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ELECTRICAL RESISTIVITY DATA AND BIBLIOGRAPHY ON TITANIUM AND TITANIUM ALLOYS

John T. Milck

Hughes Aircraft Company

Prepared for:

Air Force Materials Laboratory

March 1970

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EPIC

ELECTRONIC
PROPERTIES
INFORMATION
CENTER

HUGHES
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CULVER CITY CALIFORNIA

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INTRODUCTION

This interim report has been prepared in response to a number of requests for electrical properties information on titanium and its alloys. It does not, however, represent a comprehensive search of the literature, but does represent a fairly useful collection of data for design purposes.

Titanium has proven itself to be a very versatile metal (in the unalloyed as well as alloyed condition) for both military and non-military applications. Commercially pure titanium and the various titanium alloys offer a range of mechanical properties that make them ideal for varied applications such as corrosive-fluid pump shafts, cryogenic storage vessels, rocket engine cases, heat-exchangers, jet engine compressor wheels, blades and spacers, airframe skins and structures (the Supersonic Transport Airplane Design makes extensive use of titanium and its alloys), chlorine anodes, saline water conversion units, deep diving undersea vehicles, tank armor, hydrofoil components, etc.

In some of these above-mentioned applications, the electrical characteristics of the metal and its alloys are very important and may be critical; especially if a film of titanium oxide is involved. A titanium oxide film is insulating and can have a rectifying action.

The following table compares the electrical resistivity of pure titanium with other pure metals: (at room temperature):

Titanium	47.8 microhm-cm
Magnesium	4.6 "
Aluminum	2.824 "
Iron	10.0 "
Copper	1.724 "

Because of the wide variety of titanium alloys which have been developed to date and their varied designations or codes, a chart or table listing the code designation and approximate chemical composition is also incorporated herein. Unfortunately, it does not list every commercially available alloy.

A few typical graphs are included herein to show the effect of alloying on the electrical resistivity of titanium and their variation with temperature. The electrical properties of titanium at cryogenic temperatures are also enclosed in another set of curves. One reason for the wide scatter in property data points is the effect of interstitial impurity elements such as nitrogen, oxygen which are easily dissolved in the titanium lattice because of the gettering characteristic of titanium. Hence, the amount of control exercised by each manufacturer with regard to the gaseous impurities and other metallic elements will govern the resulting electrical properties as well as other properties, e.g., hardness, tensile strength, etc.

A comprehensive data sheet covering all the electrical properties of titanium and its alloys will be started in the near future.

A wealth of technical data on the mechanical, chemical, physical, and thermal properties of titanium and its alloys can be obtained from the Defense Metals Information Center, Battelle Memorial Institute, 505 King Avenue, Columbus, Ohio.

TITANIUM ALLOY PROPERTIES

MATERIAL	PRODUCER	COMPOSITION (% MAX)	FORMS*	TENSILE STRENGTH PSI	YIELD STRENGTH PSI	% ELONG. IN 2 In.
A-40	Rem-Cru Titanium Inc.	99 + Ti	S, B, W, T	50,000	40,000	22
RS-40	Republic Steel Corp.	C.P.; 0.20 C	S, B, F	50,000	40,000	22
Ti-55A	Titanium Metals Corp.	99 + Ti; 0.12 Fe; 0.05 N_2; 0.10 C	S, B, E, W, T	55,000	45,000	20
Ti-65A	Titanium Metals Corp.	99 + Ti; 0.12 Fe; 0.05 N_2; 0.10 C	S, B, E, W, T	65,000	55,000	20
RS-55	Republic Steel Corp.	C.P.; 0.20 C	S, B, F	65,000	50,000	20
A-55	Rem-Cru Titanium Inc.	99 + Ti; 0.20 C	S, B, W, T	65,000	55,000	20
Ti-75A	Titanium Metals Corp.	99 + Ti; 0.20 Fe; 0.08 N_2; 0.13 C	S, B, E, W, T	80,000	70,000	15
RS-70	Republic Steel Corp.	C.P.; 0.20 C	S, B, F	80,000	70,000	18
A-70	Rem-Cru Titanium Inc.	99 + Ti, 0.20 C	S, B, W, T	80,000	70,000	15
MST III	Mallory-Sharon Titanium Corp.	99 + Ti; 0.10 C	S, B, W, F	85,000	75,000	22
A-110AT	Rem-Cru Titanium Inc.	92 Ti; 5 Al; 2.50 Sn	S, B, W	115,000	110,000	20
RS-110A	Republic Steel Corp.	7 Mn; 0.20 C	S	120,000	110,000	10
RS-110BX	Republic Steel Corp	3 Mn; 1.50 Al; 0.20 C	S, B, F	120,000	110,000	10
C-110M	Rem-Cru Titanium Inc.	91 + Ti; 8 Mn	S	120,000	110,000	10
Ti-140A	Titanium Metals Corp.	93 + Ti; 2 Fe; 2 Cr; 2 Mo; 0.08 N_2; 0.10 C	S, B, E, W	130,000	115,000	15
C-120AV	Rem-Cru Titanium Inc.	[illegible] + Ti; 6 Al; 4 V	S, B, W	130,000	120,000	[illegible]
Ti-6Al-4V	Titanium Metals Corp.	89 + Ti; 6 Al; 4 V; 0.25 Fe; 0.05 N_2	S, B, E, W	130,000	120,000	10
MST 6 Al 4 V	Mallory-Sharon Titanium Corp.	5.50 to 6.50 Al; 3.50 to 4.50 V; 0.20 C	S, B, W, T, F, E	130,000	120,000	10
MST 8 Mn	Mallory-Sharon Titanium Corp.	92 Ti; 7 to 9 Mn; 0.20 C	S	135,000	120,000	12
C-130AM	Rem-Cru Titanium Inc.	91 + Ti; 4 Mn	S, B, W	140,000	130,000	10
RS-130	Republic Steel Corp.	4 Mn; 4 Al; 0.20 C	B, F	140,000	130,000	10
MST 4 Mn 4 Al	Mallory-Sharon Titanium Corp.	3.50 to 4.50 Mn; 3.50 to 4.50 Al; 0.20 C	B, W, T, F, E	140,000	130,000	12
RS-140X	Republic Steel Corp.	1.25 Fe; 2.75 Cr; 5 Al; 0.20 C	B, F	150,000	140,000	10
MST 3 Al 5 Cr	Mallory-Sharon Titanium Corp.	2.50 to 3.50 Al; 4.50 to 5.50 Cr; 0.20 C	B, E, F	150,000	140,000	12
Ti-155A	Titanium Metals Corp.	[illegible] + Ti; 1.30 Fe; 1.40 Cr; 1.40 Mo; 5 Al; 0.05 N_2; 0.10 C	B, E, W	150,000	140,000	12

*S—Rolled flat products—sheet, strip, plate E—Extrusions T—Tube

B—Bar and billet W—Wire F—Forgings

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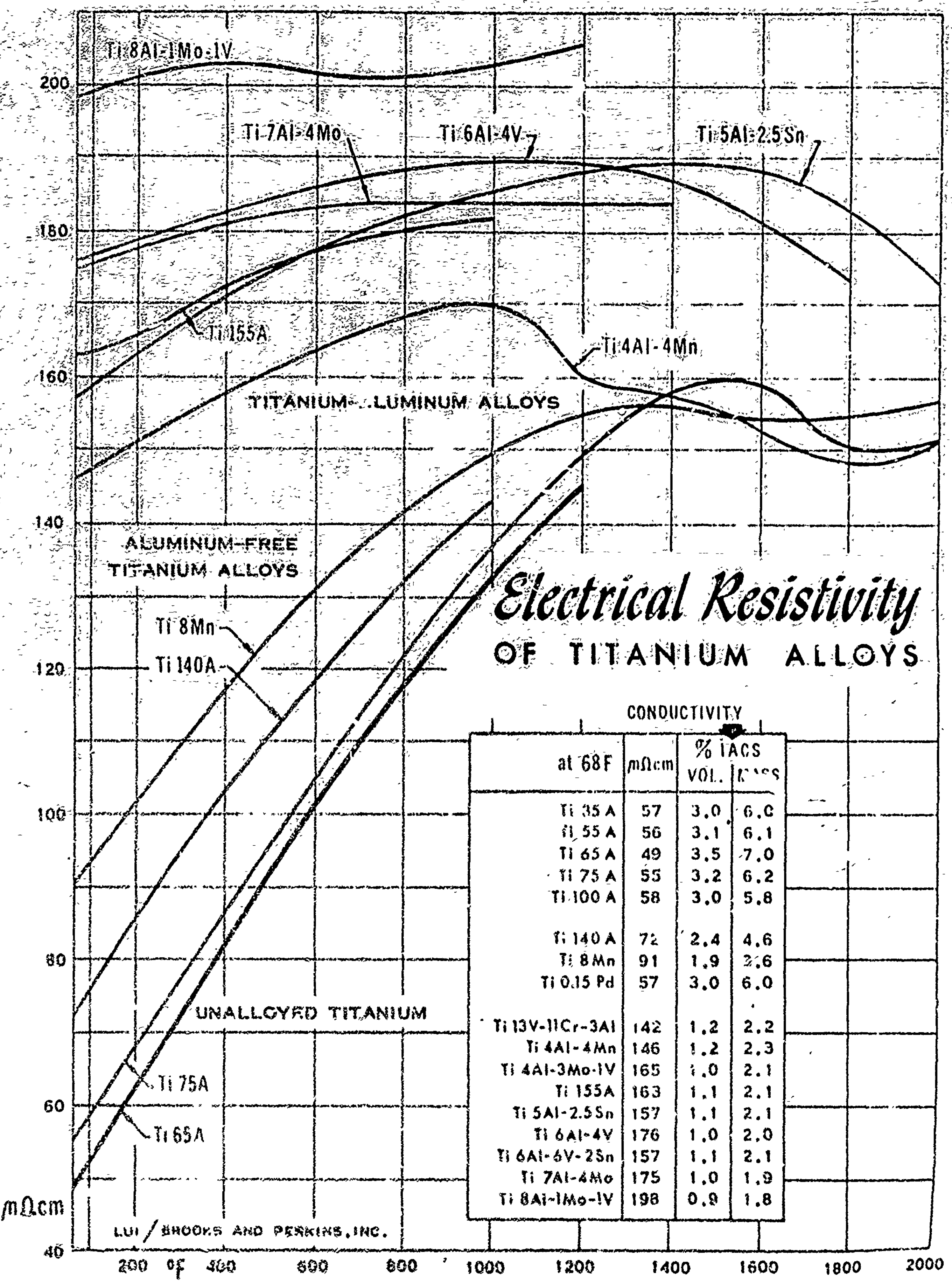

Electrical Resistivity OF TITANIUM ALLOYS

at 68F	mΩcm	CONDUCTIVITY % IACS VOL.	MASS
Ti 35 A	57	3.0	6.0
Ti 55 A	56	3.1	6.1
Ti 65 A	49	3.5	7.0
Ti 75 A	55	3.2	6.2
Ti 100 A	58	3.0	5.8
Ti 140 A	72	2.4	4.6
Ti 8Mn	91	1.9	3.6
Ti 0.15 Pd	57	3.0	6.0
Ti 13V-11Cr-3Al	142	1.2	2.2
Ti 4Al-4Mn	146	1.2	2.3
Ti 4Al-3Mo-1V	165	1.0	2.1
Ti 155A	163	1.1	2.1
Ti 5Al-2.5Sn	157	1.1	2.1
Ti 6Al-4V	176	1.0	2.0
Ti 6Al-6V-2Sn	157	1.1	2.1
Ti 7Al-4Mo	175	1.0	1.9
Ti 8Al-1Mo-1V	198	0.9	1.8

"ELECTRICAL RESISTIVITY OF TITANIUM METAL AND VARIOUS TITANIUM ALLOYS AS A FUNCTION OF TEMPERATURE AND ALLOY CONTENT."

Reference: Alexander Goldsmith (Editor)
Armour Research Foundation
Handbook of Thermophysical
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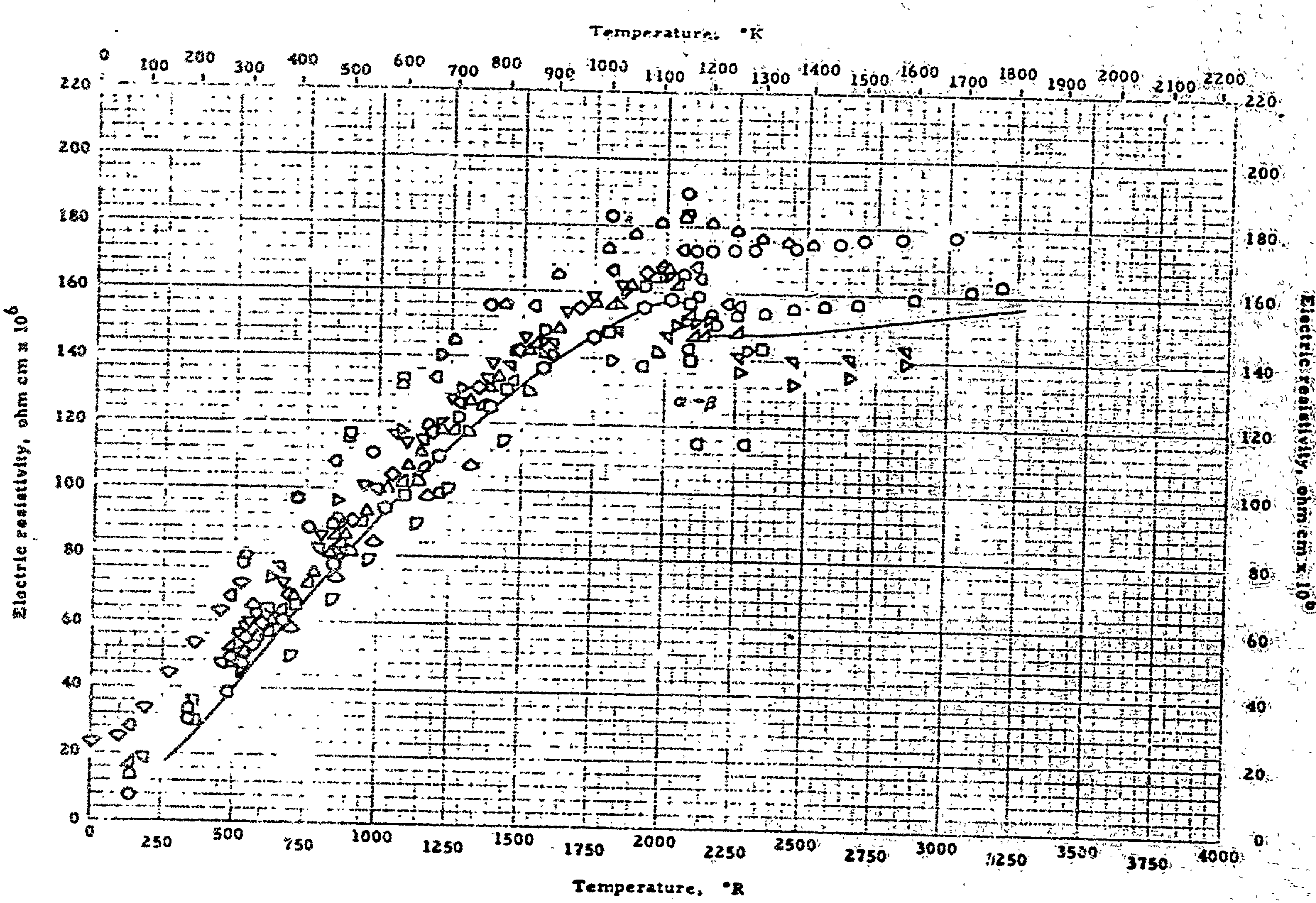
AD 253 710



ELECTRIC RESISTIVITY -- TITANIUM

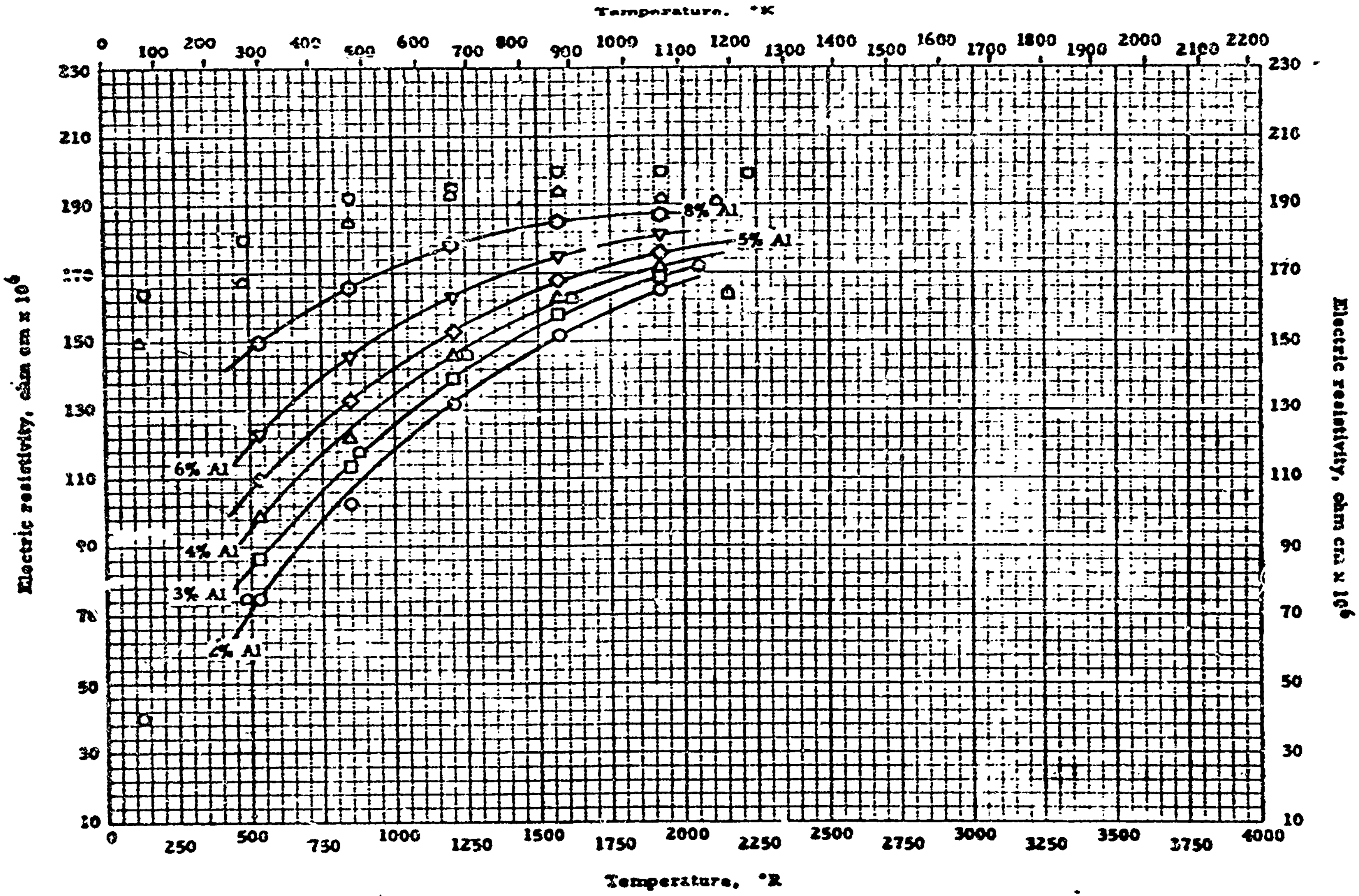
ELECTRIC RESISTIVITY -- TITANIUM

REFERENCE INFORMATION

Symbol	Investigator	Ref.	Range, °R	Material Composition	Test Method	Remarks
○	Wyatt, J. L.	53-15	137-3023	"Iodide": 99.9% Ti; 0.06% Pb; 0.012% A; 0.010% Mn; 0.004% Fe; 0.003% Sn; 0.002% N; 0.001% ea. Cu, Mg	Kelvin bridge	Data reported as r/r (77°F). Auth. est. accuracy of ± 0.02 ohm-cm at 77°F
□	Ames, S. L. and McQuillan, A. D.	54-25	760-2340	"Iodide titanium" 0.38% Zr	Kelvin bridge	Sample homogenized for 70 hr. at 1000°C, then quenched
△	Weiner, L., Chiotti, P. and Wilhelm, H. A.	52-8	535-2018	"Iodide titanium"	Potential drop	Annealed 12 hr. at 650 - 700°C. Heating and cooling runs at 45 - 65 °F/hr. Auth. est. accuracy of 0.4%
◇	Ibid.	52-8	541-1997	Same as above	Same as above	Annealed 10 hr. at 675 - 700°C. Heating run. Other conditions as above
▽	Ibid.	52-8	550-1997	Same as above	Same as above	Annealed 8 hr. at 700 - 725°C. Heating run. Other conditions as above
○	Ames, S. L. and McQuillan, A. D.	56-15	537-2024	"Iodide titanium" α-hexagonal modification	Kelvin bridge	High temp. work in vacuum of 10^{-6} mm Hg. Auth. est. accuracy 1%
○	Wyatt, J. L.	53-15	137-3195	Ti - 75A: 99.74% Ti; 0.08% Si; 0.06% O_2; 0.03% ea. Fe, Cl; 0.02% Mg; 0.015% Mn; 0.01% Al; 0.002% ea. N_2, Sb, Pb, W, Cr, Ni; 0.001% ea. Sn, Cu, V, Mo	Kelvin bridge	Data reported as r/r (77°F). Auth. est. accuracy of ± 0.02 ohm-cm at 537°R
○	Michels, W. C. and Wilford, S. E.	49-5	540-2520	Impure, commercial material	Potential drop	Auth. est. accuracy of ± 1%
○	Michels, W. C. and Wilford, S. E.	49-8	527-2075	99.5% pure	Potential drop	
▽	Worner, H. W.	49-7	519-573	0.2 - 0.3% Fe, 0.1% N_2; 0.07% C; trace of Pb, Si, Mn; faint trace of Mg, Zn, Cu, Co; ρ = 281 lb_m/ft^3	Kelvin bridge	Annealed 10 min. at 520°C
◇	Kemp, W. R. G., et al.	56-14	0-522	Nominal 98% purity, 1.63% O_2; 0.14% C; 0.13% Si; 0.081% Ni; 0.05% Fe	Potential drop	Annealed 5 hr. at 950°C in vacuum
△	Ames, S. L. and McQuillan, A. D.	56-15	492-1842	Iodide refined (α-phase); 1% Nb	Kelvin bridge	High temp. work in vacuum of 10^{-6} mm Hg. Auth. est. accuracy 1%
▽	Mikryukov, V. E.	57-50	560-1440	"Iodide titanium"; 99.9% pure	Potential drop	Annealed 5 hr. at 700°C in vacuum
◇	Ibid.	57-50	565-1320	Forged Titanium 99.6% pure	Same as above	Same as above
△	Bostrom, W. A.	57-100	139-2256	Crystal bar; 0.07% O_2; 0.032% C	Kelvin double bridge	
◁	Ibid.	57-100	139-2256	Commercial grade; 0.57% C; 0.10% O_2; 0.05% Fe	Same as above	
▷	Ames, S. L. and McQuillan, A. D.	56-95	1272-2292	β phase	Double bridge method at high temp., and knife edges at room temp.	

REFERENCE INFORMATION

Symbol	Investigator	Ref.	Range, °R	Material Composition	Test Method	Remarks
○	Peterson, V. C. and Huber, R. W.	55-101	492-2292	Not given	Potential drop	Cold swaged and drawn, annealed 2 hr. at 800 °C. α to β transformation causes drop of res. at 884-896 °C
□	Sagel, K.	56-96	528-2157	99.99% pure	Not given	Iodide titanium
◇	Deem, H. W., Wood, W. D. and Lucks, C. F.	58-21	560-1460	A-55 (formerly RC-55); unalloyed nom. 100% Ti	Potential drop	Auth. est. accuracy ± 1%
▽	Greiner, E. S. and Ellis, W. C.	48-23	139-1948	"Ductile" Ti	Potentiometer. Current reversed; Cu-Const. thermocouple low temp. Chromel-Alumel thermocouple high temp. Room temp. in oil bath	Two samples (graphically identical) Sample A annealed, sintered compact, cold swaged with intermediate vac. annealings at 800-1000 °C. Sample B rod cold swaged with intermediate annealings at, close packed hex --body centered cubic at 885 °C Annealed 2 hr. in vacuum at 800 °C
○	Ibid.	48-23	528-1932	Same as above	Same as above	Same as above. Annealed 2.5 hr. at 1000 °C
△	Lampson, F. K., Rowe, G. H., et al.	54-102	528-2960	99.8% pure; 0.10% Fe; 0.02% N_2; low C_2	Potential drop, He atmos.	Grain growth 20 fold during test. Auth. believes broad trans. range and decrease in resistivity due to impurities. Heating
▽	Ibid.	54-102	528-2960	Same as above	Same as above	Same as above. Cooling
◁	Munster, A., Sagel, K. and Zwicker, U.	56-112	528-2148	Pure iodide Ti	Potential drop	Difference between heating and cooling runs less than 5%

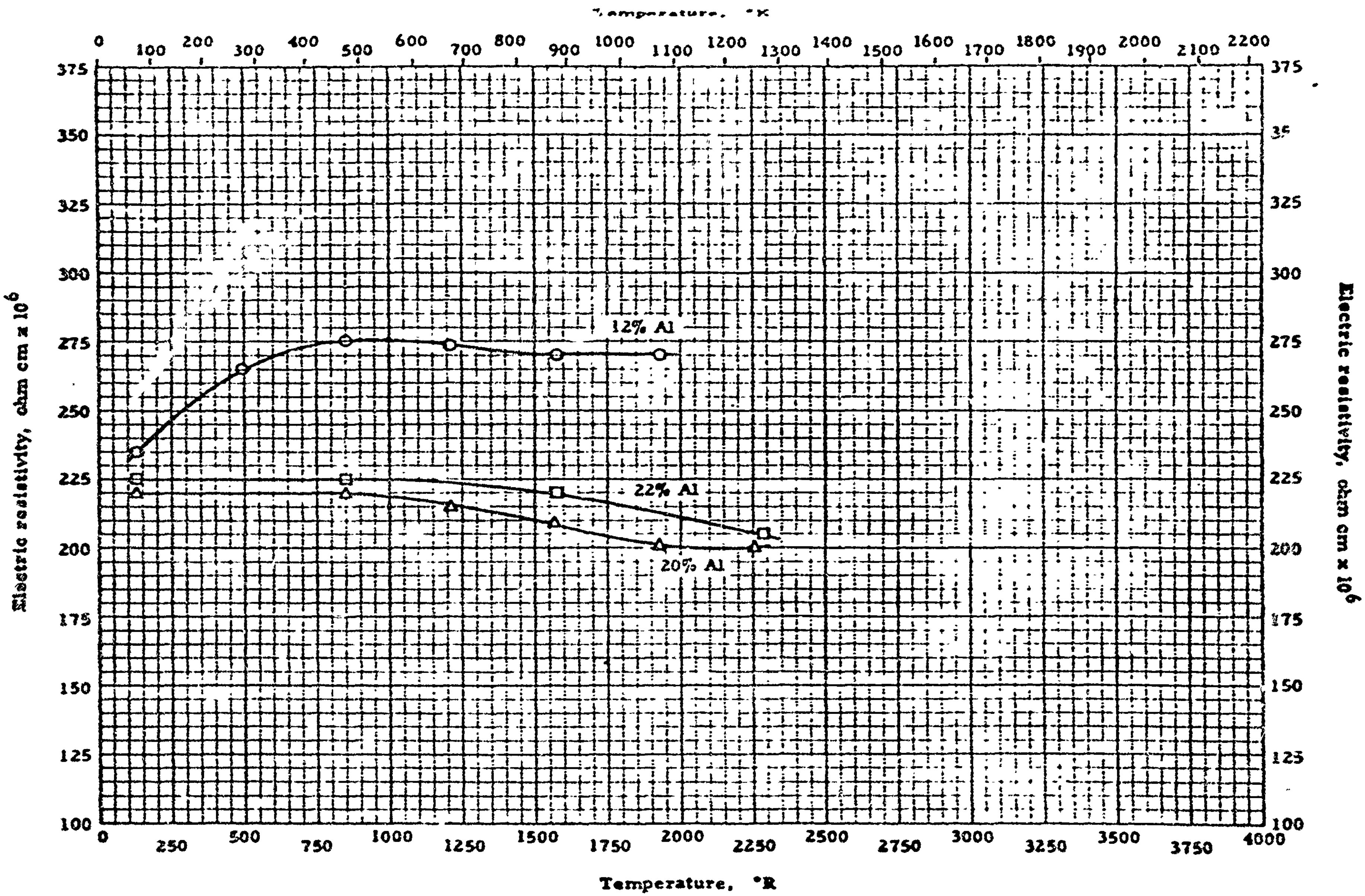


ELECTRIC RESISTIVITY -- TITANIUM + ALUMINUM
(0 - 10% Al)

ELECTRIC RESISTIVITY -- TITANIUM + ALUMINUM
(0 - 10% Al)

REFERENCE INFORMATION

Symbol	Investigator	Ref.	Range, °R	Material Composition	Test Method	Remarks
○	Ames, S. L. and McQuillan, A. D.	56-15	537-1932	Ti, α-phase; 2% Al	Double balance bridge	High temp. work in vacuum of 10^{-6} mm Hg. Auth. est. accuracy 1%
□	Ibid.	56-15	537-1932	Ti, α-phase; 3% Al	Same as above	Same as above
△	Ibid.	56-15	537-1932	Ti, α-phase; 4% Al	Same as above	Same as above
◇	Ibid.	56-15	537-1932	Ti, α-phase; 5% Al	Same as above	Same as above
▽	Ibid.	56-15	537-1932	Ti, α-phase; 6% Al	Same as above	Same as above
⬡	Ibid.	56-15	537-1932	Ti, α-phase; 8% Al	Same as above	Same as above
◘	Munster, A. Sagel, K. and Zwicker, U.	56-112 also 56-96	150-2148	1% Al	Potential drop	Made from pure iodide-titanium or 99.96% pure Mg-reduced Ti and 99.99% pure Al. Melted in arc furnace with W electrode, in 99.995% pure A atm., remelted twice more. Diff. between heating and cooling <3%
⌂	Ibid.	56-112 also 56-96	150-2094	7% Al	Same as above	Same as above
◯	Ibid.	56-112 also 56-96	150-2220	8% Al	Same as above	Same as above



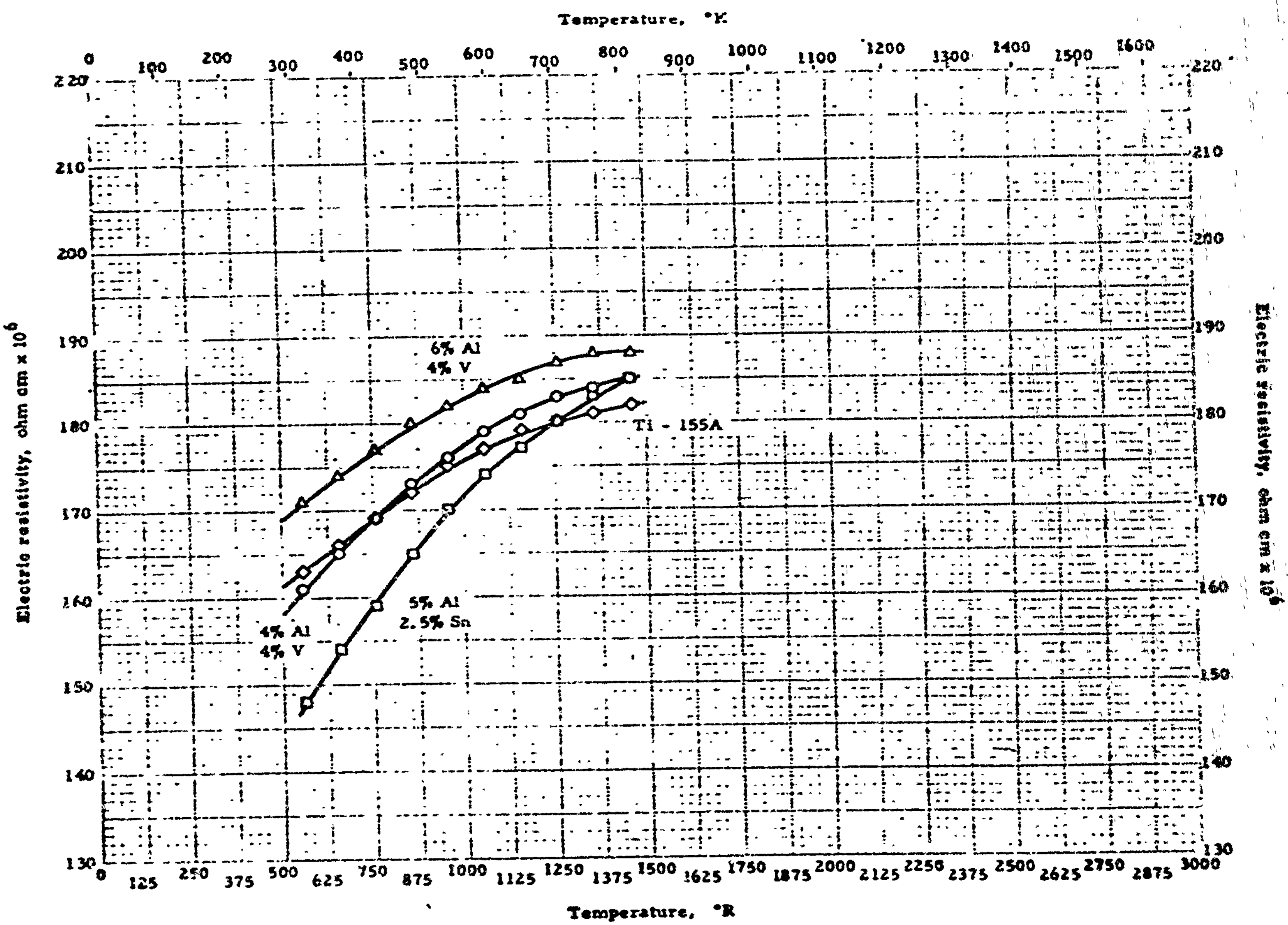
ELECTRIC RESISTIVITY -- TITANIUM + ALUMINUM
(10 - 22% Al)

V - C - 1

ELECTRIC RESISTIVITY -- TITANIUM + ALUMINUM
(10 - 22% Al)

REFERENCE INFORMATION

Symbol	Investigator	Ref.	Range, °R	Material Composition	Test Method	Remarks
○	Munster, A., Sagel, K. and Zwicker, U.	56-96 also 56-112	150-2292	12% Al	Potential drop	Prepared from iodide Ti or 99.96% pure Mg - reduced Ti and 99.99% pure Al, melted in arc furnace with W electrode in 99.995% pure A atm. and remelted twice more. Diff. between heating and cooling runs less than 3%
△	Ibid.	56-96 also 56-112	150-2004	20% Al	Same as above	Same as above
□	Ibid.	56-96 also 56-112	150-2220	22% Al	Same as above	Same as above



ELECTRIC RESISTIVITY -- TITANIUM + ALUMINUM + X

ELECTRIC RESISTIVITY -- TITANIUM + ALUMINUM + X

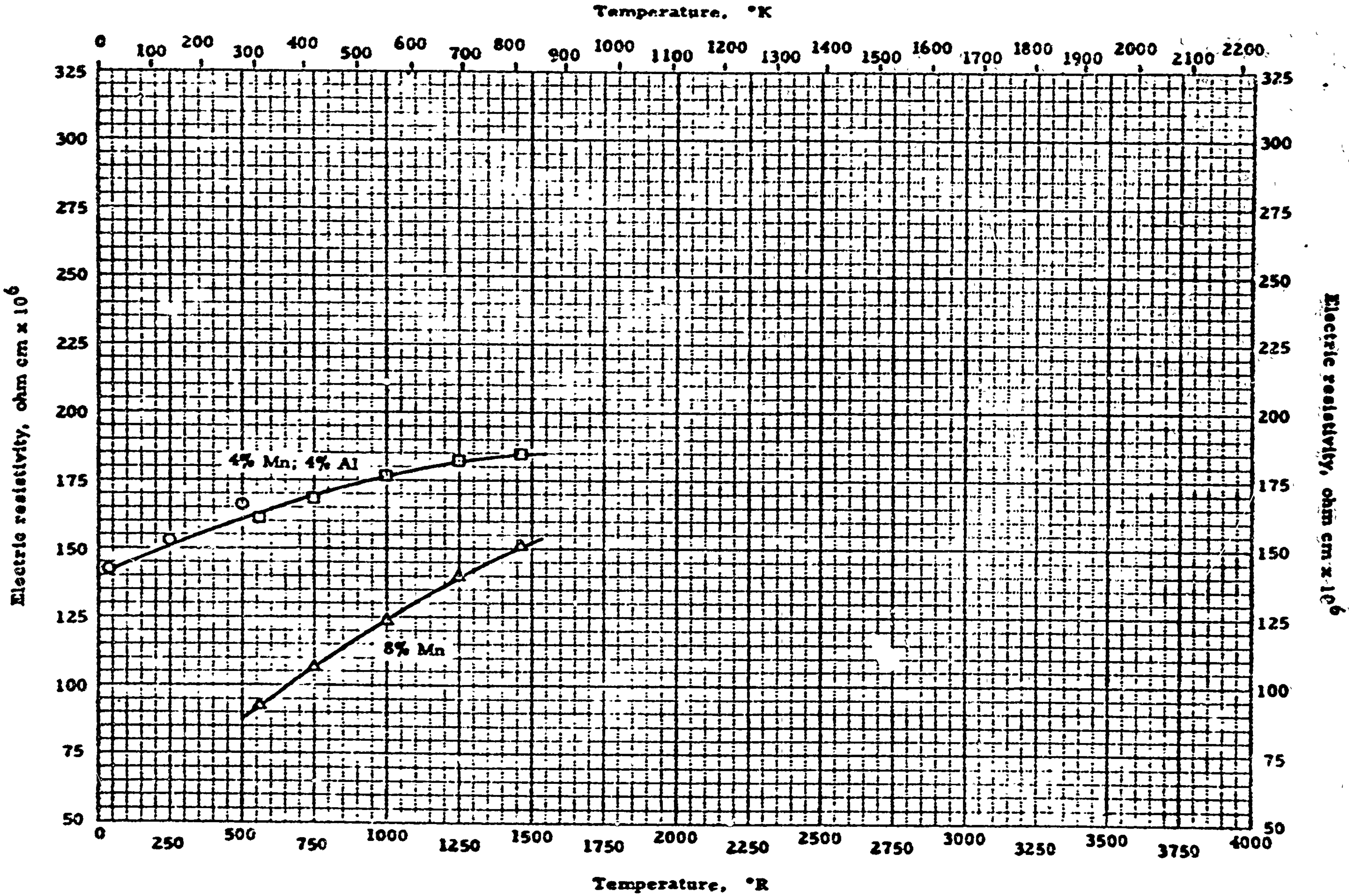
REFERENCE INFORMATION

Symbol	Investigator	Ref.	Range, °R	Material Composition	Test Method	Remarks
○	Deem, H. W., Wood, W. D. and Locke, C. F.	58-21	560-1460	C - 130 AM (Formerly RC-130B) Nominal: 4% Al; 4% Mn	Potential drop	Auth. est. accuracy ± 1%
□	Ibid	58-21	560-1460	A-110 AT Nominal: 5% Al 2.5% Sn	Same as above	Same as above
△	Ibid	58-21	560-1460	Ti-6Al-4V Nominal: 6% Al; 4% V	Same as above	Same as above
◇	Ibid	58-21	560-1460	Ti-155A Nominal: 5% Al; 1.5% Fe; 1.4% Cr; 1.2% Mo	Same as above	Same as above

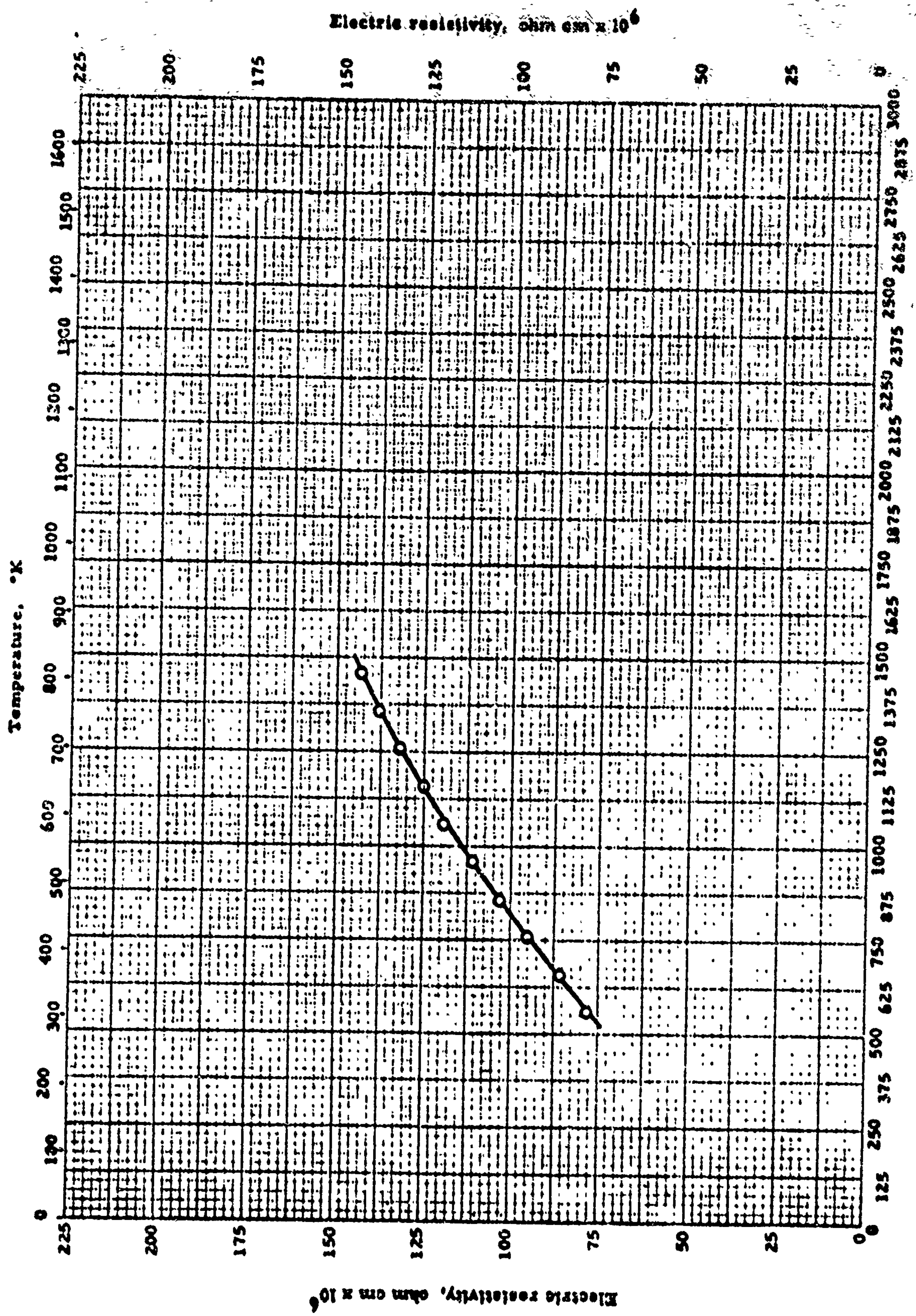
LINEAR THERMAL EXPANSION -- TITANIUM + MANGANESE + X

REFERENCE INFORMATION

Symbol	Investigator	Ref.	Range, °R	Material Composition	Test Method	Remarks
O	Bishop, S.M., Spretnak, J.W. and Fontana, M.G.	52-122	130-530	Ti-150-A. 3.8% Mn; 3.8% Al; 0.24% C	Quartz tube dilatometer with dial gauge. Temp. by thermocouple	Annealed 6 hr. at 1200°F



ELECTRIC RESISTIVITY -- TITANIUM + MANGANESE + X



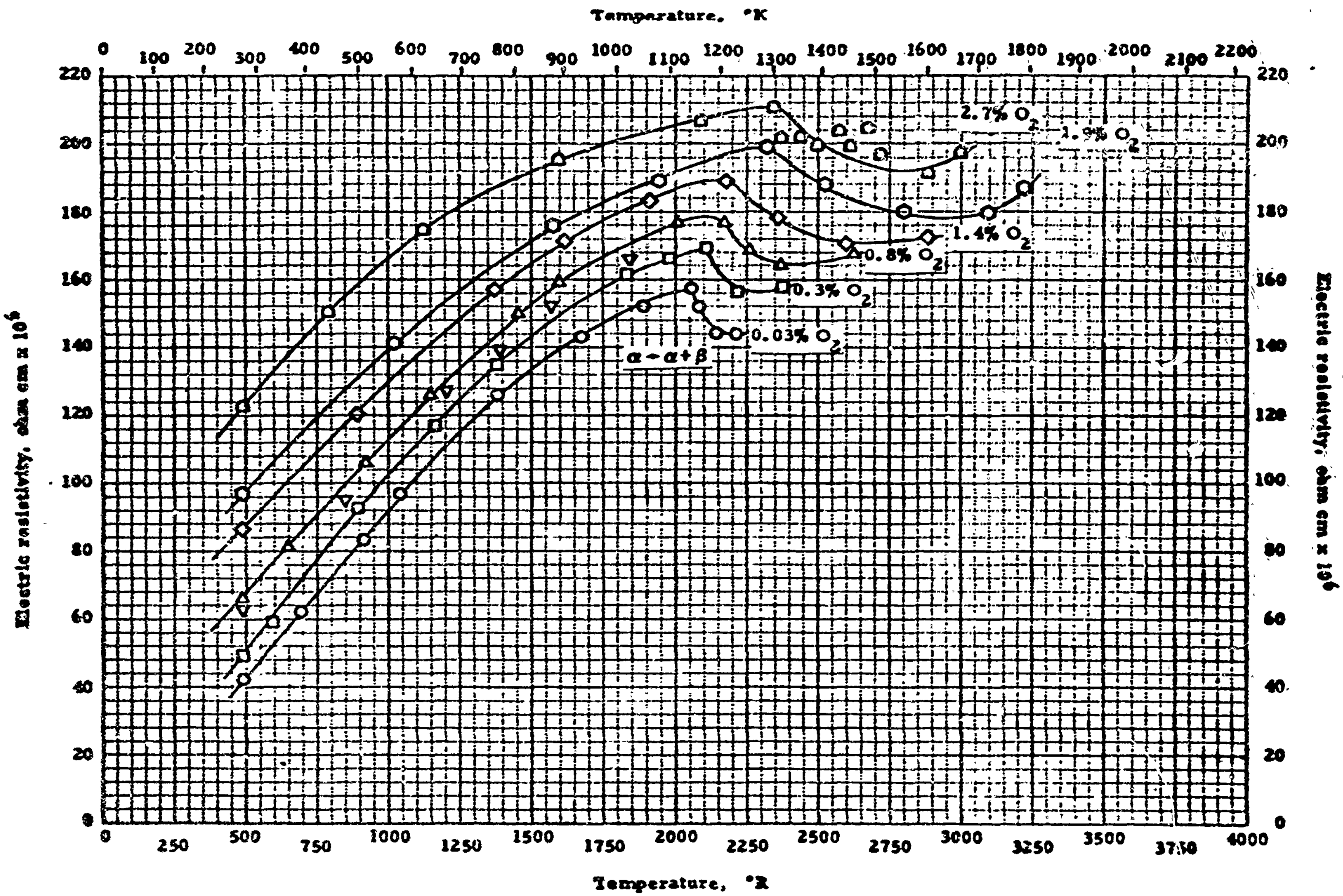
ELECTRIC RESISTIVITY -- TITANIUM + IRON + CHROMIUM + X

V - C - 7

ELECTRIC RESISTIVITY -- TITANIUM + IRON + CHROMIUM + X

REFERENCE INFORMATION

Symbol	Investigator	Ref.	Range, °R	Material Composition	Test Method	Remarks
O	Deem, H.W., Wood, W.D. and Lucks, C.F.	58-21	560-1460	Ti-140A. Nominal: 2.2% Fe; 2.1% Cr; 2.0% Mo	Potential drop	Auth. est. accuracy ± 1%

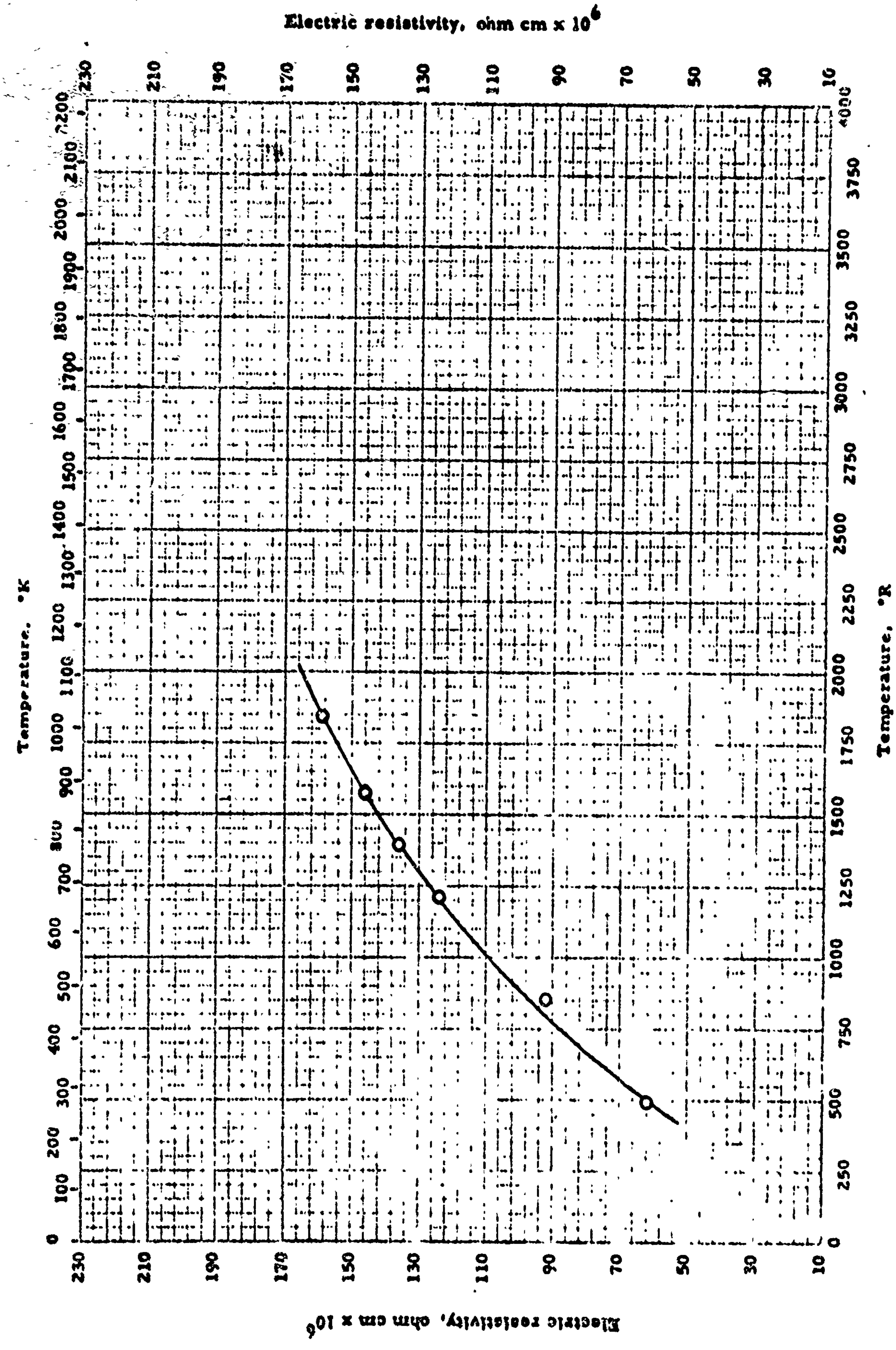


ELECTRIC RESISTIVITY -- TITANIUM + OXYGEN + X

ELECTRIC RESISTIVITY -- TITANIUM + OXYGEN + X

REFERENCE INFORMATION

Symbol	Investigator	Ref.	Range, °R	Material Composition	Test Method	Remarks
○	DePue, L. A., and Chapin, E. J.	56-9	492-2216	0.028% O_2; 0.002% N_2; Mo, Al, Si, Cu, Mg, Mn, Fe, Sn also present as impurities	Potential drop	High purity iodide titanium and pure TiO_2 fused in He atmos. and remelted several times
□	Ibid.	56-9	492-238[illegible]	[illegible] O_2; 0.001% N_2; Mo, Al, Si, Cu, Mg, Mn, Fe, Sn also present as impurities	Same as above	Same as above
△	Ibid.	56-9	492-2638	0.848% O_2; 0.002% N_2; Mo, Al, Si, Cu, Mg, Mn, Fe, Sn also present as impurities	Same as above	Same as above
◇	Ibid.	56-9	492-2891	1.40% O_2; 0.002% N_2; Mo, Al, Si, Cu Mg, Mn, Fe, Sn also present as impurities	Same as above	Same as above
▽	Ames, S. L., and McQuillan, A. D.	56-15	492-1842	1.45% O_2	Double balance bridge	Prepared from iodide refined (α-phase) titanium and spectroscopically pure TiO_2
○	DePue, L. A., and Chapin, E. J.	56-9	492-3223	1.90% O_2; 0.003% N_2; Mo, Al, Si, Cu, Mg, Mn, Fe, Sn also present as impurities	Potential drop	High purity iodide titanium and pure TiO_2 fused in He atmos. and remelted several times
○	Ibid.	56-9	492-2994	2.68% O_2; 0.006% N_2; Mo, Al, Si, Cu, Mg, Mn, Fe, Sn also present as impurities	Same as above	Same as above



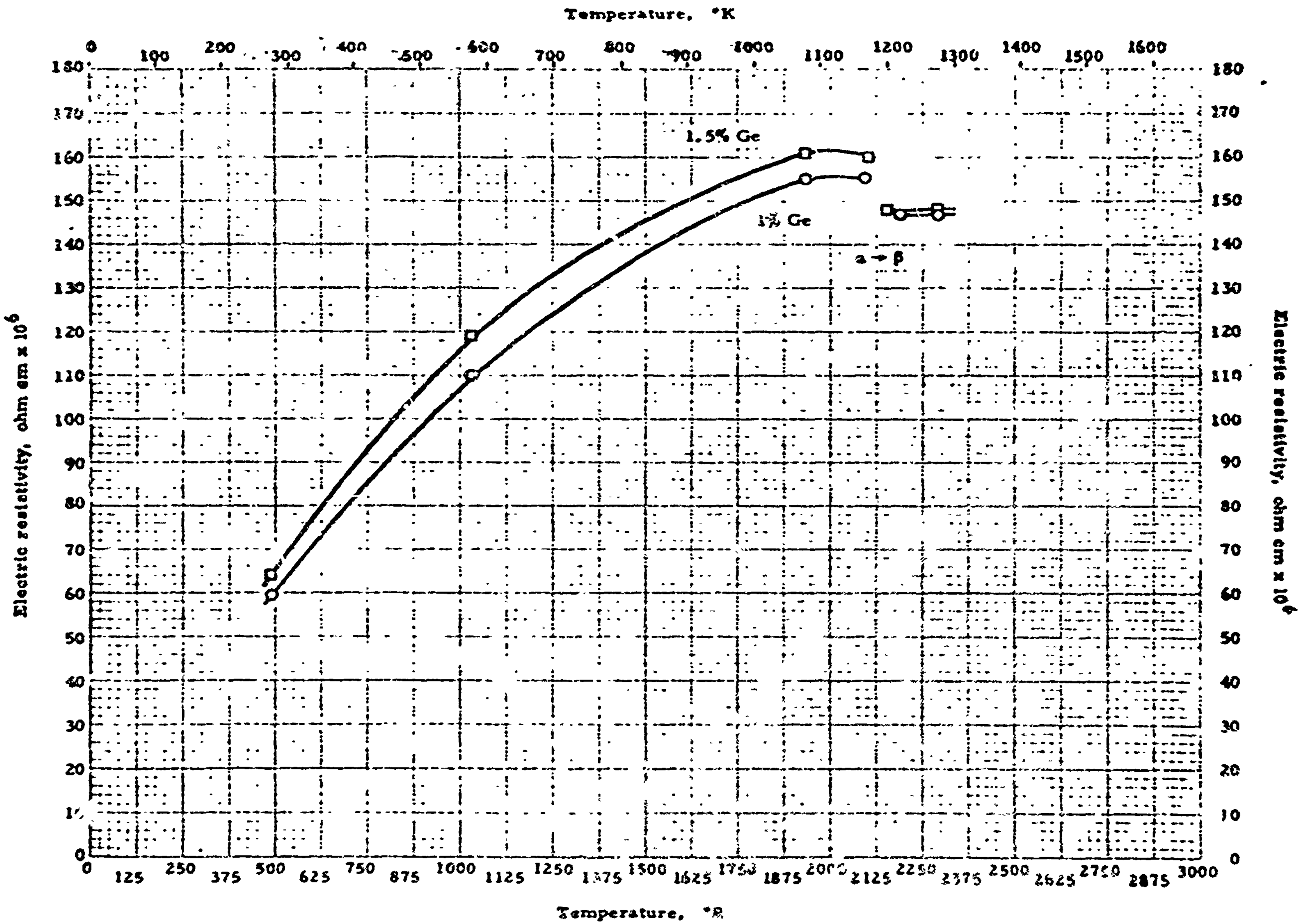
ELECTRIC RESISTIVITY -- TITANIUM + COPPER

V - C

ELECTRIC RESISTIVITY -- TITANIUM + COPPER

REFERENCE INFORMATION

Symbol	Investigator	Ref.	Range, °R	Material Composition	Test Method	Remarks
O	Ames, S. L. and McQuillan, A. D.	56-15	492-1842	Iodide Ti (α-phase); 1% Cu (99.99% pure)	Double balance bridge	High temp. work in vacuum of 10^{-6} mm Hg. Auth. est. accuracy 1%

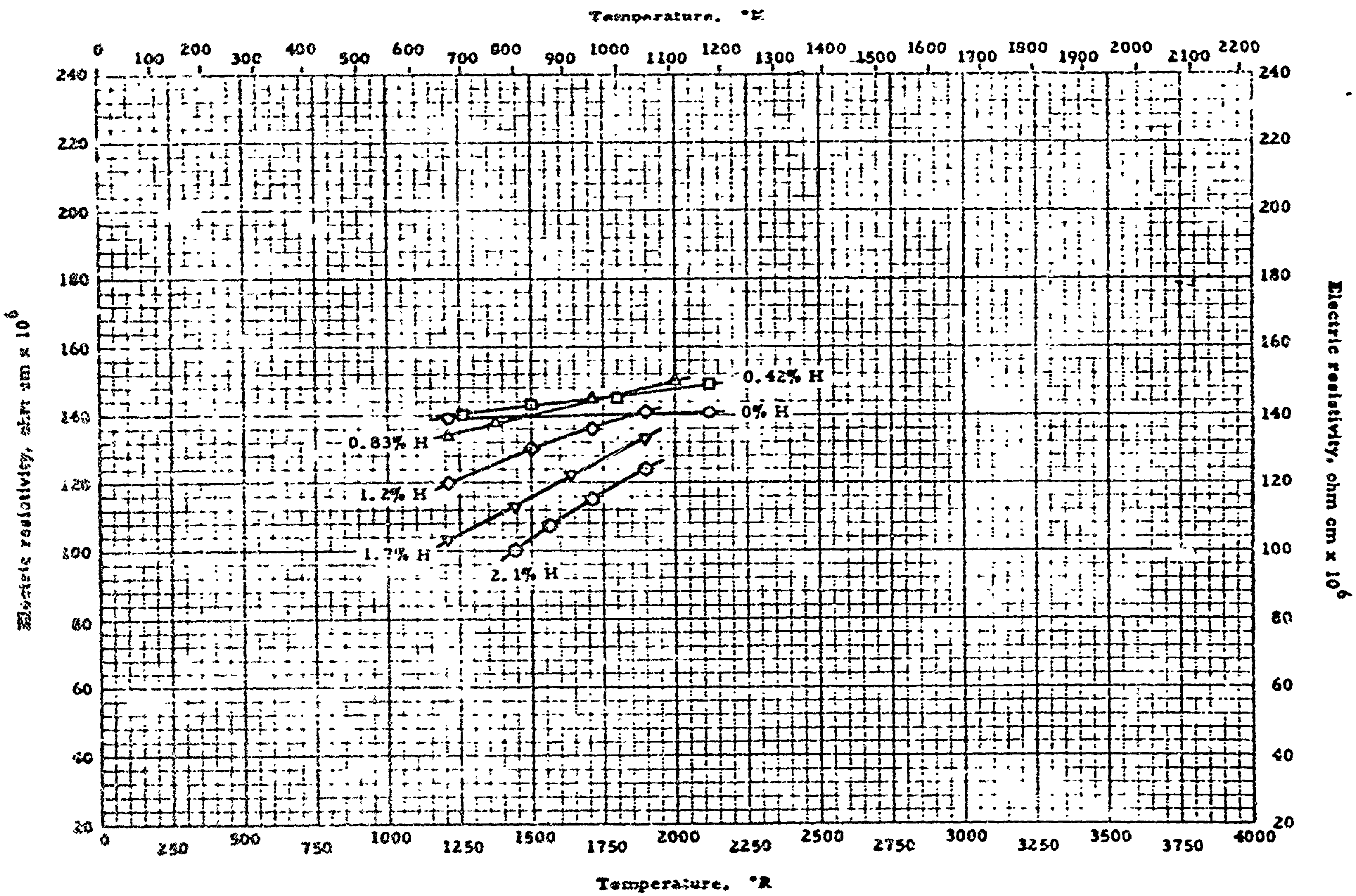


ELECTRIC RESISTIVITY -- TITANIUM + GERMANIUM

ELECTRIC RESISTIVITY -- TITANIUM + GERMANIUM

REFERENCE INFORMATION

Symbol	Investigator	Ref.	Range, °R	Material Composition	Test Method	Remarks
O	Petersen, V.C. and Huber, R. W.	55-101	492-2292	99% Ti; 1% Ge	Potential drop	Heating rate 50°C/min.
□	Ibid.	55-101	492-2292	98.5% Ti; 1.5% Ge	Same as above	Same as above

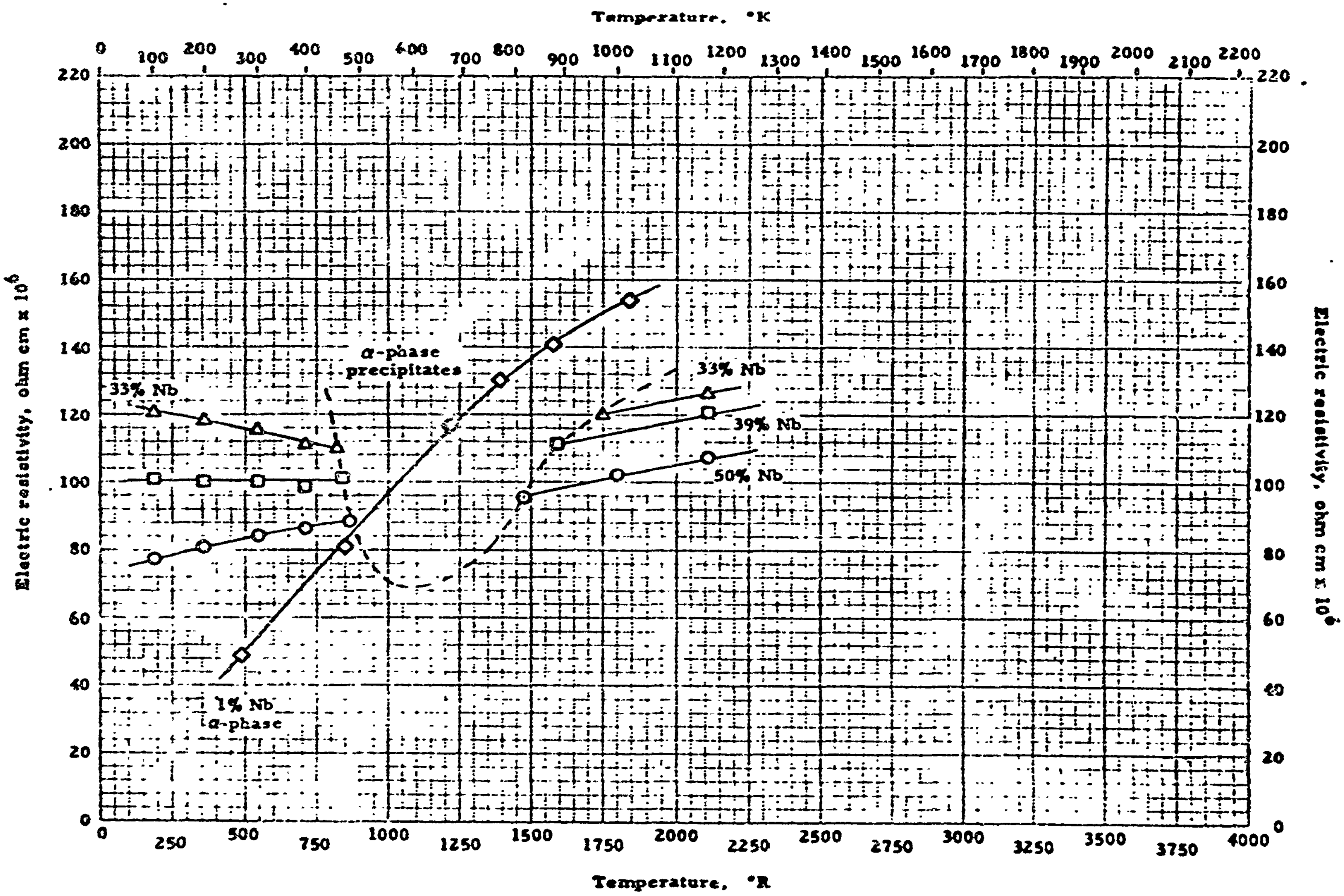


ELECTRIC RESISTIVITY -- TITANIUM + HYDROGEN

ELECTRIC RESISTIVITY -- TITANIUM + HYDROGEN

REFERENCE INFORMATION

Symbol	Investigator	Ref.	Range, °R	Material Composition	Test Method	Remarks
○	Ames, S. L. and McQuillan, A. D.	56-95	1212-2119	0% H	Double bridge	Rod of iodide-titanium in equilibrium with H_2 atm.
□	Ibid.	56-95	1212-2119	0.42% H	Same as above	Same as above
△	Ibid.	56-95	1212-2000	0.83% H	Same as above	Same as above
◇	Ibid.	56-95	1212-1896	1.2% H	Same as above	Same as above
▽	Ibid.	56-95	1212-1896	1.7% H	Same as above	Same as above
○	Ibid.	56-95	1212-1896	2.1% H	Same as above	Same as above



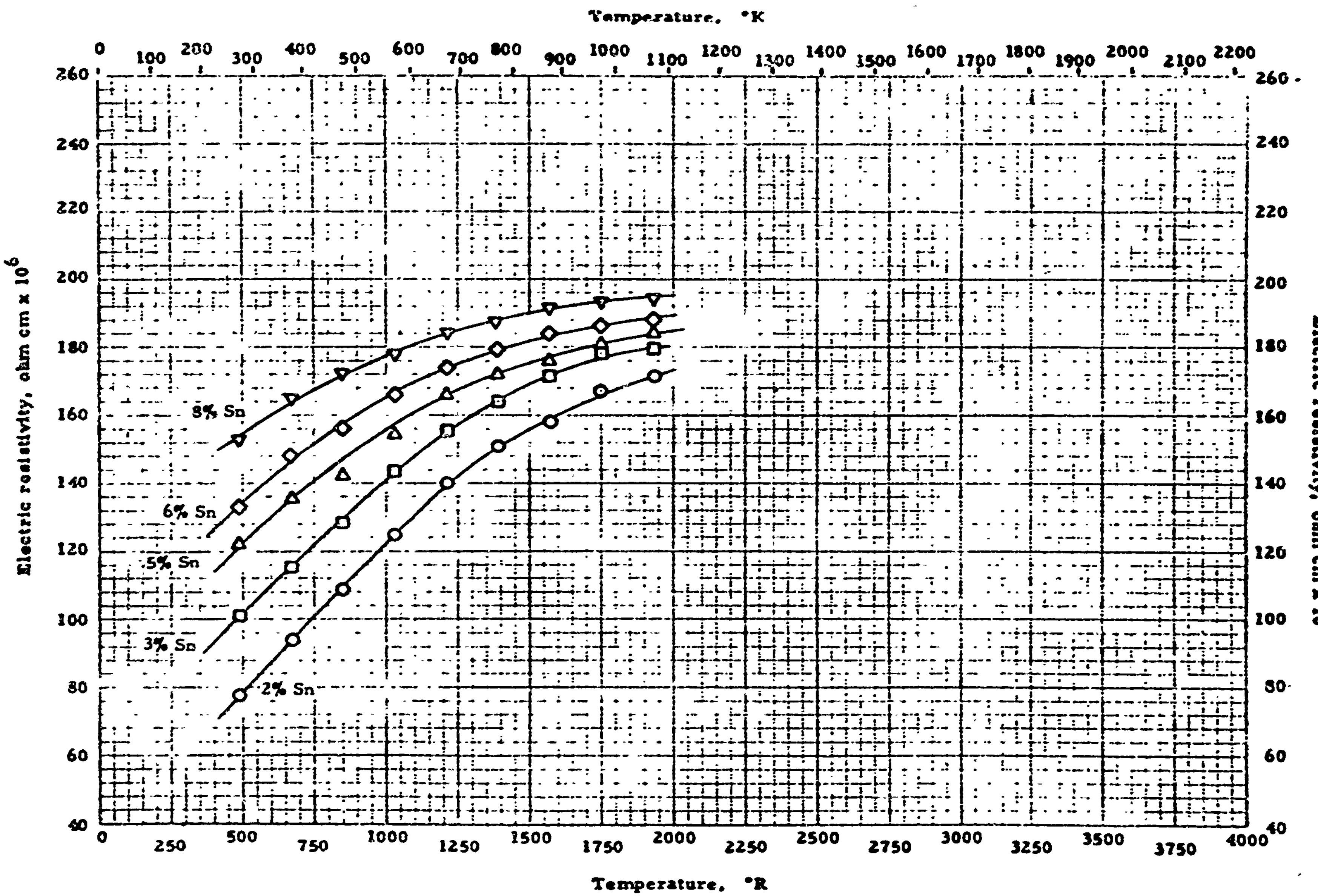
ELECTRIC RESISTIVITY -- TITANIUM + NIOBIUM

V - C

ELECTRIC RESISTIVITY -- TITANIUM + NIOBIUM

REFERENCE INFORMATION

Symbol	Investigator	Ref.	Range, °R	Material Composition	Test Method	Remarks
○	Ames, S. L. and McQuillan, A. D.	54-25	180-2112	50% Ti; 50% Nb; β-phase; prepared from spectroscopically pure Nb and iodide refined Ti (0.2 atomic% Zr)	Double bridge	Cast, rolled, remelted, hot forged, surface layers removed, cold swaged, homogenized 70 hr. at 1050°C in vacuum, quenched to retain β phase. Tested in vacuum
□	Ibid.	54-25	180-2112	60.7% Ti; 39.3% Nb; β-phase; raw materials same as above	Same as above	Same as above
△	Ibid.	54-25	180-2112	67.3% Ti; 32.7% Nb; β-phase; raw materials same as above	Same as above	Same as above
◇	Ames, S. L. and McQuillan, A. D.	56-15	492-1842	99% Ti; 1% Nb; α-phase; prepared from spectroscopically pure Nb and iodide refined Ti	Double bridge	Tested in vacuum. Auth. est. precision ± 1% Auth. states anisotropy may exist



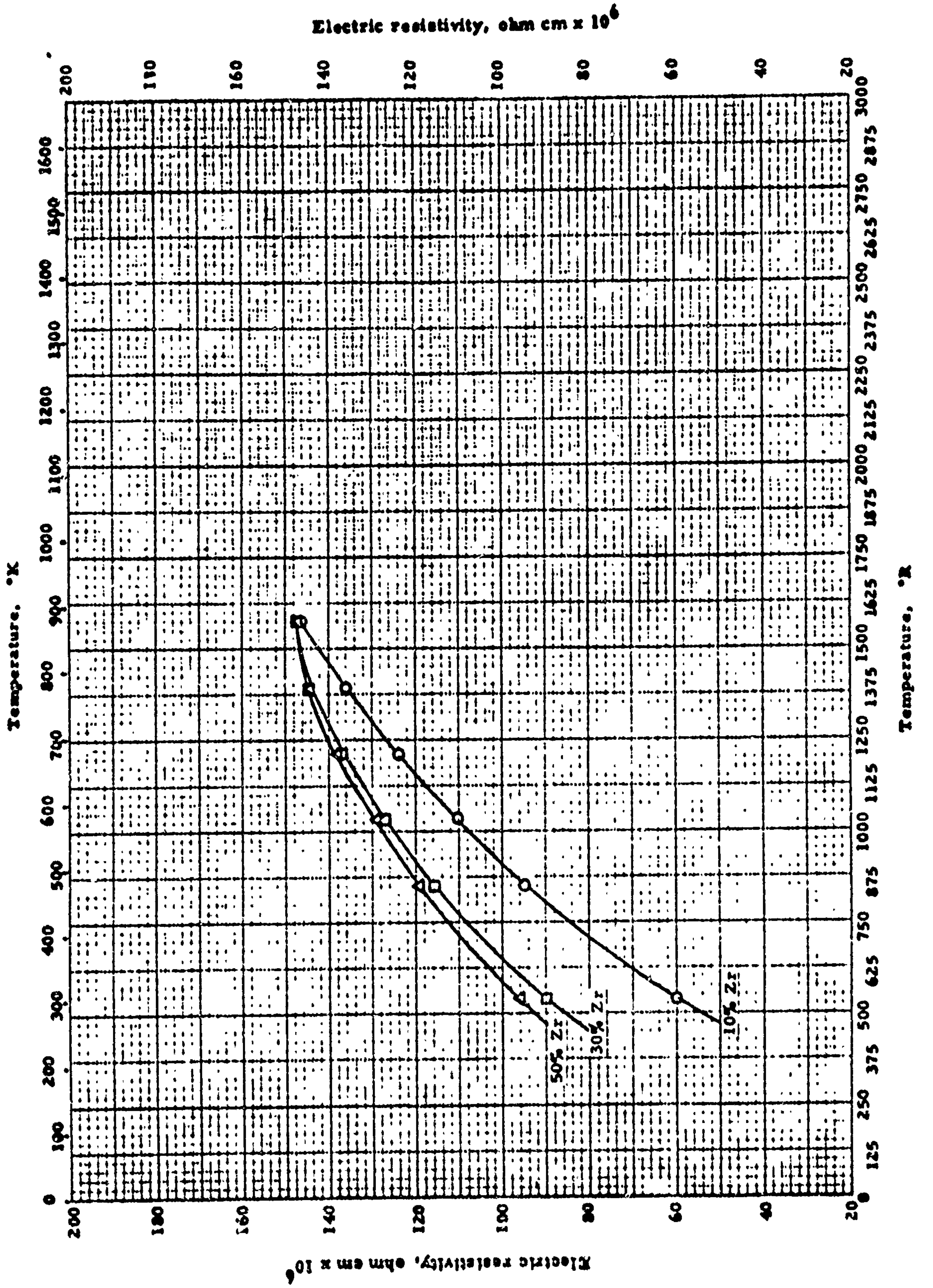
ELECTRIC RESISTIVITY -- TITANIUM + TIN

V - C

ELECTRIC RESISTIVITY -- TITANIUM + TIN

REFERENCE INFORMATION

Symbol	Investigator	Ref.	Range, °R	Material Composition	Test Method	Remarks
○	Ames, S. L. and McQuillan, A. D.	56-15	492-1932	98% Ti; 2% Sn; α-phase; prepared from iodide refined Ti and 99.99% pure Sn	Double bridge	Auth. est. accuracy ± 1%; states anisotropy may exist. Tested in vacuum
□	Ibid.	56-15	492-1932	97% Ti; 3% Sn; α-phase; raw materials same as above	Same as above	Same as above
△	Ibid.	56-15	492-1932	95% Ti; 5% Sn; α-phase; raw materials same as above	Same as above	Same as above
◇	Ibid.	56-15	492-1932	94% Ti; 6% Sn; α-phase; raw materials same as above	Same as above	Same as above
▽	Ibid.	56-15	492-1932	92% Ti; 8% Sn; α-phase; raw materials same as above	Same as above	Same as above



ELECTRIC RESISTIVITY -- TITANIUM + ZIRCONIUM

V - C

ELECTRIC RESISTIVITY -- TITANIUM + ZIRCONIUM

REFERENCE INFORMATION

Symbol	Investigator	Ref.	Range, °R	Material Composition	Test Method	Remarks
○	Ames, S. L. and McQuillan, A. D.	56-15	537-1572	90% Ti; 10% Zr; α-phase; prepared from iodide refined Ti and iodide refined Zr (containing ~ 2.5% Hf)	Double bridge	Auth. est. accuracy ±1%
□	Ibid.	56-15	537-1572	70% Ti; 30% Zr; α-phase; raw materials same as above	Same as above	Same as above
△	Ibid.	56-15	537-1572	50% Ti; 50% Zr; α-phase; raw materials same as above	Same as above	Same as above

NBS - Cryogenic Lab
A Compendium of the Props. of Mat'ls at Low Temp
WADD-TR-60-56, Part 4
Dec '61

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ELECTRICAL RESISTIVITY of TITANIUM, Ti

(Atomic Number 22)

Source of Data:

Landolt-Börnstein Zahlenwerte und Funktionen aus Physik, Chemie, Astronomie, Geophysik und Technik, sechste Auflage, II Band, 6 Teil, Springer-Verlag, Berlin (1959) pp. 1-46

Other References:

Clausing, P. and Moubis, G.; Physica 7, 245 (1927)

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Meissner, W., Franz, H. and Westerhoff, H.; Ann. Physik (5) 13, 555 (1932)

Meissner, W. and Voigt, B.; Ann. Physik (5) 7, 761, 892 (1930)

Comments:

Reference should be made to the preface at the beginning of the Electrical Resistivity section for an explanation of the graph. The value of electrical resistivity at 273°K (ρ_{273}) for titanium to be used in calculating electrical resistivity is listed below the authors' names labeling each individual curve on the graph. These curves should not be extrapolated to lower temperatures since titanium becomes a superconductor at 0.39°K.

The data for this graph were taken from the reference cited above under "Source of Data". The values taken from the Landolt-Börnstein tables are those reported by the authors listed above under "Other References". The original authors are used in labeling the three curves on the graph.

The data reported in the Landolt-Börnstein tables are listed as ratios of electrical resistivity with respect to the resistivity at a datum temperature, as listed in the following tabular data. The actual value of ρ_{273} is not available for the Meissner, Franz and Westerhoff data so a datum value reported by Fast (ρ_{273} = 42.0 x 10^{-6} ohm-cm) is suggested for calculating values of resistivity from these ratios. Fast reports very small impurities in the single crystal sample used in determining ρ_{273}.

The Landolt-Börnstein tables list the sample used by Clausing and Maubis as polycrystalline with 0.16% tungsten impurity. The sample used by Meissner and Voigt is also reported as of a polycrystalline nature drawn from a melt with 0.25% impurities of unknown type. The sample used by Meissner, Franz and Westerhoff is reported as being drawn from a melt with very small impurities. No comments were made on the mechanical working or heat treatment of the samples.

(Continued on following page.)

ELECTRICAL RESISTIVITY OF TITANIUM (cont.)

Tables of Values of Electrical Resistivity

ρ = Resistivity, (ohm-cm)

ρ_{273} = Resistivity at 273°K, (ohm-cm)

Clausing & Moubis		Meissner, Franz & Westerhoff	
Temp. °K	ρ/ρ_{273}	Temp. °K	ρ/ρ_{273}
78.5	0.2150	3.24	0.102
90.2	0.2547	20.4	0.1015
158.5	0.5178	79.1	0.211

Meissner & Voigt	
Temp. °K	ρ/ρ_{273}
1.26	0.203
4.21	0.215
20.5	0.2180
88.2	0.3505

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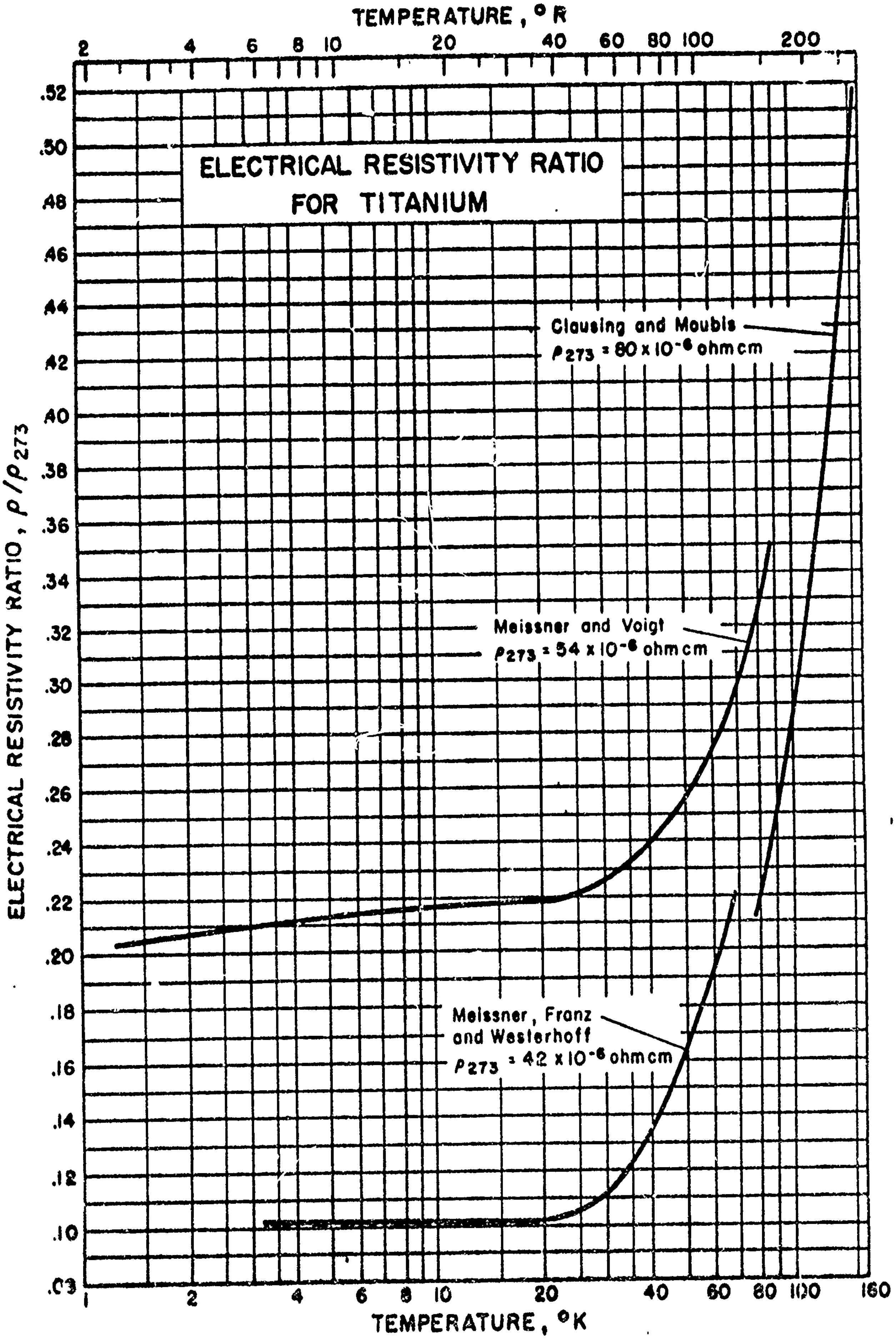

TEMPERATURE, °R
2
4
6
8
10
20
40
60
80
100
200
ELECTRICAL RESISTIVITY RATIO
FOR TITANIUM
Clausing and Moubis
ρ_{273} = 80 x 10⁻⁶ ohm cm
Meissner and Voigt
ρ_{273} = 54 x 10⁻⁶ ohm cm
Meissner, Franz
and Westerhoff
ρ_{273} = 42 x 10⁻⁶ ohm cm
ELECTRICAL RESISTIVITY RATIO, ρ/ρ_{273}
.52
.50
.48
.46
.44
.42
.40
.38
.36
.34
.32
.30
.28
.26
.24
.22
.20
.18
.16
.14
.12
.10
.08
1
2
4
6
8
10
20
40
60
80
100
160
TEMPERATURE, °K

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