The Physics of Resistance

Electrical resistance is a fundamental concept that governs the function of every circuit from a simple wire to a microchip.

Electrical resistance quantifies an object's opposition to the flow of electric current. This property is intrinsically tied to the material's nature and its physical dimensions and is described by the formula. In the formula R is resistance, ρ (rho) is the material's inherent resistivity, L and A are the conductors length and area, respectively.

$$R = \frac{\rho L}{A}$$

1. Using standard mks (meters, kilograms, seconds) units, and given that resistance is measured in ohms (Ω), use the formula above right to determine the units of resistivity, ρ (rho).

2. Using the resistivity given in the table to the right, calculate the resistance of the following. Write the formulas you use, show all steps of the computation, round the final result to three significant digits, and write the final answers using standard prefixes.

Material	**Resistivity [Ω·m]**
silver	1.58×10^{-8}
copper	1.68×10^{-8}
gold	2.44×10^{-8}
aluminum	2.65×10^{-8}
tungsten	5.60×10^{-8}
iron	9.71×10^{-8}
mercury	98.0×10^{-8}
carbon	3.50×10^{-5}
silicon	2300
wood	10^{8} to 10^{11}
glass	10^{9} to 10^{14}

   a) A cylinder of radius 1mm and length 5cm that is made of copper.

   b) A wood cylinder with the same dimensions as the cylinder in part (a), and with a resistivity $\rho = 10^{8}\ \Omega\cdot m$.

   c) How many times larger is the resistance of the wood in the example when compared to the resistance of copper (assuming the same dimensions).

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3. For this question, write the formulas you use, show all steps of the computation, round the final result to three significant digits, and write the final answers using standard prefixes.

   Prior to LED lights and even fluorescent lighting, light bulbs were made using a tungsten filament. The table of resistivity on the previous page is for the materials at 20°C. However, resistivity changes with temperature, and the tungsten filament in a light bulb reaches an extremely high temperature required to burn white-hot – around 2500°C! Given a light bulb operates on 220V (the RMS voltage of a household wall socket in China) and is rated for 60 Watts, answer the following.

   a) What is the current that is drawn from the 220V supply when light bulb is operating at its rated power (60W).

   b) Considering the light bulb dissipates 60W of power when the voltage applied is 220V, and assuming all power is dissipated by the filament, what is the resistance of the tungsten filament?

   c) The filament has an extremely small diameter of 40μm (radius of 20μm), slimmer than the average human hair, and is tightly coiled to fit into the bulb. Our light bulb has an uncoiled length of about 0.5m. Using the resistance from (b) and the filament dimensions, calculate the resistivity, ρ, of tungsten at the bulb's operating temperature.

   d) From the table on page 1, the resistivity of tungsten at 20°C is about 5.60×10^{-8}. How many times larger is the resistance at the operating temperature?

   This explains why incandescent light bulbs usually fail when they're being turned on: when the filament is cold, the resistance is much lower and a much larger current will flow through the bulb. This current surge causes a rapid thermal stress and is the most common time for failure.