



Designation: E353 – 19

Standard Test Methods for Chemical Analysis of Stainless, Heat-Resisting, Maraging, and Other Similar Chromium-Nickel-Iron Alloys¹

This standard is issued under the fixed designation E353; 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 reappraisal. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reappraisal.

1. Scope

1.1 These test methods cover the chemical analysis of stainless, heat-resisting, maraging, and other similar chromium-nickel-iron alloys having chemical compositions within the following limits:

| Element | Composition Range, % |
|------------|----------------------|
| Aluminum | 0.002 to 5.50 |
| Boron | 0.001 to 0.20 |
| Carbon | 0.01 to 1.50 |
| Chromium | 0.01 to 35.00 |
| Cobalt | 0.01 to 15.00 |
| Niobium | 0.01 to 4.00 |
| Copper | 0.01 to 5.00 |
| Lead | 0.001 to 0.50 |
| Manganese | 0.01 to 20.00 |
| Molybdenum | 0.01 to 7.00 |
| Nickel | 0.01 to 48.00 |
| Nitrogen | 0.001 to 0.50 |
| Phosphorus | 0.002 to 0.35 |
| Selenium | 0.01 to 0.50 |
| Silicon | 0.01 to 4.00 |
| Sulfur | 0.002 to 0.50 |
| Tantalum | 0.01 to 0.80 |
| Tin | 0.001 to 0.05 |
| Titanium | 0.01 to 4.50 |
| Tungsten | 0.01 to 4.50 |
| Vanadium | 0.005 to 1.00 |
| Zirconium | 0.001 to 0.20 |

1.2 The test methods in this standard are contained in the sections indicated below:

| Method | Sections |
|--------------------------------------------------------------------------------------------------|----------|
| Aluminum, Total, by the 8-Quinolinol Gravimetric Method (0.20 % to 7.00 %) | 119–126 |
| Aluminum, Total, by the 8-Quinolinol Spectrophotometric Method (0.003 % to 0.20 %) | 71–81 |
| Carbon, Total, by the Combustion–Thermal Conductivity Method– <i>Discontinued 1986</i> | 153–163 |
| Carbon, Total, by the Combustion Gravimetric Method (0.05 % to 1.50 %)– <i>Discontinued 2013</i> | 98–108 |
| Chromium by the Atomic Absorption Spectrometry Method (0.006 % to 1.00 %) | 202–211 |

| Method | Sections |
|-----------------------------------------------------------------------------------------------|----------|
| Chromium by the Peroxydisulfate Oxidation–Titration Method (0.10 % to 35.00 %) | 212–220 |
| Chromium by the Peroxydisulfate–Oxidation Titrimetric Method– <i>Discontinued 1980</i> | 145–152 |
| Cobalt by the Ion-Exchange–Potentiometric Titration Method (2 % to 15 %) | 53–60 |
| Cobalt by the Nitroso-R-Salt Spectrophotometric Method (0.01 % to 5.0 %) | 61–70 |
| Copper by the Neocuproine Spectrophotometric Method (0.01 % to 5.00 %) | 109–118 |
| Copper by the Sulfide Precipitation–Electrodeposition Gravimetric Method (0.01 % to 5.00 %) | 82–89 |
| Lead by the Ion-Exchange–Atomic Absorption Spectrometry Method (0.001 % to 0.50 %) | 127–136 |
| Manganese by the Periodate Spectrophotometric Method (0.01 % to 5.00 %) | 9–18 |
| Molybdenum by the Ion Exchange–8-Hydroxyquinoline Gravimetric Method | 242–249 |
| Molybdenum by the Thiocyanate Spectrophotometric Method (0.01 % to 1.50 %) | 190–201 |
| Nickel by the Dimethylglyoxime Gravimetric Method (0.1 % to 48.0 %) | 172–179 |
| Phosphorus by the Alkalimetric Method (0.02 % to 0.35 %) | 164–171 |
| Phosphorus by the Molybdenum Blue Spectrophotometric Method (0.002 % to 0.35 %) | 19–30 |
| Silicon by the Gravimetric Method (0.05 % to 4.00 %) | 46–52 |
| Sulfur by the Gravimetric Method– <i>Discontinued 1988</i> | 30–36 |
| Sulfur by the Combustion–Iodate Titration Method (0.005 % to 0.5 %)– <i>Discontinued 2014</i> | 37–45 |
| Sulfur by the Chromatographic Gravimetric Method– <i>Discontinued 1980</i> | 137–144 |
| Tin by the Solvent Extraction–Atomic Absorption Spectrometry Method (0.002 % to 0.10 %) | 180–189 |
| Tin by the Sulfide Precipitation–Iodometric Titration Method (0.01 % to 0.05 %) | 90–97 |
| Titanium by the Diantipryl/methane Spectrophotometric Method (0.01 % to 0.35 %) | 231–241 |
| Vanadium by the Atomic Absorption Spectrometry Method (0.006 % to 0.15 %) | 221–230 |

1.3 Test methods for the determination of carbon and sulfur not included in this standard can be found in Test Methods E1019.

1.4 Some of the composition ranges given in 1.1 are too broad to be covered by a single test method and therefore this standard contains multiple test methods for some elements. The user must select the proper test method by matching the information given in the Scope and Interference sections of each method with the composition of the alloy to be analyzed.

¹ These test methods are under the jurisdiction of ASTM Committee E01 on Analytical Chemistry for Metals, Ores, and Related Materials and are the direct responsibility of Subcommittee E01.01 on Iron, Steel, and Ferroalloys.

Current edition approved Nov. 15, 2019. Published February 2020. Originally approved in 1968. Last previous edition approved in 2014 as E353–14. DOI: 10.1520/E0353-19.

1.5 The values stated in SI units are to be regarded as standard.

1.6 *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, health, and environmental practices and determine the applicability of regulatory limitations prior to use.* Specific hazards statements are given in Section 6 and in special “Warning” paragraphs throughout these test methods.

1.7 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 ASTM Standards:²

D1193 Specification for Reagent Water

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

E135 Terminology Relating to Analytical Chemistry for Metals, Ores, and Related Materials

E173 Practice for Conducting Interlaboratory Studies of Methods for Chemical Analysis of Metals (Withdrawn 1998)³

E350 Test Methods for Chemical Analysis of Carbon Steel, Low-Alloy Steel, Silicon Electrical Steel, Ingot Iron, and Wrought Iron

E351 Test Methods for Chemical Analysis of Cast Iron—All Types

E352 Test Methods for Chemical Analysis of Tool Steels and Other Similar Medium- and High-Alloy Steels

E354 Test Methods for Chemical Analysis of High-Temperature, Electrical, Magnetic, and Other Similar Iron, Nickel, and Cobalt Alloys

E882 Guide for Accountability and Quality Control in the Chemical Analysis Laboratory

E1019 Test Methods for Determination of Carbon, Sulfur, Nitrogen, and Oxygen in Steel, Iron, Nickel, and Cobalt Alloys by Various Combustion and Inert Gas Fusion Techniques

E1024 Guide for Chemical Analysis of Metals and Metal Bearing Ores by Flame Atomic Absorption Spectrophotometry (Withdrawn 2004)³

E1601 Practice for Conducting an Interlaboratory Study to Evaluate the Performance of an Analytical Method

E1806 Practice for Sampling Steel and Iron for Determination of Chemical Composition

2.2 Other Document:

ISO 5725 Precision of Test Methods—Determination of Repeatability and Reproducibility for Inter-Laboratory Tests⁴

3. Terminology

3.1 For definitions of terms used in these test methods, refer to Terminology **E135**.

4. Significance and Use

4.1 These test methods for the chemical analysis of metals and alloys are primarily intended as referee methods to test such materials for compliance with compositional specifications, particularly those under the jurisdiction of ASTM Committee A01 on Steel, Stainless Steel, and Related Alloys. 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 under appropriate quality control practices such as those described in Guide **E882**.

5. Apparatus, Reagents, and Instrumental Practices

5.1 *Apparatus*—Specialized apparatus requirements are listed in the “Apparatus” Section in each method.

5.1.1 In the methods specifying spectrophotometric testing, the cells utilized to contain the reference material solutions and the sample solutions in spectrophotometers are referred to as “absorption cells.” Please note that the radiant energy passed through the cells can be measured as absorbance or transmittance. These methods refer to absorbance measurements. Refer to Practices **E60** for details.

5.2 Reagents:

5.2.1 *Purity of Reagents*—Unless otherwise indicated, all reagents used in these test methods shall conform to the “Reagent Grade” Specifications of the American Chemical Society.⁵ Other chemicals may be used, provided it is first ascertained that they are of sufficiently high purity to permit their use without adversely affecting the expected performance of the determination, as indicated in the Precision and Bias section.

5.2.2 *Purity of Water*—Unless otherwise indicated, references to water shall mean reagent water as conforming to Type I or Type II of Specification **D1193**. Type III or IV may be used if they effect no measurable change in the blank or sample.

5.3 *Spectrophotometric Practice*—Spectrophotometric practice prescribed in these test methods shall conform to Practice **E60**.

² 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.

³ The last approved version of this historical standard is referenced on www.astm.org.

⁴ Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, www.ansi.org.

⁵ “Reagent Chemicals, American Chemical Society Specifications,” American Chemical Society, Washington, DC, www.acs.org. For suggestions on the testing of Reagents not listed by the American Chemical Society, see the *United States Pharmacopeia and National Formulary*, U.S. Pharmacopeial Convention, Inc. (USPC), Rockville, MD, www.uspnf.com.

6. Hazards

6.1 For precautions to be observed in the use of certain reagents and equipment in these methods, refer to Practices [E50](#).

7. Sampling

7.1 For procedures to sample the material, refer to Practice [E1806](#).

8. Interlaboratory Studies and Rounding Calculated Values

8.1 These test methods have been evaluated as directed in Practice [E173](#) (withdrawn 1997) or ISO 5725. Practice [E173](#) has been replaced by Practice [E1601](#). The reproducibility, R_2 , of Practice [E173](#) corresponds to the reproducibility index R of Practice [E1601](#). The repeatability, RI , of Practice [E173](#) corresponds to the repeatability index, r , of Practice [E1601](#).

8.2 Rounding of test results obtained using this test method shall be performed as directed in ASTM [E29](#), Rounding Method, unless an alternative rounding method is specified by the customer or applicable material specification.

MANGANESE BY THE META PERIODATE SPECTROPHOTOMETRIC METHOD

9. Scope

9.1 This method covers the determination of manganese from 0.01 % to 5.00 %.

10. Summary of Method

10.1 Manganous ions are oxidized to permanganate ions by treatment with periodate. Tungsten when present at compositions greater than 0.5 % is kept in solution with H_3PO_4 . Solutions of the samples are fumed with $HClO_4$ so that the effect of periodate is limited to the oxidation of manganese. Spectrophotometric absorbance measurement is made at 545 nm.

11. Concentration Range

11.1 The recommended concentration range is 0.15 mg to 0.8 mg of manganese per 50 mL of solution, using a 1-cm cell (see [Note 1](#)) and a spectrophotometer with a band width of 10 nm or less.

NOTE 1—This method has been written for cells having a 1-cm light path and a “narrow-band” instrument. The concentration range depends upon band width and spectral region used as well as cell optical path length. Cells having other dimensions may be used, provided suitable adjustments can be made in the amounts of sample and reagents used.

12. Stability of Color

12.1 The color is stable for at least 24 h.

13. Interferences

13.1 $HClO_4$ treatment, which is used in the procedure, yields solutions which can be highly colored due to the presence of Cr (VI) ions. Although these ions and other colored ions in the sample solution undergo no further change in color quality upon treatment with metaperiodate ion, the following

precautions must be observed when filter spectrophotometers are used: Select a filter with maximum transmittance between 545 nm and 565 nm. The filter must transmit not more than 5 % of its maximum at a wavelength shorter than 530 nm. The band width of the filter should be less than 30 nm when measured at 50 % of its maximum transmittance. Similar restrictions apply with respect to the wavelength region employed when other “wide-band” instruments are used.

13.2 The spectral transmittance curve of permanganate ions exhibits two useful minima, one at approximately 526 nm, and the other at 545 nm. The latter is recommended when a “narrow-band” spectrophotometer is used.

13.3 Tungsten, when present in amounts of more than 0.5 % interferes by producing a turbidity in the final solution. A special procedure is provided for use with samples containing more than 0.5 % tungsten which eliminates the problem by preventing the precipitation of the tungsten.

14. Reagents

14.1 *Manganese, Standard Solution* (1 mL = 0.032 mg Mn)—Transfer the equivalent of 0.4000 g of assayed, high-purity manganese (purity: 99.99 % minimum), to a 500-mL volumetric flask and dissolve in 20 mL of HNO_3 by heating. Cool, dilute to volume, and mix. Using a pipet, transfer 20 mL to a 500-mL volumetric flask, dilute to volume, and mix.

14.2 *Nitric-Phosphoric Acid Mixture*—Cautiously, while stirring, add 100 mL of HNO_3 and 400 mL of H_3PO_4 to 400 mL of water. Cool, dilute to 1 L, and mix. Prepare fresh as needed.

14.3 *Potassium Metaperiodate Solution* (7.5 g/L)—Dissolve 7.5 g of potassium metaperiodate (KIO_4) in 200 mL of hot HNO_3 (1 + 1), add 400 mL of H_3PO_4 , cool, dilute to 1 L, and mix.

14.4 *Water, Pretreated with Metaperiodate*—Add 20 mL of KIO_4 solution to 1 L of water, mix, heat at not less than 90°C for 20 min to 30 min, and cool. Use this water to dilute solutions to volume that have been treated with KIO_4 solution to oxidize manganese, and thus avoid reduction of permanganate ions by any reducing agents in the untreated water. **Caution**—Avoid the use of this water for other purposes.

15. Preparation of Calibration Curve

15.1 *Calibration Solutions*—Using pipets, transfer 5 mL, 10 mL, 15 mL, 20 mL, and 25 mL of manganese standard solution (1 mL = 0.032 mg Mn) to 50-mL borosilicate glass volumetric flasks, and if necessary, dilute to approximately 25 mL. Proceed as directed in [15.3](#).

15.2 *Reference Solution*—Transfer approximately 25 mL of water to a 50-mL borosilicate glass volumetric flask. Proceed as directed in [15.3](#).

15.3 *Color Development*—Add 10 mL of KIO_4 solution, and heat the solutions at not less than 90°C for 20 min to 30 min ([Note 2](#)). Cool, dilute to volume with pretreated water, and mix.

NOTE 2—Immersing the flasks in a boiling water bath is a preferred

means of heating them for the specified period to ensure complete color development.

15.4 Spectrophotometry:

15.4.1 *Multiple-Cell Spectrophotometer*—Measure the cell correction using the Reference Solution (15.2) in absorption cells with a 1-cm light path and using a light band centered at 545 nm. Using the test cell, take the spectrophotometric absorbance readings of the calibration solutions versus the Reference Solution (15.2).

15.4.2 *Single-Cell Spectrophotometer*—Transfer a suitable portion of the Reference Solution (15.2) to an absorption cell with a 1-cm light path and adjust the spectrophotometer to the initial setting, using a light band centered at 545 nm. While maintaining this adjustment, take the spectrophotometric absorbance readings of the calibration solutions.

15.5 *Calibration Curve*—Follow the instrument manufacturer's instructions for generating the calibration curve. Plot the net spectrophotometric absorbance readings of the calibration solutions against the milligrams of manganese per 50 mL of solution.

16. Procedure

16.1 *Test Solution*—Select and weigh a sample as follows:

| Manganese, % | Sample Mass, g | Tolerance in Sample Mass, mg | Dilution, mL | Aliquot Volume, mL |
|--------------|----------------|------------------------------|--------------|--------------------|
| 0.01 to 0.5 | 0.80 | 0.5 | 100 | 20 |
| 0.45 to 1.0 | 0.35 | 0.3 | 100 | 20 |
| 0.85 to 2.0 | 0.80 | 0.5 | 500 | 20 |
| 1.95 to 5.0 | 0.80 | 0.5 | 500 | 10 |

Transfer it to a 300-mL Erlenmeyer flask.

16.1.1 To dissolve samples that do not require HF, add 8 mL to 10 mL of HCl (1 + 1), and heat. Add HNO₃ as needed to hasten dissolution, and then add 3 mL to 4 mL in excess. When dissolution is complete, cool, then add 10 mL of HClO₄; evaporate to fumes to oxidize chromium, if present, and to expel HCl. Continue fuming until salts begin to separate. Cool, add 50 mL of water, and digest if necessary to dissolve the salts. Cool and transfer the solution to either a 100-mL or 500-mL volumetric flask as indicated in 16.1. Proceed to 16.2.2.

16.2 For samples whose dissolution is hastened by HF, add 8 mL to 10 mL of HCl (1 + 1), and heat. Add HNO₃ and a few drops of HF as needed to hasten dissolution, and then add 3 mL to 4 mL of HNO₃. When dissolution is complete, cool, then add 10 mL of HClO₄, evaporate to fumes to oxidize chromium, if present, and to expel HCl. Continue fuming until salts begin to separate. Cool, add 50 mL of water, digest if necessary to dissolve the salts, cool, and transfer the solution to either a 100-mL or 500-mL volumetric flask as indicated in 16.1. Proceed to 16.2.2.

16.2.1 *For Samples Containing More Than 0.5 % Tungsten:*

16.2.1.1 To dissolve samples that do not require HF, add 8 mL to 10 mL of H₃PO₄, 10 mL of HClO₄, 5 mL to 6 mL of H₂SO₄, and 3 mL to 4 mL of HNO₃. Heat moderately until the sample is decomposed, and then heat to copious white fumes for 10 min to 12 min or until the chromium is oxidized and the HCl is expelled, but avoid heating to fumes of SO₃. Cool, add

50 mL of water, and digest, if necessary, to dissolve the salts. Transfer the solution to either a 100-mL or 500-mL volumetric flask as directed in 16.1. Proceed to 16.2.2.

16.2.1.2 For samples whose dissolution is hastened by HF: Add 8 mL to 10 mL of H₃PO₄, 10 mL of HClO₄, 5 mL to 6 mL of H₂SO₄, 3 mL to 4 mL of HNO₃, and a few drops of HF. Heat moderately until the sample is decomposed, and then heat to copious white fumes for 10 min to 12 min or until the chromium is oxidized and the HCl is expelled, but avoid heating to fumes or SO₃. Cool, add 50 mL of water, digest, if necessary, to dissolve the salts, cool, and transfer the solution to a 100-mL or 500-mL volumetric flask as directed in 16.1. Proceed to 16.2.2.

16.2.2 Cool the solution to room temperature, dilute to volume, and mix. Allow insoluble matter to settle, or dry-filter through a coarse paper and discard the first 15 mL to 20 mL of the filtrate, before taking aliquots.

16.2.3 Using a pipet, transfer 10 mL to 20 mL aliquots as specified in 16.1 to two 50-mL borosilicate glass volumetric flasks. Treat one portion as directed in 16.4. Treat the other portion as directed in 16.5.1.

16.3 *Reagent Blank Solution*—Carry a reagent blank through the entire procedure using the same amounts of all reagents with the sample omitted.

16.4 *Color Development*—Proceed as directed in 15.3.

16.5 *Reference Solutions:*

16.5.1 *Background Color Solution*—To one of the sample aliquots in a 50-mL volumetric flask, add 10 mL of HNO₃-H₃PO₄ mixture, and heat the solution at not less than 90 °C for 20 min to 30 min (Note 2). Cool, dilute to volume (with untreated water), and mix.

16.5.2 *Reagent Blank Reference Solution*—Transfer the reagent blank solution (16.3) to the same size volumetric flask as used for the test solutions and transfer the same size aliquots as used for the test solutions to two 50-mL volumetric flasks. Treat one portion as directed in 16.4 and use as reference solution for test samples. Treat the other as directed in 16.5.1 and use as reference solution for Background Color Solutions.

16.6 *Spectrophotometry*—Establish the cell corrections with the Reagent Blank Reference solution to be used as a reference solution for Background Color solutions. Take the spectrophotometric absorbance readings of the Background Color Solutions and the test solutions versus the respective Reagent Blank Reference Solutions as directed in 15.4.

17. Calculation

17.1 Convert the net spectrophotometric absorbance reading of the test solution and of the background color solution to milligrams of manganese by means of the calibration curve. Calculate the percentage of manganese as follows:

$$\text{Manganese, \%} = (A - B)/(C \times 10) \quad (1)$$

where:

A = manganese, mg, found in 50 mL of the final test solution,

B = apparent manganese, mg, found in 50 mL of the final background color solution, and

C = sample mass, g, represented in 50 mL of the final test solution.

18. Precision and Bias

18.1 *Precision*—Nine laboratories cooperated in testing this method and obtained the data summarized in [Table 1](#).

18.2 *Bias*—The accuracy of this test method has been deemed satisfactory based upon the data for the certified reference materials in [Table 1](#). Users are encouraged to use these or similar reference materials to verify that the test method is performing accurately in their laboratories.

PHOSPHORUS BY THE MOLYBDENUM BLUE SPECTROPHOTOMETRIC METHOD

19. Scope

19.1 This method covers the determination of phosphorus from 0.002 % to 0.35 %.

20. Summary of Method

20.1 The sample is dissolved in mixed acids and the solution is fumed with HClO_4 . Ammonium molybdate is added to react with the phosphorus to form the heteropoly phosphomolybdate. This species is then reduced with hydrazine sulfate to form the molybdenum blue complex. Spectrophotometric absorbance measurement is made at 650 nm or 825 nm, depending upon the concentration.

21. Concentration Range

21.1 The recommended concentration range is from 0.005 mg to 0.05 mg of phosphorus per 100 mL of solution when measured at 825 nm and from 0.05 mg to 0.3 mg of phosphorus per 100 mL of solution when measured at 650 nm, using a 1-cm cell.

NOTE 3—This test method has been written for cells having a 1-cm light path. Cells having other dimensions may be used, provided suitable adjustments are made in the amounts of sample and reagents used.

TABLE 1 Statistical Information—Manganese by the Metaperiodate Spectrophotometric Method

| Test Material | Manganese Found, % | Repeatability (R_1 , E173) | Reproducibility (R_2 , E173) |
|-----------------------------------------------------|--------------------|-------------------------------|---------------------------------|
| 1. Maraging steel 18Ni-8Co-5Mo | 0.020 | 0.005 | 0.007 |
| 2. Maraging steel (NIST 1156, 0.21 Mn) | 0.209 | 0.009 | 0.017 |
| 3. Stainless steel 24Cr-13Ni (NIST 447, 0.23 Mn) | 0.208 | 0.008 | 0.016 |
| 4. Stainless steel 18Cr-9Ni (NIST 101e, 1.77 Mn) | 1.79 | 0.04 | 0.06 |
| 5. Stainless steel 18.5Cr-9.5Ni (NIST 443, 3.38 Mn) | 3.37 | 0.05 | 0.11 |
| 6. Stainless steel 20.5Cr-10Ni (NIST 444, 4.62 Mn) | 4.60 | 0.04 | 0.13 |

22. Stability of Color

22.1 The molybdenum blue complex is stable for at least 2 h.

23. Interferences

23.1 None of the elements usually present interfere except arsenic, which is removed by volatilization as the bromide.

24. Apparatus

24.1 Glassware must be phosphorus- and arsenic-free. Boil the glassware with HCl and rinse with water before use. It is recommended that the glassware used for this determination be reserved for this use only. Many detergents contain phosphorus and must not be used for cleaning purposes.

25. Reagents

25.1 *Ammonium Molybdate Solution (20 g/L)*—Cautiously, while stirring and cooling, add 300 mL of H_2SO_4 to 500 mL of water and cool. Add 20 g of ammonium heptamolybdate ($(\text{NH}_4)_6\text{Mo}_7\text{O}_{24}\cdot 4\text{H}_2\text{O}$), cautiously dilute to 1 L, and mix.

25.2 *Ammonium Molybdate-Hydrazine Sulfate Solution*—Dilute 250 mL of the ammonium molybdate solution to 600 mL, add 100 mL of the hydrazine sulfate solution, dilute to 1 L, and mix. Do not use a solution that has stood for more than 1 h.

25.3 *Hydrazine Sulfate Solution (1.5 g/L)*—Dissolve 1.5 g of hydrazine sulfate ($(\text{NH}_2)_2 \cdot \text{H}_2\text{SO}_4$) in water, dilute to 1 L, and mix. Discard any unused solution after 24 h.

25.4 *Phosphorus Standard Solution A (1 mL = 1.0 mg P)*—Transfer 2.292 g of anhydrous disodium hydrogen phosphate (Na_2HPO_4), previously dried to constant mass at 105 °C, to a 500-mL volumetric flask; dissolve in about 100 mL of water, dilute to volume, and mix.

25.5 *Phosphorus Standard Solution B (1 mL = 0.01 mg P)*—Using a pipet, transfer 10 mL of Solution A (1 mL = 1.0 mg P) to a 1-L volumetric flask, add 50 mL of HClO_4 (1 + 5), dilute to volume, and mix.

25.6 *Phosphorus Standard Solution C (1 mL = 0.10 mg P)*—Using a pipet, transfer 50 mL of Solution A (1 mL = 1.0 mg P) to a 500-mL volumetric flask, add 50 mL of HClO_4 (1 + 5), dilute to volume, and mix.

25.7 *Sodium Sulfite Solution (100 g/L)*—Dissolve 100 g of sodium sulfite (Na_2SO_3) in water, dilute to 1 L, and mix.

26. Preparation of Calibration Curve for Concentrations from 0.005 mg/100 mL to 0.05 mg/100 mL

26.1 *Calibration Solutions*—Using pipets, transfer 5 mL, 10 mL, 15 mL, 25 mL, and 50 mL of Phosphorus Standard Solution B (1 mL = 0.01 mg P) to 100-mL volumetric flasks. Add 20 mL of HClO_4 , dilute to volume, and mix. Using a pipet, transfer 10 mL of each solution to a 100-mL borosilicate glass volumetric flask. Proceed as directed in [26.3](#).

26.2 *Reagent Blank*—Transfer 12 mL of HClO_4 (1 + 5) to a 100-mL borosilicate glass volumetric flask.

26.3 *Color Development:*

26.3.1 Add 15 mL of Na₂SO₃ solution, boil gently for 30 s, and add 50 mL of ammonium molybdate-hydrazine sulfate solution that has been prepared within the hour.

26.3.2 Heat the solutions at not less than 90 °C for 20 min, quickly cool, dilute to volume, and mix.

NOTE 4—Immersing the flasks in a boiling water bath is the preferred means of heating them for complete color development.

26.4 *Reference Solution*—Water.

26.5 *Spectrophotometry*:

26.5.1 *Multiple-Cell Spectrophotometer*—Measure the reagent blank (which includes the cell correction) versus the reference solution (26.4) using absorption cells with a 1-cm light path and using a light band centered at 825 nm. Using the test cell, take the spectrophotometric absorbance readings of the calibration solutions versus the reference solution.

26.5.2 *Single-Cell Spectrophotometer*—Transfer a suitable portion of the reference solution (26.4) to an absorption cell with a 1-cm light path and adjust the spectrophotometer to the initial setting using a light band centered at 825 nm. While maintaining this adjustment, take the spectrophotometric absorbance readings of the reagent blank solution and of the calibration solutions.

26.6 *Calibration Curve*—Follow the instrument manufacturer's instructions for generating the calibration curve. Plot the net spectrophotometric absorbance readings of the calibration solutions against the milligrams of phosphorus per 100 mL of solution.

27. Preparation of Calibration Curve for Concentrations from 0.05 mg/100 mL to 0.30 mg/100 mL

27.1 —*Calibration Solutions*—Using pipets, transfer 5 mL, 10 mL, 15 mL, 20 mL, 25 mL, and 30 mL of Phosphorus Standard Solution C (1 mL = 0.10 mg P) to 100-mL volumetric flasks. Add 20 mL of HClO₄, dilute to volume, and mix. Using a pipet, transfer 10 mL of each solution to a 100-mL borosilicate glass volumetric flask.

27.2 *Reagent Blank*—Proceed as directed in 26.2.

27.3 *Color Development*—Proceed as directed in 26.3.

27.4 *Reference Solution*—Water.

27.5 *Spectrophotometry*:

27.5.1 *Multiple-Cell Spectrophotometer*—Measure the reagent blank (which includes the cell correction) versus the reference solution (27.4) using absorption cells with a 1-cm light path and a light band centered at 650 nm. Using the test cell, take the spectrophotometric absorbance readings of the calibration solutions versus the reference solution.

27.5.2 *Single-Cell Spectrophotometer*—Transfer a suitable portion of the reference solution (27.4) to an absorption cell with a 1-cm light path and adjust the spectrophotometer to the initial setting using a light band (no change) centered at 650 nm. While maintaining this adjustment, take the spectrophotometric absorbance readings of the reagent blank solution and of the calibration solutions.

27.6 *Calibration Curve*—Follow the instrument manufacturer's instructions for generating the calibration curve. Plot

the net spectrophotometric absorbance readings of the calibration solutions against the milligrams of phosphorus per 100 mL of solution.

28. Procedure

28.1 *For Samples Containing Less Than 0.5 % Tungsten*:

28.1.1 *Test Solution*:

28.1.1.1 For compositions not greater than 0.30 % phosphorus, use a 1.0-g sample; for the composition range from 0.30 % to 0.35 % phosphorus, use a 0.85-g sample. Weigh the sample to the nearest 0.5 mg, and transfer it to a 250-mL Erlenmeyer flask.

28.1.1.2 Add 15 mL of a freshly prepared mixture of 1 volume of HNO₃ and 3 volumes of HCl, slowly and in small portions. When the reaction has ceased, add 10 mL of HClO₄ and evaporate to fumes. Remove the flask immediately to avoid undue loss of HClO₄, cool, and add 20 mL of HBr (1 + 4). Evaporate the solution to copious white fumes and then, without delay, fume strongly enough to cause the white fumes to clear the neck of the flask, and continue at this rate for 1 min.

28.1.1.3 Cool the solution, add 60 mL of HClO₄ (1 + 5), and swirl to dissolve the salts. Transfer to a 100-mL volumetric flask, cool, dilute to volume, and mix. Allow insoluble matter to settle or dry filter the solution. Using a pipet, transfer 10-mL portions to two 100-mL borosilicate glass volumetric flasks; treat one as directed in 28.1.3 and the other as directed in 28.1.4.2.

28.1.2 *Reagent Blank Solution*—Carry a reagent blank through the entire procedure using the same amount of all reagents with the sample omitted.

28.1.3 *Color Development*—Proceed with one of the 10-mL portions obtained in 28.1.1.3, as directed in 26.3.

28.1.4 *Reference Solutions*:

28.1.4.1 *Water*—Use this as the reference solution for the reagent blank solution.

28.1.4.2 *Background Color Reference Solution*—Add 15 mL of Na₂SO₃ solution to the second 10-mL portion obtained in 28.1.1.3. Boil gently for 30 s, add 50 mL of H₂SO₄ (3 + 37), cool, dilute to volume, and mix. Use this as the reference solution for the test solution.

28.1.5 *Spectrophotometry*—Take the spectrophotometric absorbance readings of the reagent blank solution and of the test solution (using the respective reference solutions) as directed in 26.5 or 27.5 depending upon the estimated composition of phosphorus in the sample.

28.2 *For Samples Containing More Than 0.5 % Tungsten*:

28.2.1 *Test Solution*:

28.2.1.1 For compositions not greater than 0.30 % phosphorus, transfer 0.100-g samples, weighed to the nearest 0.1 mg, to two 100-mL Erlenmeyer flasks; for the composition range from 0.30 % to 0.35 % phosphorus, transfer 0.085-g samples, weighed to the nearest 0.1 mg, to two 100-mL Erlenmeyer flasks.

28.2.1.2 Add 5 mL of a mixture of 1 volume of HNO₃ and 3 volumes of HCl. When the reaction has ceased, add 2.5 mL of HClO₄ and 5 mL of HBr (1 + 4). Evaporate the solutions to

copious white fumes; then, without delay, fume strongly enough to cause the white fumes to clear the neck of the flasks, and continue at this rate for 1 min.

28.2.1.3 Cool the solutions, and add 10 mL of water. Filter through a 9-cm fine paper collecting the filtrate in a 100-mL borosilicate glass volumetric flask. Wash the paper and insoluble matter 5 times with 3-mL portions of water. Treat one solution as directed in 28.2.3 and the other as directed in 28.2.4.

28.2.2 *Reagent Blank Solution*—Proceed as directed in 28.2.1.2 and 28.2.1.3.

28.2.3 *Color Development*—Proceed as directed in 26.3.

28.2.4 *Reference Solutions*:

28.2.4.1 *Water*—Use this as the reference solution for the reagent blank solution.

28.2.4.2 *Background Color Reference Solution*—Add 15 mL of Na₂SO₃ solution to the second 10-mL portion obtained in 28.2.1.3. Boil gently for 30 s, add 50 mL of H₂SO₄ (3 + 37), cool, dilute to volume, and mix. Use this as the reference solution for the test solution.

28.2.5 *Spectrophotometry*—Proceed as directed in 28.1.5.

29. Calculation

29.1 Convert the net spectrophotometric absorbance reading of the test solution and of the reagent blank solution to milligrams of phosphorus by means of the appropriate calibration curve. Calculate the percent of phosphorus as follows:

$$\text{phosphorus, \%} = (A - B)/(C \times 10) \quad (2)$$

where:

A = phosphorus found in 100 mL of the final test solution, mg,

B = phosphorus found in 100 mL of the final reagent blank solution, mg, and

C = sample represented in 100 mL of the final test solution, g.

30. Precision and Bias

30.1 *Precision*—Nine laboratories cooperated in testing this method and obtained the data summarized in Table 2.

30.2 *Bias*—The accuracy of this test method has been deemed satisfactory based upon the data for the certified reference materials in Table 2. Users are encouraged to use these or similar reference materials to verify that the test method is performing accurately in their laboratories.

SULFUR BY THE GRAVIMETRIC METHOD

(This method, which consisted of Sections 30 through 36 of this standard, was discontinued in 1988.)

TABLE 2 Statistical Information—Phosphorus—Molybdenum Blue—Spectrophotometric Method

| Test Material | Phosphorus Found, % | Repeatability (R_1 , E173) | Reproducibility (R_2 , E173) |
|--------------------------------------------------------|---------------------|-------------------------------|---------------------------------|
| 1. Stainless steel 18Cr-9Ni (NIST 101e, 0.025 P) | 0.025 | 0.001 | 0.004 |
| 2. Stainless steel 19Cr-14Ni-3Mo (NIST 160a, 0.027 P) | 0.026 | 0.002 | 0.004 |
| 3. Stainless steel 17Cr-9Ni-0.25Se (NIST 339, 0.129 P) | 0.128 | 0.007 | 0.012 |

SULFUR BY THE COMBUSTION-IODATE TITRATION METHOD

(This method, which consisted of Sections 37 through 45 of this standard, was discontinued in 2014.)

SILICON BY THE GRAVIMETRIC METHOD

46. Scope

46.1 This method covers the determination of silicon from 0.05 % to 4.00 %.

47. Summary of Method

47.1 After dissolution of the sample, silicic acid is dehydrated by fuming with H₂SO₄ or HClO₄. The solution is filtered, and the impure silica is ignited and weighed. The silica is then volatilized with HF. The residue is ignited and weighed; the loss in mass represents silica.

48. Interferences

48.1 The elements normally present do not interfere if their compositions are under the maximum limits shown in 1.1.

49. Reagents

49.1 The analyst should ensure by analyzing blanks and other checks that possible silicon contamination of reagents will not significantly bias the results.

49.2 Perchloric Acid:

49.2.1 Select a lot of HClO₄ that contains not more than 0.0002 % silicon for the analysis of samples containing silicon in the range from 0.02 % to 0.10 % and not more than 0.0004 % silicon for samples containing more than 0.10 % by determining duplicate values for silicon as directed in 49.2.2–49.2.6.

49.2.2 Transfer 15 mL of HClO₄ (Note 5) to each of two 400-mL beakers. To one of the beakers transfer an additional 50 mL of HClO₄. Using a pipet, transfer 20 mL of Na₂SiO₃ solution (1 mL = 1.00 mg Si) to each of the beakers. Evaporate the solutions to fumes and heat for 15 min to 20 min at such a rate that HClO₄ refluxes on the sides of the beakers. Cool sufficiently, and add 100 mL of water (40 °C to 50 °C).

NOTE 5—The 15-mL addition of HClO₄ can be from the same lot as the one to be tested. Once a lot has been established as having less than 0.0002 % silicon, it should preferably be used for the 15-mL addition in all subsequent tests of other lots of acid.

49.2.3 Add paper pulp and filter immediately, using low-ash 11-cm medium-porosity filter papers. Transfer the precipitates to the papers, and scrub the beakers thoroughly with a rubber-tipped rod. Wash the papers and precipitates alternately with 3-mL to 5-mL portions of hot HCl (1 + 19) and hot water, for a total of 6 times. Finally wash the papers twice with H₂SO₄ (1 + 49). Transfer the papers to platinum crucibles.

49.2.4 Dry the papers and heat at 600 °C until the carbon is removed. Finally ignite at 1100 °C to 1150 °C to constant mass (at least 30 min). Cool in a desiccator and weigh.

49.2.5 Add enough H₂SO₄ (1 + 1) to moisten the SiO₂, and add 3 mL to 5 mL of HF. Evaporate to dryness and then heat

at a gradually increasing rate until H_2SO_4 is removed. Ignite for 15 min at 1100 °C to 1150 °C, cool in a desiccator, and weigh.

49.2.6 Calculate the percent of silicon as follows:

$$\text{silicon, \%} = [(A - B) - (C - D)] \times 0.4674E \times 100 \quad (3)$$

A = initial mass of crucible plus impure SiO_2 when 65 mL of HClO_4 was taken, g,

B = final mass of crucible plus impurities when 65 mL of HClO_4 was taken, g,

C = initial mass of crucible plus impure SiO_2 when 15 mL of HClO_4 was taken, g,

D = final mass of crucible plus impurities when 15 mL of HClO_4 was taken, g, and

E = nominal mass (80 g) of 50 mL of HClO_4 .

49.3 *Sodium Silicate Solution*—Transfer 11.0 g of sodium silicate ($\text{Na}_2\text{SiO}_3 \cdot 9\text{H}_2\text{O}$) to a 400-mL beaker. Add 150 mL of water and dissolve the salt. Filter through a medium paper, collecting the filtrate in a 1-L volumetric flask, dilute to volume, and mix. Store in a polyethylene bottle. Use this solution to determine the suitability of the HClO_4 .

49.4 *Tartaric Acid Solution (20.6 g/L)*—Dissolve 20.6 g of tartaric acid ($\text{C}_4\text{H}_6\text{O}_6$) in water, dilute to 1 L, and filter.

49.5 *Water*—Use freshly prepared Type II water known to be free of silicon. Water distilled from glass, demineralized in columns containing silicon compounds, or stored for extended periods in glass, or combination thereof, has been known to absorb silicon.

50. Procedure

50.1 Select and weigh a sample as follows:

| Silicon, % | Sample Mass, g | Tolerance in Sample Mass, mg | Dehydrating Acid, mL | |
|--------------|----------------|------------------------------|---------------------------------|-----------------|
| | | | H_2SO_4 (1 + 4) | HClO_4 |
| 0.05 to 1.00 | 4.0 | 4 | 150 | 60 |
| 1.00 to 2.00 | 3.0 | 3 | 100 | 50 |
| 2.00 to 4.00 | 2.0 | 2 | 100 | 40 |

Transfer it to a 400-mL beaker or a 300-mL porcelain casserole.

50.2 *Sulfuric Acid Dehydration*, if tungsten is greater than 0.5 %.

50.2.1 Add amounts of HCl or HNO_3 , or mixtures and dilutions of these acids, that are sufficient to dissolve the sample; and then add the H_2SO_4 (1 + 4) as specified in 50.1, and cover. Heat until dissolution is complete. Remove and rinse the cover glass; substitute a ribbed cover glass.

50.2.2 Evaporate until salts begin to separate; at this point evaporate the solution rapidly to the first appearance of fumes and fume strongly for 2 min to 3 min. Cool sufficiently, and add 100 mL of water (40 °C to 50 °C). Stir to dissolve the salts and heat, if necessary, but do not boil. Proceed immediately as directed in 50.4.

50.3 *Perchloric Acid Dehydration*, if tungsten is less than 0.5 %, or use 50.2.

50.3.1 Add amounts of HCl or HNO_3 , or mixtures and dilutions of these acids, which are sufficient to dissolve the sample, and cover. Heat until dissolution is complete. Add HNO_3 to provide a total of 35 mL to 40 mL, followed by

HClO_4 as specified in the table in 50.1. Remove and rinse the cover glass; substitute a ribbed cover glass.

50.3.2 Evaporate the solution to fumes and heat for 15 min to 20 min at such a rate that the HClO_4 refluxes on the sides of the container. Cool sufficiently and add 100 mL of water (40 °C to 50 °C). Stir to dissolve the salts and heat to boiling. If the sample solution contains more than 100 mg of chromium, add, while stirring, 1 mL of tartaric acid solution for each 25 mg of chromium.

50.4 Add paper pulp and filter immediately, on a low-ash 11-cm medium-porosity filter paper. Collect the filtrate in a 600-mL beaker. Transfer the precipitate to the paper, and scrub the container thoroughly with a rubber-tipped rod. Wash the paper and precipitate alternately with 3-mL to 5-mL portions of hot HCl (1 + 19) and hot water until iron salts are removed but for not more than a total of ten washings. If 50.3 was followed, wash the paper twice more with H_2SO_4 (1 + 49), but do not collect these washings in the filtrate; discard the washings. Transfer the paper to a platinum crucible and reserve.

50.5 Add 15 mL of HNO_3 to the filtrate, stir, and evaporate as directed in either 50.2 or 50.3, depending upon the dehydrating acid used. Filter immediately, using a low-ash, 9-cm-100-porosity filter paper, and wash as directed in 50.4.

50.6 Transfer the paper and precipitate to the reserved platinum crucible. Dry the papers and then heat the crucible at 600 °C until the carbon is removed. Finally ignite at 1100 °C to 1150 °C to constant mass (at least 30 min). Cool in a desiccator and weigh.

50.7 Add enough H_2SO_4 (1 + 1) to moisten the impure SiO_2 , and add 3 mL to 5 mL of HF . Evaporate to dryness and then heat at a gradually increasing rate until H_2SO_4 is removed. Ignite at 1100 °C to 1150 °C for 15 min, cool in a desiccator, and weigh. If the sample contains more than 0.5 % tungsten, ignite at 750 °C instead of 1100 °C to 1150 °C after volatilization of SiO_2 .

51. Calculation

51.1 Calculate the percent of silicon as follows:

$$\text{silicon, \%} = [((A - B) \times 0.4674)/C] \times 100 \quad (4)$$

where:

A = initial mass of crucible and impure SiO_2 , g,

B = final mass of crucible and residue, g, and

C = sample used, g.

52. Precision and Bias

52.1 *Precision*—Eleven laboratories cooperated in testing this method and obtained the data summarized in Table 3. Samples with silicon compositions near the extreme limits of the scope were not available for testing.

52.2 *Bias*—The accuracy of this test method has been deemed satisfactory based upon the data for the certified reference materials in Table 3. Users are encouraged to use these or similar reference materials to verify that the test method is performing accurately in their laboratories.

TABLE 3 Statistical Information—Silicon—Gravimetric Method

| Test Material | Silicon Found, % | Repeatability (R_1 , E173) | Reproducibility (R_2 , E173) |
|---------------------------------------------------------|------------------|-------------------------------|---------------------------------|
| HClO ₄ Dehydration | | | |
| 1. Stainless steel 18Cr-9Ni (NIST 101e, 0.43 Si) | 0.428 | 0.014 | 0.021 |
| 2. Stainless steel 19Cr-14Ni-3Mo (NIST 160a, 0.605 Si) | 0.602 | 0.018 | 0.031 |
| 3. Stainless steel 18Cr-10Ni-0.4Ti (NIST 121c, 0.64 Si) | 0.642 | 0.019 | 0.031 |
| H ₂ SO ₄ Dehydration | | | |
| 1. Stainless steel 18Cr-9Ni (NIST 101e, 0.43 Si) | 0.428 | 0.021 | 0.033 |
| 2. Stainless steel 19Cr-14Ni-3Mo (NBS 160a, 0.605 Si) | 0.603 | 0.017 | 0.014 |
| 3. Stainless steel 18Cr-10Ni-0.4Ti (NIST 121c, 0.64 Si) | 0.642 | 0.026 | 0.033 |

COBALT BY THE ION-EXCHANGE— POTENTIOMETRIC TITRATION METHOD

53. Scope

53.1 This method covers the determination of cobalt from 2 % to 15 %.

54. Summary of Method

Cobalt is separated from interfering elements by selective elution from an anion-exchange column using HCl. The cobalt is oxidized to the trivalent state with ferricyanide, and the excess ferricyanide is titrated potentiometrically with cobalt solution.

55. Interferences

55.1 The elements normally present do not interfere if their compositions are under the maximum limits shown in 1.1.

56. Apparatus

56.1 *Ion-Exchange Column*, approximately 25 mm in diameter and 300 mm in length, tapered at one end, and provided with a stopcock to control the flow rate, and a second, lower stopcock to stop the flow. A Jones Reductor may be adapted to this method. A reservoir for the eluants may be added at the top of the column.

56.2 *pH meter*, with a platinum and a saturated calomel electrode.

57. Reagents

57.1 *Ammonium Citrate Solution (200 g/l)*—Dissolve 200 g of di-ammonium hydrogen citrate in water and dilute to 1 L.

57.2 *Cobalt, Standard Solution (1 mL = 1.5 mg of Co)*:

57.2.1 *Preparation*—Dry a weighing bottle in an oven at 130 °C for 1 h, cool in a desiccator, and weigh. Transfer 3.945 g of cobalt sulfate (CoSO₄)⁶ that has been heated at 550 °C for 1 h to the weighing bottle. Dry the bottle and contents at 130 °C for 1 h, cool in desiccator, stopper the bottle, and weigh. The difference in mass is the amount of CoSO₄ taken. Transfer the weighed CoSO₄ to a 400-mL beaker, rinse the weighing bottle

with water, and transfer the rinsings to the beaker. Add 150 mL of water and 20 mL of HNO₃, and heat to dissolve the salts. Cool, transfer to a 1-L volumetric flask, dilute to volume, and mix.

57.2.2 *Standardization*—Calculate the cobalt concentration as follows:

$$\text{cobalt, mg/mL} = \text{mass of CoSO}_4, \text{ g} \times 0.38026 \quad (5)$$

57.3 Ion-Exchange Resin:⁷

57.3.1 Use an anion exchange resin of the alkyl quaternary ammonium type (chloride form) consisting of spherical beads having a nominal crosslinkage of 8 %, and 0.075-mm to 0.037-mm (200-nominal to 400-nominal mesh) size. To remove those beads greater than about 180- μ m in diameter as well as the excessively fine beads, treat the resin as follows: Transfer a supply of the resin to a beaker, cover with water, and allow sufficient time (at least 30 min) for the beads to undergo maximum swelling. Place a 180- μ m (No. 80) screen, 150 mm in diameter over a 2-L beaker. Prepare a thin slurry of the resin and pour it onto the screen. Wash the fine beads through the screen, using a small stream of water. Discard the beads retained on the screen, periodically, if necessary, to avoid undue clogging of the openings. When the bulk of the collected resin has settled, decant the water and transfer approximately 100 mL of resin to a 400-mL beaker. Add 200 mL of HCl (1 + 19), stir vigorously, allow the resin to settle for 4 min to 6 min, decant 150 mL to 175 mL of the suspension, and discard. Repeat the treatment with HCl (1 + 19) twice more, and reserve the coarser resin for the column preparation.

57.3.2 *Prepare the column as follows:*

57.3.2.1 Place a 10-mm to 20-mm layer of glass wool or polyvinyl chloride plastic fiber in the bottom of the column, and add a sufficient amount of the prepared resin to fill the column to a height of approximately 140 mm. Place a 20-mm layer of glass wool or polyvinyl chloride plastic fiber at the top of the resin bed to protect it from being carried into suspension when the solutions are added. While passing a minimum of 35 mL of HCl (7 + 5) through the column, with the hydrostatic head 100 mm above the top of the resin bed, adjust the flow rate to not more than 3.0 mL per min. Drain to 10 mm to 20 mm above the top of the resin bed and then close the lower stopcock.

NOTE 6—The maximum limits of 0.125 g of cobalt and 0.500 g in the sample solution take into account the exchange capacity of the resin, the physical dimensions of the column, and the volume of eluants.

57.4 *Potassium Ferricyanide, Standard Solution (1 mL = 3.0 mg of Co)*:

57.4.1 Dissolve 16.68 g of potassium ferricyanide (K₃Fe(CN)₆) in water and dilute to 1 L. Store the solution in a dark-colored bottle. Standardize the solution each day before use as follows: Transfer from a 50-mL buret approximately 20 mL of K₃Fe(CN)₆ solution to a 400-mL beaker. Record the buret reading to the nearest 0.01 mL. Add 25 mL of water, 10 mL of ammonium citrate solution, and 25 mL of NH₄OH. Cool to 5 °C to 10 °C, and maintain this temperature during the titration. Transfer the beaker to the potentiometric titration

⁶ Cobalt sulfate (99.9 % minimum) prepared from the hexamine salt by G. Frederick Smith Chemical Co., Columbus, OH, is satisfactory for this purpose.

⁷ Available from the Dow Chemical Co., Midland, MI.

apparatus. While stirring, titrate the $K_3Fe(CN)_6$ with the cobalt solution (1 mL = 1.5 mg Co) using a 50-mL buret. Titrate at a fairly rapid rate until the end point is approached, and then add the titrant in 1-drop increments through the end point. After the addition of each increment, record the buret reading and voltage when equilibrium is reached. Estimate the buret reading at the end point to the nearest 0.01 mL by interpolation.

57.4.2 Duplicate or triplicate values should be obtained for the cobalt equivalent. The values obtained should check within 1 mg/g to 2 mg/g. Calculate the cobalt equivalent as follows:

$$\text{cobalt equivalent, mg/mL} = (A \times B)/C \quad (6)$$

where:

A = cobalt standard solution required to titrate the potassium ferricyanide solution, mL,

B = cobalt standard solution, mg/mL, and

C = potassium ferricyanide solution, mL.

58. Procedure

58.1 Transfer a 0.50-g sample, weighed to the nearest 0.1 mg, to a 150-mL beaker. Add 20 mL of a mixture of 5 parts of HCl and 1 part of HNO_3 (Note 7). Cover the beaker and digest at 60 °C to 70 °C until the sample is decomposed. Rinse and remove the cover. Place a ribbed cover glass on the beaker, and evaporate the solution nearly to dryness, but do not bake. Cool, add 20 mL of HCl (7 + 5), and digest at 60 °C to 70 °C until salts are dissolved (approximately 10 min).

NOTE 7—Other ratios and concentrations of acids, with or without the addition of 1 mL to 2 mL of HF, are used for the decomposition of special grades of alloys.

NOTE 8—Some alloys are decomposed more readily by a mixture of 5 mL of bromine, 15 mL of HCl, and 1 drop to 2 drops of HF.

58.2 Cool to room temperature and transfer the solution to the ion-exchange column. Place a beaker under the column and open the lower stopcock. When the solution reaches a level 10 mm to 20 mm above the resin bed, rinse the original beaker with 5 mL to 6 mL of HCl (7 + 5) and transfer the rinsings to the column. Repeat this at 2-min intervals until the beaker has been rinsed four times. Wash the upper part of the column with HCl (7 + 5) 2 times or 3 times and allow the level to drop to 10 mm to 20 mm above the resin bed each time. Maintain the flow rate at not more than 3.0 mL/min and add HCl (7 + 5) to the column until a total of 175 mL to 185 mL of solution (sample solution and washings) containing mainly chromium, manganese, and nickel is collected (see 58.2.1). When the solution in the column reaches a level 10 mm to 20 mm above the resin bed, discard the eluate and then use a 400-mL beaker for the collection of the cobalt eluate.

58.2.1 To prevent any loss of cobalt, the leading edge of the cobalt band must not be allowed to proceed any farther than 25 mm from the bottom of the resin. Normally, when the cobalt has reached this point in the column, the chromium, manganese, and nickel have been removed. Elution can be stopped at this point, although the total volume collected may be less than 175 mL.

58.3 Add HCl (1 + 2) to the column and collect 165 mL to 175 mL of the solution while maintaining the 3.0 mL/min flow rate. Reserve the solution. If the sample solution did not

contain more than 0.200 g of iron, substitute a 250-mL beaker and precondition the column for the next sample as follows: Drain the remaining solution in the column to 10 mm to 20 mm above the resin bed, pass 35 mL to 50 mL of HCl (7 + 5) through the column until 10 mm to 20 mm of the solution remains above the resin bed, then close the lower stopcock. If the sample solution contained more than 0.200 g of iron, or if the column is not to be used again within 3 h, discard the resin and recharge the column as directed in 57.3.

58.4 Add 30 mL of HNO_3 and 15 mL of $HClO_4$ to the solution from 58.3 and evaporate to fumes of $HClO_4$. Cool, add 25 mL to 35 mL of water, boil for 1 min to 2 min, cool, and add 10 mL of ammonium citrate solution.

58.5 Using a 50-mL buret, transfer to a 400-mL beaker a sufficient volume of $K_3Fe(CN)_6$ solution to oxidize the cobalt and to provide an excess of about 5 mL to 8 mL. Record the buret reading to the nearest 0.01 mL. Add 50 mL of NH_4OH and cool to 5 °C to 10 °C. Transfer the beaker to the potentiometric titration apparatus and maintain the 5 °C to 10 °C temperature during the titration.

58.6 While stirring, add the sample solution to the solution from 58.5, rinse the beaker with water, and add the rinsings to the solution. For a successful titration, the sample solution must be added to the excess $K_3Fe(CN)_6$ solution. Using a 50-mL buret, titrate the excess $K_3Fe(CN)_6$ with the cobalt solution (1 mL = 1.5 mg Co), at a fairly rapid rate until the end point is approached, and then add the titrant in 1-drop increments through the end point. After the addition of each increment, record the buret reading and voltage when equilibrium is reached. Estimate the buret reading at the end point to the nearest 0.01 mL by interpolation.

59. Calculation

59.1 Calculate the percentage of cobalt as follows:

$$\text{cobalt, \%} = [(A B - C D)/E] \times 100 \quad (7)$$

where:

A = standard potassium ferricyanide solution, mL,

B = cobalt equivalent of the standard potassium ferricyanide solution,

C = cobalt standard solution, mL,

D = concentration of cobalt standard solution, mg/mL, and

E = sample used, mg.

60. Precision and Bias

60.1 *Precision*—Although samples covered by this method were not available for testing, the precision data obtained for other types of alloys, using the methods indicated in Table 4 should apply.

60.2 *Bias*—The accuracy of this test method has been deemed satisfactory based upon the data for the certified reference materials in Table 4. Users are encouraged to use these or similar reference materials to verify that the test method is performing accurately in their laboratories.

COBALT BY THE NITROSO-R-SALT SPECTROPHOTOMETRIC METHOD

61. Scope

TABLE 4 Statistical Information—Cobalt—Ion Exchange—Potentiometric Titration Method

| Test Material | Cobalt Found, % | Repeatability (R_1 , E173) | Reproducibility (R_2 , E173) |
|-----------------------------------------------------------------------------|-----------------|-------------------------------|---------------------------------|
| 1. No. 1, E352 (High alloy steel, 4Mo-6W-4Cr-2V) | 1.86 | 0.05 | 0.12 |
| 2. No. 2, E352 (Tool steel, 18W-4Cr-1V) | 4.82 | 0.08 | 0.11 |
| 3. No. 3, E352 (High alloy steel, 8Co-9Mo-2W-4Cr-2V, NIST 153a, 8.47 Co) | 8.46 | 0.03 | 0.07 |
| 4. No. 4, E354 (High temperature alloy, 20Cr-13Ni-5Mo-2W-1Nb) | 11.27 | 0.06 | 0.16 |
| 5. No. 5, E354 (Ni base alloy, NIST 349, 13.95 Co) | 13.88 | 0.09 | 0.18 |

61.1 This method covers the determination of cobalt from 0.01 % to 5.0 %.

62. Summary of Method

62.1 The sample solution is treated with zinc oxide to remove iron, chromium, and vanadium. Nitroso-R-salt solution is added to a portion of the filtrate which has been buffered with sodium acetate to produce an orange-colored complex with cobalt. The addition of HNO_3 stabilizes the cobalt complex and also destroys certain interfering complexes. Spectrophotometric absorbance measurement is made at 520 nm.

63. Concentration Range

63.1 The recommended concentration range is from 0.005 mg to 0.15 mg of cobalt per 50 mL of solution, using a 1-cm cell.

NOTE 9—This test method has been written for cells having a 1-cm light path. Cells having other dimensions may be used, provided suitable adjustments can be made in the amounts of sample and reagents used.

64. Stability of Color

64.1 The color is stable for at least 3 h.

65. Interferences

65.1 Nickel, manganese, and copper form complexes with nitroso-R-salt that deplete the reagent and inhibit the formation of the colored cobalt complex. A sufficient amount of nitroso-R-salt is used to provide full color development with 0.15 mg of cobalt in the presence of 41 mg of nickel, 1.5 mg of manganese, and 5 mg of copper, or 48 mg of nickel only. Colored complexes of nickel, manganese, and copper are destroyed by treating the hot solution with HNO_3 .

66. Reagents

66.1 *Cobalt, Standard Solution (1 mL = 0.06 mg Co)*—Dry a weighing bottle and stopper in an oven at 130 °C for 1 h, cool in a desiccator, and weigh. Transfer approximately 0.789 g of

cobalt sulfate (CoSO_4)⁸ that has been heated at 550 °C for 1 h to the weighing bottle. Dry the bottle and contents at 130 °C for 1 h, cool in a desiccator, stopper the bottle, and weigh. The difference in mass is the exact amount of CoSO_4 taken. Transfer the weighed CoSO_4 to a 400-mL beaker, rinse the weighing bottle with water, and transfer the rinsings to the beaker. Add 150 mL of water and 10 mL of HCl, and heat to dissolve the salts. Cool, transfer to a 500-mL volumetric flask, dilute to volume, and mix. By means of a pipet, transfer a 50-mL aliquot of this solution to a 500-mL volumetric flask, dilute to volume, and mix. The exact concentration (in milligrams of cobalt per millilitre) of the final solution is the exact mass of CoSO_4 taken multiplied by 0.076046.

66.2 *Nitroso-R Salt Solution (7.5 g/L)*—Dissolve 1.50 g of 1-nitroso-2-naphthol-3,6-disulfonic acid disodium salt (nitroso-R salt) in about 150 mL of water, filter, and dilute to 200 mL. This solution is stable for 1 week.

66.3 *Sodium Acetate Solution (500 g/L)*—Dissolve 500 g of sodium acetate trihydrate ($\text{CH}_3\text{COONa} \cdot 3\text{H}_2\text{O}$) in about 600 mL of water, filter, and dilute to 1 L.

66.4 *Zinc Oxide Suspension (166 g/L)*—Add 10 g of finely divided zinc oxide (ZnO) to 60 mL of water and shake thoroughly. Prepare fresh daily as needed.

67. Preparation of Calibration Curve

67.1 *Calibration Solutions*—Using pipets, transfer 2 mL, 5 mL, 10 mL, 15 mL, 20 mL, and 25 mL of cobalt standard solution (1 mL = 0.06 mg Co) to six 100-mL volumetric flasks, dilute to volume, and mix. Using a pipet, transfer 10 mL of each solution to a 50-mL borosilicate glass volumetric flask. Proceed as directed in 67.3.

67.2 *Reference Solution*—Transfer 10 mL of water to a 50-mL volumetric flask. Proceed as directed in 67.3.

67.3 *Color Development*—Add 5 mL of sodium acetate solution, and mix. Using a pipet, add 10 mL of nitroso-R-salt solution, and mix. Place the flask in a boiling water bath. After 6 min to 10 min, add 5 mL of HNO_3 (1 + 2), and mix. Continue the heating for 2 min to 4 min. Cool the solution to room temperature, dilute to volume, and mix.

67.4 Spectrophotometry:

67.4.1 *Multiple-Cell Spectrophotometer*—Measure the cell correction with water using absorption cells with a 1-cm light path and using a light band centered at 520 nm. Using the test cell, take the spectrophotometric absorbance readings of the calibration solutions versus the reference solution (67.2).

67.4.2 *Single-Cell Spectrophotometer*—Transfer a suitable portion of the reference solution (67.2) to an absorption cell with a 1-cm light path and adjust the spectrophotometer to the initial setting, using a light band centered at 520 nm. While maintaining this adjustment, take the spectrophotometric absorbance readings of the calibration solutions.

67.5 *Calibration Curve*—Follow the instrument manufacturer's instructions for generating the calibration curve. Plot the net spectrophotometric absorbance readings of the calibration solutions against the milligrams of cobalt per 50 mL of

⁸ Cobalt sulfate (99.9 % minimum) prepared from the hexamine salt by G. Frederick Smith Chemical Co., Columbus, OH, has been found satisfactory for this purpose.

solution.

$$\text{cobalt, \%} = A/(B \times 10) \quad (8)$$

68. Procedure

68.1 Test Solution:

68.1.1 Select and weigh a sample as follows:

| Cobalt, % | Sample Mass, g | Tolerance in Sample Mass, mg | Volume of Sample Solution, mL |
|--------------|----------------|------------------------------|-------------------------------|
| 0.01 to 0.30 | 0.500 | 0.2 | 100 |
| 0.25 to 1.00 | 0.375 | 0.2 | 250 |
| 0.90 to 3.00 | 0.125 | 0.1 | 250 |
| 2.80 to 5.00 | 0.150 | 0.1 | 500 |

Transfer it to a 100-mL, 250-mL, or 500-mL borosilicate glass volumetric flask.

68.1.2 Add 5 mL of a mixture of 1 volume of HNO₃ and 3 volumes of HCl. Heat gently until the sample is dissolved. Boil the solution until brown fumes have been expelled. Add 50 mL to 55 mL of water and cool.

68.1.3 Add ZnO suspension in portions of about 5 mL until the iron is precipitated and a slight excess of ZnO is present. Shake thoroughly after each addition of the precipitant and avoid a large excess (Note 10). Dilute to volume, and mix. Allow the precipitate to settle; filter a portion of the solution through a dry, fine-porosity filter paper and collect it in a dry, 150-mL beaker after having discarded the first 10 mL to 20 mL. Using a pipet, transfer 10 mL of the filtrate to a 50-mL borosilicate glass volumetric flask. Proceed as directed in 68.3.

NOTE 10—When sufficient ZnO has been added, further addition of the reagent causes the brown precipitate to appear lighter in color upon thorough shaking. A sufficient excess is indicated by a slightly white and milky supernatant liquid.

68.2 Reference Solution—Transfer 10 mL of water to a 50-mL volumetric flask. Proceed as directed in 68.3.

68.3 Color Development—Proceed as directed in 67.3.

68.4 Spectrophotometry—Take the spectrophotometric absorbance reading of the test solution as directed in 67.4.

TABLE 5 Statistical Information—Cobalt—Nitroso-R-Salt—Spectrophotometric Method

| Test Material | Cobalt Found, % | Repeatability (R_{11} , E173) | Reproducibility (R_{21} , E173) |
|-----------------------------------------------------------------|-----------------|----------------------------------|------------------------------------|
| 1. No. 1, E350 (Carbon steel, NIST 19g, 0.012 Co) | 0.011 | 0.005 | 0.007 |
| 2. Stainless steel, 17Cr-9Ni (NIST 339, 0.096 Co) | 0.094 | 0.006 | 0.013 |
| 3. Stainless steel, 18Cr-9Ni-0.25Se (NIST 101e, 0.18 Co) | 0.173 | 0.011 | 0.026 |
| 4. No. 4, E354 (Ni base alloy, 17Cr-15Fe, NIST 161, 0.47 Co) | 0.468 | 0.020 | 0.028 |
| 5. Stainless steel, 15Cr-15Ni-3Mo | 1.01 | 0.04 | 0.06 |
| 6. No. 2, E352 (High alloy steel, 4Mo-6W-4Cr-2V) | 1.87 | 0.09 | 0.13 |
| 7. No. 3, E352 (High-speed tool steel, 8Mo-2W-5Cr-1V) | 4.94 | 0.08 | 0.17 |

69. Calculation

69.1 Convert the net spectrophotometric absorbance reading of the test solution to milligrams of cobalt by means of the calibration curve. Calculate the percent of cobalt as follows:

where:

A = cobalt found in 50 mL of the final test solution, mg, and

B = sample represented in 50 mL of the final test solution, g.

70. Precision and Bias⁹

70.1 Precision—Eight laboratories cooperated in testing this method and obtained the data summarized in Table 5 for materials 2, 3, and 5. Although samples covered by this method with cobalt compositions near the extreme limits of the scope were not available for testing, the precision data obtained for other types of alloys, using the methods indicated in Table 5 should apply.

70.2 Bias—The accuracy of this test method has been deemed satisfactory based upon the data for the certified reference materials in Table 5. Users are encouraged to use these or similar reference materials to verify that the test method is performing accurately in their laboratories.

TOTAL ALUMINUM BY THE 8-QUINOLINOL SPECTROPHOTOMETRIC METHOD

71. Scope

71.1 This method covers the determination of total aluminum from 0.003 % to 0.20 %.

72. Summary of Method

72.1 Interfering elements are removed by means of mercury-cathode, cupferron, and NaOH separations. Aluminum quinolate is formed and is extracted with chloroform and determined spectrophotometrically. Spectrophotometric absorbance measurement is made at 395 nm.

73. Concentration Range

73.1 The recommended concentration range is from 0.015 mg to 0.10 mg of aluminum per 25 mL of solution using a 1-cm cell.

NOTE 11—This procedure has been written for cells having a 1-cm light path. Cells having other dimensions may be used, provided suitable adjustments can be made in the amounts of sample and reagents used.

74. Stability of Color

The color is relatively stable, but readings should be made within 5 min.

75. Interferences

75.1 None of the elements usually present interfere if their compositions are under the maximum limits shown in 1.1.

76. Apparatus

76.1 Glassware—To prevent contamination of the sample, all glassware must be cleaned with hot HCl (1 + 1) before use.

⁹ Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR:E01-1084.