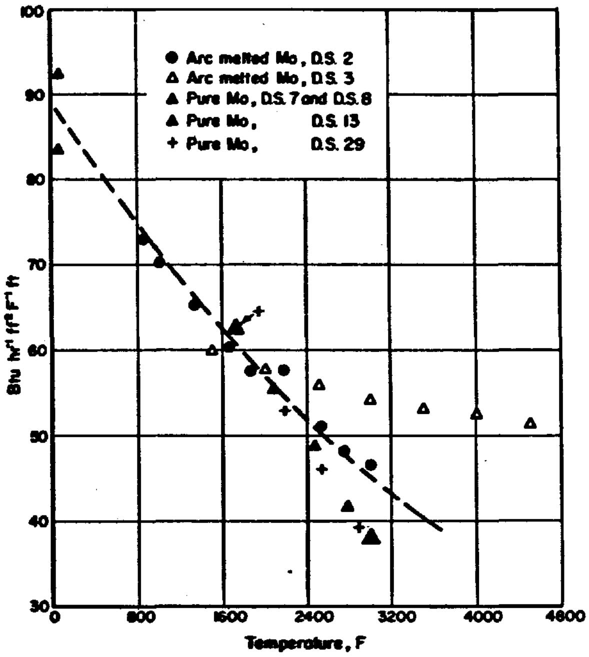
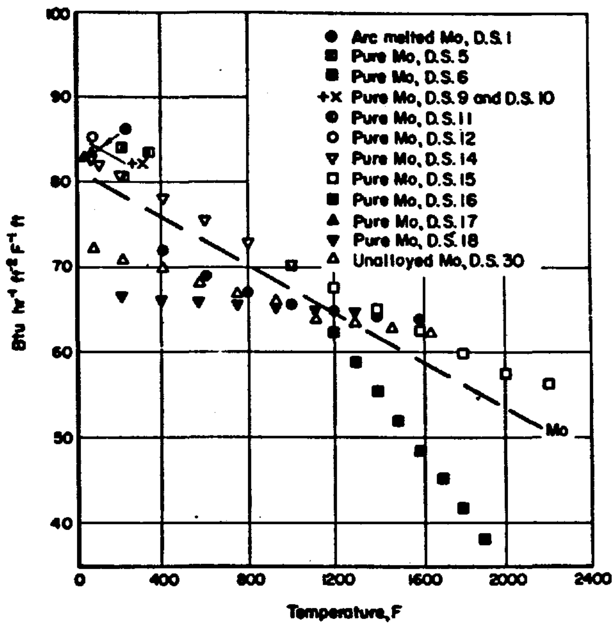
STP296-EB/Apr. 1961

# MOLYBDENUM AND ITS ALLOYS

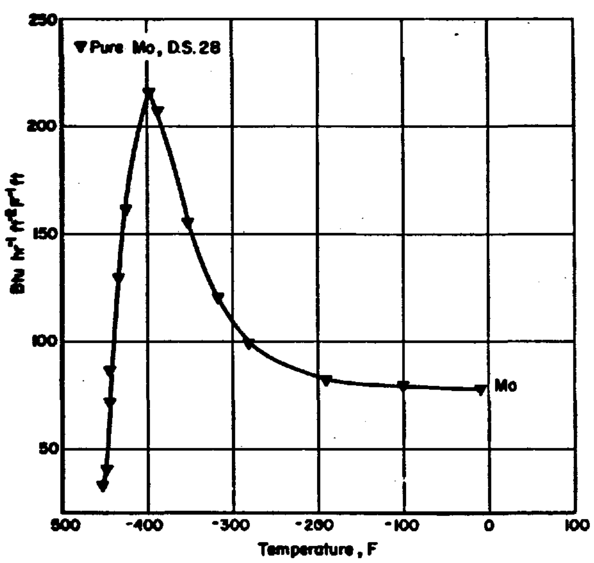
# MOLYBDENUM



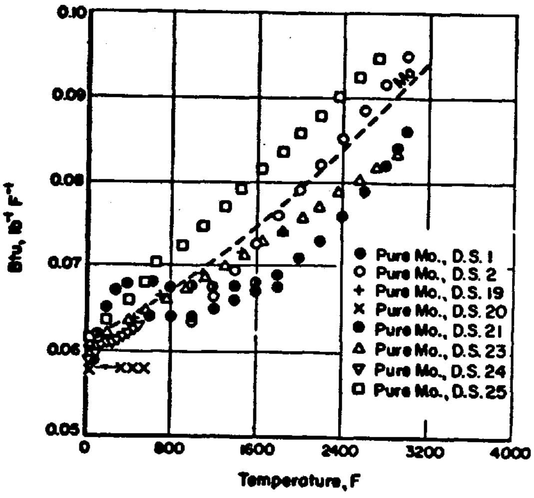

THERMAL CONDUCTIVITY OF MOLYBDENUM



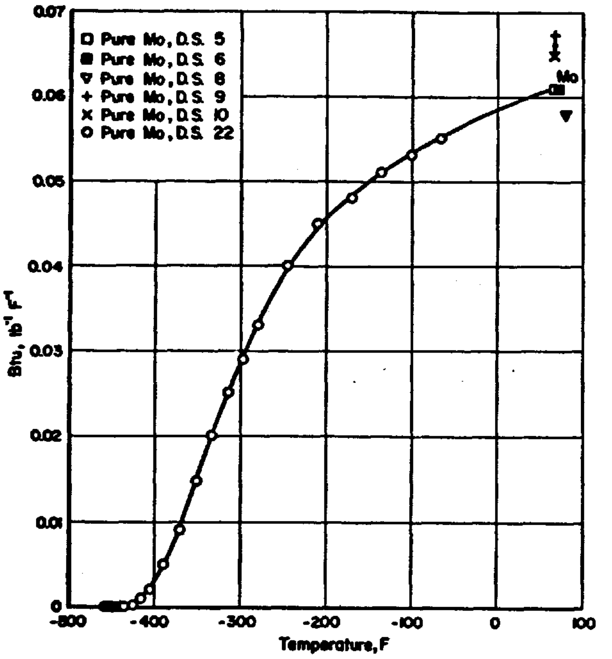

THERMAL CONDUCTIVITY OF MOLYBDENUM



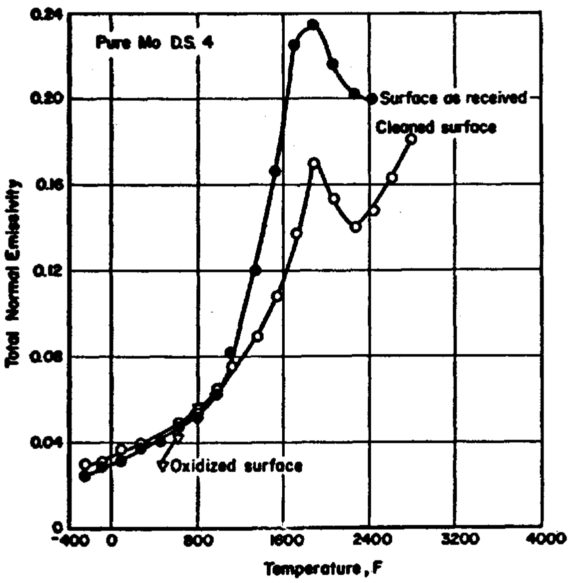

THERMAL CONDUCTIVITY OF MOLYBDENUM




SPECIFIC HEAT OF MOLYBDENUM




SPECIFIC HEAT OF MOLYBDENUM




TOTAL NORMAL EMISSIVITY OF MOLYBDENUM

## ASTM-ASME JOINT COMMITTEE ON EFFECT OF TEMPERATURE ON PROPERTIES OF METALS

(1)

| | | |
|---|---|---|
| MATERIAL | Molybdenum | HEAT NUMBER |
| CHEMICAL COMPOSITION PER CENT | | |
| FORM | | |
| HEAT TREATMENT | Arc melted, unalloyed. | |
| REFERENCE | Lucks, C. F. and Deem, H. W., "Thermal Conductivities, Heat Capacities, and Linear Thermal Expansion of Five Materials", WADC Technical Report 55-496, from Battelle Memorial Institute (August, 1956). | |

### THERMAL CONDUCTIVITY

| TEMP, F | BTU $HR^{-1}$ $FT^{-2}$ $F^{-1}$ FT | TEMP, F | BTU $HR^{-1}$ $FT^{-2}$ $F^{-1}$ FT | TEMP, F | BTU $HR^{-1}$ $FT^{-2}$ $F^{-1}$ FT | TEMP, F | BTU $HR^{-1}$ $FT^{-2}$ $F^{-1}$ FT |
|---|---|---|---|---|---|---|---|
| 400 | 72.0 | 800 | 67.0 | 1200 | 65.0 | 1600 | 64.0 |
| 600 | 69.0 | 1000 | 65.8 | 1400 | 64.5 | | |

Interpolated values.

### COEFFICIENT OF LINEAR THERMAL EXPANSION

| TEMP RANGE, F | $F^{-1} \times 10^6$ | TEMP RANGE, F | $F^{-1} \times 10^6$ | TEMP RANGE, F | $F^{-1} \times 10^6$ | TEMP RANGE, F | $F^{-1} \times 10^6$ |
|---|---|---|---|---|---|---|---|
| 68-400 | 2.96 | 68-1200 | 2.98 | 68-2000 | 3.31 | 68-2800 | 3.66 |
| 68-600 | 2.89 | 68-1400 | 3.06 | 68-2200 | 3.40 | 68-2900 | 3.70* |
| 68-800 | 2.87 | 68-1600 | 3.14 | 68-2400 | 3.49 | 68-3000 | 3.75 |
| 68-1000 | 2.92 | 68-1800 | 3.23 | 68-2600 | 3.57 | | |

Data between 68 F and given temperature.

* Extrapolated.

### SPECIFIC HEAT

| TEMP, F | BTU $LB^{-1}$ $F^{-1}$ | TEMP, F | BTU $LB^{-1}$ $F^{-1}$ | TEMP, F | BTU $LB^{-1}$ $F^{-1}$ | TEMP, F | BTU $LB^{-1}$ $F^{-1}$ |
|---|---|---|---|---|---|---|---|
| 400 | 0.065 | 1200 | 0.065 | 2000 | 0.071 | 2800 | 0.082 |
| 600 | 0.064 | 1400 | 0.066 | 2200 | 0.073 | 2900 | 0.084 |
| 800 | 0.064 | 1600 | 0.067 | 2400 | 0.076 | 3000 | 0.086 |
| 1000 | 0.064 | 1800 | 0.069 | 2600 | 0.079 | | |

### DENSITY

| TEMP, F | LB CU $IN^{-1}$ | TEMP, F | LB CU $IN^{-1}$ | TEMP, F | LB CU $IN^{-1}$ | TEMP, F | LB CU $IN^{-1}$ |
|---|---|---|---|---|---|---|---|
| 75 | 0.370 | 1000 | 0.367 | 1800 | 0.364 | 2600 | 0.360 |
| 400 | 0.369 | 1200 | 0.366 | 2000 | 0.363 | 2800 | 0.359 |
| 600 | 0.368 | 1400 | 0.366 | 2200 | 0.362 | 2900 | 0.359 |
| 800 | 0.368 | 1600 | 0.365 | 2400 | 0.361 | 3000 | 0.358 |

Data calculated from thermal expansion data and measured density of 0.370 lb cu $in^{-1}$.

### DIFFUSIVITY

| TEMP, F | $FT^2$ $HR^{-1}$ | TEMP, F | $FT^2$ $HR^{-1}$ | TEMP, F | $FT^2$ $HR^{-1}$ | TEMP, F | $FT^2$ $HR^{-1}$ |
|---|---|---|---|---|---|---|---|
| 400 | 1.74 | 800 | 1.65 | 1200 | 1.58 | 1600 | 1.51 |
| 600 | 1.70 | 1000 | 1.62 | 1400 | 1.55 | | |

## ASTM-ASME JOINT COMMITTEE ON EFFECT OF TEMPERATURE ON PROPERTIES OF METALS

(2)

| | | |
|---|---|---|
| MATERIAL | Molybdenum | HEAT NUMBER |
| CHEMICAL COMPOSITION PER CENT | | |
| FORM | | |
| HEAT TREATMENT | Arc melted, unalloyed. | |
| REFERENCE | Fieldhouse, I. B., Hedge, J. C., Lang, J. I., Takata, A. N. and Waterman, "Measurements of Thermal Properties", Armour Research Foundation, Chicago, Illinois; as found in WADC Technical Report 55-495, Part I (March, 1955). | |

### THERMAL CONDUCTIVITY

| TEMP, F | BTU $HR^{-1}$ $FT^{-2}$ $F^{-1}$ FT | TEMP, F | BTU $HR^{-1}$ $FT^{-2}$ $F^{-1}$ FT | TEMP, F | BTU $HR^{-1}$ $FT^{-2}$ $F^{-1}$ FT | TEMP, F | BTU $HR^{-1}$ $FT^{-2}$ $F^{-1}$ FT |
|---|---|---|---|---|---|---|---|
| 888 | 73.3 | 1648 | 60.2 | 2160 | 57.6 | 2755 | 48.2 |
| 1015 | 70.4 | 1650 | 62.2 | 2532 | 51.1 | 2988 | 46.50 |
| 1339 | 65.3 | 1844 | 57.7 | | | | |

### COEFFICIENT OF LINEAR THERMAL EXPANSION

| TEMP RANGE, F | $F^{-1} \times 10^6$ | TEMP RANGE, F | $F^{-1} \times 10^6$ | TEMP RANGE, F | $F^{-1} \times 10^6$ | TEMP RANGE, F | $F^{-1} \times 10^6$ |
|---|---|---|---|---|---|---|---|
| 68-200 | 2.65 | 68-1000 | 3.10 | 68-1800 | 3.23 | 68-2400 | 3.46 |
| 68-400 | 2.80 | 68-1200 | 3.14 | 68-2000 | 3.30 | 68-2600 | 3.57 |
| 68-600 | 2.95 | 68-1400 | 3.13 | 68-2200 | 3.37 | 68-2800 | 3.69 |
| 68-800 | 3.02 | 68-1600 | 3.17 | | | | |

### SPECIFIC HEAT

| TEMP, F | BTU $LB^{-1}$ $F^{-1}$ | TEMP, F | BTU $LB^{-1}$ $F^{-1}$ | TEMP, F | BTU $LB^{-1}$ $F^{-1}$ | TEMP, F | BTU $LB^{-1}$ $F^{-1}$ |
|---|---|---|---|---|---|---|---|
| 1000 | 0.06340 | 1600 | 0.07282 | 2200 | 0.08224 | 2800 | 0.09166 |
| 1200 | 0.06654 | 1800 | 0.07596 | 2400 | 0.08538 | 3000 | 0.09480 |
| 1400 | 0.06968 | 2000 | 0.07910 | 2600 | 0.08852 | | |

## ASTM-ASME JOINT COMMITTEE ON EFFECT OF TEMPERATURE ON PROPERTIES OF METALS

(3)

| | | |
|---|---|---|
| MATERIAL | Molybdenum | HEAT NUMBER |
| CHEMICAL COMPOSITION PER CENT | | |
| FORM | | |
| HEAT TREATMENT | Arc melted, unalloyed. | |
| REFERENCE | Rasor, N. S. and McClelland, J. D., "Thermal Properties of Materials--Part I", Properties of Graphite, Molybdenum and Tantalum to their Destruction Temperatures. As found in WADC Technical Report 56-400 Part I (March, 1957). | |
| REMARKS | Data taken from curve in report. | |

### THERMAL CONDUCTIVITY

| TEMP, F | BTU $HR^{-1}$ $FT^{-2}$ $F^{-1}$ FT | TEMP, F | BTU $HR^{-1}$ $FT^{-2}$ $F^{-1}$ FT | TEMP, F | BTU $HR^{-1}$ $FT^{-2}$ $F^{-1}$ FT | TEMP, F | BTU $HR^{-1}$ $FT^{-2}$ $F^{-1}$ FT |
|---|---|---|---|---|---|---|---|
| 1500 | 60.7 | 2500 | 55.9 | 3500 | 53.3 | 4500 | 51.5 |
| 2000 | 57.9 | 3000 | 54.3 | 4000 | 52.5 | | |

### COEFFICIENT OF LINEAR THERMAL EXPANSION

| TEMP RANGE, F | $F^{-1} \times 10^6$ | TEMP RANGE, F | $F^{-1} \times 10^6$ | TEMP RANGE, F | $F^{-1} \times 10^6$ | TEMP RANGE, F | $F^{-1} \times 10^6$ |
|---|---|---|---|---|---|---|---|
| 68-200 | 1.67 | 68-1400 | 2.76 | 68-2600 | 3.34 | 68-3800 | 3.97 |
| 68-400 | 1.36 | 68-1600 | 2.86 | 68-2800 | 3.44 | 68-4000 | 4.09 |
| 68-600 | 2.11 | 68-1800 | 2.92 | 68-3000 | 3.55 | 68-4200 | 4.21 |
| 68-800 | 2.46 | 68-2000 | 3.04 | 68-3200 | 3.64 | 68-4400 | 4.34 |
| 68-1000 | 2.55 | 68-2200 | 3.14 | 68-3400 | 3.75 | 68-4600 | 4.46 |
| 68-1200 | 2.65 | 68-2400 | 3.24 | 68-3600 | 3.85 | 68-4700 | 5.12 |

ASTM-ASME JOINT COMMITTEE ON EFFECT OF TEMPERATURE ON PROPERTIES OF METALS

(4)

| MATERIAL | Molybdenum | HEAT NUMBER |
|---|---|---|
| CHEMICAL COMPOSITION PER CENT | | |
| FORM | | |
| HEAT TREATMENT | Arc melted, unalloyed. | |
| REFERENCE | Betz, H. T. and Alson, O. H., "Determination of Emissivity and Reflectivity Data on Structural Materials", WADC TR 56-222, Part II; as found in WADC Technical Report 58-476. | |

EMISSIVITY

| TEMP., F | TOTAL NORMAL | TEMP., F | TOTAL NORMAL | TEMP., F | TOTAL NORMAL | TEMP., F | TOTAL NORMAL |
|---|---|---|---|---|---|---|---|
| -279 | 0.025 | 441 | 0.041 | 1161 | 0.082 | 1881 | 0.235 |
| - 99 | 0.029 | 621 | 0.048 | 1341 | 0.120 | 2061 | 0.212 |
| 81 | 0.032 | 801 | 0.052 | 1521 | 0.167 | 2241 | 0.202 |
| 261 | 0.038 | 981 | 0.063 | 1701 | 0.225 | 2421 | 0.200 |
| Surface as received. | | | | | | | |

EMISSIVITY

| TEMP., F | TOTAL NORMAL | TEMP., F | TOTAL NORMAL | TEMP., F | TOTAL NORMAL | TEMP., F | TOTAL NORMAL |
|---|---|---|---|---|---|---|---|
| -279 | 0.030 | 621 | 0.050 | 1521 | 0.108 | 2241 | 0.140 |
| - 99 | 0.032 | 801 | 0.054 | 1701 | 0.138 | 2421 | 0.148 |
| 81 | 0.037 | 981 | 0.066 | 1881 | 0.170 | 2601 | 0.163 |
| 261 | 0.040 | 1161 | 0.076 | 2061 | 0.154 | 2781 | 0.181 |
| 441 | 0.043 | 1341 | 0.090 | | | | |
| As cleaned. | | | | | | | |

EMISSIVITY

| TEMP., F | TOTAL NORMAL | TEMP., F | TOTAL NORMAL | TEMP., F | TOTAL NORMAL | TEMP., F | TOTAL NORMAL |
|---|---|---|---|---|---|---|---|
| 440 | 0.030 | 620 | 0.043 | 800 | 0.056 | | |
| Oxidized surface. | | | | | | | |

ASTM-ASME JOINT COMMITTEE ON EFFECT OF TEMPERATURE ON PROPERTIES OF METALS

(5)

| MATERIAL | Molybdenum | HEAT NUMBER |
|---|---|---|
| CHEMICAL COMPOSITION PER CENT | | |
| FORM | | |
| HEAT TREATMENT | | |
| REFERENCE | Pierce, E. C., "Molybdenum", In Metals Handbook, edited by T. Lyman, Cleveland, American Society for Metals, 1948, pp. 1139-1140; as found in WADC Technical Report 56-423 (August, 1956) p. 28. | |

THERMAL CONDUCTIVITY

| TEMP., F | BTU HR-1 FT-2 F-1 FT | TEMP., F | BTU HR-1 FT-2 F-1 FT | TEMP., F | BTU HR-1 FT-2 F-1 FT | TEMP., F | BTU HR-1 FT-2 F-1 FT |
|---|---|---|---|---|---|---|---|
| 338 | 83.7 | | | | | | |

COEFFICIENT OF LINEAR THERMAL EXPANSION

| TEMP RANGE, F | $F^{-1} \times 10^6$ | TEMP RANGE, F | $F^{-1} \times 10^6$ | TEMP RANGE, F | $F^{-1} \times 10^6$ | TEMP RANGE, F | $F^{-1} \times 10^6$ |
|---|---|---|---|---|---|---|---|
| 68-212 | 2.7 | | | | | | |

SPECIFIC HEAT

| TEMP., F | BTU LB-1 F-1 | TEMP., F | BTU LB-1 F-1 | TEMP., F | BTU LB-1 F-1 | TEMP., F | BTU LB-1 F-1 |
|---|---|---|---|---|---|---|---|
| 68 | 0.061 | | | | | | |

EMISSIVITY

| TEMP., F | TOTAL NORMAL | TEMP., F | TOTAL NORMAL | TEMP., F | TOTAL NORMAL | TEMP., F | TOTAL NORMAL |
|---|---|---|---|---|---|---|---|
| 1832 | 0.13 | 2732 | 0.19 | 3632 | 0.24 | | |
| Assumed to be total normal emissivity. | | | | | | | |

ASTM-ASME JOINT COMMITTEE ON EFFECT OF TEMPERATURE ON PROPERTIES OF METALS

(6)

| MATERIAL | Molybdenum | HEAT NUMBER |
|---|---|---|
| CHEMICAL COMPOSITION PER CENT | | |
| FORM | | |
| HEAT TREATMENT | | |
| REFERENCE | "Titanium, Molybdenum, Zirconium and Hafnium", Materials and Methods, Vol 37, June, 1953, (Materials Data Sheet No. 254); as found in WADC Technical Report 57-423, (August, 1956) p. 34. | |

THERMAL CONDUCTIVITY

| TEMP., F | BTU HR-1 FT-2 F-1 FT | TEMP., F | BTU HR-1 FT-2 F-1 FT | TEMP., F | BTU HR-1 FT-2 F-1 FT | TEMP., F | BTU HR-1 FT-2 F-1 FT |
|---|---|---|---|---|---|---|---|
| 212 | 84 | | | | | | |

COEFFICIENT OF LINEAR THERMAL EXPANSION

| TEMP RANGE, F | $F^{-1} \times 10^6$ | TEMP RANGE, F | $F^{-1} \times 10^6$ | TEMP RANGE, F | $F^{-1} \times 10^6$ | TEMP RANGE, F | $F^{-1} \times 10^6$ |
|---|---|---|---|---|---|---|---|
| 70 | 3.0 | | | | | | |
| Assumed to be instantaneous coefficient. | | | | | | | |

SPECIFIC HEAT

| TEMP., F | BTU LB-1 F-1 | TEMP., F | BTU LB-1 F-1 | TEMP., F | BTU LB-1 F-1 | TEMP., F | BTU LB-1 F-1 |
|---|---|---|---|---|---|---|---|
| 70 | 0.061 | | | | | | |

ASTM-ASME JOINT COMMITTEE ON EFFECT OF TEMPERATURE ON PROPERTIES OF METALS

(7)

| MATERIAL | Molybdenum | HEAT NUMBER |
|---|---|---|
| CHEMICAL COMPOSITION PER CENT | | |
| FORM | | |
| HEAT TREATMENT | | |
| REFERENCE | Jaffee, R. I., "Molybdenum and Molybdenum Alloys", in Encyclopedia of Chemical Technology, edited by R. E. Kirk and D. Fathmer, New York, Interscience Encyclopedia, Vol 9, (1952) p. 192; as found in WADC Technical Report 56-423 (August, 1956). | |

THERMAL CONDUCTIVITY

| TEMP, F | BTU HR-1 FT-2 F-1 FT | TEMP, F | BTU HR-1 FT-2 F-1 FT | TEMP, F | BTU HR-1 FT-2 F-1 FT | TEMP, F | BTU HR-1 FT-2 F-1 FT |
|---|---|---|---|---|---|---|---|
| 62.6 | 83.7 | 1700 | 62.7 | 2960 | 38.5 | | |

COEFFICIENT OF LINEAR THERMAL EXPANSION

| TEMP RANGE, F | $F^{-1} \times 10^6$ | TEMP RANGE, F | $F^{-1} \times 10^6$ | TEMP RANGE, F | $F^{-1} \times 10^6$ | TEMP RANGE, F | $F^{-1} \times 10^6$ |
|---|---|---|---|---|---|---|---|
| 68 | 2.7 | | | | | | |
| Data assumed to be instantaneous coefficient. | | | | | | | |

SPECIFIC HEAT

| TEMP, F | BTU LB-1 F-1 | TEMP, F | BTU LB-1 F-1 | TEMP, F | BTU LB-1 F-1 | TEMP, F | BTU LB-1 F-1 |
|---|---|---|---|---|---|---|---|
| 68 | 0.061 | | | | | | |

ASTM-ASME JOINT COMMITTEE ON EFFECT OF TEMPERATURE ON PROPERTIES OF METALS

8

| | |
|---|---|
| MATERIAL | Molybdenum HEAT NUMBER |
| CHEMICAL COMPOSITION PER CENT | |
| FORM | |
| HEAT TREATMENT | |
| REFERENCE | Killeffer, D. H. and Linz, A., "Molybdenum Compounds", New York, Interscience Publishers, 1952, p 13-14, 34. As found in WADC Technical Report 56-423, (August, 1956) p. 32. |

THERMAL CONDUCTIVITY

| TEMP, F | BTU HR-1 FT-2 F-1 FT | TEMP, F | BTU HR-1 FT-2 F-1 FT | TEMP, F | BTU HR-1 FT-2 F-1 FT | TEMP, F | BTU HR-1 FT-2 F-1 FT |
|---|---|---|---|---|---|---|---|
| 63 | 83.7 | 1700 | 62.7 | 2960 | 38.5 | | |

COEFFICIENT OF LINEAR THERMAL EXPANSION

| TEMP RANGE, F | $F^{-1} \times 10^6$ | TEMP RANGE, F | $F^{-1} \times 10^6$ | TEMP RANGE, F | $F^{-1} \times 10^6$ | TEMP RANGE, F | $F^{-1} \times 10^6$ |
|---|---|---|---|---|---|---|---|
| 32-68 | 2.97 | | | | | | |
| Values obtained from data reported by Nix and MacNair 1942. | | | | | | | |

SPECIFIC HEAT

| TEMP, F | BTU LB-1 F-1 | TEMP, F | BTU LB-1 F-1 | TEMP, F | BTU LB-1 F-1 | TEMP, F | BTU LB-1 F-1 |
|---|---|---|---|---|---|---|---|
| 77 | 0.058 | | | | | | |
| Values obtained from data reported by Kelley, 1940. | | | | | | | |

ASTM-ASME JOINT COMMITTEE ON EFFECT OF TEMPERATURE ON PROPERTIES OF METALS

9

| | |
|---|---|
| MATERIAL | Molybdenum HEAT NUMBER |
| CHEMICAL COMPOSITION PER CENT | |
| FORM | |
| HEAT TREATMENT | |
| REFERENCE | Harwood, J. J., "Molybdenum--Our Most Promising Refractory Metal", Product Eng., Vol 23 (January, 1952) pp. 121-132; as found in WADC Technical Report 56-423 (August, 1956) p. 32. |

THERMAL CONDUCTIVITY

| TEMP, F | BTU HR-1 FT-2 F-1 FT | TEMP, F | BTU HR-1 FT-2 F-1 FT | TEMP, F | BTU HR-1 FT-2 F-1 FT | TEMP, F | BTU HR-1 FT-2 F-1 FT |
|---|---|---|---|---|---|---|---|
| 68 | 84.4 | | | | | | |

COEFFICIENT OF LINEAR THERMAL EXPANSION

| TEMP RANGE, F | $F^{-1} \times 10^6$ | TEMP RANGE, F | $F^{-1} \times 10^6$ | TEMP RANGE, F | $F^{-1} \times 10^6$ | TEMP RANGE, F | $F^{-1} \times 10^6$ |
|---|---|---|---|---|---|---|---|
| 68 | 3.03 | | | | | | |
| Data assumed to be instantaneous coefficient. | | | | | | | |

SPECIFIC HEAT

| TEMP, F | BTU LB-1 F-1 | TEMP, F | BTU LB-1 F-1 | TEMP, F | BTU LB-1 F-1 | TEMP, F | BTU LB-1 F-1 |
|---|---|---|---|---|---|---|---|
| 68 | 0.065 | | | | | | |

ASTM-ASME JOINT COMMITTEE ON EFFECT OF TEMPERATURE ON PROPERTIES OF METALS

10

| | |
|---|---|
| MATERIAL | Molybdenum HEAT NUMBER |
| CHEMICAL COMPOSITION PER CENT | |
| FORM | |
| HEAT TREATMENT | |
| REFERENCE | "Materials of Construction Data", Indus. and Eng. Chem., Vol 44, October, 1952, pp. 2376-2379; as found in WADC Technical Report No. 56-423 (August, 1956) p. 33. |

THERMAL CONDUCTIVITY

| TEMP, F | BTU HR-1 FT-2 F-1 FT | TEMP, F | BTU HR-1 FT-2 F-1 FT | TEMP, F | BTU HR-1 FT-2 F-1 FT | TEMP, F | BTU HR-1 FT-2 F-1 FT |
|---|---|---|---|---|---|---|---|
| 68 | 84.4 | | | | | | |

COEFFICIENT OF LINEAR THERMAL EXPANSION

| TEMP RANGE, F | $F^{-1} \times 10^6$ | TEMP RANGE, F | $F^{-1} \times 10^6$ | TEMP RANGE, F | $F^{-1} \times 10^6$ | TEMP RANGE, F | $F^{-1} \times 10^6$ |
|---|---|---|---|---|---|---|---|
| 70 | 3.0 | | | | | | |
| Assumed to be instantaneous coefficient. | | | | | | | |

SPECIFIC HEAT

| TEMP, F | BTU LB-1 F-1 | TEMP, F | BTU LB-1 F-1 | TEMP, F | BTU LB-1 F-1 | TEMP, F | BTU LB-1 F-1 |
|---|---|---|---|---|---|---|---|
| 68 | 0.065 | | | | | | |

ASTM-ASME JOINT COMMITTEE ON EFFECT OF TEMPERATURE ON PROPERTIES OF METALS

11

| | |
|---|---|
| MATERIAL | Molybdenum HEAT NUMBER |
| CHEMICAL COMPOSITION PER CENT | |
| FORM | |
| HEAT TREATMENT | |
| REFERENCE | Fansteel Metallurgical Corporation, "Tantalum", North Chicago, Illinois, 1935, p. 41; as found in WADC Technical Report 57-423 (August, 1956) p. 25. |

THERMAL CONDUCTIVITY

| TEMP, F | BTU HR-1 FT-2 F-1 FT | TEMP, F | BTU HR-1 FT-2 F-1 FT | TEMP, F | BTU HR-1 FT-2 F-1 FT | TEMP, F | BTU HR-1 FT-2 F-1 FT |
|---|---|---|---|---|---|---|---|
| 64 | 83.7 | | | | | | |

COEFFICIENT OF LINEAR THERMAL EXPANSION

| TEMP RANGE, F | $F^{-1} \times 10^6$ | TEMP RANGE, F | $F^{-1} \times 10^6$ | TEMP RANGE, F | $F^{-1} \times 10^6$ | TEMP RANGE, F | $F^{-1} \times 10^6$ |
|---|---|---|---|---|---|---|---|
| 64 | 3.03 | | | | | | |

Assumed to be instantaneous coefficient.

SPECIFIC HEAT

| TEMP, F | BTU LB-1 F-1 | TEMP, F | BTU LB-1 F-1 | TEMP, F | BTU LB-1 F-1 | TEMP, F | BTU LB-1 F-1 |
|---|---|---|---|---|---|---|---|
| 64 | 0.0647 | | | | | | |

ASTM-ASME JOINT COMMITTEE ON EFFECT OF TEMPERATURE ON PROPERTIES OF METALS

(12)

MATERIAL Molybdenum HEAT NUMBER

CHEMICAL COMPOSITION PER CENT

FORM

HEAT TREATMENT

REFERENCE DeMant, J., Dake, H. C. and Roberts, E. R., "Rarer Metals", London, Temple Press, 1949, pp. 117-131, 324-326; as found in WADC Technical Report 56-423 (August, 1956) p. 29.

REMARKS

THERMAL CONDUCTIVITY

| TEMP, F | BTU HR-1 FT-2 F-1 FT | TEMP, F | BTU HR-1 FT-2 F-1 FT | TEMP, F | BTU HR-1 FT-2 F-1 FT | TEMP, F | BTU HR-1 FT-2 F-1 FT |
|---|---|---|---|---|---|---|---|
| 68 | 85 | | | | | | |

SPECIFIC HEAT

| TEMP, F | BTU LB-1 F-1 | TEMP, F | BTU LB-1 F-1 | TEMP, F | BTU LB-1 F-1 | TEMP, F | BTU LB-1 F-1 |
|---|---|---|---|---|---|---|---|
| 68 | 0.061 | | | | | | |

ASTM-ASME JOINT COMMITTEE ON EFFECT OF TEMPERATURE ON PROPERTIES OF METALS

(13)

MATERIAL Molybdenum HEAT NUMBER

CHEMICAL COMPOSITION PER CENT

FORM

HEAT TREATMENT

REFERENCE Yntema, L. F. and Percy, A. L., "Molybdenum", in Rare Metals Handbook, edited by C. A. Hampel, New York, Reinhold, pp. 277-279 (1954).

REMARKS

THERMAL CONDUCTIVITY

| TEMP, F | BTU HR-1 FT-2 F-1 FT | TEMP, F | BTU HR-1 FT-2 F-1 FT | TEMP, F | BTU HR-1 FT-2 F-1 FT | TEMP, F | BTU HR-1 FT-2 F-1 FT |
|---|---|---|---|---|---|---|---|
| 68 | 92.4 | 2060 | 55.6 | 2780 | 41.8 | 2960 | 38.5 |
| 1700 | 62.7 | 2470 | 48.9 | | | | |

COEFFICIENT OF LINEAR THERMAL EXPANSION

| TEMP RANGE, F | $F^{-1} \times 10^6$ | TEMP RANGE, F | $F^{-1} \times 10^6$ | TEMP RANGE, F | $F^{-1} \times 10^6$ | TEMP RANGE, F | $F^{-1} \times 10^6$ |
|---|---|---|---|---|---|---|---|
| 32-68 | 2.97 | 77-1292 | 3.2-3.4 | | | | |

This compilation includes data from the work of Nix and MacNair (1942).

ASTM-ASME JOINT COMMITTEE ON EFFECT OF TEMPERATURE ON PROPERTIES OF METALS

(14)

MATERIAL Molybdenum HEAT NUMBER

CHEMICAL COMPOSITION PER CENT

FORM Cast and wire filament.

HEAT TREATMENT

REFERENCE Barratt, Annalen Des Physik, Vol 77 (1925), "Thermal Conductivity of Wires and Rods"; as found in "Some Thermal Properties of Solid Materials, Part I, Metals", AEC Report. GEANPD (September 9, 1955).

THERMAL CONDUCTIVITY

| TEMP, F | BTU HR-1 FT-2 F-1 FT | TEMP, F | BTU HR-1 FT-2 F-1 FT | TEMP, F | BTU HR-1 FT-2 F-1 FT | TEMP, F | BTU HR-1 FT-2 F-1 FT |
|---|---|---|---|---|---|---|---|
| 60 | 82.75 | 200 | 80.9 | 600 | 75.7 | 1000 | 70.25 |
| 100 | 82.3 | 400 | 78.25 | 800 | 73.0 | | |

ASTM-ASME JOINT COMMITTEE ON EFFECT OF TEMPERATURE ON PROPERTIES OF METALS

(15)

MATERIAL Molybdenum HEAT NUMBER

CHEMICAL COMPOSITION PER CENT

FORM

HEAT TREATMENT

REFERENCE Mikol, E. P., "The Thermal Conductivity of Molybdenum Over The Temperature Range 1000-2100 F", ORNL 1131 (1952) UNCL.; as found in "Some Thermal Properties of Solid Materials, Part I, Metals", AEC Report. GEANPD (September 9, 1955).

THERMAL CONDUCTIVITY

| TEMP, F | BTU HR-1 FT-2 F-1 FT | TEMP, F | BTU HR-1 FT-2 F-1 FT | TEMP, F | BTU HR-1 FT-2 F-1 FT | TEMP, F | BTU HR-1 FT-2 F-1 FT |
|---|---|---|---|---|---|---|---|
| 1000 | 70.25 | 1400 | 65.25 | 1800 | 60.02 | 2100 | 56.5 |
| 1200 | 67.75 | 1600 | 62.7 | 2000 | 57.7 | | |

**ASTM-ASME JOINT COMMITTEE ON EFFECT OF TEMPERATURE ON PROPERTIES OF METALS** (16)

**MATERIAL** Molybdenum **HEAT NUMBER**

**CHEMICAL COMPOSITION PER CENT**

**FORM**

**HEAT TREATMENT**

**REFERENCE** "Osbora, P. H., "Thermal Conductivities of Tungsten and Molybdenum at Incandescent TemperaturesP, Jour. Opt. Soc. Amer., Vol 31 (June, 1941), pp. 428-432; as found in WADC Technical Report 56-423 (August, 1956).

**THERMAL CONDUCTIVITY**

| TEMP., F | BTU $HR^{-1}$ $FT^{-2}$ $F^{-1}$ FT | TEMP., F | BTU $HR^{-1}$ $FT^{-2}$ $F^{-1}$ FT | TEMP., F | BTU $HR^{-1}$ $FT^{-2}$ $F^{-1}$ FT | TEMP., F | BTU $HR^{-1}$ $FT^{-2}$ $F^{-1}$ FT |
|---|---|---|---|---|---|---|---|
| 1200 | 62.6 | 1400 | 55.7 | 1600 | 48.8 | 1800 | 41.9 |
| 1300 | 59.1 | 1500 | 52.2 | 1700 | 45.4 | 1900 | 38.5 |
| | | | | | | | |
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**ASTM-ASME JOINT COMMITTEE ON EFFECT OF TEMPERATURE ON PROPERTIES OF METALS** (17)

**MATERIAL** Molybdenum **HEAT NUMBER**

**CHEMICAL COMPOSITION PER CENT**

**FORM**

**HEAT TREATMENT**

**REFERENCE** Kannulecik, W. G., "On the Thermal Conductivity of Some Wires", Proc. Roy. Soc. (London), Vol 131A, (May 1, 1931) pp. 320-335; as found in WADC Technical Report 56-423 (August, 1956) p. 39.

**REMARKS**

**THERMAL CONDUCTIVITY**

| TEMP., F | BTU $HR^{-1}$ $FT^{-2}$ $F^{-1}$ FT | TEMP., F | BTU $HR^{-1}$ $FT^{-2}$ $F^{-1}$ FT | TEMP., F | BTU $HR^{-1}$ $FT^{-2}$ $F^{-1}$ FT | TEMP., F | BTU $HR^{-1}$ $FT^{-2}$ $F^{-1}$ FT |
|---|---|---|---|---|---|---|---|
| 32 | 83.0 | 62 | 83.7 | | | | |
| | | | | | | | |
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| | | | | | | | |

**ASTM-ASME JOINT COMMITTEE ON EFFECT OF TEMPERATURE ON PROPERTIES OF METALS** (18)

**MATERIAL** Molybdenum **HEAT NUMBER**

**CHEMICAL COMPOSITION PER CENT**

**FORM**

**HEAT TREATMENT**

**REFERENCE** Bell, I. P. and Makia, S. M., Department of Atomic Energy (Great Britain) Culcheth Labs., "Fast Reactor and Physical Properties of Materials of Construction", (Report No. RDB(C)/TN-70) AD50064; as found in WADC Technical Report 56-423 (August, 1956) p. 43.

**THERMAL CONDUCTIVITY**

| TEMP., F | BTU $HR^{-1}$ $FT^{-2}$ $F^{-1}$ FT | TEMP., F | BTU $HR^{-1}$ $FT^{-2}$ $F^{-1}$ FT | TEMP., F | BTU $HR^{-1}$ $FT^{-2}$ $F^{-1}$ FT | TEMP., F | BTU $HR^{-1}$ $FT^{-2}$ $F^{-1}$ FT |
|---|---|---|---|---|---|---|---|
| 212 | 66.8 | 572 | 66.0 | 932 | 65.3 | 1292 | 64.8 |
| 392 | 66.3 | 752 | 65.8 | 1112 | 65.1 | | |
| | | | | | | | |
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| | | | | | | | |

**ASTM-ASME JOINT COMMITTEE ON EFFECT OF TEMPERATURE ON PROPERTIES OF METALS** (19)

**MATERIAL** Molybdenum **HEAT NUMBER**

**CHEMICAL COMPOSITION PER CENT**

**FORM**

**HEAT TREATMENT**

**REFERENCE** Kelley, K. K., "Contributions to the Data on Theoretical Metallurgy X. High Temperature Heat-Content, Heat-Capacity and Entropy Data for Inorganic Compounds". Bul. U. S. Bur. Mines, No. 476, p.241. (1949); as found in WADC Technical Report 56-423, (August, 1956) pp. 29-30.

**SPECIFIC HEAT**

| TEMP., F | BTU $LB^{-1}$ $F^{-1}$ | TEMP., F | BTU $LB^{-1}$ $F^{-1}$ | TEMP., F | BTU $LB^{-1}$ $F^{-1}$ | TEMP., F | BTU $LB^{-1}$ $F^{-1}$ |
|---|---|---|---|---|---|---|---|
| 392 | 0.0657 | 1112 | 0.0689 | 1472 | 0.0715 | 1832 | 0.0742 |
| 752 | 0.0664 | | | | | | |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |

**ASTM-ASME JOINT COMMITTEE ON EFFECT OF TEMPERATURE ON PROPERTIES OF METALS** (20)

**MATERIAL** Molybdenum **HEAT NUMBER**

**CHEMICAL COMPOSITION PER CENT**

**FORM**

**HEAT TREATMENT**

**REFERENCE** Simon, F., and Zeidler, W., "Research Concerning the Specific Heats at Low Temperatures", (Untersuchungen uber die spezifi spezifischen Warmen bei tiefen Temperaturen). Zeitschr, Phys. Chem., Vol 123, (1926) pp. 383-405; as found in WADC Technical Report 56-423 (August, 1956) p. 18.

**SPECIFIC HEAT**

| TEMP., F | BTU $LB^{-1}$ $F^{-1}$ | TEMP., F | BTU $LB^{-1}$ $F^{-1}$ | TEMP., F | BTU $LB^{-1}$ $F^{-1}$ | TEMP., F | BTU $LB^{-1}$ $F^{-1}$ |
|---|---|---|---|---|---|---|---|
| 37 | 0.0576 | 56 | 0.0582 | 93 | 0.0586 | 95 | 0.0592 |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |

**ASTM-ASME JOINT COMMITTEE ON EFFECT OF TEMPERATURE ON PROPERTIES OF METALS** (21)

**MATERIAL** Molybdenum **HEAT NUMBER**

**CHEMICAL COMPOSITION PER CENT**

**FORM**

**HEAT TREATMENT**

**REFERENCE** Kelley, K. K., "Contributions to the Data on Theoretical Metallurgy" U. S. Bureau of Mines Bulletin 472, (1949). , as found in "Some Thermal Properties of Solid Materials, Part I, Metals", AEC Report, GEANPD (Sept.9, 1955).

**SPECIFIC HEAT**

| TEMP., F | BTU $LB^{-1}$ $F^{-1}$ | TEMP., F | BTU $LB^{-1}$ $F^{-1}$ | TEMP., F | BTU $LB^{-1}$ $F^{-1}$ | TEMP., F | BTU $LB^{-1}$ $F^{-1}$ |
|---|---|---|---|---|---|---|---|
| 68 | 0.0590 | 300 | 0.0672 | 800 | 0.0676 | 1400 | 0.0678 |
| 100 | 0.0619 | 400 | 0.0676 | 1000 | 0.06762 | 1600 | 0.0678 |
| 200 | 0.0652 | 600 | 0.0676 | 1200 | 0.06763 | 1800 | 0.0678 |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |

## ASTM-ASME JOINT COMMITTEE ON EFFECT OF TEMPERATURE ON PROPERTIES OF METALS

(22)

| | | |
|---|---|---|
| MATERIAL | Molybdenum | HEAT NUMBER |
| CHEMICAL COMPOSITION PER CENT | | |
| FORM | | |
| REFERENCE | Horowitz, M. and Daunt, J. G., Phys. Rev., Vol 91, pp. 1099-pp. 1099-1106 (1953); Rayne, J. A., Phys. Rev., Vol 95, (1954) pp. 1428-34; and Simon, F. and Zeidler, W., Z. Physik Chem., Vol 123, (1926) pp. 383-404; as found in "A Compendium of the Properties of Materials at Low Temperatures, Phase I", Part II, edited by Victor J. Johnson, NBS Cryogenic Engineering Laboratory, Boulder, Colorado (December, 1959). | |

### SPECIFIC HEAT

| TEMP., F | BTU LB-1 F-1 | TEMP., F | BTU LB-1 F-1 | TEMP., F | BTU LB-1 F-1 | TEMP., F | BTU LB-1 F-1 |
|---|---|---|---|---|---|---|---|
| -458 | 0.0000055 | -433 | 0.00031 | -334 | 0.0200 | -136 | 0.051 |
| -456 | 0.0000113 | -424 | 0.00069 | -316 | 0.025 | -100 | 0.053 |
| -454 | 0.0000178 | -415 | 0.00138 | -298 | 0.029 | - 68 | 0.055 |
| -453 | 0.000025 | -406 | 0.00229 | -280 | 0.033 | - 28 | 0.056 |
| -449 | 0.000046 | -388 | 0.0056 | -244 | 0.040 | 8 | 0.047 |
| -445 | 0.000076 | -370 | 0.0098 | -208 | 0.045 | 44 | 0.058 |
| -442 | 0.000119 | -352 | 0.0148 | -172 | 0.048 | 80 | 0.059 |

## ASTM-ASME JOINT COMMITTEE ON EFFECT OF TEMPERATURE ON PROPERTIES OF METALS

(23)

| | | |
|---|---|---|
| MATERIAL | Molybdenum | HEAT NUMBER |
| CHEMICAL COMPOSITION PER CENT | | |
| FORM | | |
| REFERENCE | Jaeger, F. M. and Veenstra, W. A., "The Exact Measurement of the Specific Heats of Solid Substances at High Temperatures. VI. The Specific Heats of Vanadium, Niobium, Tantalum and Molybdenum", Recueil Trav. Chim., Vol 53, (June 15, 1934) pp. 677-687; as found in WADC Technical Report 56-423, (August, 1956) p. 25. | |

### SPECIFIC HEAT

| TEMP., F | BTU LB-1 F-1 | TEMP., F | BTU LB-1 F-1 | TEMP., F | BTU LB-1 F-1 | TEMP., F | BTU LB-1 F-1 |
|---|---|---|---|---|---|---|---|
| 32 | 0.06105 | 932 | 0.06746 | 1652 | 0.07297 | 2372 | 0.07881 |
| 212 | 0.06229 | 1112 | 0.06881 | 1832 | 0.07440 | 2552 | 0.08033 |
| 392 | 0.06355 | 1292 | 0.07018 | 2012 | 0.07585 | 2732 | 0.08186 |
| 572 | 0.06484 | 1472 | 0.07157 | 2192 | 0.07732 | 2912 | 0.08342 |
| 752 | 0.06614 | | | | | | |

## ASTM-ASME JOINT COMMITTEE ON EFFECT OF TEMPERATURE ON PROPERTIES OF METALS

(24)

| | | |
|---|---|---|
| MATERIAL | Molybdenum | HEAT NUMBER |
| CHEMICAL COMPOSITION PER CENT | | |
| FORM | | |
| HEAT TREATMENT | | |
| REFERENCE | Cooper, D. and Langstrath, G. O., "The Specific Heat of Molybdenum From 250 to -40 C", Phys. Rev., Vol 33 (February, 1929) pp. 243-248; as found in WADC Technical Report 56-423 (August, 1956) pp. 19-20. | |

### SPECIFIC HEAT

| TEMP., F | BTU LB-1 F-1 | TEMP., F | BTU LB-1 F-1 | TEMP., F | BTU LB-1 F-1 | TEMP., F | BTU LB-1 F-1 |
|---|---|---|---|---|---|---|---|
| 32 | 0.0589 | 167 | 0.0613 | 302 | 0.0616 | 437 | 0.0625 |
| 77 | 0.0597 | 212 | 0.0612 | 347 | 0.0620 | 482 | 0.0632 |
| 122 | 0.0609 | 257 | 0.0614 | 392 | 0.0624 | | |

## ASTM-ASME JOINT COMMITTEE ON EFFECT OF TEMPERATURE ON PROPERTIES OF METALS

(25)

| | | |
|---|---|---|
| MATERIAL | Molybdenum | HEAT NUMBER |
| CHEMICAL COMPOSITION PER CENT | | |
| FORM | | |
| HEAT TREATMENT | | |
| REFERENCE | Shadger, J. F., "High Temperature Curves of Metals", Iron Age, Vol 110, (July 27, 1922) pp. 218-222; as found in WADC Technical Report 56-423 (August, 1956) p. 16. | |
| REMARKS | | |

### SPECIFIC HEAT

| TEMP., F | BTU LB-1 F-1 | TEMP., F | BTU LB-1 F-1 | TEMP., F | BTU LB-1 F-1 | TEMP., F | BTU LB-1 F-1 |
|---|---|---|---|---|---|---|---|
| 32 | 0.0616 | 752 | 0.0704 | 1472 | 0.0792 | 2192 | 0.0880 |
| 212 | 0.0638 | 932 | 0.0726 | 1652 | 0.0814 | 2372 | 0.0902 |
| 392 | 0.0660 | 1112 | 0.0748 | 1832 | 0.0836 | 2552 | 0.0924 |
| 572 | 0.0682 | 1292 | 0.0770 | 2012 | 0.0858 | 2732 | 0.0946 |

## ASTM-ASME JOINT COMMITTEE ON EFFECT OF TEMPERATURE ON PROPERTIES OF METALS

(26)

| | | |
|---|---|---|
| MATERIAL | Molybdenum | HEAT NUMBER |
| CHEMICAL COMPOSITION PER CENT | | |
| FORM | | |
| HEAT TREATMENT | | |
| REFERENCE | Bossart, P. N., "Spectral Emissivities, Resistivity and Thermal Expansion of Tungsten-Molybdenum Alloys", Physica, Vol 7, (February, 1936) pp. 50-54; as found in WADC Technical Report 56-423 (August, 1956) p. 49. | |

### EMISSIVITY

| TEMP., F | SPECTRAL (λ 6610 Å) | TEMP., F | SPECTRAL (λ 6600 Å) | TEMP., F | SPECTRAL (λ 6590 Å) | TEMP., F | SPECTRAL (λ Å) |
|---|---|---|---|---|---|---|---|
| 1880 | 0.378 | 2600 | 0.364 | 2960 | 0.360 | | |

## ASTM-ASME JOINT COMMITTEE ON EFFECT OF TEMPERATURE ON PROPERTIES OF METALS

(27)

| | | |
|---|---|---|
| MATERIAL | Molybdenum | HEAT NUMBER |
| CHEMICAL COMPOSITION PER CENT | | |
| FORM | | |
| HEAT TREATMENT | | |
| REFERENCE | Worthing, A. G., "Physical Properties of Well Seasoned Molybdenum and Tantalum as a Function of Temperature", Phys. Rev., Vol 28 (July, 1926) pp. 190-201; as found in WADC Technical Report 56-423 (August, 1956) pp. 46-47. | |

### EMISSIVITY

| TEMP, F | TOTAL NORMAL | TEMP, F | TOTAL NORMAL | TEMP, F | TOTAL NORMAL | TEMP, F | TOTAL NORMAL |
|---|---|---|---|---|---|---|---|
| 1340 | 0.096 | 2420 | 0.168 | 3500 | 0.230 | 4580 | 0.281 |
| 1700 | 0.121 | 2780 | 0.189 | 3860 | 0.248 | 4940 | 0.290 |
| 2060 | 0.145 | 3140 | 0.210 | 4220 | 0.265 | | |

### ASTM-ASME JOINT COMMITTEE ON EFFECT OF TEMPERATURE ON PROPERTIES OF METALS

(28)

| | |
|---|---|
| MATERIAL | Molybdenum |
| HEAT NUMBER | |
| CHEMICAL COMPOSITION PER CENT | |
| FORM | |
| REFERENCE | Rosenberg, H. M., Phil. Trans. Roy. Soc. (London) Vol A247, (1955) pp. 441-497; Kannuluik, W. G., Vol A141 (1933) pp. 159-168; as found in "A Compendium of the Properties of Materials at Low Temperatures, Phase I", Part II, edited by Victor J. Johnson, NBS Cryogenic Engineering Laboratory, Boulder, Colorado (December, 1959). |

### THERMAL CONDUCTIVITY

| TEMP, F | BTU HR-1 FT-2 F-1 FT | TEMP, F | BTU HR-1 FT-2 F-1 FT | TEMP, F | BTU HR-1 FT-2 F-1 FT | TEMP, F | BTU HR-1 FT-2 F-1 FT |
|---|---|---|---|---|---|---|---|
| -452 | 34 | -433 | 130.0 | -352 | 156 | -190 | 82.6 |
| -449 | 49.1 | -424 | 161.8+ | -316 | 121 | -100 | 80.3 |
| -445 | 72.2 | -397 | 216.7 | -280 | 99.1 | - 10 | 78.6 |
| -442 | 86.7 | -388 | 208 | | | | |

Values interpolated from graph.

### ASTM-ASME JOINT COMMITTEE ON EFFECT OF TEMPERATURE ON PROPERTIES OF METALS

(29)

| | |
|---|---|
| MATERIAL | Commercial Molybdenum |
| HEAT NUMBER | |
| CHEMICAL COMPOSITION PER CENT | |
| FORM | |
| HEAT TREATMENT | |
| REFERENCE | Osborn, R. H., "Thermal Conductivity of Tungsten and Molybdenum at Incandescent Temperatures", Journal of the American Optical Society, Vol 31 (1941) p. 428. |
| REMARKS | |

### THERMAL CONDUCTIVITY

| TEMP, F | BTU HR-1 FT-2 F-1 FT | TEMP, F | BTU HR-1 FT-2 F-1 FT | TEMP, F | BTU HR-1 FT-2 F-1 FT | TEMP, F | BTU HR-1 FT-2 F-1 FT |
|---|---|---|---|---|---|---|---|
| 1652 | 62.9 | 2192 | 53.0 | 2552 | 46.0 | 2912 | 39.2 |

Values interpolated from graph.

### ASTM-ASME JOINT COMMITTEE ON EFFECT OF TEMPERATURE ON PROPERTIES OF METALS

(30)

| | |
|---|---|
| MATERIAL | Unalloyed Molybdenum |
| HEAT NUMBER | |
| CHEMICAL COMPOSITION PER CENT | |
| FORM | |
| HEAT TREATMENT | |
| REFERENCE | Semchyshen, M. and Barr, R. Q., "Summary Report, Arc-Cast Molybdenum-Base Alloys" Contract N8onr-78700, Office of Naval Research, and Climax Molybdenum Company. |
| REMARKS | |

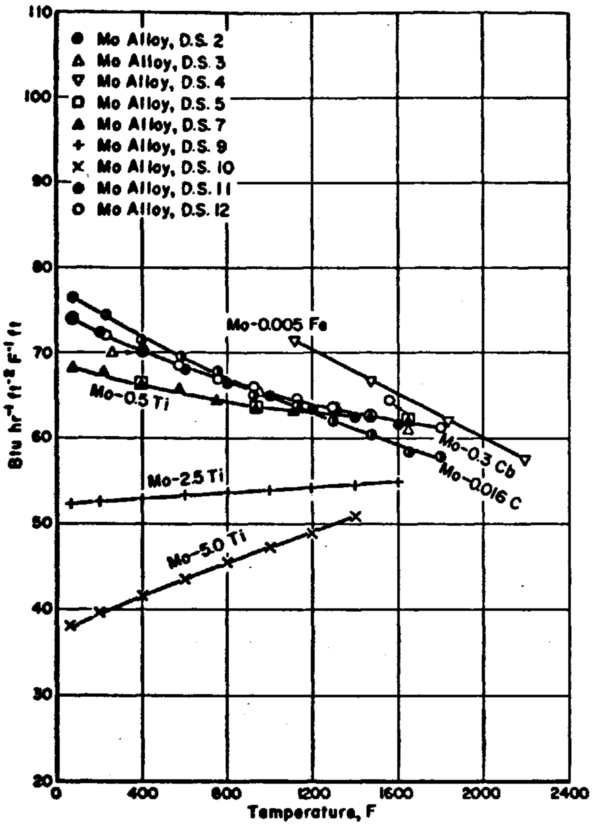
### COEFFICIENT OF LINEAR THERMAL EXPANSION

| TEMP RANGE, F | $F^{-1} \times 10^6$ | TEMP RANGE, F | $F^{-1} \times 10^6$ | TEMP RANGE, F | $F^{-1} \times 10^6$ | TEMP RANGE, F | $F^{-1} \times 10^6$ |
|---|---|---|---|---|---|---|---|
| 68-212 | 3.16 | 68-752 | 3.21 | 68-1292 | 3.28 | 68-1652 | 3.34 |
| 68-392 | 3.18 | 68-932 | 3.23 | 68-1472 | 3.31 | 68-1832 | 3.37 |
| 68-572 | 3.19 | 68-1112 | 3.26 | | | | |

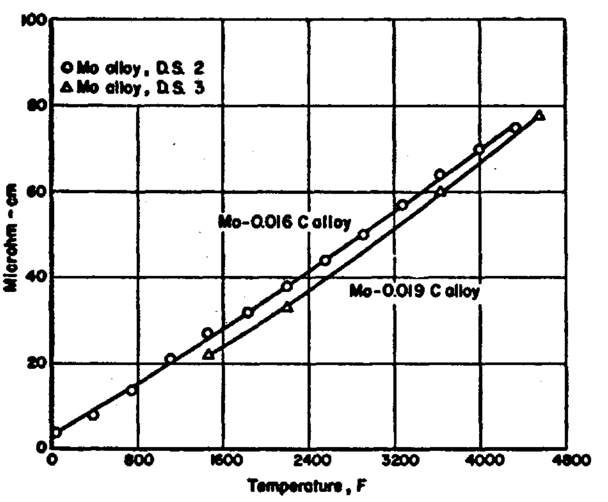
### THERMAL CONDUCTIVITY

| TEMP, F | BTU HR-1 FT-2 F-1 FT | TEMP, F | BTU HR-1 FT-2 F-1 FT | TEMP, F | BTU HR-1 FT-2 F-1 FT | TEMP, F | BTU HR-1 FT-2 F-1 FT |
|---|---|---|---|---|---|---|---|
| 68* | 72.2 | 572 | 68.2 | 1112 | 64.1 | 1472 | 63.0 |
| 212* | 71.1 | 752 | 67.0 | 1292 | 63.6 | 1652 | 62.4 |
| 392 | 69.9 | 932 | 65.9 | | | | |

* Extrapolated




THERMAL CONDUCTIVITY OF MOLYBDENUM BASE ALLOYS




ELECTRICAL RESISTIVITY OF MOLYBDENUM BASE ALLOYS

## ASTM-ASME JOINT COMMITTEE ON EFFECT OF TEMPERATURE ON PROPERTIES OF METALS

1

**MATERIAL** Molybdenum Alloy **HEAT NUMBER** 937

**CHEMICAL COMPOSITION PER CENT**

| C | Mo |
|---|---|
| 0.015 | Bal |

**FORM**

**HEAT TREATMENT** Fully recrystallized 1 hour at 2150 F.

**REFERENCE** Universal Cyclops Steel Corporation.

### COEFFICIENT OF LINEAR THERMAL EXPANSION

| TEMP RANGE, F | $F^{-1} \times 10^6$ | TEMP RANGE, F | $F^{-1} \times 10^6$ | TEMP RANGE, F | $F^{-1} \times 10^6$ | TEMP RANGE, F | $F^{-1} \times 10^6$ |
|---|---|---|---|---|---|---|---|
| 68-572 | 3.19 | 68-1112 | 3.16 | 68-1472 | 3.31 | 68-1832 | 3.37 |

## ASTM-ASME JOINT COMMITTEE ON EFFECT OF TEMPERATURE ON PROPERTIES OF METALS

2

**MATERIAL** Molybdenum Alloy **HEAT NUMBER**

**CHEMICAL COMPOSITION PER CENT**

| $O_2$ | $N_2$ | $H_2$ | C | Mo |
|---|---|---|---|---|
| 0.0007 | 0.00011 | 0.0001/0.0002 | 0.016 | Bal |

**FORM**

**HEAT TREATMENT**

**REFERENCE** Climax Molybdenum Company.

### THERMAL CONDUCTIVITY

| TEMP, F | BTU $HR^{-1}$ $FT^{-2}$ $F^{-1}$ FT | TEMP, F | BTU $HR^{-1}$ $FT^{-2}$ $F^{-1}$ FT | TEMP, F | BTU $HR^{-1}$ $FT^{-2}$ $F^{-1}$ FT | TEMP, F | BTU $HR^{-1}$ $FT^{-2}$ $F^{-1}$ FT |
|---|---|---|---|---|---|---|---|
| 75 | 76.5 | 575 | 69.5 | 1125 | 64.0 | 1650 | 58.5 |
| 225 | 74.5 | 750 | 67.8 | 1290 | 62.2 | 1800 | 58.0 |
| 390 | 71.5 | 925 | 65.5 | 1475 | 60.5 | | |

### COEFFICIENT OF LINEAR THERMAL EXPANSION

| TEMP RANGE, F | $F^{-1} \times 10^6$ | TEMP RANGE, F | $F^{-1} \times 10^6$ | TEMP RANGE, F | $F^{-1} \times 10^6$ | TEMP RANGE, F | $F^{-1} \times 10^6$ |
|---|---|---|---|---|---|---|---|
| 32-2000 | 2.67 | 32-1000 | 2.98 | 32-1800 | 3.28 | 32-2600 | 3.59 |
| 32-400 | 2.75 | 32-1200 | 3.05 | 32-2000 | 3.36 | 32-2800 | 3.66 |
| 32-600 | 2.83 | 32-1400 | 3.13 | 32-2200 | 3.43 | 32-3000 | 3.74 |
| 32-800 | 2.90 | 32-1600 | 3.21 | 32-2400 | 3.51 | | |

### SPECIFIC HEAT

| TEMP, F | BTU $LB^{-1}$ $F^{-1}$ | TEMP, F | BTU $LB^{-1}$ $F^{-1}$ | TEMP, F | BTU $LB^{-1}$ $F^{-1}$ | TEMP, F | BTU $LB^{-1}$ $F^{-1}$ |
|---|---|---|---|---|---|---|---|
| 77 | 0.06 | 930 | 0.07 | | | | |

### ELECTRICAL RESISTIVITY

| TEMP, F | MICROHM-CM | TEMP, F | MICROHM-CM | TEMP, F | MICROHM-CM | TEMP, F | MICROHM-CM |
|---|---|---|---|---|---|---|---|
| 32 | 4.0 | 1472 | 27.0 | 2552 | 44.0 | 3632 | 64.0 |
| 392 | 8.0 | 1832 | 32.0 | 2912 | 50.0 | 3992 | 70.0 |
| 752 | 14.0 | 2192 | 38.0 | 3272 | 57.0 | 4352 | 75.0 |
| 1112 | 21.0 | | | | | | |

### DENSITY

| TEMP, F | LB CU $IN^{-1}$ | TEMP, F | LB CU $IN^{-1}$ | TEMP, F | LB CU $IN^{-1}$ | TEMP, F | LB CU $IN^{-1}$ |
|---|---|---|---|---|---|---|---|
| 68 | 0.369 | | | | | | |

## ASTM-ASME JOINT COMMITTEE ON EFFECT OF TEMPERATURE ON PROPERTIES OF METALS

3

**MATERIAL** Molybdenum Alloy **HEAT NUMBER** 990

**CHEMICAL COMPOSITION PER CENT**

| C | Mo |
|---|---|
| 0.019 | Bal |

**FORM**

**HEAT TREATMENT** Recrystallized at 2250 F.

**REFERENCE** Universal Cyclops Steel Corporation.

**REMARKS** Melting point 2622 ± 40 C.

### THERMAL CONDUCTIVITY

| TEMP, F | BTU $HR^{-1}$ $FT^{-2}$ $F^{-1}$ FT | TEMP, F | BTU $HR^{-1}$ $FT^{-2}$ $F^{-1}$ FT | TEMP, F | BTU $HR^{-1}$ $FT^{-2}$ $F^{-1}$ FT | TEMP, F | BTU $HR^{-1}$ $FT^{-2}$ $F^{-1}$ FT |
|---|---|---|---|---|---|---|---|
| 390 | 70.0 | 930 | 65.9 | 1650 | 62.4 | | |

### SPECIFIC HEAT

| TEMP, F | BTU $LB^{-1}$ $F^{-1}$ | TEMP, F | BTU $LB^{-1}$ $F^{-1}$ | TEMP, F | BTU $LB^{-1}$ $F^{-1}$ | TEMP, F | BTU $LB^{-1}$ $F^{-1}$ |
|---|---|---|---|---|---|---|---|
| 68 | 0.061 | 2552 | 0.080 | | | | |

### ELECTRICAL RESISTIVITY

| TEMP, F | MICROHM-CM | TEMP, F | MICROHM-CM | TEMP, F | MICROHM-CM | TEMP, F | MICROHM-CM |
|---|---|---|---|---|---|---|---|
| 1472 | 22 | 2192 | 33 | 3632 | 60 | 4586 | 78 |

### DENSITY

| TEMP, F | LB CU $IN^{-1}$ | TEMP, F | LB CU $IN^{-1}$ | TEMP, F | LB CU $IN^{-1}$ | TEMP, F | LB CU $IN^{-1}$ |
|---|---|---|---|---|---|---|---|
| Room | 0.37 | | | | | | |

Data assumed to be at room temperature.

## ASTM-ASME JOINT COMMITTEE ON EFFECT OF TEMPERATURE ON PROPERTIES OF METALS

4

**MATERIAL** Molybdenum Alloy **HEAT NUMBER**

**CHEMICAL COMPOSITION PER CENT**

| Mo | Fe | C |
|---|---|---|
| 99.9+ | 0.005 | 0.003 |

**FORM**

**HEAT TREATMENT** Hot rolled.

**REFERENCE** Mikal, E. P., "The Thermal Conductivity of Molybdenum Over the Temperature Range 1000-2100 F", AEC Report No. ARNL-1131 (February 28, 1952).

**REMARKS**

### THERMAL CONDUCTIVITY

| TEMP, F | BTU $HR^{-1}$ $FT^{-2}$ $F^{-1}$ FT | TEMP, F | BTU $HR^{-1}$ $FT^{-2}$ $F^{-1}$ FT | TEMP, F | BTU $HR^{-1}$ $FT^{-2}$ $F^{-1}$ FT | TEMP, F | BTU $HR^{-1}$ $FT^{-2}$ $F^{-1}$ FT |
|---|---|---|---|---|---|---|---|
| 1112 | 71.4 | 1472 | 66.8 | 1832 | 62.2 | 2192 | 57.8 |

Values interpolated from graph.

### ASTM-ASME JOINT COMMITTEE ON EFFECT OF TEMPERATURE ON PROPERTIES OF METALS

5

| MATERIAL | Molybdenum Alloy | | | HEAT NUMBER 1132 |
|---|---|---|---|---|
| CHEMICAL COMPOSITION PER CENT | T | C | Mo | |
| | 0.45 | 0.016 | Bal | |
| FORM | | | | |
| HEAT TREATMENT | Recrystallized at 2700 F. | | | |
| REFERENCE | Universal Cyclops Steel Corporation. | | | |

#### THERMAL CONDUCTIVITY

| TEMP., F | BTU HR$^{-1}$ FT$^{-2}$ F$^{-1}$ FT | TEMP., F | BTU HR$^{-1}$ FT$^{-2}$ F$^{-1}$ FT | TEMP., F | BTU HR$^{-1}$ FT$^{-2}$ F$^{-1}$ FT | TEMP., F | BTU HR$^{-1}$ FT$^{-2}$ F$^{-1}$ FT |
|---|---|---|---|---|---|---|---|
| 390 | 66.6 | 930 | 63.7 | 1650 | 62.5 | | |

### ASTM-ASME JOINT COMMITTEE ON EFFECT OF TEMPERATURE ON PROPERTIES OF METALS

6

| MATERIAL | Molybdenum Alloy | | | HEAT NUMBER 1348 |
|---|---|---|---|---|
| CHEMICAL COMPOSITION PER CENT | Ti | C | Mo | |
| | 0.46 | 0.021 | Bal | |
| FORM | Rolled bar. | | | |
| HEAT TREATMENT | Fully recrystallized 1 hour at 2450 F. | | | |
| REFERENCE | Universal Cyclops Steel Corporation. | | | |

#### COEFFICIENT OF LINEAR THERMAL EXPANSION

| TEMP RANGE, F | $F^{-1} \times 10^6$ | TEMP RANGE, F | $F^{-1} \times 10^6$ | TEMP RANGE, F | $F^{-1} \times 10^6$ | TEMP RANGE, F | $F^{-1} \times 10^6$ |
|---|---|---|---|---|---|---|---|
| 68-572 | 3.09 | 68-1112 | 3.24 | 68-1472 | 3.32 | 68-1832 | 3.41 |

#### DENSITY

| TEMP., F | LB CU IN$^{-1}$ | TEMP., F | LB CU IN$^{-1}$ | TEMP., F | LB CU IN$^{-1}$ | TEMP., F | LB CU IN$^{-1}$ |
|---|---|---|---|---|---|---|---|
| Room | 0.36 | | | | | | |
| Data assumed to be at room temperature. | | | | | | | |

### ASTM-ASME JOINT COMMITTEE ON EFFECT OF TEMPERATURE ON PROPERTIES OF METALS

7

| MATERIAL | Molybdenum Alloy | | HEAT NUMBER |
|---|---|---|---|
| CHEMICAL COMPOSITION PER CENT | Ti | Mo | |
| | 0.5 | Bal | |
| FORM | | | |
| HEAT TREATMENT | | | |
| REFERENCE | Semchyshen, M. and Barr, R. Q., "Summary Report, Arc-Cast Molybdenum-Base Alloys" Contract N8onr-78700, Office of Naval Research, and Climax Molybdenum Company. | | |

#### THERMAL CONDUCTIVITY

| TEMP., F | BTU HR$^{-1}$ FT$^{-2}$ F$^{-1}$ FT | TEMP., F | BTU HR$^{-1}$ FT$^{-2}$ F$^{-1}$ FT | TEMP., F | BTU HR$^{-1}$ FT$^{-2}$ F$^{-1}$ FT | TEMP., F | BTU HR$^{-1}$ FT$^{-2}$ F$^{-1}$ FT |
|---|---|---|---|---|---|---|---|
| 68 * | 68.2 | 572 | 65.9 | 1112 | 63.6 | 1472 | 63.0 |
| 212 * | 67.6 | 752 | 64.7 | 1292 | 63.6 | 1652 | 62.4 |
| 392 | 66.5 | 932 | 63.6 | | | | |
| * Extrapolated | | | | | | | |

#### COEFFICIENT OF LINEAR THERMAL EXPANSION

| TEMP RANGE, F | $F^{-1} \times 10^6$ | TEMP RANGE, F | $F^{-1} \times 10^6$ | TEMP RANGE, F | $F^{-1} \times 10^6$ | TEMP RANGE, F | $F^{-1} \times 10^6$ |
|---|---|---|---|---|---|---|---|
| 68-212 | 3.06 | 68-752 | 3.14 | 68-1292 | 3.28 | 68-1652 | 3.36 |
| 68-392 | 3.06 | 68-932 | 3.19 | 68-1472 | 3.32 | 68-1832 | 3.41 |
| 68-572 | 3.09 | 68-1112 | 3.24 | | | | |

### ASTM-ASME JOINT COMMITTEE ON EFFECT OF TEMPERATURE ON PROPERTIES OF METALS

8

| MATERIAL | Molybdenum Alloy | | | HEAT NUMBER |
|---|---|---|---|---|
| CHEMICAL COMPOSITION PER CENT | Ti | C | Mo | |
| | 1.22 | 0.014 | Bal | |
| FORM | | | | |
| HEAT TREATMENT | | | | |
| REFERENCE | Semchyshen, M. and Barr, R. Q., "Summary Report, Arc-Cast Molybdenum-Base Alloys" Contract N8onr-78700, Office of Naval Research, and Climax Molybdenum Company. | | | |

#### COEFFICIENT OF LINEAR THERMAL EXPANSION

| TEMP RANGE, F | $F^{-1} \times 10^6$ | TEMP RANGE, F | $F^{-1} \times 10^6$ | TEMP RANGE, F | $F^{-1} \times 10^6$ | TEMP RANGE, F | $F^{-1} \times 10^6$ |
|---|---|---|---|---|---|---|---|
| 68-392 | 3.10 | 68-932 | 3.05 | 68-1292 | 3.07 | 68-1652 | 3.14 |
| 68-572 | 3.09 | 68-1112 | 3.04 | 68-1472 | 3.10 | 68-1832 | 3.19 |
| 68-752 | 3.07 | | | | | | |

### ASTM-ASME JOINT COMMITTEE ON EFFECT OF TEMPERATURE ON PROPERTIES OF METALS

9

| MATERIAL | Molybdenum Alloy | | HEAT NUMBER |
|---|---|---|---|
| CHEMICAL COMPOSITION PER CENT | Ti | Mo | |
| | 2.5 | Bal | |
| FORM | | | |
| HEAT TREATMENT | | | |
| REFERENCE | Unpublished Battelle Memorial Institute measurements. | | |

#### COEFFICIENT OF LINEAR THERMAL EXPANSION

| TEMP RANGE, F | $F^{-1} \times 10^6$ | TEMP RANGE, F | $F^{-1} \times 10^6$ | TEMP RANGE, F | $F^{-1} \times 10^6$ | TEMP RANGE, F | $F^{-1} \times 10^6$ |
|---|---|---|---|---|---|---|---|
| 68 | 52.3 | 600 | 53.2 | 1000 | 53.9 | 1400 | 54.7 |
| 200 | 52.5 | 800 | 53.6 | 1200 | 54.3 | 1600 | 55.0 |
| 400 | 52.8 | | | | | | |

### ASTM-ASME JOINT COMMITTEE ON EFFECT OF TEMPERATURE ON PROPERTIES OF METALS

10

| MATERIAL | Molybdenum Alloy | | HEAT NUMBER |
|---|---|---|---|
| CHEMICAL COMPOSITION PER CENT | Ti | Mo | |
| | 5 | Bal | |
| FORM | | | |
| HEAT TREATMENT | | | |
| REFERENCE | Unpublished Battelle Memorial Institute measurements. | | |

#### COEFFICIENT OF LINEAR THERMAL EXPANSION

| TEMP RANGE, F | $F^{-1} \times 10^6$ | TEMP RANGE, F | $F^{-1} \times 10^6$ | TEMP RANGE, F | $F^{-1} \times 10^6$ | TEMP RANGE, F | $F^{-1} \times 10^6$ |
|---|---|---|---|---|---|---|---|
| 68 | 38.1 | 400 | 41.5 | 800 | 45.4 | 1200 | 49.1 |
| 200 | 39.6 | 600 | 43.5 | 1000 | 47.3 | 1400 | 51.1 |

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## ASTM-ASME JOINT COMMITTEE ON EFFECT OF TEMPERATURE ON PROPERTIES OF METALS

| MATERIAL | Molybdenum Alloy | HEAT NUMBER |
|---|---|---|

| CHEMICAL COMPOSITION PER CENT | Cb | Mo |
|---|---|---|
| | 0.3 | Bal |

FORM

HEAT TREATMENT

REFERENCE Unpublished Battelle Memorial Institute measurements.

REMARKS

### COEFFICIENT OF LINEAR THERMAL EXPANSION

| TEMP RANGE, F | $F^{-1} \times 10^6$ | TEMP RANGE, F | $F^{-1} \times 10^6$ | TEMP RANGE, F | $F^{-1} \times 10^6$ | TEMP RANGE, F | $F^{-1} \times 10^6$ |
|---|---|---|---|---|---|---|---|
| 68 | 74.0 | 600 | 68.3 | 1000 | 65.0 | 1400 | 62.6 |
| 200 | 72.4 | 800 | 66.5 | 1200 | 63.6 | 1600 | 61.7 |
| 400 | 70.3 | | | | | | |

(12)

## ASTM-ASME JOINT COMMITTEE ON EFFECT OF TEMPERATURE ON PROPERTIES OF METALS

| MATERIAL | Molybdenum Alloy | HEAT NUMBER |
|---|---|---|

| CHEMICAL COMPOSITION PER CENT | Cb | Mo |
|---|---|---|
| | 0.3 | Bal |

FORM

HEAT TREATMENT

REFERENCE Climax Molybdenum.

REMARKS

### THERMAL CONDUCTIVITY

| TEMP, F | BTU HR-1 FT-2 F-1 FT | TEMP, F | BTU HR-1 FT-2 F-1 FT | TEMP, F | BTU HR-1 FT-2 F-1 FT | TEMP, F | BTU HR-1 FT-2 F-1 FT |
|---|---|---|---|---|---|---|---|
| 75 | 74.2 | 575 | 68.5 | 1125 | 64.8 | 1650 | 62.0 |
| 225 | 72.0 | 750 | 67.2 | 1290 | 63.8 | 1800 | 61.5 |
| 390 | 70.5 | 925 | 66.0 | 1475 | 62.8 | | |

(13)

## ASTM-ASME JOINT COMMITTEE ON EFFECT OF TEMPERATURE ON PROPERTIES OF METALS

| MATERIAL | Molybdenum Alloy | HEAT NUMBER |
|---|---|---|

| CHEMICAL COMPOSITION PER CENT | V | Mo |
|---|---|---|
| | 1.0 | Bal |

FORM

HEAT TREATMENT

REFERENCE Climax Molybdenum.

REMARKS

### COEFFICIENT OF LINEAR THERMAL EXPANSION

| TEMP RANGE, F | $F^{-1} \times 10^6$ | TEMP RANGE, F | $F^{-1} \times 10^6$ | TEMP RANGE, F | $F^{-1} \times 10^6$ | TEMP RANGE, F | $F^{-1} \times 10^6$ |
|---|---|---|---|---|---|---|---|
| 68-392 | 3.12 | 68-932 | 3.11 | 68-1292 | 3.13 | 68-1652 | 3.18 |
| 68-572 | 3.12 | 68-1112 | 3.11 | 68-1472 | 3.15 | 68-1832 | 3.17 |
| [illegible] | [illegible] | | | | | | |

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## ASTM-ASME JOINT COMMITTEE ON EFFECT OF TEMPERATURE ON PROPERTIES OF METALS

| MATERIAL | Molybdenum Alloy | | HEAT NUMBER |
|---|---|---|---|

| CHEMICAL COMPOSITION PER CENT | V | C | Mo |
|---|---|---|---|
| | 1.25 | 0.006 | Bal |

FORM

HEAT TREATMENT

REFERENCE Semchyshen, M. and Barr, R. Q., "Summary Report, Arc-Cast Molybdenum-Base Alloys", Contract N8onr-78700, Office of Naval Research, and Climax Molybdenum Company.

REMARKS

### COEFFICIENT OF LINEAR THERMAL EXPANSION

| TEMP RANGE, F | $F^{-1} \times 10^6$ | TEMP RANGE, F | $F^{-1} \times 10^6$ | TEMP RANGE, F | $F^{-1} \times 10^6$ | TEMP RANGE, F | $F^{-1} \times 10^6$ |
|---|---|---|---|---|---|---|---|
| 68-392 | 3.12 | 68-932 | 3.11 | 68-1292 | 3.13 | 68-1652 | 3.18 |
| 68-572 | 3.12 | 68-1112 | 3.11 | 68-1472 | 3.15 | 68-1832 | 3.21 |
| 68-752 | 3.11 | | | | | | |

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## ASTM-ASME JOINT COMMITTEE ON EFFECT OF TEMPERATURE ON PROPERTIES OF METALS

| MATERIAL | Molybdenum Alloy | | HEAT NUMBER |
|---|---|---|---|

| CHEMICAL COMPOSITION PER CENT | Co | C | Mo |
|---|---|---|---|
| | 0.074 | 0.020 | Bal |

FORM

HEAT TREATMENT

REFERENCE Semchyshen, M. and Barr, R. Q., "Summary Report, Arc-Cast Molybdenum-Base Alloys", Contract N8onr-78700, Office of Naval Research, and Climax Molybdenum Company.

REMARKS

### COEFFICIENT OF LINEAR THERMAL EXPANSION

| TEMP RANGE, F | $F^{-1} \times 10^6$ | TEMP RANGE, F | $F^{-1} \times 10^6$ | TEMP RANGE, F | $F^{-1} \times 10^6$ | TEMP RANGE, F | $F^{-1} \times 10^6$ |
|---|---|---|---|---|---|---|---|
| 68-392 | 3.10 | 68-932 | 3.08 | 68-1292 | 3.06 | 68-1652 | 3.12 |
| 68-572 | 3.11 | 68-1112 | 3.07 | 68-1472 | 3.08 | 68-1832 | 3.15 |
| 68-752 | 3.10 | | | | | | |

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## ASTM-ASME JOINT COMMITTEE ON EFFECT OF TEMPERATURE ON PROPERTIES OF METALS

| MATERIAL | Molybdenum Alloy | | HEAT NUMBER |
|---|---|---|---|

| CHEMICAL COMPOSITION PER CENT | Nb | C | Mo |
|---|---|---|---|
| | 0.75 | 0.033 | Bal |

FORM

HEAT TREATMENT

REFERENCE Semchyshen, M. and Barr, R. Q., "Summary Report, Arc-Cast Molybdenum-Base Alloys", Contract N8onr-78700, Office of Naval Research, and Climax Molybdenum Company.

REMARKS

### COEFFICIENT OF LINEAR THERMAL EXPANSION

| TEMP RANGE, F | $F^{-1} \times 10^6$ | TEMP RANGE, F | $F^{-1} \times 10^6$ | TEMP RANGE, F | $F^{-1} \times 10^6$ | TEMP RANGE, F | $F^{-1} \times 10^6$ |
|---|---|---|---|---|---|---|---|
| 68-392 | 3.22 | 68-932 | 3.19 | 68-1292 | 3.19 | 68-1652 | 3.23 |
| 68-572 | 3.22 | 68-1112 | 3.18 | 68-1472 | 3.21 | 68-1832 | 3.26 |
| 68-752 | 3.20 | | | | | | |