Designation: B194 – 08

StandardSpecification for Copper-Beryllium Alloy Plate, Sheet, Strip, and Rolled Bar[1]

This standard is issued under the fixed designation B194; 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 U.S. Department of Defense.

1. Scope*

1.1 This specification establishes the requirements for copper-beryllium alloy plate, sheet, strip, and rolled bar. The following alloys are specified:[2]

Copper Alloy UNS No.[2]	Previously Used Commercial Designations	Nominal Beryllium Content, %
C17000	Alloy 165	1.7
C17200	Alloy 25	1.9

1.2 Unless otherwise specified in the contract or purchase order, Copper Alloy UNS No. C17200 shall be the alloy furnished.

1.3 *Units*—The values stated in inch-pound units are to be regarded as standard. The values given in parentheses are mathematical conversions to SI units that are provided for information only and are not considered standard.

1.4 The following hazard statement pertains only to the test method portions in the annex of this specification:

1.5 *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:*[3]

B248 Specification for General Requirements for Wrought Copper and Copper-Alloy Plate, Sheet, Strip, and Rolled Bar

B601 Classification for Temper Designations for Copper and Copper Alloys—Wrought and Cast

B846 Terminology for Copper and Copper Alloys

E8 Test Methods for Tension Testing of Metallic Materials

E18 Test Methods for Rockwell Hardness of Metallic Materials

E112 Test Methods for Determining Average Grain Size

E527 Practice for Numbering Metals and Alloys in the Unified Numbering System (UNS)

3. General Requirements

3.1 The following sections of Specification B248 constitute a part of this specification:

3.1.1 Terminology
3.1.2 Materials and Manufacture
3.1.3 Dimensions, Weights, and Permissible Variations
3.1.4 Workmanship, Finish, and Appearance
3.1.5 Sampling
3.1.6 Number of Tests and Retests
3.1.7 Specimen Preparation
3.1.8 Test Methods
3.1.9 Significance of Numerical Limits
3.1.10 Inspection
3.1.11 Rejection and Rehearing
3.1.12 Certification
3.1.13 Mill Test Report
3.1.14 Packaging and Package Marking

3.2 In addition, when a section with a title identical to that referenced in 3.1 above appears in this specification, it contains additional requirements that supplement those appearing in Specification B248.

4. Terminology

4.1 For definitions of terms relating to copper and copper alloys, refer to Terminology B846.

5. Ordering Information

5.1 Include the following information when placing orders for product under this specification as applicable.

5.1.1 Quantity,
5.1.2 Copper Alloy UNS number (1.1),
5.1.3 Form of material: plate, sheet, strip, or rolled bar,
5.1.4 Temper (7.1),

[1] This specification is under the jurisdiction of ASTM Committee B05 on Copper and Copper Alloys and is the direct responsibility of Subcommittee B05.01 on Plate, Sheet, and Strip.

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[2] The UNS system for copper and copper alloys (see Practice E527) is a simple expansion of the former standard designation system accomplished by the addition of a prefix "C" and a suffix "00." The suffix can be used to accommodate composition variations of the base alloy.

[3] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

***A Summary of Changes section appears at the end of this standard**

5.1.5 Dimensions: thickness and width, and length if applicable.

5.1.6 How furnished: rolls, stock lengths with or without ends, specific lengths with or without ends,

5.1.7 Type of edge, if required: slit, sheared, sawed, square corners, rounded corners, rounded edges, or full-rounded edges (Specification B248, Section 5.6),

5.1.8 Type of width and straightness tolerances, if required: slit-metal tolerances, square-sheared-metal tolerances, sawed-metal tolerances, straightened or edge-rolled-metal tolerances (Specification B248, Section 5.3),

5.1.9 Special thickness tolerances, if required (Specification B248, Table 3),

5.1.10 Tension test or hardness as applicable (Section 8),

5.1.11 Bend test, if required (Section 11),

5.1.12 Grain size or grain count if required (Section 9 or 10),

5.1.13 Certification if required (see Specification B248, Section 14),

5.1.14 Mill Test Report, if required (see Specification B248, Section 15),

5.1.15 Specification number and year of issue, and

5.1.16 Special tests or exceptions, if any.

5.2 When material is purchased for agencies of the U.S. government, this shall be specified in the contract or purchase order, and the material shall conform to the Supplementary requirements as defined in the current issue of Specification B248.

6. Chemical Composition

6.1 The material shall conform to the chemical requirements specified in Table 1.

6.2 These specification limits do not preclude the presence of other elements. Limits for unnamed elements may be established, by agreement between manufacturer or supplier and purchaser. Copper may be given as remainder, and may be taken as the difference between the sum of all elements analyzed and 100 %. When all elements in Table 1 are analyzed, their sum shall be 99.5 % minimum.

7. Temper

7.1 Tempers available under this specification are defined in Practice B601. The standard tempers of product are as designated in Table 2, Table 3, and Table 4. Plate is generally available in the TB00 (A), TD04 (H), TF00 (AT), and TH04 (HT) tempers.

TABLE 1 Chemical Requirements

Element	Composition, %	
	Copper Alloy UNS No. C17000	Copper Alloy UNS No. C17200
Beryllium	1.60–1.85	1.80–2.00
Additive elements:		
Nickel + cobalt, min	0.20	0.20
Nickel + cobalt + iron, max	0.6	0.6
Aluminum, max	0.20	0.20
Silicon, max	0.20	0.20
Copper	remainder	remainder

8. Mechanical Property Requirements

8.1 For product less than 0.050 in. (0.127 mm) in thickness:

8.1.1 Tensile test results shall be the product acceptance criteria, when tested in accordance with Test Method E8.

8.1.2 The tensile strength requirements are given in Table 2, Table 3, and Table 4.

8.2 For product 0.050 in. (1.270 mm) and greater in thickness.

8.2.1 Rockwell hardness is the product acceptance criteria, when tested in accordance with Test Method E18.

8.2.2 The referee product rejection criteria shall be tensile test results, when tested in accordance with Test Method E8.

8.2.3 Rockwell hardness and tensile strength requirements are given in Table 2, Table 3, and Table 4.

8.3 Product, as specified in 7.1, shall conform to the requirements specified in Table 2, in the solution heat-treated, or solution heat-treated and cold-worked conditions, and in Table 3, after precipitation heat-treatment or Table 4 in the mill-hardened condition. Precipitation heat-treatment parameters for Table 2 and Table 3 are shown in Section 12.

9. Grain Size

9.1 Material over 0.010 in. (0.254 mm) in thickness shall have an average grain size in accordance with Test Method E112, not exceeding the limits specified in Table 5. The determinations are made on the separate samples and in a plane perpendicular to the surface and perpendicular to the direction of rolling.

10. Grain Count

10.1 The grain count of a sample of material, in any temper, over 0.004 to 0.010 in. (0.102 to 0.254 mm), inclusive, in thickness shall not be less than the limits specified in Table 6.

10.2 Grain count is the number of grains per stock thickness, averaged for five locations one stock thickness apart. Grain count shall be determined in a plane perpendicular to the surface and perpendicular to the direction of rolling.

11. Bend-Test Requirements

11.1 The optional bend test is a method for evaluating the ductility of precipitation heat-treated copper-beryllium strip in thin gages.

11.2 When specified in the order (see 5.1.6), material in any temper 0.004 to 0.020 in. (0.102 to 0.508 mm), inclusive, in thickness shall conform to the requirements specified in Table 7, when tested in accordance with 14.2.

11.3 Five specimens, ⅜ ± 1/16 in. (9.52 ± 1.59 mm) in width, of any convenient length, with the rolling direction parallel to the ⅜-in. dimension, shall be precipitation heat-treated in accordance with 12.2. To pass the bend test, at least four specimens out of five, and at least 80 % of the total specimens tested from a lot shall withstand the 90° bend without visible crack or fracture, when tested in accordance with 15.3.

TABLE 2 Mechanical Property Requirements for Material in the Solution-Heat-Treated or Solution-Heat-Treated and Cold-Worked Condition

Temper Designation[A]		Material Thickness, in.		Tensile Strength, ksi[B] (MPa)[C]	Elongation[D] in 2 in. or 50 mm, min,%	Rockwell Hardness[E]		
Standard	Former	Over	Incl			B Scale	30T Scale	15T Scale
TB00	A	...	...	60–78 (410–540)	35	45–78	46–67	75–85
TD01	¼ H	...	0.188	75–88 (520–610)	15	68–90	62–75	83–89
TD02	½ H	...	0.188	85–100 (590–690)	9	88–96	74–79	88–91
TD04	H	...	0.188	100–130 (690–900)	2	96–104	79–83	91–94
TD04	H	0.188	0.375	90–130 (660–900)	...	91–103	77	90
TD04	H	0.375	1.000	90–120 (620–830)	...	90–102	...	...
TD04	H	over 1.000		85–115 (590–800)	8	88–102	...	...

[A] Standard designations defined in Practice B601.
[B] ksi = 1000 psi.
[C] See Appendix X1.
[D] Elongation requirement applies to material 0.004 in. (0.102 mm) and thicker.
[E] The thickness of material that may be tested by use of the Rockwell hardness scales is as follows:
B Scale.....0.040 in. (1.016 mm) and over
30T Scale.....0.020 to 0.040 in. (0.508 to 1.016 mm), excl.
15T Scale.....0.015 to 0.020 in. (0.381 to 0.508 mm), excl.
Hardness values shown apply only to direct determinations, not converted values.

TABLE 3 Mechanical Property Requirements After Precipitation Heat-Treatment[A]

Temper Designation		Material Thickness, in.		Tensile Strength, ksi[B] (MPa)[C]	Yield Strength, ksi (MPa), min, 0.2 % Offset	Elongation in 2 in. (50 mm), min, %[D]	Rockwell Hardness[E], min		
Standard	Former	Over	Incl				C Scale	30N Scale	15N Scale
Copper Alloy UNS No. C17000									
TF00	AT	...	0.188	150–180[F] (1030–1240)	130 (890)	3	33	53	76.5
TF00	AT	0.188	...	165–195[F] (1140–1340)	130	3	36	56	78
TH01	¼ HT	...	...	160–190[F] (1100–1310)	135 (930)	2.5	35	55	77
TH02	½ HT	...	...	170–200[F] (1170–1380)	145 (1000)	1	37	57	78.5
TH04	HT	...	...	180–210[F] (1240–1450)	155 (1070)	1	38	58	79.5
Copper Alloy UNS No. C17200									
TF00	AT	...	...	165–195[F] (1140–1340)	140 (960)	3	36	56	78
TH01	¼ HT	...	0.188	175–205[F] (1210–1410)	150 (1030)	2.5	36	56	79
TH02	½ HT	...	0.188	185–215[F] (1280–1480)	160 (1100)	1	38	58	79.5
TH04	HT	...	0.188	190–220[F] (1310–1520)	165 (1140)	1	38	58	80
TH04	HT	0.188	0.375	180–215[F] (1240–1480)	160 (1100)	1	38	58	80
TH04	HT	0.375	1.000	180–210[F] (1240–1450)	155 (1070)	1	38	...	...
TH04	HT	1.000	2.000	175–205[F] (1210–1410)	150 (1030)	2	37	...	...
TH04	HT	over 2.000		165–200[F] (1140–1380)	130 (890)	2	36	...	...

[A] These values apply to mill products (Section 14). See 12.3 for exceptions in end products.
[B] ksi = 1000 psi.
[C] See Appendix X1.
[D] Elongation requirement applies to material 0.004 in. (0.102 mm) and thicker.
[E] The thickness of material that may be tested by use of the Rockwell Hardness scales is as follows:
C Scale.....0.040 in. (1.016 mm) and over
30N Scale.....0.020 to 0.040 in. (0.508 to 1.016 mm), excl.
15N Scale.....0.015 to 0.02 in. (0.381 to 0.508 mm), excl.
Hardness values shown apply only to direct determinations, not converted values.
[F] The upper limits in the tensile strength column are for design guidance only.

TABLE 4 Strip Mechanical Property Requirements—Mill-Hardened Condition[A]

Temper Designation		Tensile Strength, ksi[B] (MPa)[C]	Yield Strength, ksi (MPa), 0.2 % Offset	Elongation in 2 in. (50 mm), min, %[D]	Rockwell Hardness[E], min		
Standard	Former[B]				C Scale	30N Scale	15N Scale
Copper Alloy UNS No. C17000							
TM00	AM	100–110[F] (690–760)	70–95 (480–660)	18	18	37	67.5
TM01	¼ HM	110–120[F] (760–830)	80–110 (550–760)	15	20	42	70
TM02	½ HM	120–135[F] (830–930)	95–125 (660–860)	12	24	45	72
TM04	HM	135–150[F] (930–1040)	110–135 (760–930)	9	28	48	75
TM05	SHM	150–160[F] (1030–1100)	125–140 (860–970)	9	31	52	75.5
TM06	XHM	155–175[F] (1070– 1210)	135–165 (930–1140)	3	32	52	76
Copper Alloy UNS No. C17200							
TM00	AM	100–110[F] (690–760)	70–95 (480–660)	16	R_B95	37	67.5
TM01	¼ HM	110–120[F] (760–830)	80–110 (550–760)	15	20	42	70
TM02	½ HM	120–135[F] (830–930)	95–125 (660–860)	12	23	44	72
TM04	HM	135–150[F] (930–1030)	110–135 (760–930)	9	28	48	75
TM05	SHM	150–160[F] (1030–1100)	125–140 (860–970)	9	31	52	75.5
TM06	XHM	155–175[F] (1070–1210)	135–170 (930–1170)	4	32	52	76
TM08	XHMS	175–190[F] (1210–1310)	150–180 (1030–1240)	3	33	53	76.5

[A] These values apply to mill products (Section 14). See 12.3 for exceptions in end products.
[B] ksi = 1000 psi.
[C] See Appendix X1.
[D] Elongation requirement applies to material 0.004 in. (0.102 mm) and thicker.
[E] The thickness of material that may be tested by use of the Rockwell Hardness scales is as follows:
C Scale.....0.040 in. (1.016 mm) and over
30N Scale.....0.020 to 0.040 in. (0.508 to 1.016 mm), excl.
15N Scale.....0.015 to 0.020 in. (0.381 to 0.508 mm), excl.
Hardness values shown apply only to direct determinations, not converted values.
[F] The upper limits in the tensile strength column are for design guidance only.

TABLE 5 Grain-Size Requirements for TB00 (Solution-Heat-Treated) Material

Thickness, in. (mm)	Grain Size Specified	Maximum Average Grain Size, mm
Over 0.010 to 0.030 (0.254 to 0.762), incl	OS035	0.035
Over 0.030 to 0.090 (0.762 to 2.24), incl	OS045	0.045
Over 0.090 to 0.188 (2.24 to 4.78), incl	OS060	0.060

TABLE 6 Grain-Count Requirements

Thickness, in. (mm)	Minimum Number of Grains
Over 0.004 to 0.006 (0.102 to 0.152), incl	6
Over 0.006 to 0.008 (0.152 to 0.203), incl	7
Over 0.008 to 0.010 (0.203 to 0.254), incl	8

TABLE 7 Bend-Test Requirements After Precipitation Heat Treatment

Temper Designation		Test Radius[A]
Standard	Former	
TF00	AT	5*t*
TH01	¼ AT	6*t*
TH02	½ HT	9*t*
TH04	HT	15*t*

[A] The *t* refers to the measured average stock thickness to be tested.

TABLE 8 Precipitation-Heat-Treatment Time for Acceptance Tests

Temper Designation (Before Precipitation Heat Treatment)		Time at 600 to 675°F (316 to 357°C), h
Standard	Former	
TB00	A	3
TD01	¼ H	2
TD02	½ H	2
TD04	H	2

12. Precipitation Heat-Treatment

12.1 Solution-heat-treated or solution-heat-treated and cold-worked material is normally precipitation hardened by the purchaser after forming or machining. For the purpose of determining conformance to specified mechanical properties of Table 3, a sample of the as-supplied material shall be heat treated as shown in Table 8. Other heat treating temperatures and times may be preferred for end products of this material.

12.2 The solution-heat-treated and cold-worked test specimens shall be heat treated at a uniform temperature of 600 to 675°F (316 to 357°C) for the time shown in Table 8.

12.3 Special combinations of properties such as increased ductility, electrical conductivity, dimensional accuracy, endurance life, and resistance to elastic drift and hysteresis in springs may be obtained by special precipitation-hardening heat treatments. The mechanical requirements of Table 3 do not apply to such special heat treatments.

12.4 Mill-hardened products have been precipitation heat-treated by the manufacturer. Further thermal treatment is not normally required.

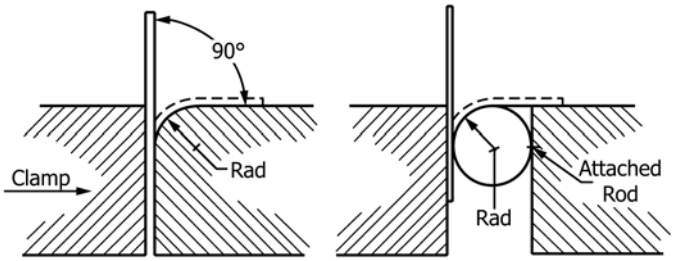

FIG. 1 Methods for Clamping Specimen to Radius for Bend Test

13. Sampling

13.1 Sampling shall be in accordance with Specification B248, Section 7, except that the heat size is defined as 12 000 lbs (5455 kg) or fraction thereof.

14. Specimen Preparation

14.1 The tension specimen direction shall have the longitudinal test-axis parallel to the rolling direction, unless mutually agreed upon between the supplier and purchaser at the time the order is placed.

14.2 When required, five bend-test specimens per test set shall be cut ⅜ ± 1/16 in. (9.52 ± 1.59 mm) in width and any convenient length. Specimens shall be precipitation heat-treated after cutting and prior to testing. Precipitation heat-treatment parameters for these bend tests shall be in accordance with 12.2.

15. Test Methods

15.1 The method for determining chemical analysis for compliance and preparation of certifications and test reports shall be at the discretion of the reporting laboratory.

15.2 In case of dispute, the test methods found in the Annex shall be used for determining chemical requirements for the elements and ranges shown in Table 1.

15.2.1 When analysis for unnamed or residual elements is required in the purchase order, the method of analysis shall be mutually agreed upon between manufacturer or supplier and purchaser.

15.3 Bend-test specimens, shall be tested by clamping them firmly between a flat jaw and the test radius, as shown in Fig. 1. The test specimen shall be bent approximately 90° around the test radius, using a tangential wiping motion with adequate radial pressure to ensure continuous contact between the specimen and the test radius. Test specimens shall be bent to the full 90° bend position. The test radius shall be within ± 6 % of the nominal radius up to 0.010 in. (0.254 mm), exclusive, and within ± 4 % for radii 0.010 in. and over.

16. Keywords

16.1 C17000; C17200; copper-beryllium; flat products; copper plate; copper rolled bar; copper strip

ANNEX

(Mandatory Information)

A1. TEST METHODS FOR DETERMINATION OF COMPLIANCE WITH COPPER-BERYLLIUM ALLOYS—CHEMICAL COMPOSITION REQUIREMENTS

A1.1. Scope

A1.1.1 These test methods establish the procedure(s) for the determination of chemical composition of copper-beryllium alloys.

A1.1.2 The analytical procedures appear in the following order:

Procedure	Sections
Test Method A—Copper by the Electrolytic Method	A1.8 to A1.15
Test Method B—Aluminum, Beryllium, Cobalt, Iron, and Nickel by the Flame Atomic Absorption Spectrophotometric Method	A1.16 to A1.24
Test Method C—Silicon by the Ammonium Molybdate Spectrophotometric Method	A1.25 to A1.35

A1.2. Referenced Documents

A1.2.1 *ASTM Standards:*

E29 Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications

E50 Practices for Apparatus, Reagents, and Safety Considerations for Chemical Analysis of Metals, Ores, and Related Materials

E60 Practice for Analysis of Metals, Ores, and Related Materials by Spectrophotometry

E255 Practice for Sampling Copper and Copper Alloys for the Determination of Chemical Composition

E663 Practice for Flame Atomic Absorption Analysis.

E1024 Guide for Chemical Analysis of Metals and Metal Bearing Ores by Flame Atomic Absorption Spectrophotometry (Withdrawn 2004)[4]

A1.3. Significance and Use

A1.3.1 These test methods are primarily intended to test for compliance with composition specifications. It is assumed that all who use these test methods will be trained analysts capable of performing common laboratory procedures skillfully and safely. It is expected that work will be performed in a properly equipped laboratory.

A1.4 Apparatus, Reagents, and Photometric Practice

A1.4.1 Apparatus and reagents required for each determination are listed in separate sections preceding the procedure. The apparatus, standard solutions, and certain other reagents are referred to by number and shall conform to the requirements prescribed in Practice E50.

A1.4.2 Flame atomic-absorption spectrophotometric practice prescribed in these test methods shall conform to the requirements prescribed in Practice E663 and Guide E1024.

A1.4.3 Spectrophotometric practice prescribed in these test methods shall conform to requirements prescribed in Practice E60.

A1.5. Hazards

A1.5.1 For precautions to be observed in these test methods, refer to Practice E50.

A1.5.2 Both beryllium metal and its compounds may be toxic. Exercise care to prevent contact of beryllium-containing solutions with the skin. Especially avoid the inhalation of any beryllium-containing substance, either as a volatile compound or as a finely divided powder. The proper precautions are to be observed in the disposition of beryllium-containing residues, especially ignited oxide.

A1.6. Sampling

A1.6.1 Sampling shall conform to the requirements of Practice E255.

A1.7 Rounding Off Calculated Values

A1.7.1 Calculated values shall be rounded off to the proper number of places in accordance with the method given in 3.4 and 3.5 of Practice E29.

TEST METHOD A—COPPER BY ELECTROLYTIC DEPOSITION AND ATOMIC-ABSORPTION SPECTROPHOTOMETRY

A1.8 Scope

A1.8.1 This test method establishes a procedure for the determination of copper in copper-beryllium alloys with silver reported as copper.

[4] The last approved version of this historical standard is referenced on www.astm.org.

A1.9 Summary of Test Methods

A1.9.1 The sample is dissolved in an acid mixture. A small amount of fluorohydric acid (HF) is added to minimize possible interferences. Copper is electrolytically deposited on a tared platinum cathode. Copper remaining in the electrolyte is determined by atomic absorption spectrophotometry.

A1.10 Interferences

A1.10.1 Elements normally present do not interfere.

A1.11 Apparatus

A1.11.1 *Electrodes for Electrolysis* —Apparatus No. 9, in Practice E50.

A1.11.2 *Atomic Absorption Spectrophotometer* —Determine the instrument to be suitable for use as directed in Guide E1024. Instrument response must permit estimation of copper concentration to within 1 mg/

A1.11.3 *Operating Parameters*—Wavelength, fuel/oxidant, and flame conditions are as follows:

Wavelength, nm	Fuel/Oxidant	Flame Condition
Copper 327.5	Acetylene/air	Oxidizing

A1.12 Reagents

A1.12.1 *Sulfuric-Nitric Acid Mixture*—While stirring, slowly add 500 mL of sulfuric acid (H_2SO_4) to 1 L of water. Cool and transfer to a 2-L volumetric flask. Add 300 mL of nitric acid (HNO_3). Cool, dilute to volume, and mix.

A1.12.2 *Copper Standard Solution* (1 mL = 1.0 mg Cu)—Transfer 1.000 g of copper metal (purity, 99.9 % min) into a 250-mL beaker. Add 20 mL of the acid mixture. Cover the beaker and allow to stand until dissolution is nearly complete. Heat at 80 to 90°C until dissolution is complete and brown fumes have been expelled. Cool, transfer into a 1-L volumetric flask, dilute to volume, and mix.

A1.12.3 *Calibration Solutions*—Pipet 5, 10, 15, 20, and 25-mL portions of the copper standard solution into individual 1-L volumetric flasks. Add 50 mL of the acid mixture to each flask, dilute to volume, and mix. These solutions are equivalent to 0.005, 0.010, 0.015, 0.020, and 0.025 g of copper respectively.

A1.12.4 *Zero-Calibration Solution*—Transfer 50 mL of the acid mixture into a 1-L volumetric flask, dilute to volume, and mix.

A1.13. Procedure

A1.13.1 Transfer a 2.500-g portion into each of two electrolysis beakers, normally 300-mL. Add 50 mL of the mixed acid, cover the beaker, and allow to stand until the reaction subsides. Heat at 80 to 90°C until dissolution is complete and brown fumes have been expelled. Cool and wash down cover glass and inside of beaker. Add 1.0 mL of HF (1 + 9) from a plastic pipet and dilute to about half volume.

A1.13.2 Insert the electrodes and dilute to submerge the cathode. Cover the beaker with a pair of split cover glasses and electrolyze at a current density of about 0.6 A/dm^2 for about 16 h.