Temperature Measurement

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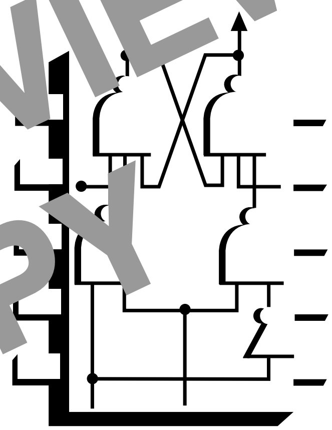
TEMPERATURE MEASUREMENT

Lesson One

Temperature Measurement Principles and Indicators



TPC Training Systems

27701

Lesson

1 Temperature Measurement Principles and Indicators

TOPICS

Temperature
Heat
Specific Heat
Changing Physical State
Fahrenheit and Celsius Temperature Scales
Rankine and Kelvin Scales
Calibration of Temperature Scales
Primary and Secondary Standards
Industrial Uses of Temperature Measurements
Temperature-Measuring Instruments
Color Change as a Temperature Indicator
Melting Point as a Temperature Indicator

OBJECTIVES

After studying this Lesson, you should be able to...

- Define thermal energy and explain the relationships among thermal energy, heat, and temperature in a substance.
- Correlate changes in temperature with changes in a substance's physical state.
- Compare four temperature scales, and convert temperature readings from one scale to another.
- Explain how primary and secondary temperature calibration standards are used.
- Describe various temperature-measuring devices and contrast thermometers and pyrometers.

KEY TECHNICAL TERMS

Temperature 1.01 an indication of a body's ability to transfer heat to its surroundings, as measured on a scale

Heat 1.03 energy that flows to a body and causes it to increase its temperature or undergo other changes

British thermal unit (Btu) 1.04 the amount of thermal energy required to raise the temperature of 1 lb of water 1°F at atmospheric pressure

Calorie 1.05 the amount of heat needed to raise the temperature of one gram of water 1°C (starting at 15°C) at atmospheric pressure; one calorie equals 4.187 joules

Specific heat 1.07 the ratio of heat needed to raise the temperature of a body 1°F to that needed to raise the temperature of an equal mass of water 1°F

Absolute zero 1.15 the hypothetical temperature at which a substance would have no thermal energy

Triple point 1.20 the temperature at which a substance exists as a solid, a gas, and a liquid

Temperature is certainly one of the most widely measured and controlled industrial variables. Temperature itself is a measure of the level of thermal energy. The actual temperature is a number that lets you know how hot or cold a substance is. A particular temperature can be critical, whether you are regulating a semiconductor clean-room environment, controlling the temperature of the uranium core of a nuclear power plant, manufacturing processed foods, preparing intravenous solutions, or heat-treating steel.

These and other applications require sensitivity, quick response, ruggedness, and accuracy from all components of the temperature-measuring system. This Lesson discusses techniques for measuring temperature and explains changes in physical state due to temperature changes.

You will read about the four main temperature scales in use today—Celsius, Fahrenheit, Kelvin, and Rankine—and will learn how to convert from one scale to another. You will also learn how temperature-measuring instruments are standardized for industrial use. In addition, this Lesson introduces the main kinds of thermometers and pyrometers you will read about in detail in later Lessons.

Temperature

1.01 If two bodies are placed in contact, the one that has a higher temperature transfers heat to the other. The word *temperature* indicates the hotness or coldness of a body as determined by the body's ability to transfer heat to its surroundings. To have meaning, temperature must be measured on a definite scale. Hotness and coldness are then expressed in the units (degrees) of that scale.

1.02 Temperature scales are based on fixed reference points—the boiling and freezing points of water, for example. Four temperature scales are widely used today. An understanding of the basic facts about heat and its effects and how the scales were derived will help you understand how to use the scales.

Heat

1.03 Energy that flows to a body and causes it to increase its temperature, melt, boil, expand, or undergo other changes, is called *heat*. As heat flows to a body, the body's thermal energy increases. That, together with pressure, determines the body's temperature and physical state. For example, assume that heat is added to water in a container at atmospheric pressure, increasing the water's thermal energy. The temperature of the water increases until it boils and evaporates to steam, thus changing state. If the thermal energy decreases, the temperature decreases. If enough thermal energy is removed, the water changes state again, becoming a solid (ice).

1.04 In the United States, the traditional unit for measuring heat is the *Btu* (British thermal unit). A Btu is defined as the amount of thermal energy required to raise the temperature of 1 lb of water 1°F at atmospheric pressure. The metric equivalent is the *joule* (J). One Btu equals 1055 J.

1.05 A *calorie* is the amount of heat needed to raise the temperature of one gram of water 1°C (starting at 15°C) at atmospheric pressure. One calorie equals 4.184 joules. Adding a fixed quantity of heat raises the temperature of a body of material (1 lb or 1 gram of water, for example) by a fixed amount, as long as there is no change in state. In general, adding heat to a body increases its thermal energy, resulting in an increase in its temperature.

1.06 An equal increase in temperature for two substances does not necessarily indicate an equal change in thermal energy. The nature of the body or material is important also. Different substances require different quantities of heat to change temperature. For example, a pound of water requires 1 Btu to change 1°F in temperature, but a pound of aluminum requires only 0.22 Btu to change 1°F. Although the temperatures of the water and the aluminum change by the same amount, the thermal energy required for each change differs.

Specific Heat

1.07 *Specific heat* is defined as the ratio of heat required to raise the temperature of a certain weight of a substance 1°F to that required to raise the temperature of the same weight of water 1°F (measured under constant pressure). The specific heat of aluminum is approximately 0.22, for example. Every substance has a specific heat that differs from that of every other substance. Thus, at the same temperature, different substances contain different amounts of thermal energy.

Changing Physical State

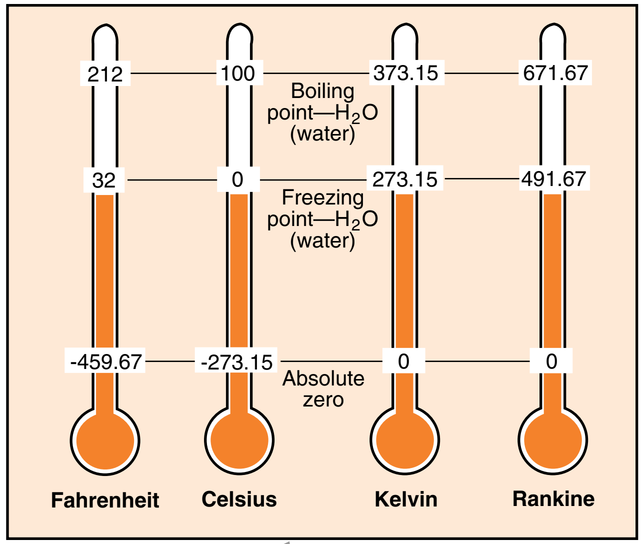
1.08 Ordinarily, substances exist in one of three physical states—solid, liquid, or gas. At high temperatures (associated with high thermal energy), all materials exist in a gaseous state. As temperatures decrease, the level of thermal energy decreases and materials generally change physical state and become liquid. For example, water is in a gaseous state (steam) at temperatures above 212°F (100°C) and at standard atmospheric pressure (14.7 psia). At 212°F (100°C), the steam condenses and changes state from gas to liquid. At 32°F (0°C), the liquid changes physical state again and becomes a solid (ice).

1.09 The change of physical state from liquid to gas is called *vaporization*, and the gas-to-liquid change is called *condensation*. The addition or removal of heat accompanies these changes. For example, 960 Btu are needed to vaporize 1 lb of water at 212°F to 1 lb of steam at 212°F. Conversely, the condensation of 1 lb of steam at 212°F to 1 lb of water at 212°F requires the removal of 960 Btu of heat. The amount of heat necessary to change a substance at the boiling point from liquid to gas is called the *latent heat of vaporization*. The addition of this heat does not raise the temperature of the substance.

Table 1-1. Latent heats of several common substances

Substance	Melting temp. (°C)	Latent heat of fusion (J/g)	Boiling temp. (°C)	Latent heat of vaporization (J/g)
Water	0	332.3	100	2231.0
Gold	1064	67.4	2660	1768.6
Mercury	-39	11.4	357	292.8
Aluminum	660	395.1	2450	10,876.3
Lead	327	26.3	1750	987.7

Fig. 1-1. Ranges of four temperature scales



1.10 The change of physical state from liquid to solid is called *fusion* (or freezing), and the change from solid to liquid is called *melting*. Again, the addition or removal of heat accompanies the change of state. To change 1 lb of water from a liquid at 32°F to a solid (ice) at 32°F, you must remove 143 Btu. Conversely, to melt 1 lb of ice at 32°F you must add 143 Btu. The heat is added to the ice at the melting point. The frozen water absorbs it, even though its temperature remains the same throughout the melting process. The amount of heat that must be removed as a substance changes from a liquid to a solid, or added as the solid becomes liquid, is referred to as the *latent heat of fusion*.

1.11 Values for the heat of fusion and the heat of vaporization vary for different substances. So do the temperatures at which the solid-to-liquid and liquid-to- gas transitions occur. Table 1-1 lists the latent heats for several common substances. The temperatures at which these transitions occur for a particular substance are called *fixed points*. For example, at standard atmospheric pressure, oxygen boils at -182.96°C and sulfur boils at 444.67°C. As you will see, fixed points are very important in the derivation of temperature scales.

Fahrenheit and Celsius Temperature Scales

1.12 Two practical temperature scales are in general use today—the *Fahrenheit* and the *Celsius* (centigrade) scales. These scales are based on the fact that the melting point of ice and the boiling point of water occur at certain fixed temperatures at standard atmospheric pressure (14.7 psi, 760 mm Hg, or 10.13 x 10^4 Pascals, or Pa).

1.13 On the Fahrenheit temperature scale, the melting point of ice is designated as 32 and the boiling point as 212. On the Celsius scale, they are assigned the values 0 and 100. Between the two fixed points, the Fahrenheit scale is divided into 180 equal divisions, and the Celsius scale is divided into 100 equal divisions.

1.14 Because both scales are linear, you can easily convert from a reading on one scale to the equivalent reading on the other scale by using the following equations:

$$°C = \frac{°F - 32}{1.8}$$

$$°F = (1.8 \times °C) + 32$$

For example, suppose that you want to convert a temperature of 50°C to its corresponding Fahrenheit temperature:

$$°F = (1.8 \times 50) + 32 = 122$$

Now suppose you want to convert a temperature of 104°F to Celsius. This temperature is:

$$°C = \frac{104 - 32}{1.8} = 40$$

Rankine and Kelvin Scales

1.15 The concept of *absolute zero* is important in many engineering calculations and in scientific research. Absolute zero is the hypothetical temperature at which a substance would have no thermal energy. It is at this temperature that all atomic and/or molecular motion theoretically ceases. It corresponds to -273.15°C or -459.67°F. The *Rankine* and *Kelvin* temperature scales are called *absolute scales* because they use absolute zero as one of their reference points.

1.16 Like the Fahrenheit scale, the Rankine scale has 180 equal degrees between the freezing and boiling points of water. You can convert from Fahrenheit (°F) to Rankine (°R) by using the equation:

$$°R = °F + 459.67$$

For example, suppose you want to convert a temperature of 50°F. On the Rankine scale, this temperature is:

$$50 + 459.67 = 509.67°R$$

1.17 The Kelvin scale, like the Celsius scale, has 100 equal units between the freezing and boiling points of water. You can convert from Celsius (°C) to Kelvin (K) by using the equation:

$$K = °C + 273.15.$$

For example, suppose you measure a temperature of 10°C. On the Kelvin scale, this temperature is:

$$10 + 273.15 = 283.15 \text{ K}.$$

The *kelvin*, expressed as K, is the unit of thermodynamic temperature and is used without the degree symbol (°).

1.18 The four temperature scales just discussed are all used in industry, and you can easily convert from one to another by using one of the four equations given. Because they are based on absolute zero, the Rankine and Kelvin scales are used primarily for engineering and scientific work. Figure 1-1 compares the four scales.

Calibration of Temperature Scales

1.19 In order to ensure accurate, uniform temperature measurements, an International Practical Temperature Scale (IPTS) has been adopted by all industrialized nations. The IPTS performs two functions necessary to ensure the standardization of temperature measurements.

- It defines eleven primary and five secondary fixed temperature points for calibrating temperature-measuring instruments.
- It specifies methods for determining temperatures between these points.

1.20 The fixed points are the boiling point, freezing point, and triple point temperatures of various substances. They are listed in Table 1-2 on the following page. The *boiling point* is the temperature

Table 1-2. Primary and secondary fixed temperature points (IPTS)

Substance	Boiling point (°C)	Freezing point (°C)	Triple point (°C)	Secondary fixed point (°C)
Hydrogen (4.834 psia)	-256.11		-259.34	
Hydrogen	-252.87			
Neon	-246.05			
Oxygen	-182.96		-218.79	
Water	+100.00		+0.01	
Zinc		+419.58		
Silver		+961.93		
Gold		+1064.43		
Tin				+231.97 (FP)
Lead				+327.50 (FP)
Sulfur				+444.67 (BP)
Antimony				+630.74 (FP)
Aluminum				+660.37 (FP)

at which the substance changes its physical state from liquid to gas. The *freezing point* is the temperature at which the substance changes its physical state from liquid to solid. The gaseous, liquid, and solid states of a substance exist simultaneously at the *triple point*.

1.21 Because these temperatures change with pressure for a particular substance, almost all points shown are at standard atmospheric pressure (14.7 psia or 760 mm Hg). The two exceptions are the boiling point of hydrogen (4.834 psia) and the triple point of water (0.0886 psia or 4.58 mm Hg).

1.22 In addition to establishing the fixed points shown in Table 1-2, the IPTS specified the methods used for determining temperatures between these points.

- A platinum resistance thermometer is used for temperatures between -259.34°C (triple point of hydrogen) and 630.74°C (the freezing point of antimony).
- For temperatures ranging from 630.74°C to 1064.43°C (the freezing point of gold), a platinum 10% rhodium-platinum thermocouple is used.
- For temperatures above 1064.43°C, an optical pyrometer is used.

The Programmed Exercises on the following page will tell you how well you understand the material you have just read. Before starting the exercises, remove the Reveal Key from the back of the book. Read the instructions printed on the Reveal Key. Follow these instructions as you work through the Programmed Exercises.

1-1. The hotness or coldness of a body is indicated by its ________, while ________ is its amount of thermal energy.	1-1. TEMPERATURE; HEAT Ref: 1.01, 1.03
1-2. In the U.S., the traditional unit of measure for heat is the ________.	1-2. BTU Ref: 1.04
1-3. At the same temperature, different substances contain different amounts of thermal energy. True or false?	1-3. TRUE Ref: 1.06
1-4. The two practical temperature scales in general use are the ________ and ________ scales.	1-4. FAHRENHEIT; CELSIUS Ref: 1.12
1-5. The temperature at which a substance theoretically would have no thermal energy is referred to as ________.	1-5. ABSOLUTE ZERO Ref: 1.15
1-6. The ________ and ________ temperature scales divide the interval between the freezing point and boiling point of water into 100 equal degrees.	1-6. CELSIUS; KELVIN Ref: 1.17
1-7. The ________ for temperature calibration are the freezing point, boiling point, and triple point of certain substances.	1-7. FIXED POINTS Ref: 1.20
1-8. The IPTS determines temperatures above 1064.43°C by means of a(n) ________.	1-8. OPTICAL PYROMETER Ref: 1.22

Primary and Secondary Standards

1.23 The platinum resistance thermometer, platinum rhodium-platinum thermocouple, and infrared optical pyrometer are the standard industrial temperature-measuring instruments. The purchase and maintenance of equipment necessary to calibrate these three standard temperature instruments requires a considerable investment in people, time, and equipment. For this reason, many industrial laboratories maintain only the three standard instruments, periodically submitting them to the National Institute of Standards and Technology (NIST) for calibration. (The NIST used to be called the National Bureau of Standards, or NBS.)

1.24 The NIST certifies the instruments' accuracy by comparing them to the fixed points on the NIST equipment and correcting the instrument if needed. Instruments calibrated by the NIST become *primary standard* instruments. They may then be used to calibrate other instruments—thermocouples and liquid-in-glass thermometers, for example.

1.25 Industrial plants and laboratories may choose to maintain quality base-metal thermocouples and liquid-in-glass thermometers for temperature standards instead of the expensive primary standard instruments. Quality instruments of this kind, called *secondary standards*, can be calibrated by the NIST. Although not capable of the same accuracy as primary standards, these instruments can be used to calibrate in-plant instrumentation.

1.26 Some calibration laboratories require a precision of only ±0.1 to ±0.01°C over a temperature range of approximately -200 to 600°C. In these cases, a liquid-in-glass thermometer provides satisfactory results. A liquid comparison bath is used to compare the plant's working thermometers with the standard thermometer. The comparison bath is equipped with heating and cooling coils that change the temperature of the liquid in the bath. The comparison bath also includes a stirrer that mixes the liquid so that both thermometers are in contact with liquid of the same temperature.

1.27 You then can calibrate the working thermometer by comparing its reading with the reading of the standard instrument at various bath temperatures. The next step is to make appropriate corrections to the working thermometer's output if necessary (or possible). If the instrument is badly in error, however, it must be discarded.

Industrial Uses of Temperature Measurements

1.28 As you probably are aware, temperature is certainly one of the most frequently measured and controlled variables in industrial processes. In general, temperature measurements are used for one or more of the following purposes:

- to provide continuous input to an automatic or human controller
- to aid operator monitoring of process variables or equipment
- to record information for trend indication or historical records
- to make infrequent spot checks of temperatures during processing.

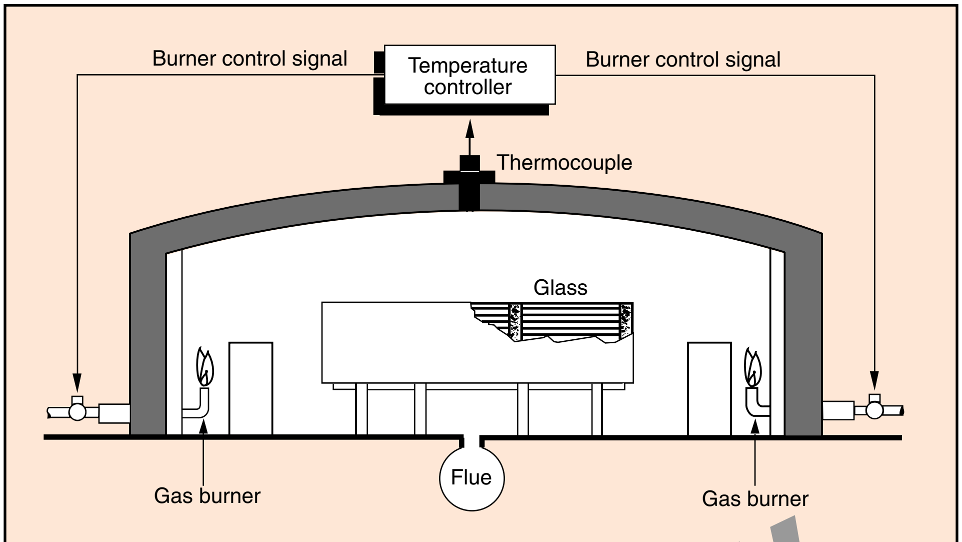
1.29 The requirements placed on temperature measurement and control systems may vary, depending on the use made of a measurement. In a nuclear steam/electric power plant, for example, the temperatures of cooling water entering and leaving the reactor core must be closely measured and controlled, because they are key indicators of the plant's performance. These measurements must:

- be highly accurate
- quickly follow temperature changes
- be very reliable, because their failure could cause plant shutdown or even catastrophe.

The measurements are used for the automatic control of the nuclear steam/electric power plant. Therefore, they are recorded and continually monitored by an operator.

1.30 Most industries can provide many examples of temperature measurement and control. In the glass-annealing process, for instance, the glass must be heated and cooled along a desired temperature/time curve. The annealing process softens the glass and makes it less brittle.

Fig. 1-2. Temperature controls for glass-annealing furnace



1.31 Figure 1-2 shows a simplified temperature control scheme for a glass kiln. Heat for the kiln is provided by gas burners. Temperature inside the kiln is sensed by the thermocouple and sent to the temperature controller. The controller compares the meas-ured temperature with the desired temperature and adjusts the gas burners to increase or decrease heat.

1.32 Figure 1-3 shows the representative temperature/time relationship for glass annealing. Depending on the properties of the glass and the desired product, the total cycle may take minutes or hours. During that time, the required annealing temperature may vary over a range of several hundred degrees Celsius (450 to 700°C is typical).

1.33 In applications where temperature must change quickly, as in the annealing of very delicate glassware, continuous automatic temperature control is essential. In the firing of other products (vitrified clay pipe, for example), the process requires one to two days and is not very critical. In this case, an operator can provide adequate control by periodically checking the process.

1.34 The food industry provides many examples of the need for temperature monitoring and control. Figure 1-4 on the following page illustrates a system for monitoring and controlling the temperature and level of hot water in a tank—a necessity for many food processes. Water temperature is monitored by a thermocouple that sends a proportional temperature signal to both a display device and a temperature controller. The display device can be mounted locally or in a central control room. The temperature controller compares water temperature with the desired value. It then opens and closes the steam valve to increase or decrease water temperature.

1.35 The level of water in the tank is determined from the pressure difference between the high and low taps in the tank. The amount of difference is sent by the level transmitter to a level display, which could be mounted locally, and to the level controller in a central control room. The level control sets the water supply valve to maintain hot water at the desired level.

Fig. 1-3. Temperature/time relationship for glass annealing

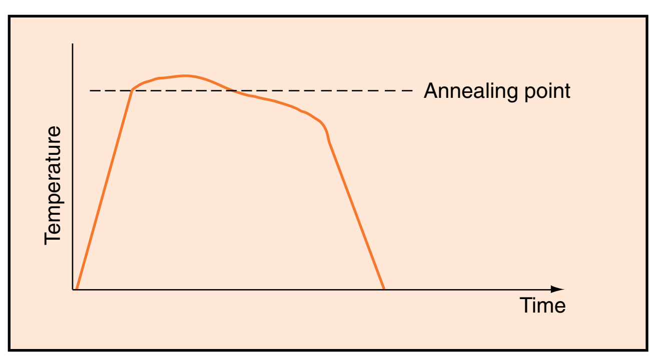
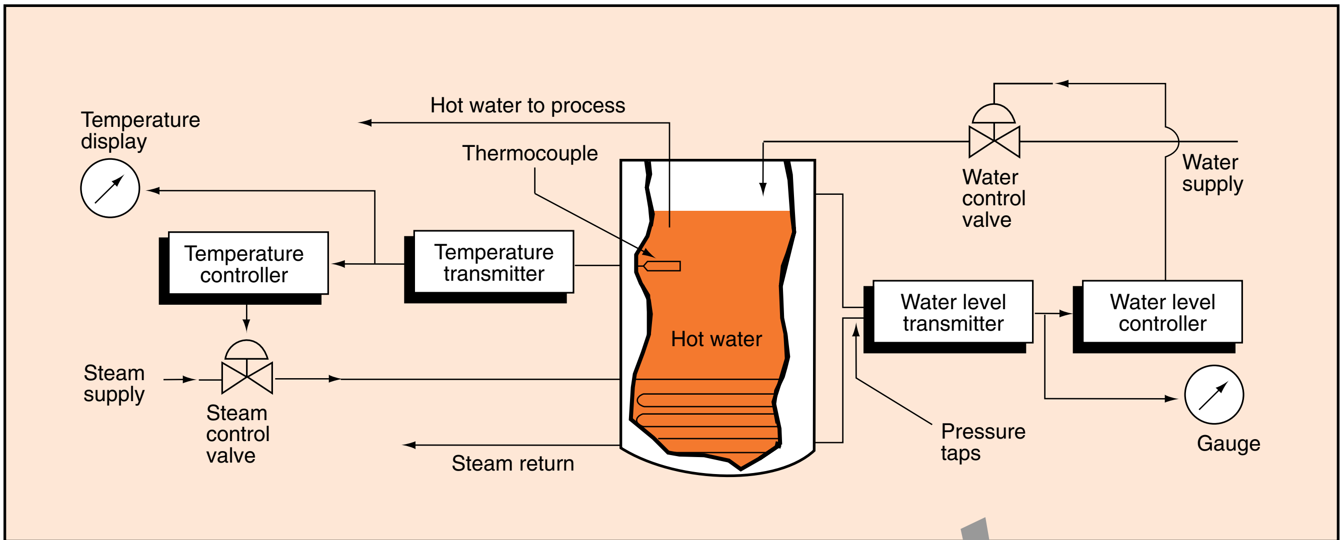


Fig. 1-4. Sensor/controller relationship in hot water supply system



Temperature-Measuring Instruments

1.36 Instruments for measuring temperature may be divided into two general groups:

- *thermometers*—instruments inserted into or attached to the substance or body that is to be measured
- *pyrometers*—instruments located at a distance from the substance or body that is to be measured.

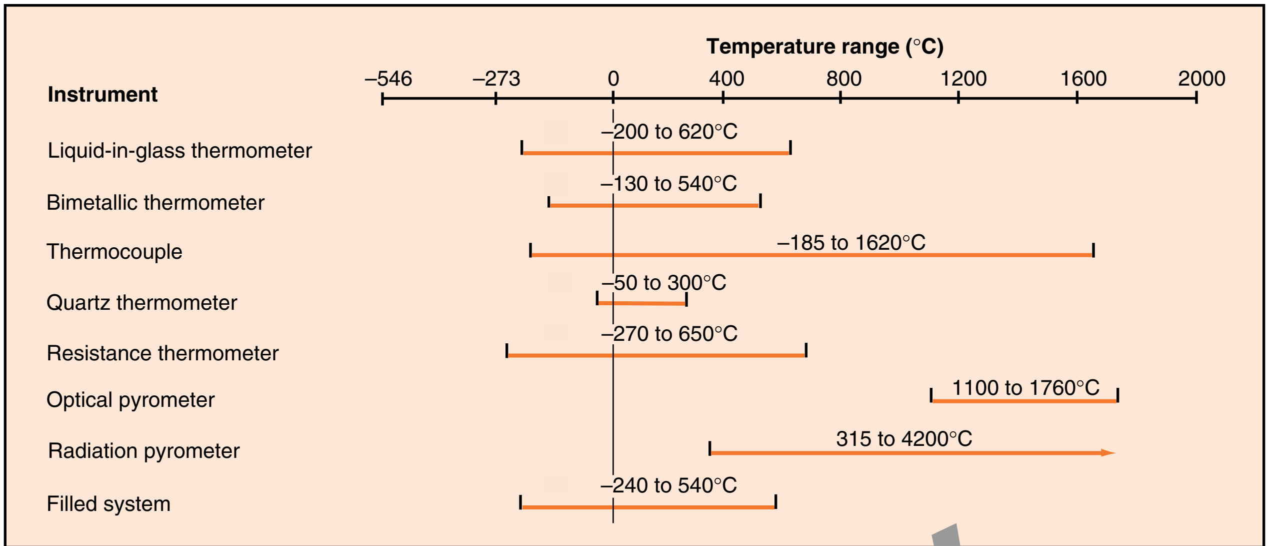
Thermometers depend on *heat conduction* or *convection* from the body to the instrument. Pyrometers measure *radiated heat* and infer temperature from that measurement.

1.37 Temperature is indicated by the changes it causes in certain instruments. The following are kinds of changes and examples of instruments based on these changes:

- changes in density (liquid-in-glass thermometers)
- changes in length or volume (bimetallic elements, filled systems)
- voltage generated at the junction of two dissimilar metals (thermocouples)
- resonant frequency of crystals (quartz thermometers)
- changes in electrical resistance (resistance thermometers—sometimes called resistance pyrometers—and thermistors).

Fig. 1-5. Sensor head of optical pyrometer

Fig. 1-6. Effective ranges of eight temperature-measuring instruments



1.38 Pyrometers use still another technique, sensing radiation and relating it to temperature. The two kinds of pyrometers are the following:

- *radiation pyrometer*, which senses the intensity of radiation emitted
- *optical pyrometer*, shown in Fig. 1-5, which senses the brightness of radiation emitted.

1.39 Eight kinds of temperature sensors and their effective ranges are shown in Fig. 1-6. Note that the ranges shown are only approximate. Some manufacturers may offer products that are slightly outside the stated range. Also remember that an instrument is chosen according to whether its accuracy, sensitivity, response time, ruggedness, reliability, and cost fit the application, not just whether it can perform a particular measurement.

1.40 In addition to the various kinds of thermometers and pyrometers described, there are other methods of temperature measurement that cannot be classified easily. These include color-change and melting-point temperature indications.

Color Change as a Temperature Indicator

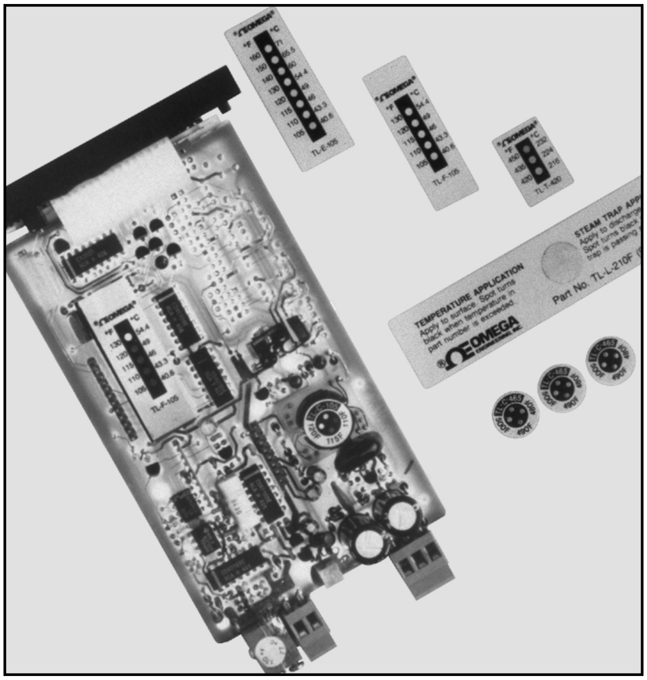
1.41 Color indicators, used to determine if a process has reached a certain temperature, are available as paint, crayon, or self-adhesive packages (reversible and irreversible). These indicators change color (gray to black or yellow to gray, for example) if the process reaches a certain temperature. Color indicators are inexpensive and are available in various ratings that range from 100 to 2500°F.

1.42 Figure 1-7 on the following page shows a typical application of nonreversible color-change indicators. This application is on a circuit board for the purpose of checking for overtemperature in critical circuits, much as described in Application 1-1. Other typical applications include the following:

- on the outside of a piping system to monitor process temperatures, because the labels are rugged and usually resistant to water and steam, they can withstand harsh environments
- near a damper arrangement used in an environmental system
- in the firing of clay bricks or terra cotta tile in small kilns
- in sterilizing processes to ensure that the necessary minimum temperature is achieved. There, a fixed temperature *must* be attained and an observer should be present.

1.43 A label package usually consists of four or five indicators, each of which changes color at a fixed

Fig. 1-7. Nonreversible color change indicators



temperature—105, 110, 115, 120, and 130°F, for example. The color of the indicators shows whether the maximum attained temperature was less than 105°F, between 105 and 110°F, between 110 and 115°F, between 115 and 120°F, between 120 and 130°F, or greater than 130°F.

Application 1-1

A manufacturer of home computers was receiving many complaints of defects, which were traceable to particular circuits. Now a technician mounts nonreversible color-change labels on op amps in those circuits. The accuracy of the op amp output is permanently reduced if it overheats, as might happen if a related component—a capacitor perhaps—fails and feeds excessive voltage to the op amp. If the temperature of the op amp reaches 130°F (54°C), the indicator changes color and keeps a permanent record of the overtemperature. The indicator can help the technician troubleshoot the problem.

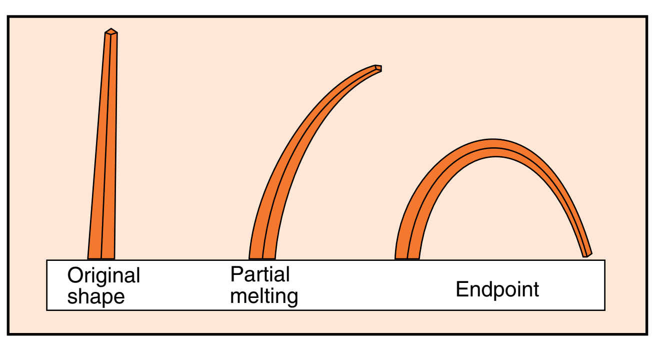
1.44 Temperature-indicating paints and crayons may be used in exactly the same manner. You can paint several marks on the walls of a kiln or on a piece of material. By observing the marks, you can bracket the maximum temperature reached according to the color changes of the paint.

1.45 Because color-change indicators are dependent on both temperature and time, accuracy is sometimes a problem. For instance, the accuracy of a 300°F color indicator might be specified as ±1% of temperature rating. This implies that the indicator will change color somewhere between 297 and 303°F. Because the color change might require 15 minutes, however, the temperature could exceed the stated range for a short period of time—two to three minutes perhaps—without a visible change in the indicator.

1.46 In addition to paints and crayons, liquid crystals that change color at specified temperatures are also used as indicators. Kits are available for preparing desired mixtures. As temperature increases, the liquid crystals continuously change color. You determine the actual temperature on the surface of an object by reading inscribed degrees or checking a reference color code. Unlike the crayons and paints previously discussed, the color change is not permanent, and continuous observation is necessary to determine temperature history. Typical response time varies between 0.5 and 2 seconds, with an accuracy of ±1°F.

Fig. 1-8. Melting-point crayon

Fig. 1-9. Effect of heat on pyrometric cone



Melting Point as a Temperature Indicator

1.47 In addition to changing color, crayons, pellets, paints, and similar devices can also indicate temperature by melting if they reach specific fixed temperatures. A typical melting-point crayon is shown in Fig. 1-8. You mark the surface to be observed with the paints and crayons. The crayon mark melts if the surface reaches a specific temperature. Just as with color indicators, you can use several marks to bracket a temperature range.

1.48 Pyrometric cones (also called *Seger cones*) are used in the ceramics industry to help an experienced operator sense conditions inside a furnace or kiln. Unlike crayons or paints, however, they do not melt at a specific temperature. Instead, they soften as the temperature increases over time.

1.49 In practice, several different cones, each with a different temperature sensitivity, are placed in the furnace. Normally they are slightly slanted—about 8° from a vertical position. As temperature increases, the cones soften and droop, as shown in Fig. 1-9. The operator then has a visual indication of furnace conditions. About 60 different cones are available, covering the temperature range of 1000 to 3600°F (538 to 1982°C).

1-9. An instrument certified by the ________ becomes a primary standard instrument.	1-9. NIST Ref: 1.24
1-10. Pyrometers measure ________ heat, from which temperature is inferred.	1-10. RADIATED Ref: 1.36
1-11. Resistance thermometers and ________ indicate temperature by sensing changes in electrical resistance.	1-11. THERMISTORS Ref: 1.37
1-12. An optical pyrometer senses the ________ of emitted radiation.	1-12. BRIGHTNESS Ref: 1.38
1-13. Paints, crayons, and labels that change ________ can be used to determine if a process has reached a certain temperature.	1-13. COLOR Ref: 1.41
1-14. A label indicator is dependent on both temperature and ________.	1-14. TIME Ref: 1.45
1-15. Instead of changing color, crayons, pellets, and paints may ________ when they reach a specified temperature.	1-15. MELT Ref: 1.47
1-16. Temperature can be determined with ________ cones that soften and droop as temperature increases.	1-16. PYROMETRIC or SEGER Ref: 1.48

Answer the following questions by marking an "X" in the box next to the best answer.

1-1. As a substance or body increases in temperature,

- ☐ a. it becomes slightly smaller in size
- ☐ b. it may give off heat to its surroundings
- ☐ c. its internal energy decreases
- ☐ d. its thermal energy remains constant

1-2. Adding heat to a substance always

- ☐ a. causes a change of state
- ☐ b. decreases its thermal energy
- ☐ c. increases its thermal energy
- ☐ d. raises its temperature

1-3. Thermal energy in a substance is

- ☐ a. equal in units to the temperature
- ☐ b. lowered as a liquid substance becomes a gas
- ☐ c. measured in Btu or joules
- ☐ d. raised as its temperature decreases

1-4. Which of the following correctly converts one temperature scale to another?

- ☐ a. °C = K + 273.15
- ☐ b. °F = (1.8 x °C) + 32
- ☐ c. K = °F + 459.67
- ☐ d. °R = °F - 459.67

1-5. According to the IPTS,

- ☐ a. eleven primary fixed temperatures are defined for calibration purposes
- ☐ b. the liquid-in-glass thermometer is a standard temperature instrument
- ☐ c. the Rankine scale is preferred over the Kelvin scale for scientific research
- ☐ d. triple point is a temperature expressed in three different scales

1-6. For calibrating instruments in an industrial laboratory,

- ☐ a. you may use secondary instruments calibrated by the NIST
- ☐ b. you must use the platinum resistance thermometer for temperatures above 1064.43°C
- ☐ c. you must use three primary standard instruments
- ☐ d. you use the liquid-in-glass thermometer as a primary standard

1-7. Bimetallic thermometers indicate temperature by means of a temperature-induced change in

- ☐ a. brightness of radiation
- ☐ b. capacitance
- ☐ c. density
- ☐ d. length or volume

1-8. The device that indicates temperature changes by sensing voltage generated at the junction of two dissimilar metals is the

- ☐ a. bimetallic element
- ☐ b. quartz thermometer
- ☐ c. thermistor
- ☐ d. thermocouple

1-9. Which of the following are kinds of pyrometers?

- ☐ a. Bimetallic and filled
- ☐ b. Optical and radiation
- ☐ c. Thermistors and quartz crystal
- ☐ d. Thermistors and thermocouples

1-10. Pyrometric cones indicate temperature by

- ☐ a. changing color
- ☐ b. changing resistance
- ☐ c. expanding
- ☐ d. softening

SUMMARY

Temperature is defined as a measure of the level of thermal energy. The four temperature scales you will probably use are the Fahrenheit, Celsius, Kelvin, and Rankine scales. The Kelvin and Rankine scales are absolute scales.

Thermal energy, or heat, is measured in Btu or joules. If a substance changes its state from a liquid to a gas, it boils (or vaporizes). If it changes from gas to liquid, it condenses. These changes of state are accompanied by either a gain of heat (heat of vaporization) or a loss of heat (heat of fusion).

The International Practical Temperature Scale lists eleven primary fixed temperature points and five secondary points for use in calibrating temperature-measuring instruments. The platinum resistance thermometer, platinum rhodium-platinum thermocouple, and infrared optical pyrometer are standard industrial temperature-measuring instruments. They are called primary standards and are used for the calibration of other instruments—thermocouples and liquid-in-glass thermometers, for example.

Temperature-measuring instruments are usually divided into two groups—thermometers and pyrometers. Thermometers depend upon heat conduction or convection from the body to the instrument, while pyrometers measure radiated heat.

Many industries use indicators that respond to certain temperatures. Paints and crayons change color or melt, and cones soften.

Answers to Self-Check Quiz

1-1. b. It may give off heat to its surroundings. Ref: 1.01

1-2. c. Increases its thermal energy. Ref: 1.03

1-3. c. Measured in Btu or joules. Ref: 1.04

1-4. b. °F = (1.8 x °C) + 32. Ref: 1.14

1-5. a. Eleven primary fixed temperatures are defined for calibration purposes. Ref. 1.19

1-6. a. You may use secondary instruments calibrated by the NIST. Ref: 1.25

1-7. d. Length or volume. Ref. 1.37

1-8. d. Thermocouple. Ref: 1.37

1-9. b. Optical and radiation. Ref. 1.38

1-10. d. Softening. Ref. 1.48

Contributions from the following sources are appreciated:

Figure 1-5 IRCON, Inc.
Figure 1-7 REPRODUCED WITH THE PERMISSION OF OMEGA ENGINEERING, INC.
Figure 1-8 Mitchell Instrument Co.