Chapter 19

Temperature

19.1 Temperature and the Zeroth Law of Thermodynamics

19.2 Thermometers and the Celsius Temperature Scale

19.3 The Constant-Volume Gas Thermometer and the Absolute Temperature Scale

Temperature

- We associate the concept of temperature with how hot or cold an object feels
- Our senses provide us with a qualitative indication of temperature
- Our senses are unreliable for this purpose
- We need a reliable and reproducible method for measuring the relative hotness or coldness of objects
  - We need a technical definition of temperature

Thermal Contact

- Two objects are in **thermal contact** with each other if energy can be exchanged between them
  - The exchanges we will focus on will be in the form of heat or electromagnetic radiation
  - The energy is exchanged due to a temperature difference

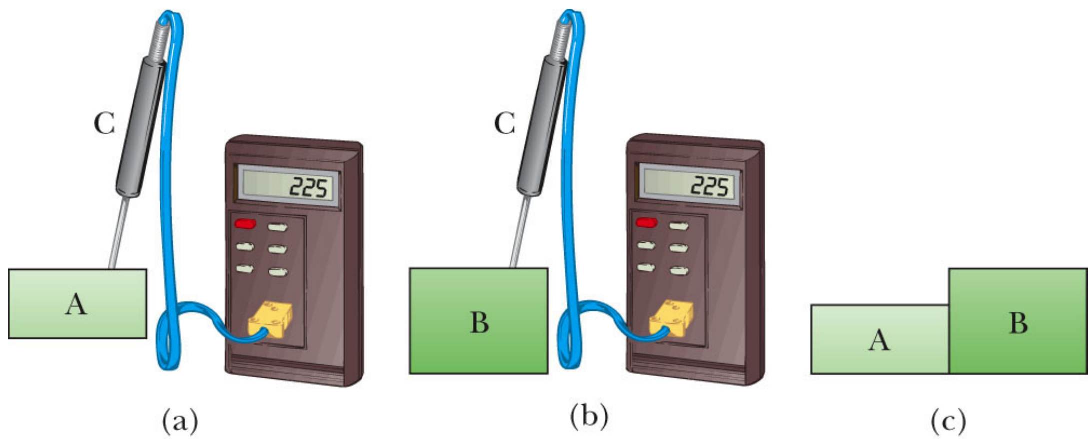
Thermal Equilibrium

- **Thermal equilibrium** is a situation in which two objects would not exchange energy by heat or electromagnetic radiation if they were placed in thermal contact
  - The thermal contact does not have to also be physical contact

Zeroth Law of Thermodynamics

- If objects A and B are separately in thermal equilibrium with a third object C, then A and B are in thermal equilibrium with each other
  - Let object C be the thermometer
  - Since they are in thermal equilibrium with each other, there is no energy exchanged among them

Zeroth Law of Thermodynamics, Example



- Object C (thermometer) is placed in contact with A until they achieve thermal equilibrium
  - The reading on C is recorded
- Object C is then placed in contact with object B until they achieve thermal equilibrium
  - The reading on C is recorded again
- If the two readings are the same, A and B are also in thermal equilibrium

Temperature – Definition

- **Temperature** can be thought of as the property that determines whether an object is in thermal equilibrium with other objects
- Two objects in thermal equilibrium with each other are at the same temperature
  - If two objects have different temperatures, they are not in thermal equilibrium with each other

Thermometers

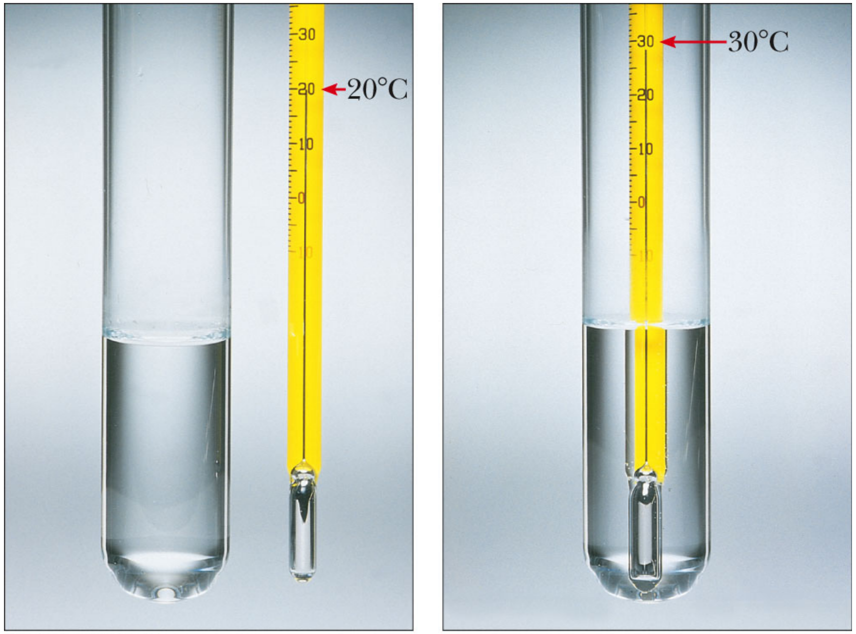
- A **thermometer** is a device that is used to measure the temperature of a system
- Thermometers are based on the principle that some physical property of a system changes as the system's temperature changes

Thermometers, cont

- These properties include:
  - The volume of a liquid
  - The dimensions of a solid
  - The pressure of a gas at a constant volume
  - The volume of a gas at a constant pressure
  - The electric resistance of a conductor
  - The color of an object
- A temperature scale can be established on the basis of any of these physical properties

Thermometer, Liquid in Glass

- A common type of thermometer is a liquid-in-glass
- The material in the capillary tube expands as it is heated
- The liquid is usually mercury or alcohol



Calibrating a Thermometer

- A thermometer can be calibrated by placing it in contact with some natural systems that remain at constant temperature
- Common systems involve water
  - A mixture of ice and water at atmospheric pressure
    - Called the *ice point* of water
  - A mixture of water and steam in equilibrium
    - Called the *steam point* of water
- Once these points are established, the length between them can be divided into a number of segments

Celsius Scale

- The ice point of water is defined to be 0^o C
- The steam point of water is defined to be 100^o C
- The length of the column between these two points is divided into 100 increments, called degrees

Problems with Liquid-in-Glass Thermometers

- An alcohol thermometer and a mercury thermometer may agree only at the calibration points
- The discrepancies between thermometers are especially large when the temperatures being measured are far from the calibration points
- The thermometers also have a limited range of values that can be measured
  - Mercury cannot be used under –39^{o} C
  - Alcohol cannot be used above 85^{o} C

Absolute Temperature Scale

- Absolute zero is used as the basis of the absolute temperature scale
- The size of the degree on the absolute scale is the same as the size of the degree on the Celsius scale
- To convert:
  - $T_C = T - 273.15$

Absolute Temperature Scale, 2

- The absolute temperature scale is now based on two new fixed points
  - Adopted by in 1954 by the International Committee on Weights and Measures
  - One point is absolute zero
  - The other point is the **triple point** of water
    - This is the combination of temperature and pressure where ice, water, and steam can all coexist

Absolute Temperature Scale, 3

- The triple point of water occurs at 0.01^{o} C and 4.58 mm of mercury
- This temperature was set to be 273.16 on the absolute temperature scale
  - This made the old absolute scale agree closely with the new one
  - The units of the absolute scale are **kelvins**

Absolute Temperature Scale, 4

- The absolute scale is also called the Kelvin scale
  - Named for William Thomson, Lord Kelvin
- The triple point temperature is 273.16 K
  - No degree symbol is used with kelvins
- The kelvin is defined as 1/273.16 of the difference between absolute zero and the temperature of the triple point of water

Fahrenheit Scale

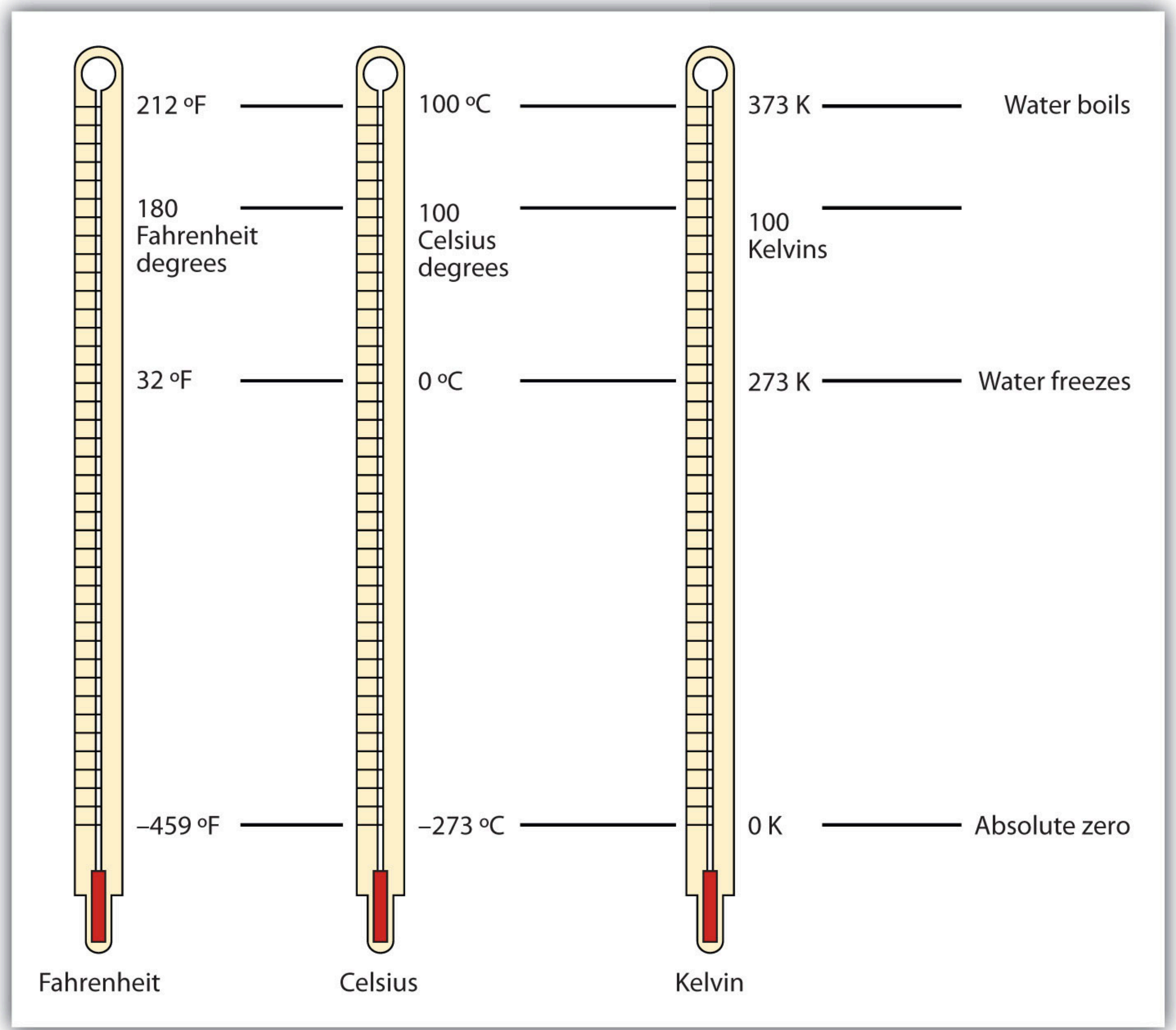
- A common scale in everyday use in the US
- Named for Daniel Fahrenheit
- Temperature of the ice point is 32^{o}F
- Temperature of the steam point is 212^{o}F
- There are 180 divisions (degrees) between the two reference points

Comparison of Scales

- Celsius and Kelvin have the same size degrees, but different starting points
  - $T_C = T - 273.15$
- Celsius and Fahrenheit have different sized degrees and different starting points

$$T_F = \frac{9}{5} T_C + 32^{\circ} F$$

Comparison of Scales, cont



Example 19.1 Converting Temperatures

On a day when the temperature reaches 50°F, what is the temperature in degrees Celsius and in kelvins?

SOLUTION

Conceptualize In the United States, a temperature of 50°F is well understood. In many other parts of the world, however, this temperature might be meaningless because people are familiar with the Celsius temperature scale.

Categorize This example is a simple substitution problem.

Solve Equation 19.2 for the Celsius temperature and substitute numerical values:

$$T_C = \frac{5}{9}(T_F - 32) = \frac{5}{9}(50 - 32) = \boxed{10°C}$$

Use Equation 19.1 to find the Kelvin temperature:

$$T = T_C + 273.15 = 10°C + 273.15 = \boxed{283\ K}$$

A convenient set of weather-related temperature equivalents to keep in mind is that 0°C is (literally) freezing at 32°F, 10°C is cool at 50°F, 20°C is room temperature, 30°C is warm at 86°F, and 40°C is a hot day at 104°F.

HomeWork

- 1. Liquid nitrogen has a boiling point of -195.81°C at atmospheric pressure. Express this temperature (a) in degrees Fahrenheit and (b) in kelvins.
- 2. Convert the following to equivalent temperatures on the Celsius and Kelvin scales: (a) the normal human body temperature, 98.6°F; (b) the air temperature on a cold day, -5.00°F.3.

1.

(a) $T_F = \frac{9}{5}T_C + 32.0°\mathrm{F} = \frac{9}{5}(-195.81) + 32.0 = \boxed{-320°\mathrm{F}}$

(b) $T = T_C + 273.15 = -195.81 + 273.15 = \boxed{77.3\ \mathrm{K}}$

2.

(a) To convert from Fahrenheit to Celsius, we use $T_C = \frac{5}{9}(T_F - 32.0) = \frac{5}{9}(98.6 - 32.0) = \boxed{37.0°\mathrm{C}}$

and the Kelvin temperature is found as $T = T_C + 273 = \boxed{310\ \mathrm{K}}$

(b) In a fashion identical to that used in (a), we find $T_C = \boxed{-20.6°\mathrm{C}}$

and $T = \boxed{253\ \mathrm{K}}$