E. Martell. 1976. Critical stability constants. Volume 4. Inorganic Complexes. Plenum Press, New York.
- Sposito, G. and V. Mattigod. 1980. GEOCHEM: A computer program for the calculation of chemical equilibria in soil solution and other natural water systems. The Kearney Foundation of Soil Science, Univ. of California, Riverside.
- Staskiewicz, B. A., J. R. Tucker and P. E. Snyder. 1955. The heat of formation of molybdenum dioxide and molybdenum trioxide. J. Am. Chem. Soc. 77:2987-2989.
- Stull, D. R. 1971. JANAF Thermochemical tables. 2nd edition. Nat. Stand. Ref. Ser., Natl. Bur. Stand. U. S. 37:1-1141.
- Wagman, D. D., W. H. Evans, V. B. Parker, I. Halow, S. M. Baily, and R. H. Schuman. 1968. Selected Values of Chemical Thermodynamic Properties. Nat. Bur. Std. Tech. Note 270-3.
- Wagman, D. D., W. H. Evans, V. B. Parker, I. Halow, S. M. Baily and R. H. Schuman. 1969. Selected values of Chemical Thermodynamic properties. Nat. Bur. Std. Tech. Note 270-4.
- Wagman, D. D., W. H. Evans, V. B. Parker, I. Halow, S. M. Baily and R. H. Schuman. 1982. Selected values for inorganic C and C₂ organic substances in SI units. Nat. Bur. Std. Tech. Note 11:Supplement No.2.
- Weller, W. W. and E. G. King. 1963. Low temperature heat capacities and entropies at 298.15°K of monomolybdate of sodium, magnesium, and calcium. U. S. Bur. Mines. Inv. Rept. 6147.
- Westrum, E. F. and J. J. McBride. 1965. Temperature dependence of the heat capacity of molybdenite. Phys. Rev. 98:270.
- Woods, T. L. and R. M. Garrels. 1987. Thermodynamics values at low temperature for natural inorganic materials. An uncritical summary 1987. Oxford Univ. Press. New York.

Yang, W. and Pourbaix. 1981. Effect of chromium and molybdenum on the propagation of logical corrosion of steel, CEBELCOR Rapt. Tech. 262.