Designation: B 193 – 0~~1~~2

Standard Test Method for Resistivity of Electrical Conductor Materials[1]

This standard is issued under the fixed designation B 193; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope

1.1 This test method covers the determination of the electrical resistivity of metallic electrical conductor material. It provides for an accuracy of ±0.30 % on test specimens having a resistance of 0.00001 Ω (10 μΩ) or more. Weight resistivity accuracy may be adversely affected by possible inaccuracies in the assumed density of the conductor.

1.2 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

A 111 Specification for Zinc-Coated (Galvanized) "Iron" Telephone and Telegraph Line Wire[2]

[1] This test method is under the jurisdiction of ASTM Committee B01 on Electrical Conductors and is the direct responsibility of Subcommittee B01.02 on Methods of Test and Sampling Procedure.

Current edition approved Apr. 10, 200~~1~~2. Published ~~May 2001.~~ April 2002. Originally published as B 193 – 44 T. Last previous edition B 193 – 0~~0~~1.

A 326 Specification for Zinc-Coated (Galvanized) High Tensile Steel Telephone and Telegraph Line Wire[3]
B 9 Specification for Bronze Trolley Wire[4]
B 105 Specification for Hard-Drawn Copper Alloy Wires for Electric Conductors[4]
B 298 Specification for Silver-Coated Soft or Annealed Copper Wire[4]
B 355 Specification for Nickel-Coated Soft or Annealed Copper Wire[4]
B 415 Specification for Hard-Drawn Aluminum-Clad Steel Wire[4]
B 566 Specification for Copper-Clad Aluminum Wire[4]
B 800 Specification for 8000 Series Aluminum Alloy Wire for Electrical Purposes—Annealed and Intermediate Tempers[4]
2.2 *NIST Document:*
NBS *Handbook 100— Copper Wire Tables*[5]

3. Resistivity

3.1 *Resistivity* (Explanatory Note 1) is the electrical resistance of a body of unit length, and unit cross-sectional area or unit weight.

3.2 *Volume Resistivity* is commonly expressed in ohms for a theoretical conductor of unit length and cross-sectional area; in inch-pound units in Ω·cmil/ft and in acceptable metric units in Ω· mm²/m. It may be calculated by the following equation:

$$\rho_v = (A/L)R$$

where:
ρ_v = volume resistivity, Ω·cmil/ft or Ω·mm ²/m,
A = cross-sectional area, cmil or mm²,
L = gage length, used to determine R, ft or m, and
R = measured resistance, Ω.

3.3 *Weight Resistivity* is commonly expressed in ohms for a theoretical conductor of unit length and weight. The method for calculating weight resistivity, based on resistance, length, and weight measurements, of a test specimen is given in Explanatory Note 2.

4. Apparatus

4.1 Resistance shall be measured with a ~~Kelvin-type double bridge or~~ circuit configuration and instrumentation that has a ~~potentiometer if the~~ resistance measurement capability of ~~the specimen is below 1 Ω. If it is 1 Ω or more, a Wheatstone bridge may be used. Where applicable, a Hoopes conductivity bridge may be used.~~ ±0.15 % accuracy.

5. Test Specimen

5.1 The test specimen may be in the form of a wire, strip, rod, bar, tube, or shape. It shall be of uniform cross section throughout its length within ±0.75 % of the cross-sectional area. Wherever possible it shall be the full cross section of the material it represents, if the full cross section is such that the uniformity of the cross-sectional area can be accurately determined.

5.2 The test specimen shall have the following characteristics:

5.2.1 A resistance of at least 0.00001 Ω (10 μΩ) in the test length between potential contacts,

5.2.2 A test length of at least 1 ft or 300 mm,

5.2.3 A diameter, thickness, width, or other dimension suitable to the limitations of the resistance measuring instrument,

5.2.4 No surface cracks or defects visible to the unaided normal eye, and substantially free from surface oxide, dirt, and grease, and

5.2.5 No joints or splices.

6. Procedure

6.1 Make all determinations of the dimensions and weight of the test specimen using instruments accurate to ±0.05 %. In order to assure this accuracy in measuring the length between potential contacts, the surface in contact with the test specimen shall be a substantially sharp knife-edge when using a Kelvin-type bridge or a potentiometer.

6.2 The cross-sectional dimensions of the specimen may be determined by micrometer measurements, and a sufficient number of measurements shall be made to obtain the mean cross section to within ±0.10 %. In case any dimension of the specimen is less than 0.100 in. and cannot be measured to the required accuracy, determine the cross-section from the weight, density, and length of the specimen.

[2] *Annual Book of ASTM Standards,* Vol 01.06.
[3] Discontinued; see 1989 *Annual Book of ASTM Standards,* Vol 021.036.
[4] ~~Available from the National Institute~~
[4] *Annual Book of ASTM Standards* ~~and Technology (NIST), Gaithersburg, MD 20899.~~, Vol 02.03.
[5] Available from the National Institute of Standards and Technology (NIST), Gaithersburg, MD 20899.

6.3 When the density is unknown, determine the density by weighing a specimen first in air and then in a liquid of known density at the test temperature, which shall be room temperature to avoid errors due to convection currents. Exercise care in removing all air bubbles from the specimen when weighing it in the liquid. Calculate the density from the following equation:

$$\delta = (W_a \times d)/(W_a - W_l)$$

where:
δ = density of the specimen, g/cm^3,;
W_a = weight of the specimen in air, g, g;
W_l = weight of the specimen in the liquid, g, g; and
d = density of the liquid at the test temperature, g/cm^3.

6.4 When potential leads are used, make sure the distance between each potential contact and the corresponding current contact is at least equal to 1½ times the cross-sectional perimeter of the specimen. Make sure the yoke resistance (between reference standard and test specimen) is appreciably smaller than that of either the reference standard or the test specimen unless a suitable lead compensation method is used, or it is known that the coil and lead ratios are sufficiently balanced so that variation in yoke resistance will not decrease the bridge accuracy below stated requirements.

6.5 Make resistance measurements to an accuracy of ±0.15 %. To ensure a correct reading, allow the reference standard and the test specimen to come to the same temperature as the surrounding medium. (If the reference standard is made of manganin it is possible to obtain correct readings with the test specimen at reference temperatures other than room temperature). In all resistance measurements, the measuring current raises the temperature of the medium. Therefore, take care to keep the magnitude of the current low, and the time of its use short enough so that the change in resistance cannot be detected with the galvanometer. To eliminate errors due to contact potential, take two readings, one direct and one with current reversed, in direct succession. Check tests are recommended whereby the specimen is turned end for end, and the test repeated. Surface cleaning of the specimen at current and potential contact points may be necessary to obtain good electrical contact.

7. Temperature Correction

7.1 When the measurement is made at any other than a reference temperature, the resistance may be corrected for moderate temperature differences to what it would be at the reference temperature, as follows:

$$R_T = \frac{R_t}{1 + \alpha_T(t - T)}$$

where:
R_T = resistance at reference temperature T,
R_t = resistance as measured at temperature t,
α_T = known or given temperature coefficient of resistance of the specimen being measured at reference temperature T,
T = reference temperature, and
t = temperature at which measurement is made.

NOTE 1—The parameter α_T, in the above equation, varies with conductivity and temperature. For copper of 100 % conductivity and a reference temperature of 20°C, its value is 0.00393. Values at other conductivities and temperatures will be found in *NBS Handbook 100*.[5] Table 1 lists temperature coefficients for the common electrical conductor materials.

8. Report

8.1 For referee tests, report the following information:

8.1.1 Identification of test specimen,

8.1.2 Kind of material,

8.1.3 Test temperature,

8.1.4 Test length of specimen,

8.1.5 Method of obtaining cross-sectional area:

8.1.5.1 *If by micrometer*, the average values of micrometer readings, or

8.1.5.2 *If by weighing*, a record of length, weight, any density determinations that may be made, and calculated cross-sectional areas.

8.1.6 Weight, if used,

8.1.7 Method of measuring resistance,

8.1.8 Value of resistance,

8.1.9 Reference temperature,

8.1.10 Calculated value of resistivity at the reference temperature, and

8.1.11 Previous mechanical and thermal treatments. (Since the resistivity of a material usually depends upon them, these shall be stated whenever the information is available.)

8.2 For routine tests, only such of the items in 8.1 as apply to the particular case, or are significant, shall be reported.

TABLE 1 Resistivity and Conductivity Conversion

NOTE 1—These factors are applicable only to resistivity and conductivity values corrected to 20°C (68°F). They are applicable for any temperature when used to convert between volume units only or between weight units only. Values of density, δ, for the common electrical conductor materials, are listed in Table 3.

Given N→ Perform indicated operation to obtain ↓	Volume Resistivity at 20°C				Weight Resistivity at 20°C		Conductivity at 20°C	
	Ω·cmil/ft	Ω·mm²/m	μΩ·in.	μΩ·cm	Ω·lb/mile²	Ω·g/m²	% IACS (Volume Basis)	% IACS (Weight Basis)
Volume Resistivity at 20°C								
Ω·cmil/ft	. . .	N × 601.52	N × 15.279	N × 6.0153	N × 0.10535 × (I / δ)	N × 601.53 × (I / δ)	(I/N) × 1037.1	(I/N) × 9220.0 × (I / δ)
Ω·mm²/m	N × 0.0016624	. . .	N × 0.025400	N × 0.010000	N × 0.00017513 × (I / δ)	N × (I/δ)	(I/N) × 1.7241	(I/N) × 15.328 × (I / δ)
μΩ·in.	N × 0.065450	N × 39.370	. . .	N × 0.39370	N × 0.0068950 × (I / δ)	N × 39.370 × (I /δ)	(I/N) × 67.879	(I/N) × 603.45 × (I / δ)
μΩ·cm	N × 0.16624	N × 100.00	N × 2.5400	. . .	N × 0.017513 × (I / δ)	N × 100.00 × (I / δ)	(I/N) × 172.41	(I/N) × 1532.8 × (I / δ)
Weight Resistivity at 20°C								
Ω·lb/mile²	N × 9.4924 × δ	N × 5710.0 × δ	N × 145.03 × δ	N × 57.100 × δ	. . .	N × 5710.0	(I/N) × 9844.8 × δ	(I/N) × 87520
Ω·g/m²	N × 0.0016624 × δ	N × δ	N × 0.025400 × δ	N × 0.010000 × δ	N × 0.00017513	. . .	(I/N) × 1.7241 × δ	(I/N) × 15.328
Conductivity at 20°C								
% IACS (volume basis)	(I/N) × 1037.1	(I/N) × 1.7241	(I/N) × 67.879	(I/N) × 172.41	(I/N) × 9844.8 × δ	(I/N) × 1.7241 × δ	. . .	N × 0.11249 × δ
% IACS (weight basis)	(I/N) × 9220.0 × (I / δ)	(I/N) × 15.328 × (I / δ)	(I/N) × 603.45 × (I / δ)	(I/N) × 1532.8 × (I / δ)	(I/N) × 87520	(I/N) × 15.328	N 8.89 × (I/δ)	. . .

9. Precision and Bias

9.1 *Precision*—This test method has been in use for many years. No statement of precision has been made and no work has been planned to develop such a statement.

9.2 *Bias*—This test method has no bias because the value for resistivity is determined solely in terms of this test method.

10. Keywords

10.1 conductivity; electrical conductor materials; resistivity; resistivity of electrical conductor; volume resistivity; weight resistivity

EXPLANATORY NOTES

NOTE 1—*Volume resistivity ~~is~~* is used in place of "weight resistivity" and "percent conductivity."

Resistivity units are based on the International Annealed Copper Standard (IACS) adopted by IEC in 1913, which is 1/58 Ω·mm²/m at 20°C (68°F) for 100 % conductivity. The value of 0.017241 Ω·mm ²/m and the value of 0.15328 Ω·g/m² at 20°C (68°F) are respectively the international equivalent of volume and weight resistivity of annealed copper equal (to five significant figures) to 100 % conductivity. The latter term means that a copper wire 1 m in length and weighing 1 g would have a resistance of 0.15328 Ω. This is equivalent to a resistivity value of 875.20 Ω·lb/mile², which signifies the resistance of a copper wire 1 mile in length weighing 1 lb. It is also equivalent, for example, to 1.7241 μΩ/cm of length of a copper bar 1 cm² in cross section. A complete discussion of this subject is contained in *NBS Handbook 100*.[5] The use of five significant figures in expressing resistivity does not imply the need for greater accuracy of measurement than that specified in Test Method B 193. The use of five significant figures is required for reasonably accurate reversible conversion from one set of resistivity units to another. The equivalent resistivity values in Table 2 were derived from the fundamental IEC value (1/58 Ω·mm²/m) computed to seven significant figures and then rounded to five significant figures.

NOTE 2—*Weight resistivity* is expressed in U.S. customary units in Ω·lb/mile² and in metric units in Ω·g/m². It may be calculated as follows:

$$\rho_w = (W/L_1L_2)R$$

where:

ρ_w = weight resistivity, Ω·lb/mile² or Ω·g/m²,
W = weight of the test specimen, lb or g,
L_2 = length of the test specimen, miles or m,
L_1 = gage length, used to determine R, miles or m, and
R = measured resistance, Ω

NOTE 3—*Resistivity and Conductivity Conversion*—Conversion of the various units of volume resistivity, weight resistivity, and conductivity, may be facilitated by employing the formulas and factors shown in Table 1. The factors given therein are applicable to all metallic electrical conductor material. Table 3 lists values of density, δ, for the common electrical conductor materials.

NOTE 4—*Density*—For the purpose of resistivity and conductivity conversion, the density of the various conductor materials may be taken as shown in Table 3, based on a temperature of 20°C (68°F).

However, if the conversion is for specification acceptance purposes, the density used shall be that specified in the product specification involved.

TABLE 2 Equivalent Resistivity Values for Copper[A]

Conductivity at 20°C (68°F) percent IACS	100.0
Volume Resistivity	
Ω·cmil/ft	10.371
Ω·mm^2/m	0.017241
μΩ·in.	0.67879
μΩ·cm	1.7241
Weight Resistivity	
Ω·lb/mile^2	875.20
Ω·g/m^2	0.15328

[A] The equivalent resistivity values for 100 % IACS (soft copper) were each computed from the fundamental IEC value (1/58 Ω·mm^2/m) using conversion factors each accurate to at least seven significant figures. Corresponding values for other conductivities (aluminum, etc.) may be derived from these by multiplying by the reciprocal of the conductivity ratios and where applicable also by the density ratios, both accurate to at least seven significant figures.

TABLE 3 Density and Temperature Coefficient of Resistance for Electrical Conductor Materials

Material	Approximate Density, δ, at 20°C, g/cm³	Temperature Coefficient of Resistance, α, at 20°C
Copper, % IACS:		
101	8.89	0.00397
100	8.89	0.00393
98.40	8.89	0.00387
98.16	8.89	0.00386
97.80	8.89	0.00384
97.66	8.89	0.00384
97.40	8.89	0.00383
97.16	8.89	0.00382
96.66	8.89	0.00380
96.16	8.89	0.00378
94.16	8.89	0.00370
93.15	8.89	0.00366
Silver Coated Copper, Specification B 298:		
Class A	8.91	0.00393
Class B	8.93	0.00393
Class C	8.95	0.00394
Class D	8.99	0.00394
Class E	9.05	0.00395
Nickel Coated Copper, Specification B 355:		
Class 2	8.89	0.00395
Class 4	8.89	0.00397
Class 7	8.89	0.00400
Class 10	8.89	0.00404
Class 27	8.89	0.00422
Bronze, Specification B 9:		
Alloy 40	8.89	0.00157
Alloy 55	8.89	0.00224
Alloy 80	8.89	0.00322
Copper Alloy, Specification B 105:		
Grade 8.5	8.78	0.00042
Grade 13	8.78	0.00063
Grade 15	8.54	0.00072
Grade 20	8.89	0.00079
Grade 30	8.89	0.00118
Grade 40	8.89	0.00157
Grade 55	8.89	0.00224
Grade 74	8.89	0.00299
Grade 80	8.89	0.00322
Grade 85	8.89	0.00342
Aluminum 1350, % IACS:		
61.8	2.705	0.00408
61.5	2.705	0.00406
61.4	2.705	0.00406
61.3	2.705	0.00405
61.2	2.705	0.00404
61.0	2.705	0.00403
Aluminum Alloy 8000, Specification B 800, % IACS:		
61.8	2.71	0.00408
61.5	2.71	0.00406
61.4	2.71	0.00406
61.3	2.71	0.00405
61.2	2.71	0.00404
61.0	2.71	0.00403
60.9	2.71	0.00402
60.8	2.71	0.00402
60.7	2.71	0.00401
60.6	2.71	0.00400
Aluminum Alloy 6101, % IACS:		
59.5	2.70	0.00393
59.0	2.70	0.00390
57.0	2.70	0.00377
56.5	2.70	0.00373
56.0	2.70	0.00370
55.0	2.70	0.00363
54.0	2.70	0.00357
53.0	2.70	0.00350
Aluminum Alloy, % IACS:		
5005-H19 53.5	2.70	0.00353
6201-T81 52.5	2.69	0.00347
Aluminum Clad Steel, % IACS:		
20.3	6.59	0.0036
27	5.91	0.0036
30	5.61	0.0038
40	4.64	0.0040
Copper Clad Steel:		
Grade 30 A, HS, EHS	8.15	0.00378
Grade 40 A, HS, EHS	8.25	0.00378
Galvanized Steel (Telephone and Telegraph), Specification A 111:		
Class A Coating:		
Grade EBB (Non cu-brg)	7.83	0.0056
Grade BB (Cu-brg)	7.83	0.0046
Grade BB (Non cu-brg)	7.83	0.0042
Class B Coating:		
Grade EBB (Non cu-brg)	7.80	0.0056
Grade BB (Cu-brg)	7.80	0.0046
Grade BB (Non cu-brg)	7.80	0.0042
Class C Coating:		
Grade EBB (Non cu-brg)	7.77	0.0056
Grade BB (cu-brg)	7.77	0.0046
Grade BB (Non cu-brg)	7.77	0.0042
Copper Clad Aluminum, Specification B 566:		
Class 10A and 10H	3.32	0.00405
Class 15A and 15H	3.63	0.00404
Galvanized Steel, Specification A 326:		
Class A Coating:		
Grade 85	7.83	0.0046
Grade 135 and 195	7.83	0.0042
Class B Coating:		
Grade 85	7.80	0.0046
Grade 135 and 195	7.80	0.0042
Class C Coating:		
Grade 85	7.77	0.0046
Grade 135 and 195	7.77	0.0042