AMERICAN SOCIETY FOR TESTING AND MATERIALS
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Standard Test Method for Comparing EMF Stabilities of Base-Metal Thermoelements in Air Using Dual, Simultaneous, Thermal-EMF Indicators[1]

This standard is issued under the fixed designation E 710; 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.

1. Scope

1.1 This test method provides tests to compare the emf stabilities of base-metal thermoelements using dual, simultaneous, thermal-emf indicators. The tests are conducted in air at a specified constant temperature, and the emfs of the base-metal thermoelements are measured against a platinum thermoelement. Thus, the method also yields the time-dependent change of the emf of a base-metal thermoelement relative to a platinum thermoelement. The total life (time to open circuit) of the thermoelement can be determined by the method, if desired.

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:*

E 220 Test Method for Calibration of Thermocouples by Comparison Techniques[2]

E 230 Specification and Temperature-Electromotive Force (EMF) Tables for Standardized Thermocouples[2]

E 344 Terminology Relating to Thermometry and Hydrometry[2]

E 563 Practice for Preparation and Use of Freezing Point Reference Baths[3]

3. Terminology

3.1 *Definitions*—The definitions given in Terminology E 344 shall apply.

3.2 *Definition of Term Specific to This Standard:*

3.2.1 *emf stability*—The change in output expressed in millivolts (or in equivalent degrees if the thermoelectric power is known) occurring over a specified time at a specified temperature.

4. Summary of Test Method

4.1 In this test method, dual, thermal-emf indicators are used to measure simultaneously the emf E_1 of a thermocouple used to measure the test temperature and the emf E_2 of a base-metal thermoelement relative to a platinum thermoelement. The test method consists of the measurement of E_2 at specified time intervals and at a specified constant value of E_1, which corresponds to a specified, constant indicated temperature, until the required time of the test is exceeded or until an open circuit in the base-metal thermoelement results. Because all the measurements are made at the same indicated test temperature (E_2 is measured at a specified constant value of E_1), temperature corrections to E_2 are not needed.

4.2 This test method is based on Method A of Test Method E 220, where the standard thermocouple of Test Method E 220 becomes the thermocouple used to measure the test temperature of this method, and a specified constant temperature replaces the series of measured temperatures of Test Method E 220.

4.3 The accuracy of this test method depends on the emf stability of the platinum thermoelement. If there is concern that the platinum thermoelement has become unstable, the procedure described in Appendix X1 shall be performed.

5. Significance and Use

5.1 This test method is important because the accuracy of the temperature measurement is related to the emf stability of the thermoelements.

5.2 This test method is used primarily by users of thermocouples to verify that they meet the intended requirements.

5.3 This test method is useful in comparing the emf stability of two base metal thermoelements using dual thermal emf indicators.

5.4 The relative stabilities of base metal thermoelements determined by this test method are valid only under the specified test conditions and would be affected by changes in the following conditions: (1) temperature profile or gradient along the length of the thermoelements; (2) abundance, velocity and composition of the air surrounding the test pieces; (3) relative inhomogeneity of the test thermoelements; (4) purity level of the platinum thermoelement.

5.5 The test method does not include the determination of the stabilities of base metal thermoelements following changes from one constant temperature to another.

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[1] This test method is under the jurisdiction of ASTM Committee E-20 on Temperature Measurement and is the direct responsibility of Subcommittee E20.04 on Thermocouples.

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[2] *Annual Book of ASTM Standards*, Vol 14.03.

[3] Discontinued; see *1994 Annual Book of ASTM Standards*, Vol 14.03.

6. Apparatus

6.1 *Test Temperature Medium*—The test shall be conducted in an electrically heated tube furnace such as described in Sections A1.1 and A1.2 of Test Method E 220. The furnace employed shall have the following capabilities:

6.1.1 The furnace tube shall be long enough to permit a depth of immersion of the thermocouple measuring junctions that is sufficient to assure that the temperature of the measuring junctions is not affected by temperature gradients along the thermoelements.

6.1.2 Means shall be provided to control the temperature of the furnace to within ±10°C (±18°F) of the test temperature during the performance of the test.

6.2 *Thermocouple Used to Measure the Test Temperature*—A calibrated platinum 10 % rhodium/platinum (Type S), or a platinum—13% rhodium/platinum (Type R) thermocouple of 24-gage (0.511-mm) wire shall be used to measure the test temperature. The limit of error of this thermocouple shall be the same as given in Table 1 of Specification E 230 for a Type S or R thermocouple. The length of this thermocouple shall exceed that of the test specimen to prevent the transfer of heat from the measuring junction to the reference junction during testing.

6.3 *Platinum Thermoelement*—The emf of the test thermoelements shall be measured relative to a 24-gage (0.511-mm) platinum wire. This wire may be the platinum wire of the Type S or R temperature-measurement thermocouple or a second 24-gage (0.511-mm) platinum wire. The length of this wire shall exceed that of the test specimen to prevent the transfer of heat from the measuring junction to the reference junction during testing.

6.4 *Reference Junction*—The reference junction ends of the test specimens, the thermocouple used to measure the test temperature, and the platinum reference wire, if used, shall be maintained at a known constant temperature whenever emf measurements are being made. The limit of error attributable to the reference junction temperature shall be less than ±0.1°C. Ice point reference junction baths provide a relatively simple and reliable means of maintaining the reference junctions at 0°C (32°F) when proper precautions are exercised in their use. Ice point reference junction baths are described in Practice E 563, and an acceptable method for utilizing the ice point as a reference junction bath is given in A1.3 of Test Method E 220.

6.5 *Thermal EMF Indicators*—The emf measurements required by this test method shall be made using two identical emf indicators. These instruments shall have a limit of error of less than 1 µV at 1000 µV and 12 µV at 50 000 µV and a resolution of at least 1 µ V. The emf indicators may be potentiometers, digital voltmeters, or analog-to-digital converters. Paragraph 4.4 of Test Method E 220 may be consulted for further discussions of thermal emf indicators.

6.5.1 Each potentiometer is provided with a reflecting, light-beam galvanometer. The spots of light are reflected from the galvanometers onto a common scale (Fig. 1), and the galvanometers are adjusted so that both spots coincide at zero of the scale when the potentiometers are balanced.

6.5.2 The outputs of the digital voltmeters or analog-to-digital converters may be read visually, or preferably, triggered to record on paper tapes or on magnetic memories, or fed directly into computer systems for analysis.

6.6 *Connecting Wire*—Conductors from the reference junctions to the thermal-emf indicators shall be of insulated copper, covered with electrical insulation. If the test is conducted in an area of electrostatic interference, the wires should be run in a flexible, metallic sheath or in a conduit. If electromagnetic

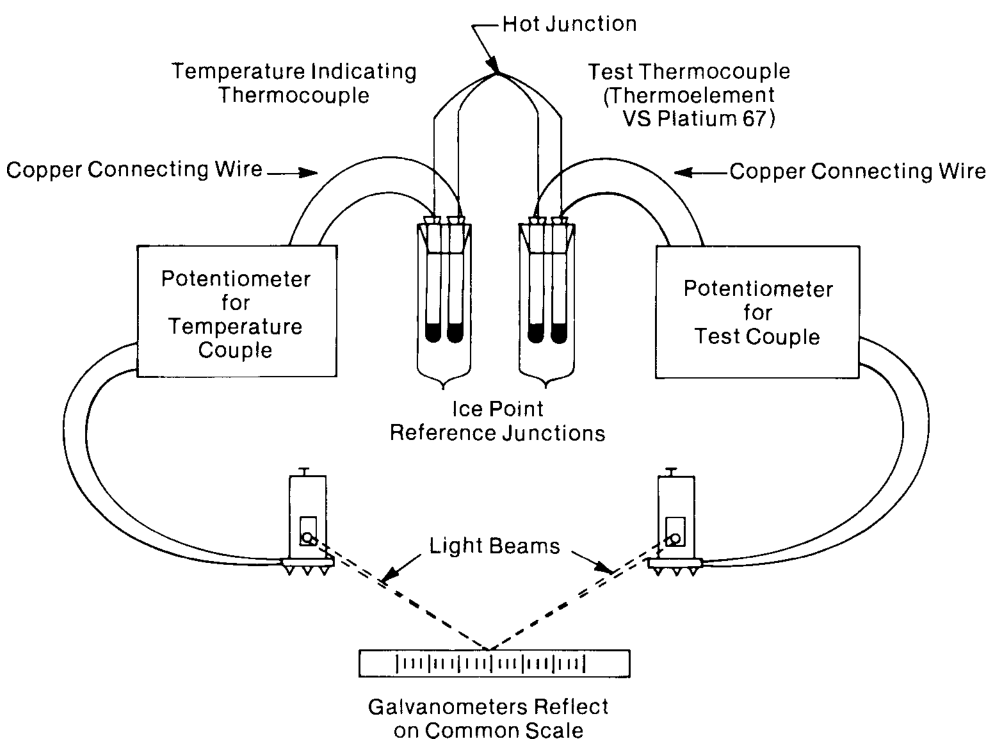

FIG. 1 Schematic Arrangement for Two-Potentiometer Methods with a Single Test Thermoelement

interference is present, the conductors should be twisted to minimize this effect.

6.7 *Selector Switches*—When more than one thermoelement is to be tested, a selector switch is introduced into the copper part of the circuit between the reference junctions and the thermal-emf indicators, as shown in Fig. 2. These switches shall comply with 4.4.4.1 of Test Method E 220.

6.8 *Thermocouple Insulation*—Ceramic tubing may be used to support and electrically insulate the test thermoelement, the thermocouple used to measure the test temperature, and the platinum reference thermoelement, if used. The ceramic tubing shall be aluminum oxide ($Al_2 O_3$) with total impurities of less than 0.5 %.

6.8.1 To avoid unnecessary mass and to minimize axial heat conduction in the region of the measuring junction, the ceramic tubing should be relatively thin-walled and should have bore diameters that provide a loose fit for the thermocouple wires to prohibit binding.

7. Test Specimens

7.1 The test specimens shall be lengths of wires, rods, ribbons, or strips of the coils or spools of the base-metal thermoelements to be evaluated. Their lengths shall be adequate to prevent the transfer of heat from the measuring junctions to the reference junctions during the period of test. The lengths shall be 0.6 to1.2 m (2 to 4 ft), depending on the length of the testing medium and the transverse sizes of the thermoelements. The specimens shall be free of kinks or other defects due to mechanical deformation, and shall be continuous without splices between the measuring and reference junctions.

8. Preparation of Thermoelements for Test

8.1 The measuring junction shall consist of a union of the test specimen thermoelements, the thermoelements of the temperature measurement thermocouple, and the platinum reference thermoelement, if used. Prepare the measuring junction by welding as described in the Related Material section of Part 44 of the 1980 Book of ASTM Standards. Except at the measuring junction, insulate the thermoelements from each other using the ceramic tubing described in 6.8.

8.2 The number of test specimens of a single test shall be as many as the volume of the testing medium permits. It is important, however, that the size of the mass of the specimens plus the insulation be controlled, so that the axial heat conduction through the specimen and insulation does not impair the isothermal conditions around the measuring junction.

8.3 Join the reference junction ends of the test specimen thermoelements, the thermoelements of the thermocouple used to measure the test temperature, and the platinum reference thermoelement to the copper connecting wires (see section6.6). The connecting wires extend from the reference junctions to the thermal-emf indicators, as shown in Figs. 1 and 2.

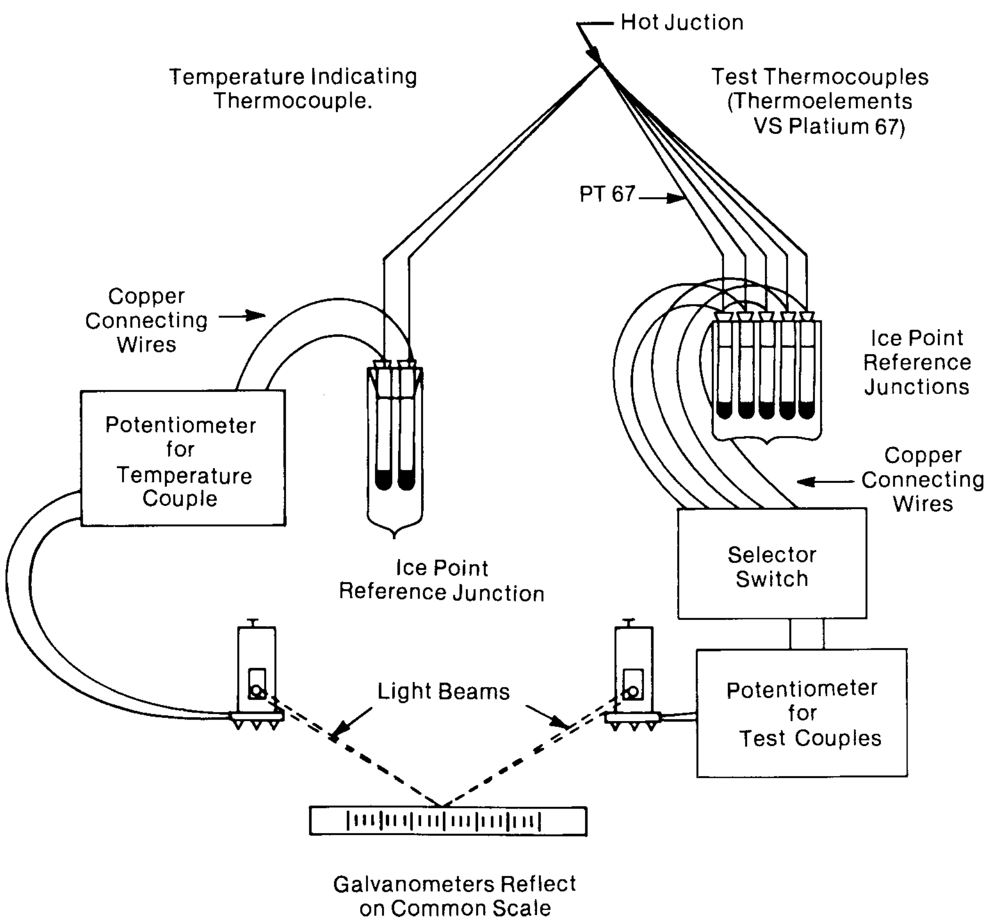

FIG. 2 Schematic Arrangement for Two-Potentiometer Methods with Multiple Test Thermoelements

9. Procedure

9.1 Heat the tube furnace to the test temperature, which is measured by an independent furnace pyrometer. A second independent furnace pyrometer, which would turn off the furnace power should an upper limit temperature be exceeded, is recommended to avoid furnace burn up in the event of the controller failure. Insert the measuring junction end of the test assembly into the furnace after the test temperature has been reached and the furnace is in thermal equilibrium. Place the measuring junction near the center of the uniform temperature zone of the furnace. Take care to ensure that the test assembly does not move within the furnace throughout the duration of the test.

9.2 Either Method A or B may be used, depending on the type of thermal emf indicators employed.

9.2.1 *Method A—Potentiometers*—Set the potentiometer connected to the thermocouple used to measure the test temperature to the emf corresponding to the desired test temperature. Adjust the furnace temperature control to achieve a temperature slightly above the test temperature. With the power reduced or off, lower the temperature through the test point at a rate not exceeding 0.5°C (1°F)/min. Occasional adjustment of the spots from the two galvanometers will be necessary to keep the null positions coincident on the common scale at all times. As the furnace cools, adjust the potentiometer connected to the test specimen continuously until its associated galvanometer spot crosses its null position, at the same time as the galvanometer spot for the thermocouple used to measure the test temperature crosses its null position. The emf of the test specimen corresponds to the test temperature. Repeat the measurement with power to the furnace and the temperature increasing at nearly the same rate achieved in the first measurement with the temperature decreasing. The average value of the two measurements, which shall not differ by more than 5 μV, is assigned as the emf of the test specimen at the test temperature. If no difference is discernible between the two measurements, one measurement shall suffice for subsequent readings. Repeat the procedure for any other test specimen.

9.2.2 *Method B—Digital Voltmeters or Analog-To-Digital Converters*—The procedure is exactly the same as that for potentiometers, that is the emf of the test specimen is read when the emf of the thermocouple used to measure the test temperature corresponds to the test temperature during the cooling and heating cycles.

9.3 Make the initial emf readings as soon as the thermocouple used to measure the test temperature reaches a steady-state value after insertion of the test assembly into the furnace. The initial emf reading shall be within the given limits of error for the thermoelements being tested, if such limits have been specified. After the initial readings are made, repeat the measurements after 4 h, then every 24 h for 4 weeks, and then twice weekly until the test is completed.

10. Calculations

10.1 This test method results in measurements of the emf versus time of each base-metal thermoelement relative to platinum. Calculate the equivalent temperature change versus time of each base-metal thermoelement as follows:

$$\Delta T_t(\theta) = \frac{E_t(\theta) - E_o(\theta)}{\alpha(\theta)} \tag{1}$$

where:

$\Delta T_t(\theta)$ = equivalent temperature change of test thermoelement at elapsed time t at test temperature θ ,
$E_t(\theta)$ = emf vs platinum of the test thermoelement after elapsed time t at test temperature θ,
$E_o(\theta)$ = initial emf vs platinum of the test thermoelement at test temperature θ, and
$\alpha(\theta)$ = thermoelectric power of the associated test thermocouple at the test temperature θ.

10.2 Calculate an approximate value of α(θ) from the tables in Specification E 230 as follows:

$$\alpha(\theta) = \frac{\epsilon(\theta + 5) - \epsilon(\theta - 5)}{10} \tag{2}$$

where:

$\epsilon(\theta + 5)$ = = emf from Specification E 230 at temperature (θ + 5)°C for the associated test thermocouple, and
$\epsilon(\theta - 5)$ = = emf from Specification E 230 at temperature (θ − 5)°C for the associated test temperature.

10.3 *Example A*—A positive Type K thermoelement being tested at 1000°C had E_o (1000) = 32.523 mV and E_t (1000) = 32.609 mV. Thus, from Eq 2:

$$\alpha(1000) = \frac{41.463 - 41.074}{10} = 0.0389 \frac{\text{mV}}{°\text{C}}$$

and from Eq 1 for the positive thermoelement,

$$[\Delta T_t(1000)]_p = \frac{32.609 - 32.523}{0.0389} = 2.2°C$$

10.4 *Example B*—A negative Type K thermoelement being tested at 1000°C had E_o (1000) = −8.745 mV and E_t (1000) = −8.768 mV. Thus, from Eq 1 for the negative thermoelement is:

$$[\Delta T_t(1000)]_N = \frac{-8.768 - (-8.745)}{0.0389} = -0.6°C$$

10.5 After the temperature change of the positive and negative thermoelements of a thermocouple have been determined, the temperature change of the associated thermocouple can be determined by:

$$[\Delta T_t(\theta)]_{T/C} = [\Delta T_t(\theta)]_P - [\Delta T_t(\theta)]_N \tag{3}$$

where:

$[\Delta T_t(\theta)]_{T/C}$ = temperature change of the associated thermocouple at time t and test temperature θ,
$[\Delta T_t(\theta)]_P$ = temperature change of the positive thermoelement at time t and test temperature θ, and
$[\Delta T_t(\theta)]_N$ = temperature change of the negative thermoelement at time t and test temperature θ.

10.6 *Example C*—The results of examples A and B can be combined to find the temperature change of the associated Type K thermocouple at t using Eq 3:

$$[\Delta T_t(1000)]_{T/C} = 2.2 - (-0.6) = 2.8°C$$

11. Precision and Bias

11.1 This test method provides a comparison of the stabilities of the emfs of base-metal thermoelements. In general, the stabilities of the emfs of base-metal thermoelements depend on their chemical and metallurgical stabilities in their environment, which for this method is air. The rates of chemical and metallurgical reactions of metals usually increase exponentially with temperature; often decrease logarithmically with time; increase logarithmically with partial pressures of reactive gases, such as oxygen and water vapor; and are affected by small variations in chemical composition of the metals. Consequentially, the results of this or any similar method must be viewed as qualitative and intended strictly for comparison of the stabilities of two particular lots of thermoelements tested under identical conditions, preferably at the same time.

11.2 No quantitative assessment of the general precision and bias of this test method is possible, nor would it be meaningful.

APPENDIX

(Nonmandatory Information)

X1. DETERMINATION OF CHANGE IN PLATINUM REFERENCE AND TYPE S THERMOCOUPLE DURING TESTING

X1.1 At the conclusion of the stability test, the platinum reference, if used, and the Type S thermocouple used to measure the test temperature may be checked for stability as follows:

X1.1.1 Remove the entire test assembly from the furnace. Weld an unused Type R or S thermocouple, made from adjacent lengths of the same lots of thermocouple wires as was assembled for the original test-temperature thermocouple, to the measuring junction of the test assembly. Place the test assembly in the furnace at the test temperature, and locate the test assembly in the same position as it was during the original tests. This should assure that the same temperature profile exists along the thermoelements as during the original tests. After temperature stability has been obtained, measure the emf deviation between the new and the original test temperature thermocouple. Assuming that the platinum reference, if used, is from the same lot as the thermocouple platinum, use its deviation in millivolts as a correction of the last reading for any of the tested thermoelements. It is important to maintain the same conditions throughout this checking procedure as prevailed for the stability test.