Manual of Petroleum Measurement Standards Chapter 7—Temperature Determination

Section 2—Dynamic Temperature Determination

SECOND EDITION, MARCH 1995

American Petroleum Institute
1220 L Street, Northwest
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Measurement Coordination

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FOREWORD

This foreword is for information and is not part of this standard. This standard discusses methods, equipment, and procedures for determining the temperature of hydrocarbon fluids under flowing conditions.

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Suggested revisions are invited and should be submitted to the Measurement Coordinator, Exploration and Production Department, American Petroleum Institute, 1220 L Street, Northwest, Washington, D.C. 20005.

CONTENTS

Chapter 7—Temperature Determination

SECTION 2—DYNAMIC TEMPERATURE DETERMINATION

7.2.0 Introduction

The purpose of this section is to describe methods and practices that may be used to obtain accurate measurement of temperature under dynamic conditions. The accurate measurement of temperature is essential to accurately determine the volume of hydrocarbon liquids corrected to standard conditions.

7.2.1 Scope And Field Of Application

This section describes methods, equipment, and procedures for the proper determination of the temperature of hydrocarbon liquids under dynamic (flowing) conditions.

The requirements of this section are based on practices for custody transfers of crude oils covered by Table 6A and products covered by Table 6B, both from API MPMS Chapter 11.1. Requirements in this document may be used for other fluids and other applications; however, other applications may require different performances and installation specifications.

7.2.2 Referenced Publications

The following documents are cited in this publication:

API

Manual of Petroleum Measurement Standards (MPMS)

Chapter 1, "Vocabulary"

Chapter 4, "Proving Systems"

Chapter 5, "Metering"

Chapter 6, "Metering Assemblies"

Chapter 7.3, "Static Temperature Determination Using Portable Electronic Thermometers"

Chapter 11.1, "Volume Correction Factors"

Chapter 12.2, "Calculation of Liquid Petroleum Quantities Using Dynamic Measurement Methods" (most recent edition)

Chapter 15, "Guidelines for Use of the International System of Units (SI) in the Petroleum and Allied Industries"

RP 500 *Recommended Practice for Classification of Locations for Electrical Installations at Petroleum Facilities*

RP 550 *Manual on Installation of Refinery Instruments and Control Systems*, Part I, Section 3, "Temperature" (out of print—to be replaced over the next several years with new recommended practices containing updated information)

ASTM[1]

E 1 *Standard Specification for ASTM Thermometers*

E 77 *Standard Test Method for Inspection and Verification of Liquid-in-glass Thermometers*

E 344 *Terminology Relating to Thermometry and Hydrometry*

NFPA[2]

70 *National Electrical Code*

7.2.3 Definitions

The following terms are defined in 7.2.3.1 through 7.2.3.9 as they apply to this standard.

7.2.3.1 *Discrimination* is the ability to sense and record the actual temperature of a liquid to the specified temperature increments.

7.2.3.2 A *temperature measurement device* consists of a sensor, transmission medium, and readout equipment in an operating configuration used to determine the temperature of a liquid for measurement purposes.

7.2.3.3 A *temperature sensor* consists of a sensing element and its housing, if any, and is defined as the part of a temperature device that is positioned in a liquid the temperature of which is being measured.

7.2.3.4 A *field standard test measure* is a portable certified vessel which is primarily used for the purpose of prover water draw calibrations (see Chapter 1, *Test Measures, field standard*).

7.2.3.5 The *Celsius scale* (°C) is a temperature scale with the ice point at zero degrees and the boiling point of water at 100 degrees. The Celsius scale (°C) is the international name for the Centigrade scale. [°C = 5/9 (°F - 32)].

7.2.3.6 The *Fahrenheit scale* is a temperature scale on which the freezing point of water is 32 degrees and the boiling point 212 degrees, both at standard pressure. [°F = 9/5°C + 32].

7.2.3.7 A *complete-immersion thermometer* is a thermometer designed to indicate temperatures correctly when the entire thermometer is exposed to the temperature being measured. No ASTM thermometer is designed to be used at complete immersion.

7.2.3.8 A *partial-immersion thermometer* is a thermometer designed to indicate temperatures correctly when the bulb and a specified part of the stem are exposed to the temperature being measure.

[1]American Society of Testing and Materials, 1916 Race Street, Philadelphia, PA 19103-1187.

[2]National Fire Protection Association, 1 Batterymarch Park, Quincy, MA 02269.

7.2.3.9 A *total-immersion thermometer* is a thermometer designed to indicate temperatures correctly when just that portion of the thermometer containing the liquid is exposed in the temperature being measured.

7.2.4 Selecting a Temperature Device

Accuracy requirements, mechanical limits, operating limits, ambient conditions, and individual preferences must be considered when selecting a temperature device to be used for temperature determination on a metered stream or meter prover. In addition, the ability of the temperature device to make a discrimination (see 7.2.3 for definition) must be evaluated (see 7.2.8).

Table 1 provides a guide to the minimum acceptable discrimination for dynamic temperature determination in custody transfer measurement of petroleum and petroleum products.

The use of a temperature device that can perform to a more stringent discrimination than that outlined in Table 1 is acceptable provided that the selection, installation, maintenance, operations, and calibration practices are adequate to ensure temperature-device performance to the level chosen and agreed to by all parties involved.

Table 1—Minimum Temperature Discrimination in Dynamic Measurement of Petroleum or Petroleum Products

Service	°F	°C
Meter Prover Calibration	0.1	0.05
Meter Proving	0.5	0.25
Measurement Tickets	1.0	0.50

7.2.5 Temperature Sensor Placement

7.2.5.1 METERS

The objective when determining the temperature of metered liquid, for use in correcting for the thermal effects on the liquid, is to obtain an accurate liquid temperature inside the meter body. Some meters make provision for the installation of a temperature sensor in the meter body; however, with many meters this type of installation is impractical as a result of meter construction or the type of temperature sensor selected for use.

Where it is impractical to mount the temperature sensor within the meter body, the sensor should be installed either immediately downstream or upstream of the meter consistent with flow conditioning requirements. Caution should be exercised if placing the temperature sensor upstream in a turbine meter run so as not to disturb the flow profile. Where several meters are manifolded in parallel, one temperature sensor located in the total liquid stream is acceptable, provided the temperature at each meter and at the temperature sensor location agree within the discrimination limits listed in Table 1. Test thermowells should be provided in each meter run to verify that the individual meter-run temperatures compare with that of the total liquid stream. This verification should be done as frequently as necessary to satisfy all parties involved.

In all cases, the temperature sensor must be positioned within the flowing liquid stream to ensure fast response and accuracy. (Refer to MPMS Chapters 5 and 6.)

7.2.5.2 PIPE PROVERS

When determining the temperature of a liquid flowing through a prover, for use in correcting for the thermal effects on the liquid and prover, the liquid temperature shall be measured as close to the prover inlet and/or as close to the prover outlet as is practical. When two measurements are taken, they shall be averaged to arrive at the prover temperature.

In many cases, the inlet and outlet liquid temperature are the same (for example, on provers with high flow rates or on well insulated provers). Under these conditions, one temperature sensor is acceptable if temperature measurements are performed periodically on the opposite end of the prover to verify that the two temperatures agree within the temperature limits given in Table 2. (Refer to MPMS Chapter 4.)

Table 2—Deviation Limits: Temperature Device Versus Temperature Standard

Service	°F	°C
Meter Prover Calibration	0.1	0.05
Meter Proving	0.2	0.10
Measurement Tickets	0.5	0.25

7.2.5.3 PROVER TANKS

When determining the temperature of a liquid contained in a tank prover, for use in correcting for the thermal effects on the liquid and tank material, the following numbers of temperature sensors are recommended for both insulated and noninsulated tanks:

a. Tanks with less than 100 gallons (less than 380 liters): 1 sensor.
b. Tanks with 100 to 500 gallons (380 to 1900 liters): 2 sensors.
c. Tanks with greater than 500 gallons (greater than 1900 liters): 3 sensors.

If one temperature sensor is used, it should be placed in the center of the tank vertical height. If two temperature sensors are used, one should be located in the upper one-third of the vertical height, and the other in the lower one-third. If three temperature sensors are used, one should be located in the upper one-third of the tank vertical height, one in the center, and one in the lower one-third of the tank vertical height. When two or more temperature sensors are used, they should be equally spaced around the tank's circumference.

Where a tank prover is insulated and/or its cycle is rapid, two temperature sensors may be sufficient in tanks over 500 gallons (1900 liters) capacity.

The temperature sensor element shall be positioned a minimum of 12 inches (0.3 meter) from the tank shell. (Refer to MPMS Chapter 4.)

7.2.5.4 FIELD STANDARD TEST MEASURE

When using field standard test measures (primarily for water draw calibrations) ranging in size up to 10 gallons (38 liters), immerse the temperature sensor into the center of the test measure through its neck. A total glass thermometer or a portable electronic immersion thermometer may be used (see MPMS Chapter 7.3). Volume readings should be taken immediately prior to immersion of a temperature sensor into the field standard test measure. Caution should be exercised to ensure that volume readings are not taken on the test measures while the temperature sensor is immersed in the water.

With larger field standard test measures, the temperature sensor is commonly held in the water stream during drainage of the field standard immediately after recording the volume reading. However, alternative methods of determining the water temperature in the field standard test measure may be required as a result of the unique characteristics of the temperature sensor or of the operating conditions.

On some large field-standard test measures, thermowells may be installed to house temperature sensors as outlined in 7.2.6. (Refer to MPMS Chapter 4.)

7.2.5.5 TEST FACILITIES

A test thermowell should be provided close to temperature sensors that are permanently mounted in piping systems, such as in meter runs or meter prover systems. Caution should be exercised to be sure the thermowell is installed to a depth which will allow the test thermometer to be inserted to approximately the same depth as the permanently installed temperature sensor (see 7.2.6.4). The test thermowell is used to make on-stream comparisons between the sensor and a thermometer certified by the National Institute of Standards and Technology (NIST) or a precision thermometer traceable to a certified thermometer (see 7.2.11).

7.2.6 Thermowell Selection

The use of thermowells may be required in dynamic temperature measurement to isolate the liquid material from the temperature sensor. Thermowells should be selected, based on the application criteria described in 7.2.6.1 through 7.2.6.4. Thermowells should be designed to resist flow-induced vibration.

7.2.6.1 PRESSURE RATING

The thermowell selected shall comply with design codes for the operating pressures and temperatures of the system.

7.2.6.2 INSTALLATION

The thermowell should be selected to conform to code and user installation practices. Thermowells are typically threaded, welded, or flange mounted. The immersion length of the thermowell should be sufficient to put the sensor element within the center one-third of the pipe's diameter or provide immersion of 12 inches (0.3 meter) unless limited by fluid velocity considerations. The thermowell should be installed in as near to a vertical position as practical to allow it to be filled with an appropriate heat conducting material (see 7.2.6.4).

7.2.6.3 MATERIAL

The thermowell should be constructed of a material that is compatible with the liquid material that the thermowell is exposed to and should provide a degree of corrosion resistance for all surfaces. Usually Type 304 or 316 stainless steel is specified.

7.2.6.4 Thermal Conductivity

In cases where the temperature sensor does not come into contact with the thermowell walls, the space between the sensor and the thermowell wall should be filled with an appropriate amount of heat-conducting material. This will improve heat conduction between the wall of the thermowell and the sensor and improve the temperature sensor's response time. Do not use a heat-conducting material that will freeze should freezing conditions exist.

Some applications may warrant special design to provide the fastest possible thermal response (for example, truck loading meters).

7.2.7 Thermowell Types

7.2.7.1 TEST WELLS

Thermowells installed for occasional use (temperature checking) are known as test wells and should be capped when not in use. Capping prevents foreign material from accumulating in the well bore. A clogged thermowell may cause measurement errors and may damage thermometers. It is recommended that thermowells be checked periodically for an accumulation of foreign material and cleaned if needed.

7.2.7.2 SENSOR WELLS

Thermowells installed for use with a permanently installed temperature sensor are known as *sensor wells* and should be matched to the temperature sensor.

7.2.8 Temperature Devices

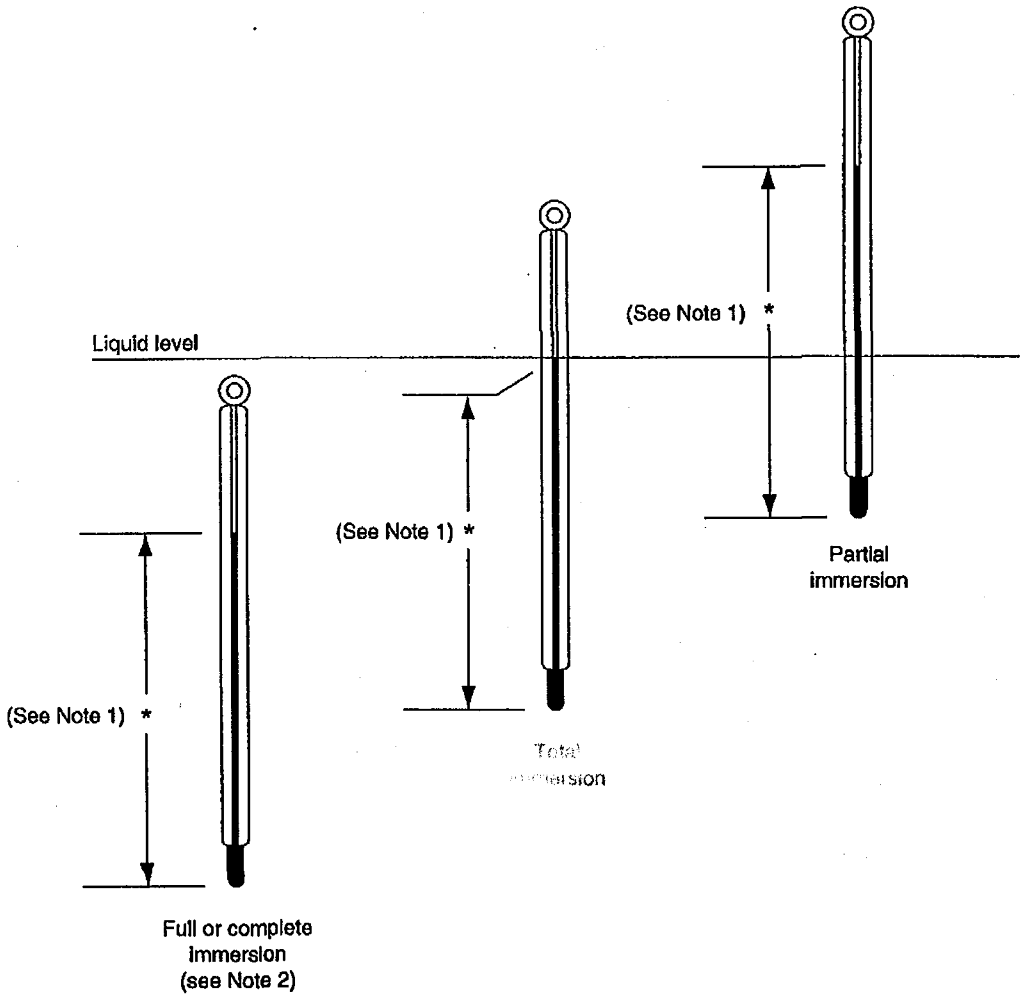
Many types of temperature devices are available. The temperature device must be selected to match application requirements. Considerations should include temperature range, scale (°F or °C), response time, accuracy, discrimination, repeatability, and ambient temperature and atmospheric conditions where the device is installed. The ultimate use of the temperature data must also be considered. (See 7.2.4)

7.2.8.1 GLASS TEST THERMOMETERS

Glass test thermometers include complete-immersion thermometers, partial-immersion thermometers, and total immersion thermometers (see 7.2.3.7–7.2.3.9 and Figure 1). (Refer to ASTM E 344.) These thermometers should conform to ASTM E 1 specifications for thermometers or to NIST specifications. Calibration must be traceable to NIST certified instruments.

CAUTION: No ASTM thermometer is designed to be used at complete immersion. See Figure 1.

ASTM E 1 glass thermometers that meet the Table 1 discrimination requirements for meter prover calibration and for checking and calibrating temperature devices used in prover calibration and meter proving are normally the total immersion type. These glass thermometers are designed and calibrated for immersion to the scale level corresponding to the temperature of the liquid. These thermometers normally have



Notes:
1. * = Liquid-In-Glass
2. No ASTM thermometer is designed to be used at complete immersion.

Figure 1—Types of Thermometers and Their Use

a scale graduation of 0.1°F (0.05°C) or 0.2°F (0.10°C) and a tolerance of 0.2°F (0.10°C) and when used in a manner other than total immersion may experience errors due to the differential expansion of the glass and liquid column in the stem.

When used for meter prover calibration and for checking and calibrating temperature devices used for meter proving, potential scale errors and stem corrections should be analyzed, and corrections should be applied when the effect is equal to or greater than the deviation limits given in Table 2. Normally, stem corrections are not significant unless the difference between the average stem temperature and liquid temperature are greater than 15°F (8.00°C). The stem correction should be considered on a case-by-case basis.

7.2.8.2 PERMANENT GLASS THERMOMETERS

Permanently installed glass thermometers should be securely mounted in a thermowell and protected from breakage by a housing. These thermometers should be calibrated and checked using test thermometers as described in 7.2.11.

7.2.8.3 FILLED BULB SYSTEMS

Filled bulb systems consist of a temperature sensor bulb connected via capillary tubing to a pressure sensitive transducer. Three types of filled systems are in common use—Class I, liquid-expansion; Class II, vapor-pressure; and Class III, gas-pressure. System selection depends on application, maintenance philosophy, and temperature range. Care must be exercised during installation and use to prevent damage (crimping or puncture) to the filled bulb system.

7.2.8.4 ELECTRONIC TEMPERATURE DEVICES

Electronic temperature devices for dynamic measurement generally use one of the following temperature sensors:

a. Thermistor.
b. Resistance temperature detector (RTD).

These devices are usually housed in metal probes that mount into thermowells. The probes are generally tip sensitive. Thus, the probes must be securely seated in the bottom of the thermowell for optimum heat transfer. Spring loaded or adjustable length probes are recommended. An appropriate heat-conducting material should be used between the temperature sensor and the thermowell wall (see 7.2.6.4). The wiring to the probe is critical because of the low signal levels of the devices. These devices should be installed as recommended by the manufacturer for best accuracy. The transducers must have special linearization circuits. Each type of probe requires its own type of circuit.

Safety must also be included in the equipment specifications. The equipment and transducers should be installed in accordance with all API (refer to API RP 500 and RP 550) and the NFPA National Electrical Code (NEC) hazardous area specifications.

7.2.8.4.1 Thermistors

A thermistor is a semiconductor manufactured from various metallic oxides to provide an element with electrical resistance that is a function of temperature.

7.2.8.4.2 Resistance Temperature Detectors

A resistance temperature detector (RTD) is a sensing element with an electrical resistance that is a function of temperature. The resistance temperature detector is usually a small coil of platinum wire and when used with appropriate circuits will provide temperature signals to readouts and other equipment.

7.2.9 Temperature Determination Procedures

A temperature sensor selected to meet the requirements of 7.2.4 must be positioned in the flowing liquid and allowed to remain there until the temperature of the liquid and the sensor have stabilized before any reading is recorded.

7.2.9.1 TEMPERATURE REQUIREMENTS FOR PROVER CALIBRATION

Prover calibration procedures require temperature discrimination to 0.1°F (0.05°C). Thermometers graduated to 0.2°F (0.1°C) and read to 0.1°F (0.05°C) are normally used to assure reliability and accuracy. All temperature devices, regardless of type, should be inspected and checked for accuracy prior to their use.

Pipe prover calibration calculations require prover temperature and withdrawal (water in test measure) temperatures read to 0.1°F (0.05°C).

Tank prover calibration by water draw requires prover temperatures taken as specified in 7.2.5.3, and the withdrawal temperatures (water in test measures) taken as specified in 7.2.5.4 and read to 0.1°F (0.05°C).

Master meter calibration of a pipe prover requires that the master meter be proved against a master prover. If a master tank prover is used, the temperatures taken as specified in 7.2.5.3 are to be read to 0.1°F (0.05°C). If a master pipe prover is used, the prover liquid temperature is read to 0.1°F (0.05°C). In either case, the liquid temperature at the master meter is to be read to 0.1°F (0.05°C). The subsequent calibration of the pipe prover requires prover and master meter liquid temperatures read to 0.1°F (0.05°C).

7.2.9.2 TEMPERATURE REQUIREMENTS FOR METER PROVING

Meter proving procedures require that all temperatures be read to a minimum discrimination level of the nearest 0.5°F (0.25°C), and to higher levels of discrimination (for example, 0.1°F) if practical. Tank prover techniques require that temperatures taken as specified in 7.2.5.3 be read to 0.5°F

(0.25°C), while pipe prover techniques require prover and meter temperatures read to 0.5°F (0.25°C).

The above reading, or the average of a series of these readings, are rounded to a minimum discrimination level of the nearest 0.5°F (0.25°C), and to higher levels of discrimination (for example, 0.1°F) if practical before being used in calculations discussed in MPMS Chapter 12.2.

7.2.9.3 TEMPERATURE REQUIREMENTS FOR MEASUREMENT TICKETS

Measurement ticket temperature requirements are for temperature discrimination to the nearest 1.0°F (0.5°C). Various methods of applying temperature compensation are available to meet the requirements of MPMS Chapter 12.2.

7.2.10 Verification Procedures

Operational procedures for individual companies, for most petroleum measurement techniques include routine steps for verifying accuracy and performance of equipment.

Just as flow meters are proved against a reference standard, temperature devices must be verified frequently as part of normal operations to assure proper performance. Facilities should be provided to frequently and routinely verify the operational unit. Two or more operational devices can be compared as a check, but a NIST certified thermometer or a thermometer traceable to a NIST certified thermometer should be used to verify the operational unit. Differences in the readings may indicate the need for calibration or replacement of the device as prescribed in 7.2.11.

Temperature devices may require checks or calibrations based on the use of a temperature controlled source as reference. The use of such a source is often impractical in a field environment and is better accomplished in a shop or test facility in accordance with manufacturer's recommendations (refer to ASTM E-77).

7.2.11 Check And Calibration Procedures

Temperature devices must be checked against a NIST certified thermometer or a thermometer traceable to a certified thermometer to ensure accuracy.

Temperature devices that are used for intermittent service, such as prover calibration or off-line meter proving, should be checked prior to each use against a NIST certified thermometer or a thermometer traceable to a certified thermometer.

Temperature devices that are in continuous service shall be periodically, and while on line, compared with temperature devices in the system and with a test thermometer (see 7.2.5.5). The check period will vary depending on system volume, attended or unattended operation, and other factors. Quarterly comparison checks are recommended as a minimum. Temperature devices installed in systems that are in periodic service should be checked on a frequency consistent with these continuous service guidelines.

The recommended maximum deviation limits between the operating device and the certified thermometer are shown in Table 2. Deviations greater than these limits indicate that corrective actions are required in the form of calibration or replacement of the inaccurate device. These limits may be subject to other guidelines existing in agreements, contracts, regulations, or company policy. Table 2 is provided as a reference for limits considered acceptable for dynamic temperature determinations in custody transfer measurement of petroleum and petroleum products.

Inspect all thermometers to ensure that the medium columns are continuous (no separations) and that the thermometer is clean and free of insulating coatings. If the scale graduations are not legible, replace the device.

7.2.11.1 CHECK PROCEDURES

The check procedure shall consist of at least one comparison at a temperature within the operating range, between the temperature device and the test thermometer. If the deviation limits of Table 2 are exceeded, then the temperature device shall be calibrated or replaced.

The check is accomplished by placing the operational temperature device and the test thermometer into a source of uniform temperature. This may be done by using a temperature-controlled source, but should preferably be performed in the operating pipe or vessel, providing that suitable facilities exist for the simultaneous registration of temperature by the operational device and the calibration instrument. The check point positions should be adjacent to one another and the temperature must be allowed to stabilize before recording the comparative readings.

7.2.11.2 CALIBRATION PROCEDURES

Calibration of an existing or new temperature device should consist of temperature comparisons, within the tolerances of Table 2 at a minimum of three temperatures on uniform intervals over the operating range of the device.

The calibration can be accomplished similar to the check procedure, except that a temperature controlled source will facilitate the three point test. The certification calibration corrections must be applied to the test thermometer readings. The certified test thermometer shall be graduated with scale marks at intervals not greater than twice the discrimination requirement of the temperature measuring instrument. In the case of instruments having a discrimination requirement larger than 0.1°F (0.05°C), the test thermometer should preferably have scale marks at intervals of, or less than, the discrimination, though not necessarily less than 0.2°F (0.1°C).

Calibration of electronic temperature devices should be performed in accordance with the recommended calibration procedure provided by the manufacturer.

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