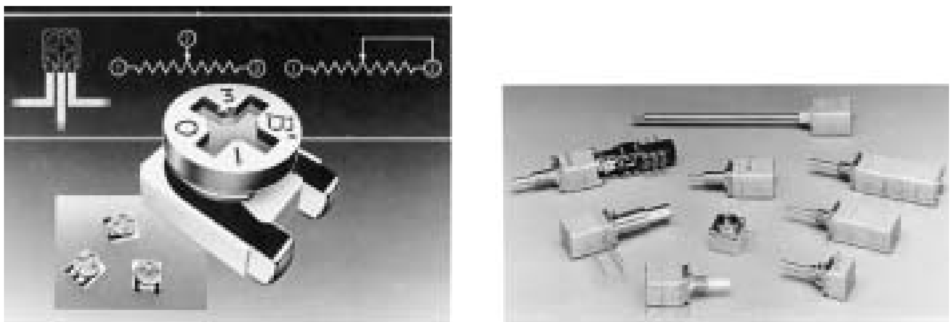
Therefore, as the resistance from the wiper arm to one outside contact increases, the resistance between the wiper arm and the other outside terminal must decrease accordingly. For example, if $R_{ab}$ of a 1-kΩ potentiometer is 200 Ω, then the resistance $R_{bc}$ must be 800 Ω. If $R_{ab}$ is further decreased to 50 Ω, then $R_{bc}$ must increase to 950 Ω, and so on.

The molded carbon composition potentiometer is typically applied in networks with smaller power demands, and it ranges in size from 20 Ω to 22 MΩ (maximum values). Other commercially available potentiometers appear in Fig. 3.26.



(a) (b)

**FIG. 3.26**
*Potentiometers: (a) 4-mm (≈5/32″) trimmer (courtesy of Bourns, Inc.); (b) conductive plastic and cermet element (courtesy of Clarostat Mfg. Co.).*

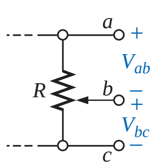



**FIG. 3.27**
*Potentiometer control of voltage levels.*

When the device is used as a potentiometer, the connections are as shown in Fig. 3.27. It can be used to control the level of $V_{ab}$, $V_{bc}$, or both, depending on the application. Additional discussion of the potentiometer in a loaded situation can be found in the chapters that follow.

## 3.8 COLOR CODING AND STANDARD RESISTOR VALUES

A wide variety of resistors, fixed or variable, are large enough to have their resistance in ohms printed on the casing. Some, however, are too small to have numbers printed on them, so a system of **color coding** is used. For the fixed molded composition resistor, four or five color bands are printed on one end of the outer casing, as shown in Fig. 3.28. Each color has the numerical value indicated in Table 3.7. The color bands are always read from the end that has the band closest to it, as shown in Fig. 3.28. The first and second bands represent the first and second digits, respectively. The third band determines the power-of-ten multiplier for the first two digits (actually the number of zeros that follow the second digit) or a multiplying factor if gold or silver. The fourth band is the manufacturer's tolerance, which is an indication of the precision by which the resistor was made. If the fourth band is omitted, the tolerance is assumed to be ±20%. The fifth band is a reliability factor, which gives the percentage of failure per 1000 hours of use. For instance,

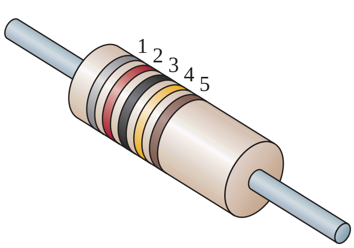



**FIG. 3.28**
*Color coding of fixed molded composition resistor.*

**TABLE 3.7**
*Resistor color coding.*

| Bands 1–3* | Band 3 | Band 4 | Band 5 |
|---|---|---|---|
| 0 Black | 0.1 Gold } multiplying factors | 5% Gold | 1% Brown |
| 1 Brown | 0.01 Silver } multiplying factors | 10% Silver | 0.1% Red |
| 2 Red | | 20% No band | 0.01% Orange |
| 3 Orange | | | 0.001% Yellow |
| 4 Yellow | | | |
| 5 Green | | | |
| 6 Blue | | | |
| 7 Violet | | | |
| 8 Gray | | | |
| 9 White | | | |

*With the exception that black is not a valid color for the first band.

a 1% failure rate would reveal that one out of every 100 (or 10 out of every 1000) will fail to fall within the tolerance range after 1000 hours of use.

**EXAMPLE 3.13** Find the range in which a resistor having the following color bands must exist to satisfy the manufacturer's tolerance:

a.

| 1st band | 2nd band | 3rd band | 4th band | 5th band |
|---|---|---|---|---|
| Gray | Red | Black | Gold | Brown |
| 8 | 2 | 0 | ±5% | 1% |

b.

| 1st band | 2nd band | 3rd band | 4th band | 5th band |
|---|---|---|---|---|
| Orange | White | Gold | Silver | No color |
| 3 | 9 | 0.1 | ±10% | |

***Solutions:***

a. **82 Ω ± 5% (1% reliability)**

Since 5% of 82 = 4.10, the resistor should be within the range 82 Ω ± 4.10 Ω, or *between 77.90 and 86.10 Ω*.

b. **3.9 Ω ± 10% = 3.9 ± 0.39 Ω**

The resistor should lie somewhere *between 3.51 and 4.29 Ω*.

One might expect that resistors would be available for a full range of values such as 10 Ω, 20 Ω, 30 Ω, 40 Ω, 50 Ω, and so on. However, this is not the case with some typical commercial values, such as 27 Ω, 56 Ω, and 68 Ω. This may seem somewhat strange and out of place. There is a reason for the chosen values, which is best demonstrated by examining the list of standard values of commercially available resistors in Table 3.8. The values in boldface blue are available with 5%, 10%, and 20% tolerances, making them the most common of the commercial variety. The values in boldface black are typically available with 5% and 10% tolerances, and those in normal print are available only in the 5% variety. If we separate the values available into tolerance levels, we have Table 3.9, which clearly reveals how few are available up to 100 Ω with 20% tolerances.

An examination of the impact of the tolerance level will now help explain the choice of numbers for the commercial values. Take the