TEMPERATURE MEASUREMENT

Temperature scales were defined originally in terms of certain fixed points, usually an easily reproduced phase transition such as melting of ice or boiling of water. Only a finite number of fixed points are readily available, and we need some means of interpolation.

The Second Law of Thermodynamics provides a rational definition for a temperature scale, based on the efficiency of a Carnot engine.

$$n = 1 - T_2/T_1 = 1 - Q_2/Q_1$$

The Second Law provides not only a definition of the zero point but also a conceptual way of defining the intermediate temperatures. Since only the ratio of two temperatures is specified, we still need to establish the size of a degree, defined by the temperature difference between two fixed points Two scales are commonly used, the Kelvin scale and the Rankine scale. The Kelvin scale has 100° between the temperatures melting ice and

boiling water; the Rankine scale has 180^o. Because temperatures we normally encounter are well above the zero on the Kelvin and Rankine scales, we also use the Celsius and Fahrenheit scales.

	Kelvin	**Rankine**	**Celsius**	**Fahrenheit**
Absolute Zero	**0**	**0**	**-273**	**-492**
Melting Ice	**273**	**460**	**0**	**32**
Boiling Water	**373**	**572**	**100**	**212**

These latter two scales are not thermodynamic scales, so cannot be used, for example, in the ideal gas equation of state.

Unfortunately Carnot engines do not exist, so we need a practical alternative. This is provided by the ideal gas equation of state:

$$T = \frac{pV}{RT}$$

(figures from Doebelin, E. O. <u>Measurement Systems</u>, 4th Ed., McGraw-Hill, 1990)

Thermometer Physical Principles

- Thermal Expansion
- Electrical Resistance
- Thermoelectric
- Radiation
- Change-of-State

Temperature Sensors

- **Fluid-Expansion**
    - Household thermometer
    - Mercury, Alcohol, gas
- **Bimetalic**
    - Dial Thermometer
- **Resistance Temperature Devices**
    - RTDs (resistance change in a metal)
    - Thermistors (resistance change in a ceramic semiconductor)
- **Thermocouple**
    - Two dissimilar metals joined at one end
- **Infrared Detectors**
    - Cameras
    - Spot detectors
- **Change-of-State**
    - Labels, pellets, crayons, lacquers
    - liquid crystals

Thermal Expansion:

Liquid-in-glass:

FIGURE 7.2 Liquid-in-glass thermometer.

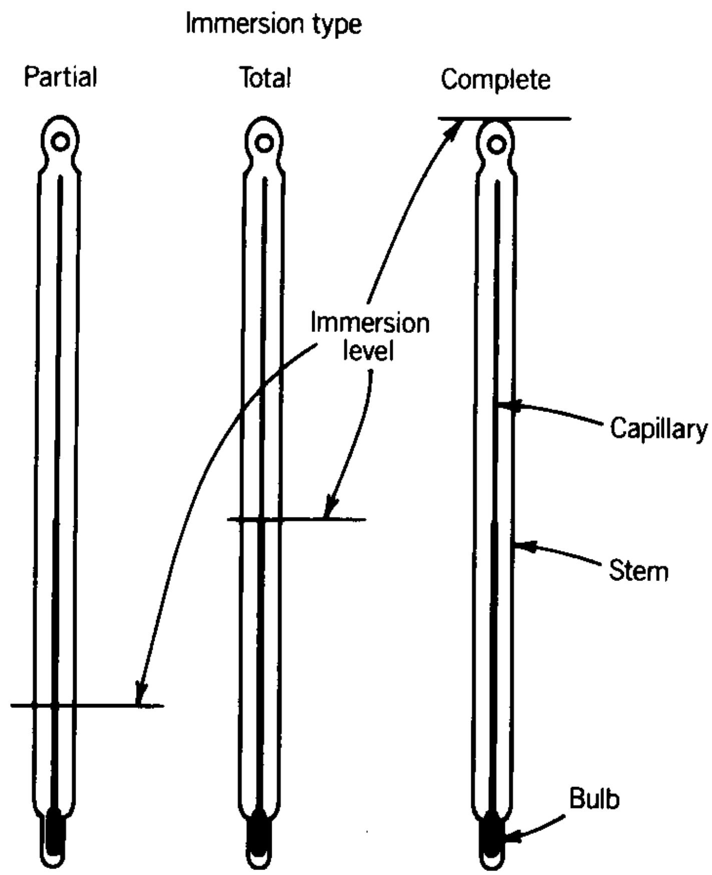


Figure 8.2 in 2nd and 3rd Edition

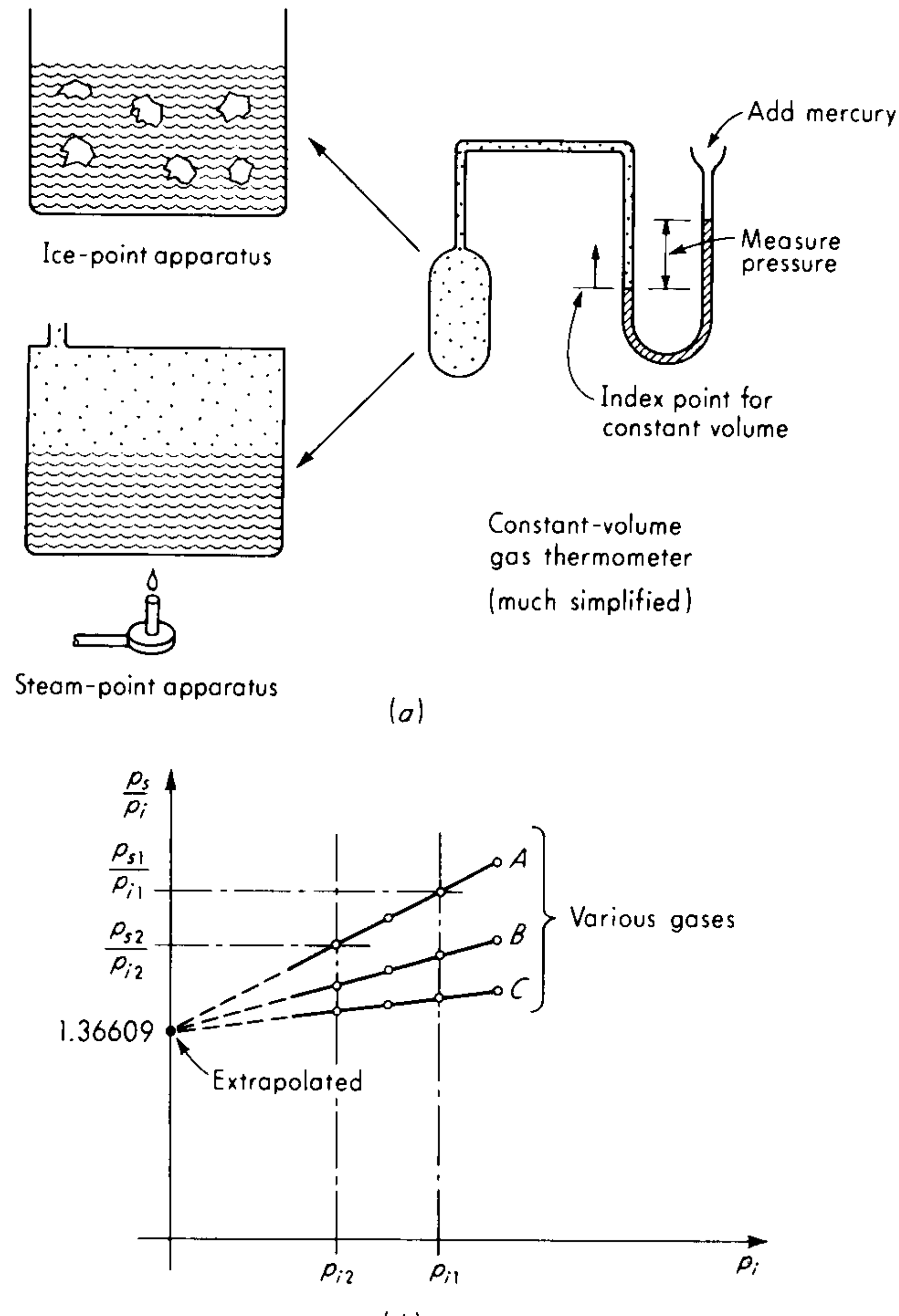


Figure 8.1 Gas-thermometer temperature scale.

Gas thermometers are cumbersome and not commonly used, but they provide a means for calibrating other thermometers.

Bimetallic Temperature Measurement Devices

Bimetallic devices take advantage of the difference in rate of thermal expansion between different metals. Strips of two metals are bonded together. When heated, one side will expand more than the other, and the resulting bending is translated into a temperature reading by mechanical linkage to a pointer. These devices are portable and they do not require a power supply, but they are usually not as accurate as thermocouples or RTDs and they do not readily lend themselves to temperature recording.

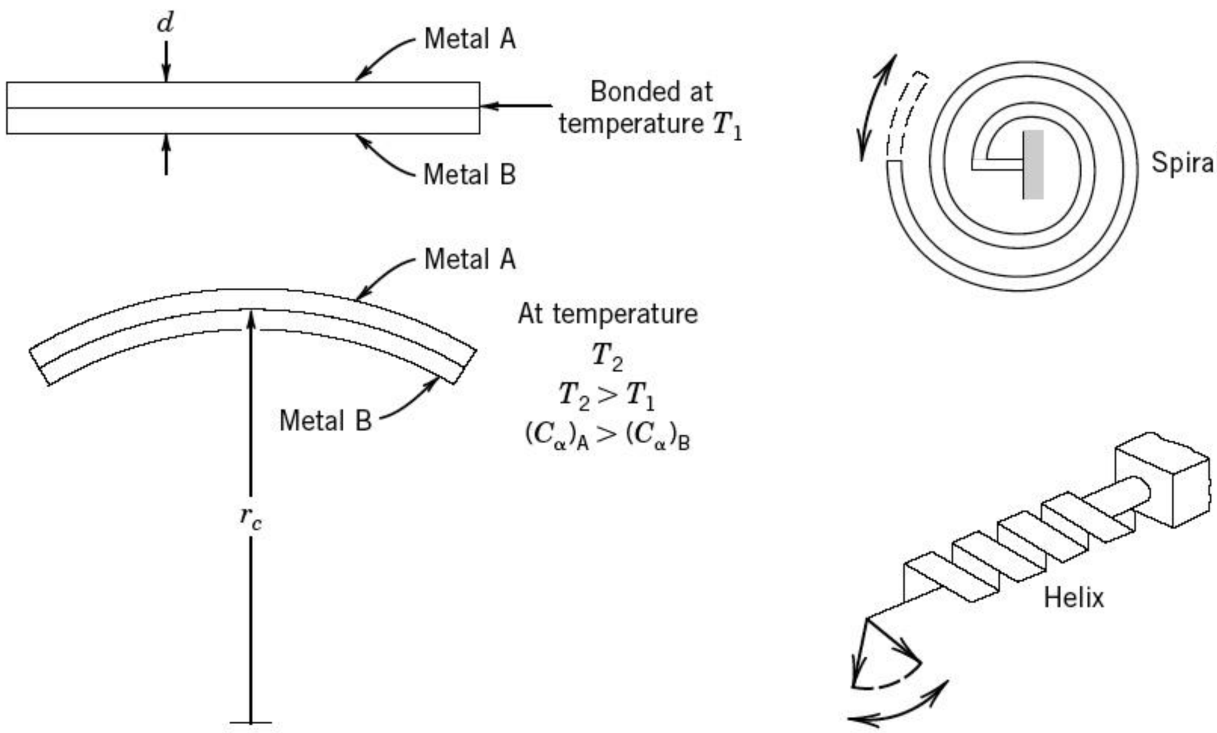


Figure 8.3 Expansion thermometry: bimetallic strip.

Resistance Temperature Devices(RTD)

Resistive temperature devices capitalize on the fact that the electrical resistance of a material changes as its temperature changes. Two key types are the metallic devices (commonly referred to as RTDs), and thermistors. As their name indicates, RTDs rely on resistance change in a metal, with the resistance rising more or less linearly with temperature.

$$\boldsymbol{R = R_0\left[1 + \propto (T - T_0) + \beta(T - T_0)^2 + \cdots\right]}$$

Table 8.3 Uncertainties in β

	Uncertainty (95%)		
	Random	Systematic	Total
T [°C]	P_β [K]	B_β [K]	u_β [K]
100	13.3	74.7	79.7
125	10.6	107.6	109.9
150	8.8	156.7	157.8

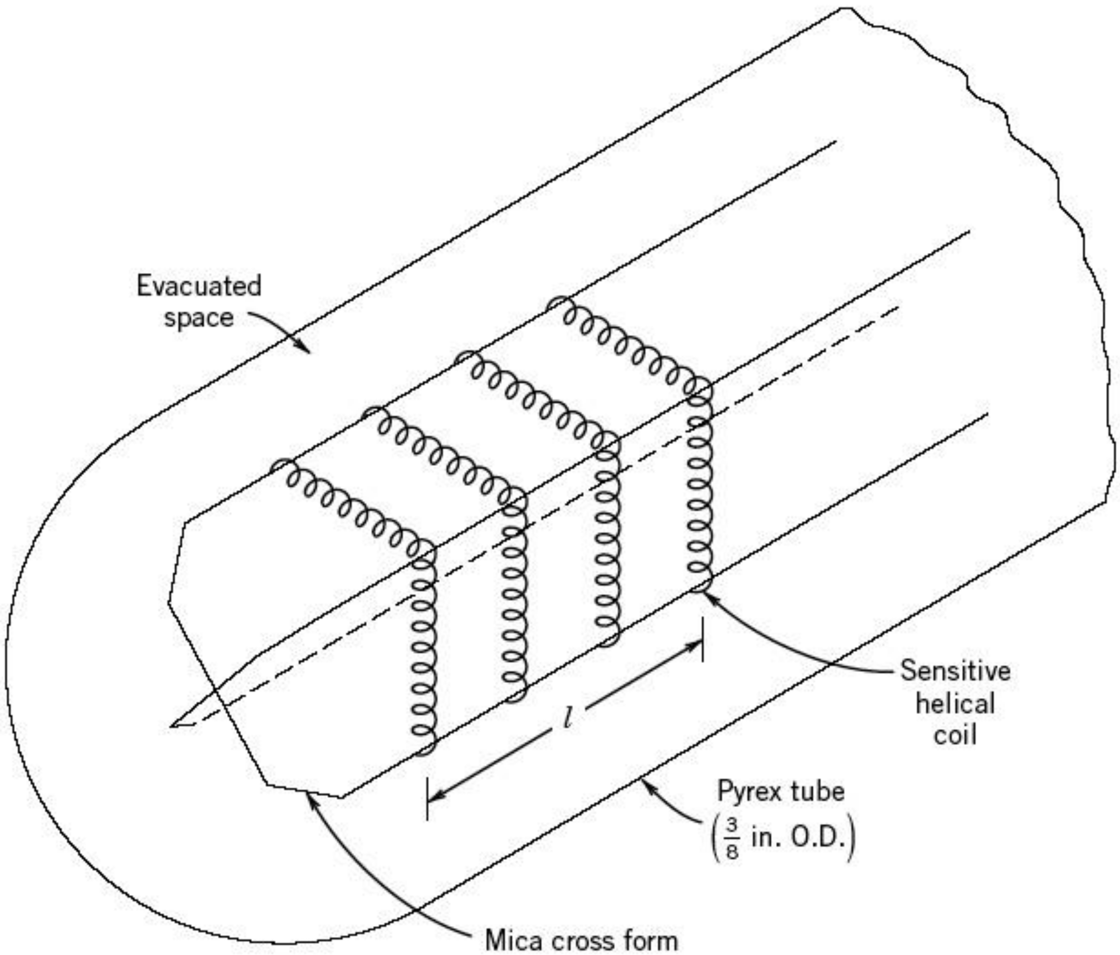


Figure 8.4 Construction of a platinum RTD.

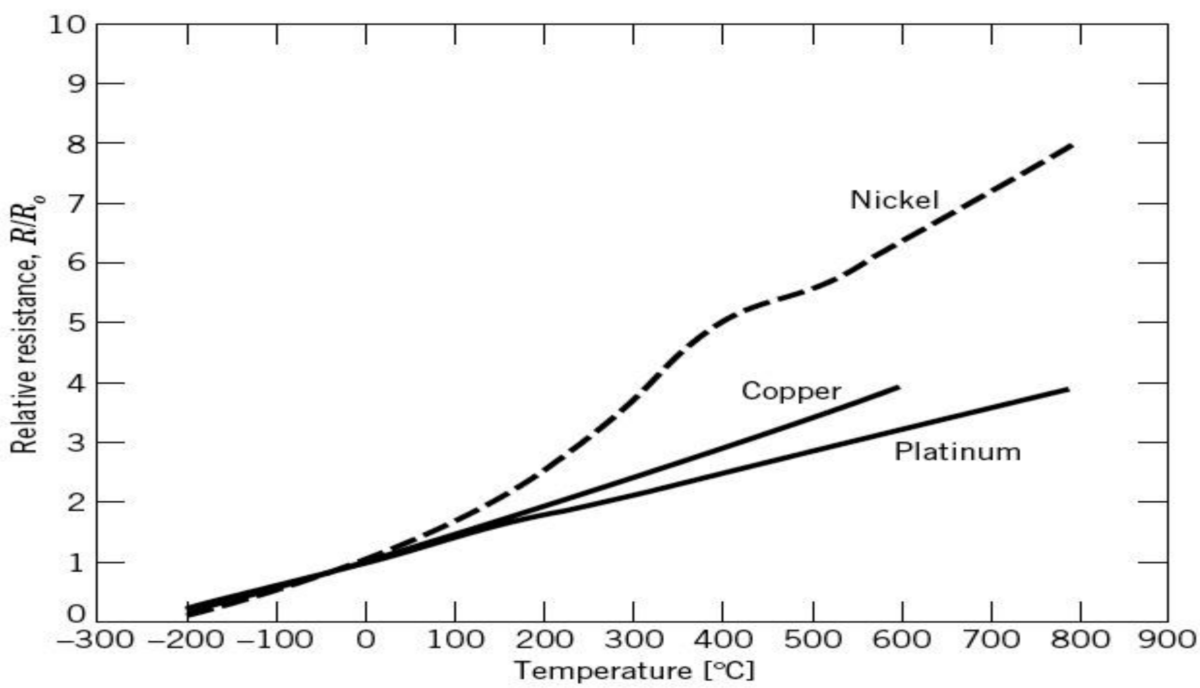
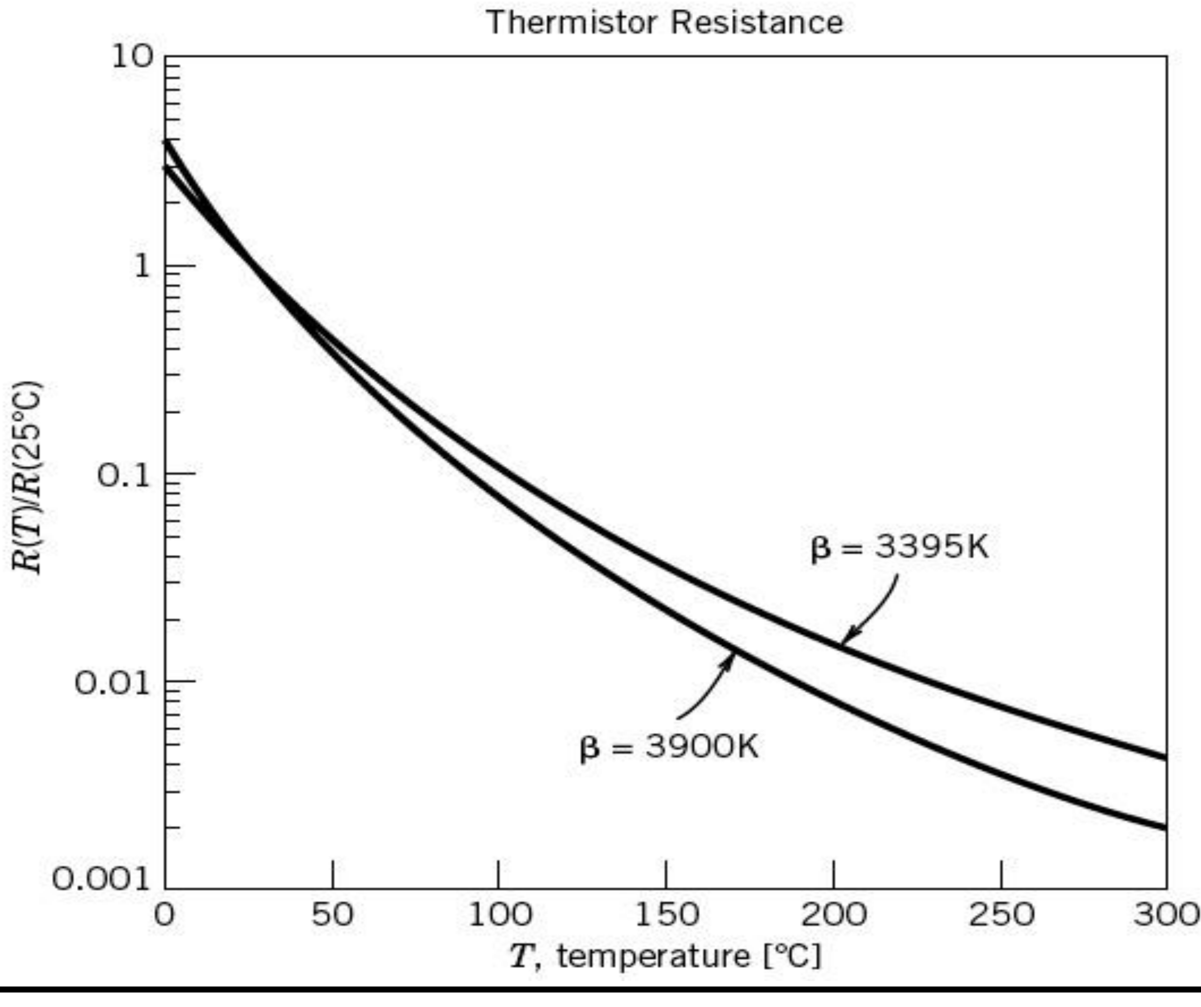


Figure 8.5 Relative resistance of several pure metals (R_o at 0°C).

Thermistors

Thermistors are based on resistance change in a ceramic semiconductor; the resistance drops nonlinearly with temperature rise.

$$R = R_0 e^{\beta\left(\frac{1}{T} - \frac{1}{T_0}\right)}$$



Infrared Temperature Measurement Devices

Infrared sensors are non-contacting devices. They infer temperature by measuring the thermal radiation emitted by a material.

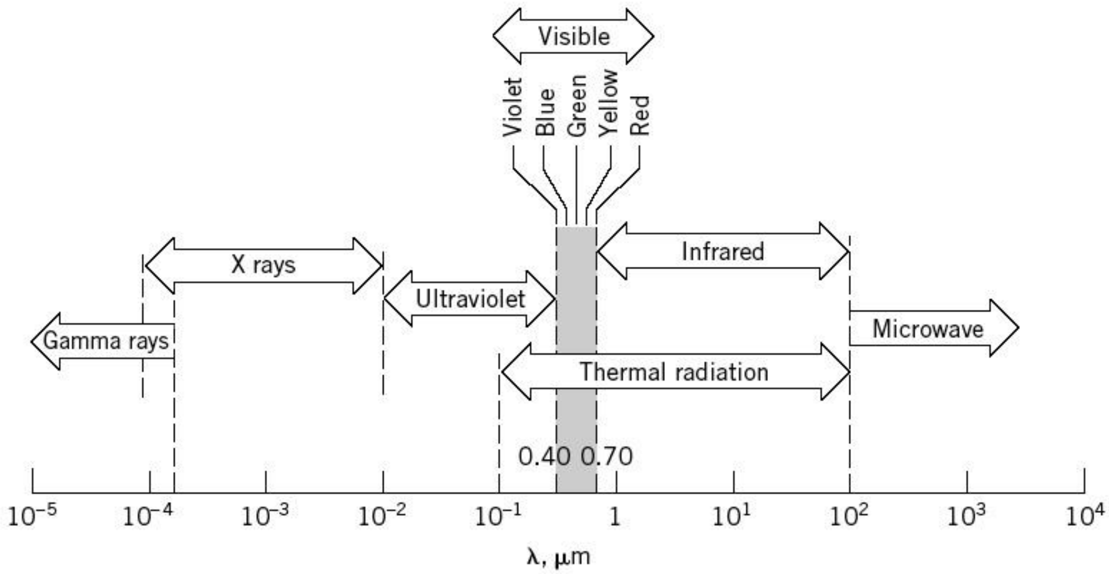
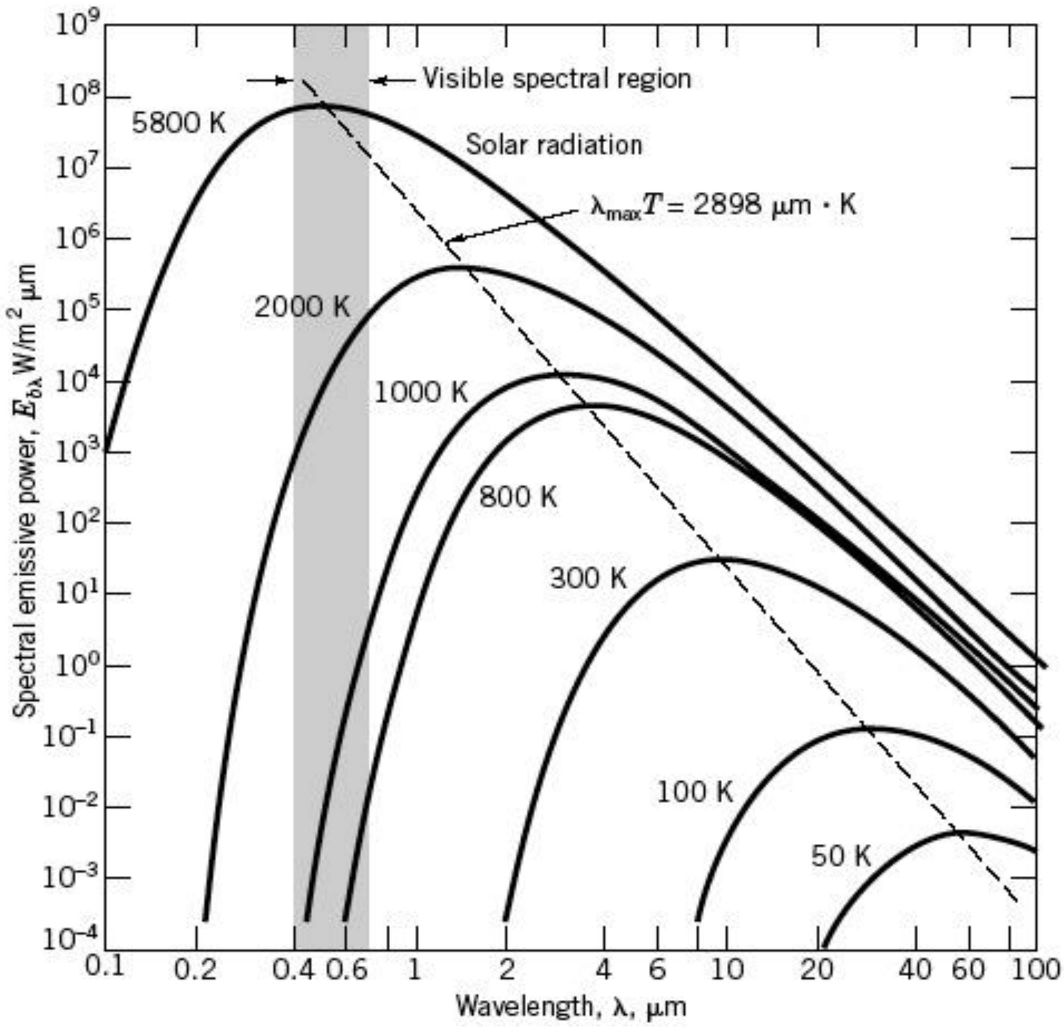


Figure 8.24 The electromagnetic spectrum. (From F. P. Incropera and D. P. DeWitt, *Fundamentals of Heat and Mass Transfer*, 2d ed., copyright © 1985 by John Wiley & Sons, New York. Reprinted by permission.)



Change-of-State Temperature Measurement Devices

Change-of-state temperature sensors consist of labels, pellets, crayons, lacquers or liquid crystals whose appearance changes once a certain temperature is reached. They are used, for instance, with steam traps - when a trap exceeds a certain temperature, a white dot on a sensor label attached to the trap will turn black. Response time typically takes minutes, so these devices often do not respond to transient temperature changes. And accuracy is lower than with other types of sensors. Furthermore, the change in state is irreversible, except in the case of liquid-crystal displays. Even so, change-of-state sensors can be handy when one needs confirmation that the temperature of a piece of equipment or a material has not exceeded a certain level, for instance for technical or legal reasons during product shipment.