## Tungsten (W) CRYSTAL $A_r = 183.85$

$S°(298.15\ K) = 32.660 \pm 0.10\ J{\cdot}K^{-1}{\cdot}mol^{-1}$
$T_{fus} = 3680 \pm 20\ K$

$\Delta_f H°(0\ K) = 0\ kJ{\cdot}mol^{-1}$
$\Delta_f H°(298.15\ K) = 0\ kJ{\cdot}mol^{-1}$
$\Delta_{fus} H° = 35.40 \pm 10.5\ kJ{\cdot}mol^{-1}$

### Enthalpy of Formation

Zero by definition.

### Heat Capacity and Entropy

There have been several investigations of the low temperature heat capacity of tungsten, Lange[1] covered the range 26–91 K. Horowitz and Daunt[2] reported values in the range 1–77 K, while Waite *et al.*[3] worked from 4–15° and DeSorbo[4] from 15–90 K. Zwikker and Schmidt[5] covered the range from 90 to 2521 K. Clusius *et al.*[6] made a thorough study of the heat capacity in the range 12–274 K, and their measurements were adopted leading to $S°(298.15\ K) = 7.806\ cal{\cdot}K^{-1}{\cdot}mol^{-1}$ based on $S°(12.5) = 0.0088\ cal{\cdot}K^{-1}{\cdot}mol^{-1}$. This value is in disagreement with the quoted value of $7.83\ cal{\cdot}K^{-1}{\cdot}mol^{-1}$ but agrees exactly with a separate integration by Kirillin *et al*[7] In the intermediate temperature range the adiabatic heat capacity measurements of Bronson *et al.*[8] from 253 to 773 K joined well with the low temperature measurements and were adopted. The high temperature enthalpies have been measured by several investigators from which were selected the values of Jaeger and Rosenbohm[9] from 273–1800 K; Magnus and Holzmann[10] who covered the range 373 to 1173 K; Hoch and Johnston,[11] who made measurements between 1382 and 2900 K; Kirillin *et al.*[7] who have made several determinations over the range 600 to 3100 K, and have also analysed the above data and have presented smooth functions from 0 to 3500 K. The present table agreess with that of Kirillin *et al.*[7] up to 2700 K, above this temperature the values of $C_p$ adopted follow those reported by Novikov *et al.*[12] measured by an electric modulation method, up to the melting point. These values rise rapidly above 2700 K and are not inconsistent with the individual measurements of Kirillin *et al.*[7] at their highest temperatures.

### Fusion Data

Langmuir[13] determined the melting point as 3540 K from intrinsic brilliance measurements, this was later corrected to 3655 ± 30 K by Jones *et al.*,[14] and Pirani and Alterthum[15] from pyrometer measurements on a black body hole found 3660 ± 60 K. Using the same technique Zalabak[16] reports 3680 K on a low carbon specimen. He reports a decrease of the melting point with increasing carbon content. Rudy and Windisch[17] report a melting point of 3696 ± 20 K. The value adopted is 3680 K ± 20 K. The enthalpy of melting is obtained by assuming an entropy of melting of $2.3\ cal{\cdot}K^{-1}{\cdot}mol^{-1}$ obtained from a comparison of several high melting metals (Fe, Cu, Co, Mg, Al).

### Sublimation Data

Refer to the ideal gas table for details.

### References


[1]F. Lange, Z. physik. Chem. **110**, 343 (1924).
[2]M. Horowitz and J. G. Daunt, Phys. Rev. **91**, 1099 (1953).
[3]T. R. Waite, R. S. Craig, and W. E. Wallace, Phys. Rev. **104**, 1240 (1956).
[4]W. DeSorbo, J. Phys. Chem. **62**, 965 (1958).
[5]C. Zwikker and G. Schmidt, Z. Physik. **52**, 668 (1928).
[6]K. Clusius and P. Franzozini, Z. Naturforsch. **14A**, 99 (1959).
[7]V. A. Kirillin, A. E. Sheindlin, V. Ya. Chekhovskoi and V. A. Petrov, Zhur. Fiz. Khim. **37**, 2249 (1963).
[8]H. L. Bronson, H. M. Chisholm and S. M. Dockerty, Can. J. Research 8, 282 (1933).
[9]F. M. Jaeger and E. Rosenbohm, Rec. trav. chim. **51**, 1 (1932).
[10]A. Magnus and H. Holzmann, Ann. Physik. Ser 5, **3**, 585 (1929).
[11]M. Hoch and H. L. Johnston, J. Phys. Chem. **65**, 855 (1961).
[12]I. I. Novikov and P. G. Strelkov, Vestnik. Akad. Nauk SSSR **34**, 26 (1964).
[13]I. Langmuir, Phys. Rev. **6**, 138 (1915).
[14]H. A. Jones, I. Langmuir and G. M. J. Mackay, Phys. Rev. **30**, 201 (1927).
[15]M. Pirani and H. Alterthum, Z. Elektrochem. **29**, 5 (1923).
[16]C. F Zalabak, NASA Tech. Note D–761 (1961).
[17]E. Rudy and S. Windisch, Aerojet–General Tech. Rept. No. AFML– TR–65–2 Part 1, Vol. III (July 1965).


## Tungsten (W) $W_1(cr)$

Enthalpy Reference Temperature = $T_r$ = 298.15 K — Standard State Pressure = $p°$ = 0.1 MPa

| T/K | $C_p°$ | $S°$ | $-[G°-H°(T_r)]/T$ | $H°-H°(T_r)$ | $\Delta_f H°$ | $\Delta_f G°$ | log $K_f$ |
|---|---|---|---|---|---|---|---|
| | $J{\cdot}K^{-1}mol^{-1}$ | | | $kJ{\cdot}mol^{-1}$ | | | |
| 0 | 0. | 0. | INFINITE | -4.973 | 0. | 0. | 0. |
| 100 | 16.033 | 9.612 | 52.820 | -4.321 | 0. | 0. | 0. |
| 200 | 22.489 | 23.273 | 34.839 | -2.313 | 0. | 0. | 0. |
| 250 | 23.686 | 28.431 | 33.056 | -1.156 | 0. | 0. | 0. |
| 298.15 | 24.295 | 32.660 | 32.660 | 0. | 0. | 0. | 0. |
| 300 | 24.313 | 32.810 | 32.660 | 0.045 | 0. | 0. | 0. |
| 350 | 24.644 | 36.583 | 32.957 | 1.269 | 0. | 0. | 0. |
| 400 | 24.928 | 39.893 | 33.622 | 2.509 | 0. | 0. | 0. |
| 450 | 25.144 | 42.842 | 34.485 | 3.760 | 0. | 0. | 0. |
| 500 | 25.359 | 45.502 | 35.456 | 5.023 | 0. | 0. | 0. |
| 600 | 25.790 | 50.163 | 37.529 | 7.580 | 0. | 0. | 0. |
| 700 | 26.229 | 54.172 | 39.627 | 10.181 | 0. | 0. | 0. |
| 800 | 26.669 | 57.703 | 41.670 | 12.826 | 0. | 0. | 0. |
| 900 | 27.112 | 60.870 | 43.631 | 15.515 | 0. | 0. | 0. |
| 1000 | 27.564 | 63.750 | 45.501 | 18.249 | 0. | 0. | 0. |
| 1100 | 28.017 | 66.398 | 47.282 | 21.028 | 0. | 0. | 0. |
| 1200 | 28.472 | 68.855 | 48.978 | 23.852 | 0. | 0. | 0. |
| 1300 | 28.930 | 71.152 | 50.596 | 26.722 | 0. | 0. | 0. |
| 1400 | 29.393 | 73.313 | 52.143 | 29.639 | 0. | 0. | 0. |
| 1500 | 29.862 | 75.357 | 53.623 | 32.601 | 0. | 0. | 0. |
| 1600 | 30.334 | 77.299 | 55.042 | 35.611 | 0. | 0. | 0. |
| 1700 | 30.807 | 79.152 | 56.407 | 38.668 | 0. | 0. | 0. |
| 1800 | 31.284 | 80.927 | 57.720 | 41.773 | 0. | 0. | 0. |
| 1900 | 31.765 | 82.631 | 58.986 | 44.925 | 0. | 0. | 0. |
| 2000 | 32.254 | 84.273 | 60.210 | 48.126 | 0. | 0. | 0. |
| 2100 | 32.744 | 85.858 | 61.394 | 51.376 | 0. | 0. | 0. |
| 2200 | 33.238 | 87.393 | 62.541 | 54.675 | 0. | 0. | 0. |
| 2300 | 33.736 | 88.881 | 63.654 | 58.024 | 0. | 0. | 0. |
| 2400 | 34.233 | 90.328 | 64.735 | 61.422 | 0. | 0. | 0. |
| 2500 | 34.736 | 91.735 | 65.787 | 64.870 | 0. | 0. | 0. |
| 2600 | 35.246 | 93.106 | 66.812 | 68.366 | 0. | 0. | 0. |
| 2700 | 36.192 | 94.453 | 67.811 | 71.935 | 0. | 0. | 0. |
| 2800 | 37.447 | 95.791 | 68.786 | 75.613 | 0. | 0. | 0. |
| 2900 | 39.120 | 97.133 | 69.740 | 79.440 | 0. | 0. | 0. |
| 3000 | 41.003 | 98.490 | 70.676 | 83.442 | 0. | 0. | 0. |
| 3100 | 43.430 | 99.873 | 71.595 | 87.662 | 0. | 0. | 0. |
| 3200 | 46.024 | 101.292 | 72.501 | 92.132 | 0. | 0. | 0. |
| 3300 | 48.953 | 102.752 | 73.396 | 96.877 | 0. | 0. | 0. |
| 3400 | 52.300 | 104.261 | 74.281 | 101.933 | 0. | 0. | 0. |
| 3500 | 56.484 | 105.835 | 75.160 | 107.363 | 0. | 0. | 0. |
| 3600 | 61.714 | 107.499 | 76.035 | 113.270 | 0. | 0. | 0. |
| 3680.000 | 66.149 | 108.904 | 76.734 | 118.383 | --- CRYSTAL <--> LIQUID --- | | |
| 3700 | 67.205 | 109.265 | 76.909 | 119.716 | -34.775 | 0.191 | -0.003 |
| 3800 | 72.697 | 111.130 | 77.785 | 126.712 | -31.336 | 1.091 | -0.015 |
| 3900 | 78.188 | 113.089 | 78.665 | 134.256 | -27.348 | 1.893 | -0.025 |
| 4000 | 83.680 | 115.138 | 79.551 | 142.349 | -22.811 | 2.587 | -0.034 |
| 4100 | 89.171 | 117.272 | 80.445 | 150.992 | -17.725 | 3.160 | -0.040 |
| 4200 | 94.663 | 119.487 | 81.348 | 160.184 | -12.090 | 3.602 | -0.045 |
| 4300 | 100.154 | 121.778 | 82.261 | 169.924 | -5.905 | 3.904 | -0.047 |
| 4400 | 105.646 | 124.144 | 83.186 | 180.214 | 0.828 | 4.055 | -0.048 |
| 4500 | 111.137 | 126.579 | 84.123 | 191.054 | 8.111 | 4.047 | -0.047 |
| 4600 | 116.629 | 129.082 | 85.073 | 202.442 | 15.943 | 3.872 | -0.044 |
| 4700 | 122.120 | 131.649 | 86.037 | 214.379 | 24.324 | 3.520 | -0.039 |
| 4800 | 127.612 | 134.278 | 87.014 | 226.866 | 33.254 | 2.984 | -0.032 |

PREVIOUS: December 1961 — CURRENT: June 1966

Tungsten (W) $W_1(cr)$

$S°(298.15\ K) = [45.678]\ J \cdot K^{-1} \cdot mol^{-1}$
$T_{fus} = 3680 \pm 20\ K$

$\Delta_f H°(298.15\ K) = [46.896]\ kJ \cdot mol^{-1}$
$\Delta_{fus}H° = 35.40 \pm 10.5\ kJ \cdot mol^{-1}$

## Enthalpy of Formation

The enthalpy of formation at 298.15 K was calculated from that of the crystal by adding $\Delta_{fus}H°$ and the difference in nthalpy, $H°(3680\ K)$–$H°(298.15\ K)$, between the crystal and liquid.

## Heat Capacity and Entropy

The heat capacity was estimated as 8.5 $cal \cdot mol^{-1}\ K^{-1}$ by analogy with other monatomic metals. The entropy at 298.15 K was calculated in manner analogous to that used for the enthalpy of formation. At 2450 K a glass transition is assumed below which the heat capacity was that of the crystal.

## Fusion Data

Refer to the crystal table for details.

## Vaporization Data

The boiling point and enthalpy of vaporization are calculated from the adopted functions and enthalpy of sublimation in order to maintain proper thermodynamic consistency.

Enthalpy Reference Temperature = $T_r$ = 298.15 K; Standard State Pressure = $p°$ = 0.1 MPa

| T/K | $C_p°$ (J·K⁻¹mol⁻¹) | $S°$ (J·K⁻¹mol⁻¹) | $-[G°-H°(T_r)]/T$ (J·K⁻¹mol⁻¹) | $H°-H°(T_r)$ (kJ·mol⁻¹) | $\Delta_f H°$ (kJ·mol⁻¹) | $\Delta_f G°$ (kJ·mol⁻¹) | log $K_f$ |
|---|---|---|---|---|---|---|---|
| 0 | | | | | | | |
| 100 | | | | | | | |
| 200 | | | | | | | |
| 250 | | | | | | | |
| 298.15 | 24.296 | 45.678 | 45.678 | 0. | 46.896 | 43.015 | −7.536 |
| 300 | 24.310 | 45.828 | 45.678 | 0.045 | 46.896 | 42.991 | −7.485 |
| 350 | 24.642 | 49.601 | 45.975 | 1.269 | 46.896 | 42.340 | −6.319 |
| 400 | 24.928 | 52.911 | 46.640 | 2.508 | 46.896 | 41.689 | −5.444 |
| 450 | 25.144 | 55.859 | 47.503 | 3.760 | 46.896 | 41.038 | −4.764 |
| 500 | 25.359 | 58.519 | 48.474 | 5.023 | 46.896 | 40.388 | −4.219 |
| 600 | 25.790 | 63.181 | 50.547 | 7.580 | 46.896 | 39.086 | −3.403 |
| 700 | 26.229 | 67.190 | 52.645 | 10.181 | 46.896 | 37.784 | −2.819 |
| 800 | 26.669 | 70.721 | 54.688 | 12.826 | 46.896 | 36.482 | −2.382 |
| 900 | 27.112 | 73.887 | 56.648 | 15.515 | 46.896 | 35.180 | −2.042 |
| 1000 | 27.564 | 76.767 | 58.518 | 18.249 | 46.896 | 33.879 | −1.770 |
| 1100 | 28.017 | 79.416 | 60.299 | 21.028 | 46.896 | 32.577 | −1.547 |
| 1200 | 28.472 | 81.873 | 61.996 | 23.852 | 46.896 | 31.275 | −1.361 |
| 1300 | 28.930 | 84.170 | 63.614 | 26.722 | 46.896 | 29.973 | −1.204 |
| 1400 | 29.393 | 86.331 | 65.160 | 29.638 | 46.896 | 28.672 | −1.070 |
| 1500 | 29.862 | 88.375 | 66.640 | 32.601 | 46.896 | 27.370 | −0.953 |
| 1600 | 30.334 | 90.317 | 68.060 | 35.611 | 46.896 | 26.068 | −0.851 |
| 1700 | 30.806 | 92.170 | 69.424 | 38.668 | 46.896 | 24.766 | −0.761 |
| 1800 | 31.284 | 93.944 | 70.737 | 41.772 | 46.896 | 23.465 | −0.681 |
| 1900 | 31.768 | 95.649 | 72.004 | 44.925 | 46.896 | 22.163 | −0.609 |
| 2000 | 32.254 | 97.291 | 73.228 | 48.126 | 46.897 | 20.861 | −0.545 |
| 2100 | 32.745 | 98.876 | 74.411 | 51.376 | 46.897 | 19.559 | −0.487 |
| 2200 | 33.238 | 100.411 | 75.558 | 54.675 | 46.897 | 18.258 | −0.433 |
| 2300 | 33.735 | 101.899 | 76.672 | 58.024 | 46.897 | 16.956 | −0.385 |
| 2400 | 34.233 | 103.345 | 77.753 | 61.422 | 46.897 | 15.654 | −0.341 |
| 2450.000 | 34.483 | 104.054 | 78.283 | 63.140 | GLASS <−−> LIQ | | |
| 2450.000 | 35.564 | 104.054 | 78.283 | 63.140 | TRANSITION | | |
| 2500 | 35.564 | 104.772 | 78.805 | 64.918 | 46.944 | 14.352 | −0.300 |
| 2600 | 35.564 | 106.167 | 79.831 | 68.475 | 47.005 | 13.047 | −0.262 |
| 2700 | 35.564 | 107.509 | 80.831 | 72.031 | 46.992 | 11.740 | −0.227 |
| 2800 | 35.564 | 108.803 | 81.807 | 75.587 | 46.870 | 10.437 | −0.195 |
| 2900 | 35.564 | 110.051 | 82.760 | 79.144 | 46.600 | 9.140 | −0.165 |
| 3000 | 35.564 | 111.256 | 83.690 | 82.700 | 46.155 | 7.855 | −0.137 |
| 3100 | 35.564 | 112.423 | 84.598 | 86.257 | 45.491 | 6.589 | −0.111 |
| 3200 | 35.564 | 113.552 | 85.485 | 89.813 | 44.577 | 5.348 | −0.087 |
| 3300 | 35.564 | 114.646 | 86.352 | 93.369 | 43.388 | 4.139 | −0.066 |
| 3400 | 35.564 | 115.708 | 87.200 | 96.926 | 41.889 | 2.972 | −0.046 |
| 3500 | 35.564 | 116.739 | 88.030 | 100.482 | 40.015 | 1.853 | −0.028 |
| 3600 | 35.564 | 117.741 | 88.841 | 104.039 | 37.665 | 0.795 | −0.012 |
| 3680.000 | 35.564 | 118.522 | 89.478 | 106.884 | −−− CRYSTAL <−−> LIQUID −−− | | |
| 3700 | 35.564 | 118.715 | 89.635 | 107.595 | 0. | 0. | 0. |
| 3800 | 35.564 | 119.663 | 90.413 | 111.151 | 0. | 0. | 0. |
| 3900 | 35.564 | 120.587 | 91.175 | 114.708 | 0. | 0. | 0. |
| 4000 | 35.564 | 121.488 | 91.922 | 118.264 | 0. | 0. | 0. |
| 4100 | 35.564 | 122.366 | 92.653 | 121.821 | 0. | 0. | 0. |
| 4200 | 35.564 | 123.223 | 93.371 | 125.377 | 0. | 0. | 0. |
| 4300 | 35.564 | 124.060 | 94.075 | 128.933 | 0. | 0. | 0. |
| 4400 | 35.564 | 124.877 | 94.766 | 132.490 | 0. | 0. | 0. |
| 4500 | 35.564 | 125.676 | 95.444 | 136.046 | 0. | 0. | 0. |
| 4600 | 35.564 | 126.458 | 96.110 | 139.603 | 0. | 0. | 0. |
| 4700 | 35.564 | 127.223 | 96.764 | 143.159 | 0. | 0. | 0. |
| 4800 | 35.564 | 127.972 | 97.406 | 146.715 | 0. | 0. | 0. |
| 4900 | 35.564 | 128.705 | 98.037 | 150.272 | 0. | 0. | 0. |
| 5000 | 35.564 | 129.423 | 98.658 | 153.828 | 0. | 0. | 0. |
| 5200 | 35.564 | 130.818 | 99.868 | 160.941 | 0. | 0. | 0. |
| 5400 | 35.564 | 132.161 | 101.039 | 168.054 | 0. | 0. | 0. |
| 5600 | 35.564 | 133.454 | 102.174 | 175.167 | 0. | 0. | 0. |
| 5800 | 35.564 | 134.702 | 103.274 | 182.279 | 0. | 0. | 0. |
| 6000 | 35.564 | 135.908 | 104.342 | 189.392 | 0. | 0. | 0. |

PREVIOUS: December 1961 CURRENT: June 1966

Tungsten (W) CRYSTAL-LIQUID

| | | | | |
|---|---|---|---|---|
| 0 | to | 3680 | K | crystal |
| above | | 3680 | K | liquid |

Refer to the individual tables for details.

$A_r$ = 183.85 Tungsten (W) $W_1(cr,l)$

Enthalpy Reference Temperature = $T_r$ = 298.15 K — Standard State Pressure = $p^\circ$ = 0.1 MPa

| | J·K⁻¹mol⁻¹ | | | kJ·mol⁻¹ | | | |
|---|---|---|---|---|---|---|---|
| T/K | $C_p^\circ$ | $S^\circ$ | $-[G^\circ-H^\circ(T_r)]/T$ | $H^\circ-H^\circ(T_r)$ | $\Delta_fH^\circ$ | $\Delta_fG^\circ$ | log $K_f$ |
| 0 | 0. | 0. | INFINITE | −4.973 | 0. | 0. | 0. |
| 100 | 16.033 | 9.612 | 52.820 | −4.321 | 0. | 0. | 0. |
| 200 | 22.489 | 23.273 | 34.839 | −2.313 | 0. | 0. | 0. |
| 250 | 23.686 | 28.431 | 33.056 | −1.156 | 0. | 0. | 0. |
| 298.15 | 24.295 | 32.660 | 32.660 | 0. | 0. | 0. | 0. |
| 300 | 24.313 | 32.810 | 32.660 | 0.045 | 0. | 0. | 0. |
| 350 | 24.644 | 36.583 | 32.957 | 1.269 | 0. | 0. | 0. |
| 400 | 24.928 | 39.893 | 33.622 | 2.509 | 0. | 0. | 0. |
| 450 | 25.144 | 42.842 | 34.485 | 3.760 | 0. | 0. | 0. |
| 500 | 25.359 | 45.502 | 35.456 | 5.023 | 0. | 0. | 0. |
| 600 | 25.790 | 50.163 | 37.529 | 7.580 | 0. | 0. | 0. |
| 700 | 26.229 | 54.172 | 39.627 | 10.181 | 0. | 0. | 0. |
| 800 | 26.669 | 57.703 | 41.670 | 12.826 | 0. | 0. | 0. |
| 900 | 27.112 | 60.870 | 43.631 | 15.515 | 0. | 0. | 0. |
| 1000 | 27.564 | 63.750 | 45.501 | 18.249 | 0. | 0. | 0. |
| 1100 | 28.017 | 66.398 | 47.282 | 21.028 | 0. | 0. | 0. |
| 1200 | 28.472 | 68.855 | 48.978 | 23.852 | 0. | 0. | 0. |
| 1300 | 28.930 | 71.152 | 50.596 | 26.722 | 0. | 0. | 0. |
| 1400 | 29.393 | 73.313 | 52.143 | 29.639 | 0. | 0. | 0. |
| 1500 | 29.862 | 75.357 | 53.623 | 32.601 | 0. | 0. | 0. |
| 1600 | 30.334 | 77.299 | 55.042 | 35.611 | 0. | 0. | 0. |
| 1700 | 30.807 | 79.152 | 56.407 | 38.668 | 0. | 0. | 0. |
| 1800 | 31.284 | 80.927 | 57.720 | 41.773 | 0. | 0. | 0. |
| 1900 | 31.765 | 82.631 | 58.986 | 44.925 | 0. | 0. | 0. |
| 2000 | 32.254 | 84.273 | 60.210 | 48.126 | 0. | 0. | 0. |
| 2100 | 32.744 | 85.858 | 61.394 | 51.376 | 0. | 0. | 0. |
| 2200 | 33.238 | 87.393 | 62.541 | 54.675 | 0. | 0. | 0. |
| 2300 | 33.736 | 88.881 | 63.654 | 58.024 | 0. | 0. | 0. |
| 2400 | 34.233 | 90.328 | 64.735 | 61.422 | 0. | 0. | 0. |
| 2500 | 34.736 | 91.735 | 65.787 | 64.870 | 0. | 0. | 0. |
| 2600 | 35.246 | 93.106 | 66.812 | 68.366 | 0. | 0. | 0. |
| 2700 | 36.192 | 94.453 | 67.811 | 71.935 | 0. | 0. | 0. |
| 2800 | 37.447 | 95.791 | 68.786 | 75.613 | 0. | 0. | 0. |
| 2900 | 39.120 | 97.133 | 69.740 | 79.440 | 0. | 0. | 0. |
| 3000 | 41.003 | 98.490 | 70.676 | 83.442 | 0. | 0. | 0. |
| 3100 | 43.430 | 99.873 | 71.595 | 87.662 | 0. | 0. | 0. |
| 3200 | 46.024 | 101.292 | 72.501 | 92.132 | 0. | 0. | 0. |
| 3300 | 48.953 | 102.752 | 73.396 | 96.877 | 0. | 0. | 0. |
| 3400 | 52.300 | 104.261 | 74.281 | 101.933 | 0. | 0. | 0. |
| 3500 | 56.484 | 105.835 | 75.160 | 107.363 | 0. | 0. | 0. |
| 3600 | 61.714 | 107.499 | 76.035 | 113.270 | 0. | 0. | 0. |
| 3680.000 | 66.149 | 108.904 | 76.734 | 118.383 | CRYSTAL <––> LIQUID TRANSITION | | |
| 3680.000 | 35.564 | 118.522 | 76.734 | 153.780 | | | |
| 3700 | 35.564 | 118.715 | 76.961 | 154.491 | 0. | 0. | 0. |
| 3800 | 35.564 | 119.663 | 78.072 | 158.048 | 0. | 0. | 0. |
| 3900 | 35.564 | 120.587 | 79.150 | 161.604 | 0. | 0. | 0. |
| 4000 | 35.564 | 121.488 | 80.197 | 165.161 | 0. | 0. | 0. |
| 4100 | 35.564 | 122.366 | 81.215 | 168.717 | 0. | 0. | 0. |
| 4200 | 35.564 | 123.223 | 82.205 | 172.273 | 0. | 0. | 0. |
| 4300 | 35.564 | 124.060 | 83.169 | 175.830 | 0. | 0. | 0. |
| 4400 | 35.564 | 124.877 | 84.108 | 179.386 | 0. | 0. | 0. |
| 4500 | 35.564 | 125.676 | 85.023 | 182.943 | 0. | 0. | 0. |
| 4600 | 35.564 | 126.458 | 85.915 | 186.499 | 0. | 0. | 0. |
| 4700 | 35.564 | 127.223 | 86.786 | 190.055 | 0. | 0. | 0. |
| 4800 | 35.564 | 127.972 | 87.636 | 193.612 | 0. | 0. | 0. |
| 4900 | 35.564 | 128.705 | 88.467 | 197.168 | 0. | 0. | 0. |
| 5000 | 35.564 | 129.423 | 89.279 | 200.725 | 0. | 0. | 0. |
| 5100 | 35.564 | 130.128 | 90.073 | 204.281 | 0. | 0. | 0. |
| 5200 | 35.564 | 130.818 | 90.850 | 207.837 | 0. | 0. | 0. |
| 5300 | 35.564 | 131.496 | 91.610 | 211.394 | 0. | 0. | 0. |
| 5400 | 35.564 | 132.161 | 92.355 | 214.950 | 0. | 0. | 0. |
| 5500 | 35.564 | 132.813 | 93.085 | 218.507 | 0. | 0. | 0. |
| 5600 | 35.564 | 133.454 | 93.800 | 222.063 | 0. | 0. | 0. |
| 5700 | 35.564 | 134.083 | 94.501 | 225.619 | 0. | 0. | 0. |
| 5800 | 35.564 | 134.702 | 95.189 | 229.176 | 0. | 0. | 0. |
| 5900 | 35.564 | 135.310 | 95.864 | 232.732 | 0. | 0. | 0. |
| 6000 | 35.564 | 135.908 | 96.526 | 236.289 | 0. | 0. | 0. |

PREVIOUS: CURRENT: June 1966

Tungsten (W) $W_1(cr,l)$

IP(W,g) = 64400 ± 100 $cm^{-1}$
$S°(298.15\ K)$ = 173.95 ± 0.08 $J\cdot K^{-1}\cdot mol^{-1}$

$\Delta_f H°(0\ K)$ = 849.8 ± 6.3 $kJ\cdot mol^{-1}$
$\Delta_f H°(298.15\ K)$ = 851.0 ± 6.3 $kJ\cdot mol^{-1}$

Electronic Levels and Quantum Weights

| State | $\epsilon_i$, $cm^{-1}$ | $g_i$ |
|---|---|---|
| $^5D_0$ | 0.00 | 1 |
| $^5D_1$ | 1670.29 | 3 |
| $^5D_2$ | 3325.53 | 5 |
| $^5D_3$ | 4830.00 | 7 |
| $^5D_4$ | 6219.33 | 9 |
| . | . | |
| . | . | |
| . | . | |
| – | 62154.50 | 11 |
| IP | 66400.00 | |

## Enthalpy of Formation

The enthalpy of formation is the enthalpy of sublimation at 298.15 K; this has been obtained by a 2nd and 3rd law analysis of the vapor pressure data of three investigators.

| Source | T/K** | Data Points | $\Delta_{sub}H°(298.15\ K)$, $kcal\cdot mol^{-1}$ 2nd law | 3rd law | Drift $cal\cdot K^{-1}\cdot mol^{-1}$ |
|---|---|---|---|---|---|
| 1 | 2511–3053 | 12* | 200.9 ± 3.6 | 201.57 ± 1.6 | 0.1 ± 1.4 |
| 2 | 2383–3123 | 14 | 214.8 ± 1.4 | 202.17 ± 2.5 | −4.7 ± 0.5 |
| 3 | 2574–3183 | 10 | 202.4 ± 2.7 | 203.35 ± 1.2 | 0.4 ± 1.0 |

* 1 point rejected due to failure of a statistical test.
** All temperatures are taken from Szwarc[3] who has corrected the earlier measurements.

The values are remarkably good since even at the highest temperature the pressures are less than $10^{-6}$ atm; all workers used the Langmuir technique. Since the data of references 1 and 3 do not drift, it may be assumed that the accommodation coefficient is unity or close to unity. The drift in the second set cannot be eliminated by assuming a non–unity coefficient, nor does there appear to be a constant pressure error. Most probably the drift is due to slight errors in temperature, for example if the readings were 24 K high at the low end and 10 K low at the high end the drift would be eliminated; errors of this magnitude are quite possible. The value adopted for $\Delta_{sub}H°(298.15\ K)$ is 203.4 ± 1.5 $kcal\cdot mol^{-1}$.

## Heat Capacity and Entropy

The electronic energy levels are taken from those listed by Moore.[4] Levels above 25000 $cm^{-1}$ were averaged.

## References


[1]H. A. Jones, I. Langmuir and G. M. J. Mackay, Phys. Rev. 30, 201 (1927).
[2]C. Zwikker, Physica 5, 249 (1925).
[3]R. Szwarc, E. R. Plante, and J. J. Diamond, J. Research Nat. Bur. Stand. 69A, 417 (1965).


Enthalpy Reference Temperature = $T_r$ = 298.15 K — Standard State Pressure = $p°$ = 0.1 MPa

| T/K | $C_p°$ ($J\cdot K^{-1}mol^{-1}$) | $S°$ | $-[G°-H°(T_r)]/T$ | $H°-H°(T_r)$ ($kJ\cdot mol^{-1}$) | $\Delta_f H°$ | $\Delta_f G°$ | log $K_f$ |
|---|---|---|---|---|---|---|---|
| 0 | .000 | .000 | INFINITE | −6.216 | 849.782 | 849.782 | INFINITE |
| 100 | 20.786 | 151.176 | 192.554 | −4.138 | 851.209 | 837.052 | −437.231 |
| 200 | 20.808 | 165.586 | 175.880 | −2.059 | 851.280 | 822.817 | −214.898 |
| 250 | 20.941 | 170.240 | 174.303 | −1.016 | 851.166 | 815.714 | −170.434 |
| 298.15 | 21.306 | 173.955 | 173.955 | .000 | 851.026 | 808.898 | −141.716 |
| 300 | 21.326 | 174.087 | 173.955 | .039 | 851.020 | 808.637 | −140.796 |
| 350 | 22.059 | 177.425 | 174.217 | 1.123 | 850.879 | 801.585 | −119.630 |
| 400 | 23.163 | 180.438 | 174.809 | 2.252 | 850.769 | 794.550 | −103.758 |
| 450 | 24.611 | 183.247 | 175.592 | 3.445 | 850.710 | 787.527 | −91.414 |
| 500 | 26.344 | 185.927 | 176.493 | 4.717 | 850.720 | 780.507 | −81.539 |
| 600 | 30.337 | 191.077 | 178.497 | 7.548 | 850.993 | 766.445 | −66.725 |
| 700 | 34.381 | 196.061 | 180.652 | 10.786 | 851.631 | 752.308 | −56.138 |
| 800 | 37.765 | 200.883 | 182.881 | 14.402 | 852.601 | 738.057 | −48.190 |
| 900 | 40.071 | 205.476 | 185.139 | 18.303 | 853.814 | 723.668 | −42.001 |
| 1000 | 41.235 | 209.768 | 187.390 | 22.377 | 855.154 | 709.136 | −37.041 |
| 1100 | 41.438 | 213.714 | 189.607 | 26.518 | 856.516 | 694.468 | −32.978 |
| 1200 | 40.951 | 217.303 | 191.768 | 30.642 | 857.815 | 679.678 | −29.586 |
| 1300 | 40.037 | 220.547 | 193.859 | 34.694 | 858.997 | 664.785 | −26.711 |
| 1400 | 38.900 | 223.473 | 195.871 | 38.642 | 860.029 | 649.806 | −24.245 |
| 1500 | 37.687 | 226.115 | 197.801 | 42.472 | 860.896 | 634.758 | −22.104 |
| 1600 | 36.488 | 228.509 | 199.647 | 46.180 | 861.595 | 619.659 | −20.230 |
| 1700 | 35.360 | 230.687 | 201.409 | 49.772 | 862.129 | 604.521 | −18.575 |
| 1800 | 34.331 | 232.678 | 203.092 | 53.255 | 862.508 | 589.355 | −17.103 |
| 1900 | 33.417 | 234.510 | 204.698 | 56.642 | 862.742 | 574.173 | −15.785 |
| 2000 | 32.621 | 236.203 | 206.232 | 59.943 | 862.842 | 558.982 | −14.599 |
| 2100 | 31.943 | 237.778 | 207.697 | 63.170 | 862.820 | 543.789 | −13.526 |
| 2200 | 31.379 | 239.250 | 209.098 | 66.335 | 862.686 | 528.600 | −12.551 |
| 2300 | 30.922 | 240.635 | 210.439 | 69.449 | 862.451 | 513.419 | −11.660 |
| 2400 | 30.566 | 241.943 | 211.725 | 72.523 | 862.126 | 498.251 | −10.844 |
| 2500 | 30.304 | 243.185 | 212.959 | 75.566 | 861.721 | 483.097 | −10.094 |
| 2600 | 30.129 | 244.370 | 214.144 | 78.586 | 861.246 | 467.961 | −9.401 |
| 2700 | 30.035 | 245.505 | 215.285 | 81.594 | 860.685 | 452.845 | −8.761 |
| 2800 | 30.013 | 246.596 | 216.384 | 84.596 | 860.008 | 437.752 | −8.166 |
| 2900 | 30.060 | 247.650 | 217.444 | 87.599 | 859.184 | 422.686 | −7.613 |
| 3000 | 30.167 | 248.671 | 218.468 | 90.610 | 858.194 | 407.650 | −7.098 |
| 3100 | 30.331 | 249.663 | 219.458 | 93.634 | 856.998 | 392.651 | −6.616 |
| 3200 | 30.545 | 250.629 | 220.417 | 96.678 | 855.571 | 377.695 | −6.165 |
| 3300 | 30.805 | 251.573 | 221.347 | 99.745 | 853.893 | 362.786 | −5.742 |
| 3400 | 31.106 | 252.497 | 222.250 | 102.840 | 851.933 | 347.933 | −5.345 |
| 3500 | 31.446 | 253.403 | 223.127 | 105.967 | 849.630 | 333.142 | −4.972 |
| 3600 | 31.822 | 254.294 | 223.980 | 109.130 | 846.886 | 318.423 | −4.620 |
| 3700 | 32.230 | 255.172 | 224.811 | 112.333 | 808.867 | 303.977 | −4.291 |
| 3800 | 32.670 | 256.037 | 225.622 | 115.578 | 808.555 | 290.336 | −3.991 |
| 3900 | 33.141 | 256.892 | 226.413 | 118.868 | 808.289 | 276.702 | −3.706 |
| 4000 | 33.642 | 257.737 | 227.185 | 122.207 | 808.072 | 263.075 | −3.435 |
| 4100 | 34.174 | 258.574 | 227.941 | 125.597 | 807.906 | 249.452 | −3.178 |
| 4200 | 34.738 | 259.404 | 228.680 | 129.043 | 807.795 | 235.833 | −2.933 |
| 4300 | 35.335 | 260.229 | 229.404 | 132.546 | 807.742 | 222.215 | −2.699 |
| 4400 | 35.968 | 261.048 | 230.114 | 136.111 | 807.750 | 208.598 | −2.476 |
| 4500 | 36.638 | 261.864 | 230.810 | 139.741 | 807.824 | 194.980 | −2.263 |
| 4600 | 37.348 | 262.677 | 231.494 | 143.440 | 807.966 | 181.360 | −2.059 |
| 4700 | 38.102 | 263.488 | 232.166 | 147.212 | 808.182 | 167.736 | −1.864 |
| 4800 | 38.900 | 264.298 | 232.827 | 151.061 | 808.475 | 154.107 | −1.677 |
| 4900 | 39.746 | 265.109 | 233.478 | 154.993 | 808.851 | 140.470 | −1.497 |
| 5000 | 40.642 | 265.921 | 234.119 | 159.012 | 809.313 | 126.825 | −1.325 |
| 5100 | 41.590 | 266.735 | 234.750 | 163.124 | 809.868 | 113.170 | −1.159 |
| 5200 | 42.591 | 267.552 | 235.373 | 167.332 | 810.520 | 99.503 | −1.000 |
| 5300 | 43.646 | 268.374 | 235.988 | 171.644 | 811.275 | 85.823 | −.846 |
| 5400 | 44.755 | 269.200 | 236.595 | 176.063 | 812.139 | 72.127 | −.698 |
| 5500 | 45.916 | 270.031 | 237.196 | 180.596 | 813.115 | 58.414 | −.555 |
| 5600 | 47.129 | 270.870 | 237.790 | 185.248 | 814.211 | 44.683 | −.417 |
| 5700 | 48.391 | 271.715 | 238.377 | 190.024 | 815.430 | 30.931 | −.283 |
| 5800 | 49.698 | 272.568 | 238.959 | 194.928 | 816.778 | 17.156 | −.155 |
| 5900 | 51.046 | 273.429 | 239.536 | 199.965 | 818.258 | 3.357 | −.030 |
| 6000 | 52.431 | 274.298 | 240.108 | 205.138 | 819.875 | −10.468 | .091 |

PREVIOUS. June 1966 (1 atm) CURRENT: June 1966 (1 bar)

$IP(W^+, g) = 142800 \pm 4000\ cm^{-1}$
$S°(298.15\ K) = 179.74 \pm 0.08\ J{\cdot}K^{-1}{\cdot}mol^{-1}$

$\Delta_f H°(0\ K) = 1620.2 \pm 7\ kJ{\cdot}mol^{-1}$
$\Delta_f H°(298.15\ K) = [1627.623]\ kJ{\cdot}mol^{-1}$

Electronic Levels and Quantum Weights

| State | $\epsilon_i$, $cm^{-1}$ | $g_i$ |
|---|---|---|
| $^6D_{1/2}$ | 0.00 | 2 |
| $^6D_{3/2}$ | 1518.78 | 4 |
| $^6D_{5/2}$ | 3172.52 | 6 |
| $^6D_{7/2}$ | 4716.32 | 8 |
| $^6D_{9/2}$ | 6147.16 | 10 |
| . | . | . |
| . | . | . |
| . | . | . |
| $^4H_{9/2}$ | 64516.37 | 10 |
| IP | [142800] | |

## Enthalpy of Formation

$\Delta_f H°(W^+, g, 0\ K)$ is calculated from $\Delta_f H°(W, g, 0\ K)$[1] using the spectroscopic value of IP(W) = 64400 ± 100 $cm^{-1}$ (770.40 ± 1.20 $kJ{\cdot}mol^{-1}$) from Moore.[2] The ionization limit is converted from $cm^{-1}$ to $kJ{\cdot}mol^{-1}$ using the factor, 1 $cm^{-1}$ = 0.01196266 $kJ{\cdot}mol^{-1}$, which is derived from the 1973 CODATA fundamental constants.[3] Rosenstock *et al.*[4] and Levin and Lias[5] have summarized additional ionization and appearance potential data.

$\Delta_f H°(W^+, g, 298.15\ K)$ is calculated from $\Delta_f H°(W, g, 0\ K)$ by using IP(W) with JANAF[1] enthalpies, $H°(0\ K)-H°(298.15\ K)$, for W(g), $W^+(g)$, and $e^-$(ref). $\Delta_f H°(W \rightarrow W^+ + e^-, 298.15\ K)$ differs from a room temperature threshold energy due to inclusion of these enthalpies and to threshold effects discussed by Rosenstock *et al.*[4] $\Delta_f H°(298.15\ K)$ should be changed by −6.197 $kJ{\cdot}mol^{-1}$ if it is to be used in the ion convention that excludes the enthalpy of the electron.

## Heat Capacity and Entropy

The information on electronic energy levels and quantum weights, given by Moore,[2] is incomplete because many theoretically predicted levels have not been observed. Although we have listed only the ground, the first four excited states, the highest observed excited state, and the ionization potential for $W^+(g)$, all levels listed by Moore[6] as well as estimated levels, are used in the calculation. The observed levels are too numerous to list completely. The calculations indicate that for $W^+(g)$, the thermodynamic functions are independent of the estimated missing levels (for $n = 6$) and the cut-off procedure; the Gibbs energy function showing variations of 0.8% at this temperature. The reported uncertainty is $S°(298.15\ K)$ is due to uncertainties in the relative ionic mass, the fundamental constants, and the low lying atomic energy levels. Extension of these calculations above 6000 K may require consideration of the higher excited states ($n > 6$), and use of different fill and cut-off procedures.[7]

## References


[1] JANAF Thermochemical Tables: W(g), 6-30-66; $e^-$(ref), 3-31-82.
[2] C. E. Moore, U. S. Nat. Bur. Stand., NSRDS-NBS-34, 8 pp. (1970).
[3] E. R. Cohen and B. N. Taylor, J. Phys. Chem. Ref. Data **2**, 663 (1973).
[4] H. M. Rosenstock, K. Draxl *et al.*, J. Phys. Chem. Ref. Data **6**, Supp. 1, 783 pp. (1977).
[5] R. D Levin and S. G. Lias, U S. Natl. Bur. Stand. NSRDS-NBS-71, 634 pp. (1982).
[6] C. E. Moore, U. S. Nat. Bur. Stand., NSRDS-NBS-35, Volume III, (1970) [Reprint of NBS Circular 467, Volume III, 1958].
[7] J. R. Downey, Jr., The Dow Chemical Company, AFOSR-TR-78-0960, Contract No. F44620-75-1-0048, (1978).


Enthalpy Reference Temperature = $T_r$ = 298.15 K — Standard State Pressure = $p°$ = 0.1 MPa

| | $J{\cdot}K^{-1}mol^{-1}$ | | | $kJ{\cdot}mol^{-1}$ | | | |
|---|---|---|---|---|---|---|---|
| T/K | $C_p°$ | $S°$ | $-[G°-H°(T_r)]/T$ | $H°-H°(T_r)$ | $\Delta_f H°$ | $\Delta_f G°$ | log $K_f$ |
| 0 | .000 | .000 | INFINITE | −6.221 | 1620.178 | | |
| 100 | 20.786 | 156.939 | 198.365 | −4.143 | | | |
| 200 | 20.822 | 171.350 | 181.667 | −2.063 | | | |
| 250 | 20.989 | 176.011 | 180.086 | −1.019 | | | |
| 298.15 | 21.372 | 179.737 | 179.737 | .000 | 1627.623 | 1577.517 | −276.374 |
| 300 | 21.391 | 179.869 | 179.737 | .040 | 1627.656 | 1577.206 | −274.616 |
| 350 | 22.045 | 183.213 | 180.000 | 1.125 | 1628.556 | 1568.727 | −234.120 |
| 400 | 22.891 | 186.210 | 180.592 | 2.247 | 1629.479 | 1560.117 | −203.730 |
| 450 | 23.844 | 188.961 | 181.371 | 3.415 | 1630.434 | 1551.390 | −180.081 |
| 500 | 24.828 | 191.524 | 182.260 | 4.632 | 1631.428 | 1542.554 | −161.150 |
| 600 | 26.695 | 196.219 | 184.202 | 7.210 | 1633.527 | 1524.585 | −132.727 |
| 700 | 28.294 | 200.458 | 186.226 | 9.962 | 1635.757 | 1506.253 | −112.398 |
| 800 | 29.616 | 204.325 | 188.250 | 12.860 | 1638.088 | 1487.595 | −97.130 |
| 900 | 30.703 | 207.878 | 190.237 | 15.877 | 1640.495 | 1468.639 | −85.238 |
| 1000 | 31.603 | 211.161 | 192.167 | 18.994 | 1642.957 | 1449.412 | −75.710 |
| 1100 | 32.347 | 214.209 | 194.034 | 22.193 | 1645.455 | 1429.937 | −67.902 |
| 1200 | 32.956 | 217.051 | 195.835 | 25.459 | 1647.975 | 1410.233 | −61.386 |
| 1300 | 33.441 | 219.709 | 197.570 | 28.780 | 1650.505 | 1390.319 | −55.864 |
| 1400 | 33.813 | 222.201 | 199.242 | 32.143 | 1653.031 | 1370.210 | −51.123 |
| 1500 | 34.082 | 224.544 | 200.851 | 35.539 | 1655.542 | 1349.921 | −47.008 |
| 1600 | 34.261 | 226.750 | 202.401 | 38.957 | 1658.029 | 1329.465 | −43.403 |
| 1700 | 34.362 | 228.830 | 203.896 | 42.389 | 1660.482 | 1308.854 | −40.216 |
| 1800 | 34.401 | 230.795 | 205.336 | 45.827 | 1662.895 | 1288.100 | −37.380 |
| 1900 | 34.393 | 232.655 | 206.725 | 49.267 | 1665.261 | 1267.214 | −34.838 |
| 2000 | 34.351 | 234.419 | 208.066 | 52.705 | 1667.576 | 1246.204 | −32.547 |
| 2100 | 34.288 | 236.093 | 209.361 | 56.137 | 1669.837 | 1225.079 | −30.472 |
| 2200 | 34.218 | 237.687 | 210.613 | 59.562 | 1672.042 | 1203.848 | −28.583 |
| 2300 | 34.148 | 239.206 | 211.823 | 62.980 | 1674.190 | 1182.518 | −26.856 |
| 2400 | 34.087 | 240.658 | 212.995 | 66.392 | 1676.282 | 1161.096 | −25.271 |
| 2500 | 34.041 | 242.048 | 214.129 | 69.798 | 1678.319 | 1139.588 | −23.810 |
| 2600 | 34.013 | 243.383 | 215.229 | 73.201 | 1680.304 | 1118.000 | −22.461 |
| 2700 | 34.008 | 244.666 | 216.296 | 76.602 | 1682.214 | 1096.336 | −21.210 |
| 2800 | 34.026 | 245.904 | 217.331 | 80.003 | 1684.016 | 1074.603 | −20.047 |
| 2900 | 34.067 | 247.098 | 218.337 | 83.407 | 1685.672 | 1052.809 | −18.963 |
| 3000 | 34.130 | 248.254 | 219.315 | 86.817 | 1687.159 | 1030.960 | −17.951 |
| 3100 | 34.216 | 249.375 | 220.267 | 90.234 | 1688.435 | 1009.065 | −17.003 |
| 3200 | 34.320 | 250.462 | 221.193 | 93.661 | 1689.470 | 987.133 | −16.113 |
| 3300 | 34.442 | 251.520 | 222.096 | 97.099 | 1690.241 | 965.172 | −15.277 |
| 3400 | 34.578 | 252.551 | 222.977 | 100.550 | 1690.715 | 943.192 | −14.490 |
| 3500 | 34.725 | 253.555 | 223.836 | 104.015 | 1690.828 | 921.204 | −13.748 |
| 3600 | 34.882 | 254.535 | 224.676 | 107.495 | 1690.480 | 899.218 | −13.047 |
| 3700 | 35.044 | 255.493 | 225.496 | 110.991 | 1654.834 | 877.440 | −12.387 |
| 3800 | 35.209 | 256.430 | 226.297 | 114.504 | 1656.869 | 856.402 | −11.772 |
| 3900 | 35.375 | 257.347 | 227.082 | 118.033 | 1658.920 | 835.311 | −11.188 |
| 4000 | 35.538 | 258.244 | 227.850 | 121.579 | 1660.988 | 814.166 | −10.632 |
| 4100 | 35.698 | 259.124 | 228.602 | 125.141 | 1663.072 | 792.970 | −10.103 |
| 4200 | 35.851 | 259.986 | 229.339 | 128.718 | 1665.172 | 771.723 | −9.598 |
| 4300 | 35.996 | 260.831 | 230.061 | 132.311 | 1667.286 | 750.425 | −9.116 |
| 4400 | 36.132 | 261.660 | 230.770 | 135.917 | 1669.415 | 729.078 | −8.655 |
| 4500 | 36.257 | 262.474 | 231.466 | 139.537 | 1671.557 | 707.683 | −8.215 |
| 4600 | 36.370 | 263.272 | 232.149 | 143.168 | 1673.710 | 686.240 | −7.792 |
| 4700 | 36.471 | 264.055 | 232.819 | 146.810 | 1675.875 | 664.750 | −7.388 |
| 4800 | 36.559 | 264.824 | 233.478 | 150.462 | 1678.049 | 643.213 | −7.000 |
| 4900 | 36.634 | 265.579 | 234.125 | 154.122 | 1680.231 | 621.632 | −6.627 |
| 5000 | 36.695 | 266.319 | 234.762 | 157.788 | 1682.419 | 600.005 | −6.268 |
| 5100 | 36.743 | 267.047 | 235.388 | 161.460 | 1684.614 | 578.335 | −5.923 |
| 5200 | 36.778 | 267.760 | 236.003 | 165.136 | 1686.812 | 556.622 | −5.591 |
| 5300 | 36.800 | 268.461 | 236.609 | 168.815 | 1689.013 | 534.867 | −5.271 |
| 5400 | 36.811 | 269.149 | 237.206 | 172.496 | 1691.216 | 513.070 | −4.963 |
| 5500 | 36.810 | 269.825 | 237.792 | 176.177 | 1693.419 | 491.232 | −4.665 |
| 5600 | 36.799 | 270.488 | 238.370 | 179.858 | 1695.622 | 469.354 | −4.378 |
| 5700 | 36.779 | 271.139 | 238.940 | 183.537 | 1697.823 | 447.437 | −4.100 |
| 5800 | 36.749 | 271.778 | 239.500 | 187.213 | 1700.022 | 425.481 | −3.832 |
| 5900 | 36.713 | 272.406 | 240.053 | 190.886 | 1702.217 | 403.488 | −3.572 |
| 6000 | 36.669 | 273.023 | 240.597 | 194.555 | 1704.409 | 381.457 | −3.321 |

PREVIOUS: CURRENT: March 1984 (1 bar)

**Tungsten, Ion ($W^-$)** **IDEAL GAS** **$M_r$ = 183.85055 Tungsten, Ion ($W^-$)** **$W_1^-(g)$**

EA(W, g) = 0.815 ± 0.008 eV
$S°$(298.15 K) = 188.781 ± 0.08 J·K$^{-1}$·mol$^{-1}$

$\Delta_f H°$(0 K) = 771.147 ± 2.0 kJ·mol$^{-1}$
$\Delta_f H°$(298.15 K) = [766.174] kJ·mol$^{-1}$

| Electonic Level and Quantum Weight | | |
|---|---|---|
| State | $\epsilon_i$, cm$^{-1}$ | $g_i$ |
| $^6S_{5/2}$ | 0.0 | 6 |

## Enthalpy of Formation

$\Delta_f H°(W^-$, g, 0 K) is calculated from $\Delta_f H°$(W, g, 0 K)[1] using the adopted electron affinity of EA(W) = 0.815 ± 0.008 eV (78.635 ± 0.772 kJ·mol$^{-1}$). This value, recommended by Hotop and Lineberger,[2] is based on a laser photodetachment electron spectrometry study.[3] Additional information on $W^-$(g) may be obtained in the critical discussions of Hotop and Lineberger,[2,4] Rosenstock *et al.*[5] and Massey.[6]

$\Delta_f H°(W^-$, g, 298 15 K) is obtained from $\Delta_f H°$(W, g, 0 K) by using EA(W) with JANAF[1] enthalpies, $H°(0\ K)-H°(298.15\ K)$, for $W^-$(g), W(g), and $e^-$(ref). $\Delta_r H°(W^- \rightarrow W + e^-$, 298.15 K) differs from a room–temperature threshold energy due to inclusion of these enthalpies and to threshold effects discussed by Rosenstock *et al.*[5] $\Delta_f H°$(298.15 K) should be changed by + 6.197 kJ·mol$^{-1}$ if it is to be used in the ion convention that excludes the enthalpy of the electron.

## Heat Capacity and Entropy

The ground state electronic configuration for $W^-$(g) is given by Hotop and Lineberger[2,4] and Rosenstock *et al.*[5] Lacking any experimental evidence as to the stability of any excited states, we assume that no stable excited states exist.

## References


[1]JANAF Thermochemical Tables: W(g), 6–30–66; $e^-$(ref), 3–31–82.
[2]H. Hotop and W. C. Lineberger, J. Phys. Chem. Ref. Data, 14, 731 (1985).
[3]C. S. Feigerle, R. R. Cordermann, S. V. Bobashev and W. C. Lineberger, J. Chem. Phys. 74, 1580 (1981).
[4]H. Hotop and W. C. Lineberger, J. Phys. Chem. Ref. Data 4, 539 (1975).
[5]H. M. Rosenstock, K. Draxl *et al.* J. Phys. Chem. Ref. Data 6, Supp. 1, 783 pp. (1977).
[6]H. S. W. Massey, "Negative Ions", 3rd ed., Cambridge University Press, Cambridge, 741 pp. (1976).


Enthalpy Reference Temperature = $T_r$ = 298.15 K — Standard State Pressure = $p°$ = 0.1 MPa

| | J·K$^{-1}$mol$^{-1}$ | | | kJ·mol$^{-1}$ | | | |
|---|---|---|---|---|---|---|---|
| T/K | $C_p°$ | $S°$ | $-[G°-H°(T_r)]/T$ | $H°-H°(T_r)$ | $\Delta_f H°$ | $\Delta_f G°$ | log $K_f$ |
| 0 | 0. | 0. | INFINITE | -6.197 | 771.147 | | |
| 100 | 20.786 | 166.073 | 207.261 | -4.119 | | | |
| 200 | 20.786 | 180.481 | 190.682 | -2.040 | | | |
| 250 | 20.786 | 185.119 | 189.123 | -1.001 | | | |
| 298.15 | 20.786 | 188.781 | 188.781 | 0. | 766.174 | 725.882 | -127.171 |
| 300 | 20.786 | 188.909 | 188.781 | 0.038 | 766.129 | 725.632 | -126.344 |
| 350 | 20.786 | 192.113 | 189.034 | 1.078 | 764.905 | 718.979 | -107.302 |
| 400 | 20.786 | 194.889 | 189.596 | 2.117 | 763.666 | 712.502 | -93.043 |
| 450 | 20.786 | 197.337 | 190.323 | 3.156 | 762.414 | 706.182 | -81.971 |
| 500 | 20.786 | 199.527 | 191.136 | 4.196 | 761.151 | 700.001 | -73.129 |
| 600 | 20.786 | 203.317 | 192.860 | 6.274 | 758.594 | 688.011 | -59.897 |
| 700 | 20.786 | 206.521 | 194.588 | 8.353 | 755.993 | 676.452 | -50.477 |
| 800 | 20.786 | 209.297 | 196.257 | 10.431 | 753.348 | 665.269 | -43.438 |
| 900 | 20.786 | 211.745 | 197.845 | 12.510 | 750.659 | 654.420 | -37.982 |
| 1000 | 20.786 | 213.935 | 199.346 | 14.589 | 747.925 | 643.873 | -33.632 |
| 1100 | 20.786 | 215.916 | 200.764 | 16.667 | 745.146 | 633.602 | -30.087 |
| 1200 | 20.786 | 217.725 | 202.103 | 18.746 | 742.322 | 623.586 | -27.144 |
| 1300 | 20.786 | 219.388 | 203.370 | 20.824 | 739.452 | 613.807 | -24.663 |
| 1400 | 20 786 | 220.929 | 204.569 | 22.903 | 736.536 | 604.251 | -22.545 |
| 1500 | 20.786 | 222.363 | 205.708 | 24.982 | 733.573 | 594.906 | -20.716 |
| 1600 | 20.786 | 223.704 | 206.792 | 27.060 | 730.563 | 585.759 | -19.123 |
| 1700 | 20.786 | 224.965 | 207.824 | 29.139 | 727.506 | 576.802 | -17.723 |
| 1800 | 20.786 | 226.153 | 208.810 | 31.217 | 724.402 | 568.027 | -16.484 |
| 1900 | 20.786 | 227.277 | 209.752 | 33.296 | 721.249 | 559.425 | -15.380 |
| 2000 | 20.786 | 228.343 | 210.655 | 35.375 | 718.049 | 550.990 | -14.390 |
| 2100 | 20.786 | 229.357 | 211.522 | 37.453 | 714.799 | 542.717 | -13.499 |
| 2200 | 20.786 | 230.324 | 212.355 | 39.532 | 711.500 | 534.600 | -12.693 |
| 2300 | 20.786 | 231.248 | 213.156 | 41.610 | 708.151 | 526.634 | -11.960 |
| 2400 | 20.786 | 232.132 | 213.929 | 43.689 | 704.752 | 518.814 | -11.292 |
| 2500 | 20.786 | 232.981 | 214.674 | 45.768 | 701.304 | 511.138 | -10.680 |
| 2600 | 20.786 | 233.796 | 215.394 | 47.846 | 697.809 | 503.600 | -10.117 |
| 2700 | 20.786 | 234.581 | 216.090 | 49.925 | 694.239 | 496.198 | -9.600 |
| 2800 | 20.786 | 235.337 | 216.764 | 52.004 | 690.561 | 488.930 | -9.121 |
| 2900 | 20.786 | 236.066 | 217.417 | 54.082 | 686.734 | 481.796 | -8.678 |
| 3000 | 20.786 | 236.771 | 218.050 | 56.161 | 682.733 | 474.797 | -8.267 |
| 3100 | 20.786 | 237.452 | 218.665 | 58.239 | 678.512 | 467.934 | -7.885 |
| 3200 | 20.786 | 238.112 | 219.263 | 60.318 | 674.042 | 461.212 | -7.529 |
| 3300 | 20.786 | 238.752 | 219.844 | 62.397 | 669.297 | 454.634 | -7.196 |
| 3400 | 20.786 | 239.372 | 220.409 | 64.475 | 664.241 | 448.204 | -6.886 |
| 3500 | 20.786 | 239.975 | 220.960 | 66.554 | 658.811 | 441.928 | -6.595 |
| 3600 | 20.786 | 240.560 | 221.496 | 68.632 | 652.904 | 435.813 | -6.323 |
| 3700 | 20.786 | 241.130 | 222.019 | 70.711 | 611.683 | 430.061 | -6.071 |
| 3800 | 20.786 | 241.684 | 222.529 | 72.790 | 608.127 | 425.200 | -5.845 |
| 3900 | 20.786 | 242.224 | 223.027 | 74.868 | 604.570 | 420.433 | -5.631 |
| 4000 | 20.786 | 242.750 | 223.514 | 76.947 | 601.014 | 415.757 | -5.429 |
| 4100 | 20.786 | 243.264 | 223.989 | 79.025 | 597.457 | 411.169 | -5.238 |
| 4200 | 20.786 | 243.765 | 224.454 | 81.104 | 593.901 | 406.669 | -5.058 |
| 4300 | 20.786 | 244.254 | 224.909 | 83.183 | 590.345 | 402.253 | -4.886 |
| 4400 | 20.786 | 244.732 | 225.354 | 85.261 | 586.788 | 397.920 | -4.724 |
| 4500 | 20 786 | 245.199 | 225.790 | 87.340 | 583.232 | 393.667 | -4.570 |
| 4600 | 20.786 | 245.656 | 226.217 | 89.418 | 579.675 | 389.494 | -4.423 |
| 4700 | 20.786 | 246.103 | 226.635 | 91.497 | 576.119 | 385.398 | -4.283 |
| 4800 | 20.786 | 246.540 | 227.045 | 93.576 | 572.563 | 381.377 | -4.150 |
| 4900 | 20.786 | 246.969 | 227.448 | 95.654 | 569.006 | 377.431 | -4.023 |
| 5000 | 20.786 | 247.389 | 227.842 | 97.733 | 565.450 | 373.558 | -3.903 |
| 5100 | 20.786 | 247.800 | 228.229 | 99.811 | 561.893 | 369.755 | -3.787 |
| 5200 | 20.786 | 248.204 | 228.610 | 101.890 | 558.337 | 366.022 | -3.677 |
| 5300 | 20.786 | 248.600 | 228.983 | 103.969 | 554.781 | 362.358 | -3.571 |
| 5400 | 20.786 | 248.988 | 229.350 | 106.047 | 551.224 | 358.761 | -3.470 |
| 5500 | 20.786 | 249.370 | 229.711 | 108.126 | 547.668 | 355.229 | -3.374 |
| 5600 | 20.786 | 249.744 | 230.065 | 110.204 | 544.111 | 351.762 | -3.281 |
| 5700 | 20.786 | 250.112 | 230.414 | 112.283 | 540.555 | 348.359 | -3.192 |
| 5800 | 20.786 | 250.474 | 230.756 | 114.362 | 536.999 | 345.018 | -3.107 |
| 5900 | 20.786 | 250.829 | 231.093 | 116.440 | 533.442 | 341.739 | -3.026 |
| 6000 | 20.786 | 251.178 | 231.425 | 118.519 | 529.886 | 338.520 | -2.947 |

PREVIOUS: CURRENT: March 1984 (1 bar)