

Programming Assignment #3: Wire Resistance

Background Information:

Calculating the resistance of a wire depends on the length of the wire and:

- The resistivity of the material, ρ
- The diameter (gauge) of the wire as specified by the AWG table
- The temperature (and the temperature coefficient of the material)

Resistivity:

The resistance, R , of a wire in ohms (Ω) can be calculated using the following relationship:

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

R = resistance (in Ω)
 ρ = resistivity of the material (in $\Omega \cdot m$)
 L = length of the wire (in m)
 A = cross-sectional area of the wire (in m^2)

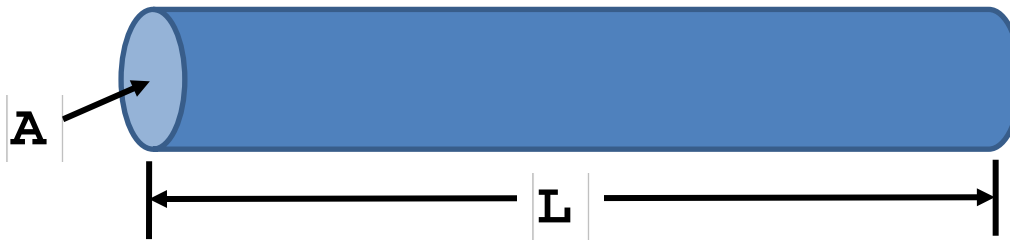


Table 1: Resistivity of various materials at 20 °C.

Material	Resistivity, ρ ($\Omega \cdot m$)
Aluminum	2.65×10^{-8}
Brass	7.5×10^{-8}
Copper	1.68×10^{-8}
Gold	2.4×10^{-8}
Iron	9.71×10^{-8}
Manganin	4.82×10^{-7}
Mercury	9.8×10^{-7}
Platinum	1.06×10^{-7}
Silver	1.59×10^{-8}
Tungsten	5.6×10^{-8}
Zinc	5.5×10^{-8}

American Wire Gauge (AWG):

Wire is commercially available in standard sizes (gauges) where the diameter is specified by the American Wire Gauge (AWG) Table. You might be familiar with the commonly used wire gauges specified below:

Wire for a breadboard:

#20 (20 gauge) wire

Diameter: 31.96×10^{-3} inches (or 31.96 mil)

Wire for an electrical outlet:

#14 (14 gauge) wire

Diameter: 64.08×10^{-3} inches (or 64.08 mil)



Table 2: American Wire Gauge (AWG) Table – for solid round wire at 20 °C.

Gauge	Diameter (mil)	Gauge	Diameter (mil)	Gauge	Diameter (mil)	Gauge	Diameter (mil)
0	324.9	11	90.74	22	25.35	33	7.080
1	289.3	12	80.81	23	22.60	34	6.305
2	257.6	13	71.96	24	20.10	35	5.615
3	229.4	14	64.08	25	17.90	36	5.000
4	204.3	15	57.07	26	15.94	37	4.453
5	181.9	16	50.82	27	14.20	38	3.965
6	162.0	17	45.26	28	12.64	39	3.531
7	144.3	18	40.30	29	11.26	40	3.145
8	128.5	19	35.89	30	10.03		
9	114.4	20	31.96	31	8.928		
10	101.9	21	28.46	32	7.950		

Example: Determine the resistance of 10 m of #24 copper wire at 20 °C.

$$\begin{aligned} D &= 20.10 \text{ mil} = 0.02010 \text{ in} \\ D &= 0.02010 \text{ in} \left[\frac{1 \text{ m}}{39.37 \text{ in}} \right] = 5.10541 \cdot 10^{-4} \text{ m} \\ A &= \pi \left(\frac{D}{2} \right)^2 = \pi \left(\frac{5.1028 \cdot 10^{-4}}{2} \right)^2 = 2.04716 \cdot 10^{-7} \text{ m}^2 \\ R &= \frac{\rho \cdot L}{A} = \frac{(1.68 \cdot 10^{-8} \Omega \cdot \text{m}) \cdot (10 \text{ m})}{(2.0451 \cdot 10^{-7} \text{ m}^2)} = 0.82065 \Omega \end{aligned}$$

Temperature Coefficient

The resistance of many materials changes as temperature changes. If the temperature coefficient, α , is positive, then resistance will increase as temperature increases. The new resistance, R_2 , can be calculated using the relationship shown below:

$$R_2 = R_1 [1 + \alpha(T_2 - T_1)]$$

R_1 = resistance (in Ω) at temperature T_1 (in $^{\circ}\text{C}$)

R_2 = resistance (in Ω) at temperature T_2 (in $^{\circ}\text{C}$)

α = temperature coefficient (in $1/^{\circ}\text{C}$)

Table 3: Temperature coefficients of various materials at 20 $^{\circ}\text{C}$.

Material	Temperature Coefficient, α ($1/^{\circ}\text{C}$)
Aluminum	4.29×10^{-3}
Brass	1.0×10^{-3}
Copper	3.86×10^{-3}
Gold	3.4×10^{-3}
Iron	6.51×10^{-3}
Manganin	0.002×10^{-3}
Mercury	0.9×10^{-3}
Platinum	3.927×10^{-3}
Silver	3.8×10^{-3}
Tungsten	4.5×10^{-3}
Zinc	3.6×10^{-3}

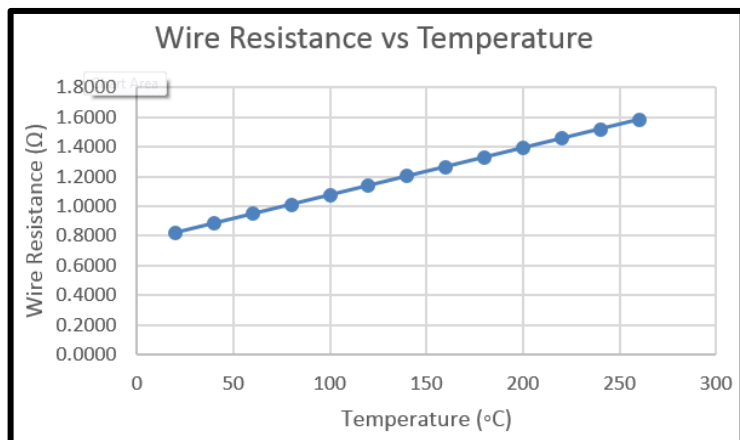
Example: In the previous example, it was determined that the resistance of 10 m of #24 copper wire at 20 $^{\circ}\text{C}$ is 0.82065 Ω . Determine the resistance at 50 $^{\circ}\text{C}$ and 100 $^{\circ}\text{C}$.

at 20 $^{\circ}\text{C}$, $R = 0.82065 \Omega$

at 50 $^{\circ}\text{C}$, $R = 0.82065 [1 + 3.86 \cdot 10^{-3} (50 - 20)] = 0.91674 \Omega$

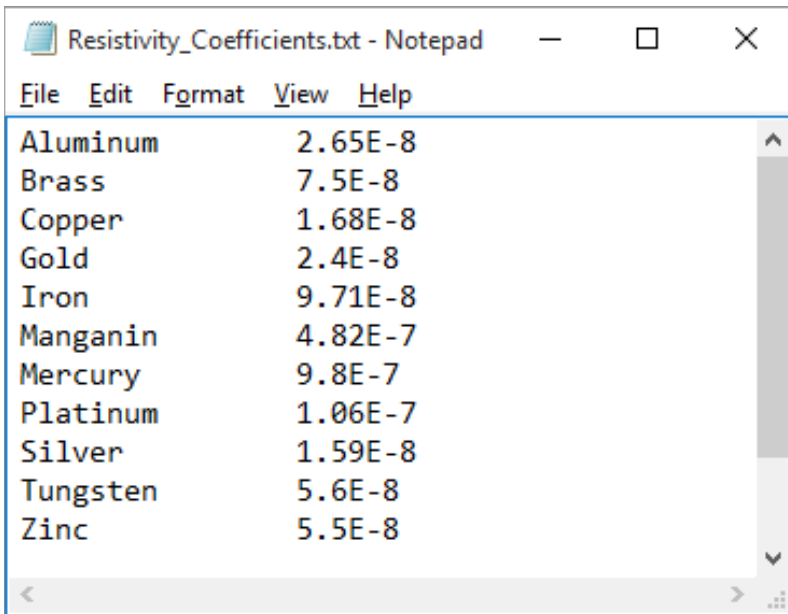
at 100 $^{\circ}\text{C}$, $R = 0.82065 [1 + 3.86 \cdot 10^{-3} (100 - 20)] = 1.07531 \Omega$

The graph below shows R as a function of T for $T = 20 - 260 \text{ }^{\circ}\text{C}$.



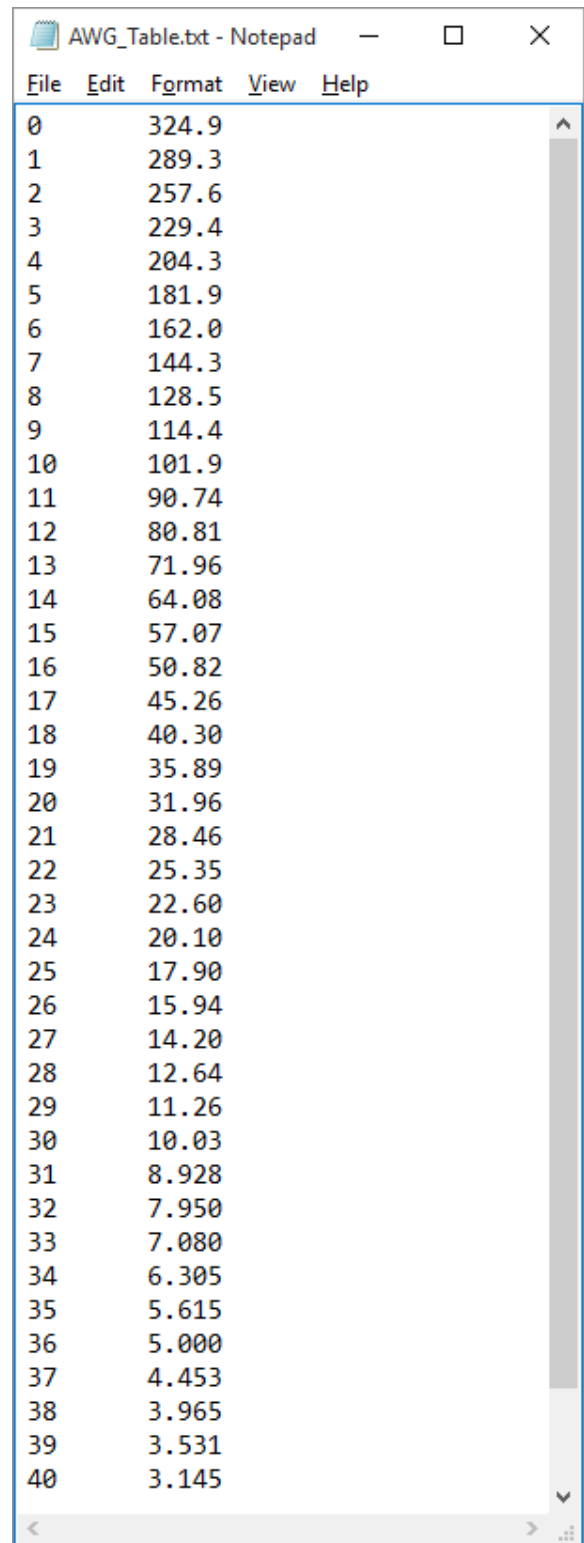
The following three data files are available on the course website. They correspond to Tables 1-3 above.

- **Resistivity_Coefficients.txt** – Contains resistivity values (in $\Omega\cdot\text{m}$) for various materials at 20 °C
- **AWG_Table.txt** – Contains wire diameters (in mils) at 20 °C for American Wire Gauge (AWG) sizes 0 – 40. Note that 1 mil = 0.001 in.
- **Temperature_Coefficients.txt** – Contains temperature coefficients (in $1/^\circ\text{C}$) for various materials at 20 °C



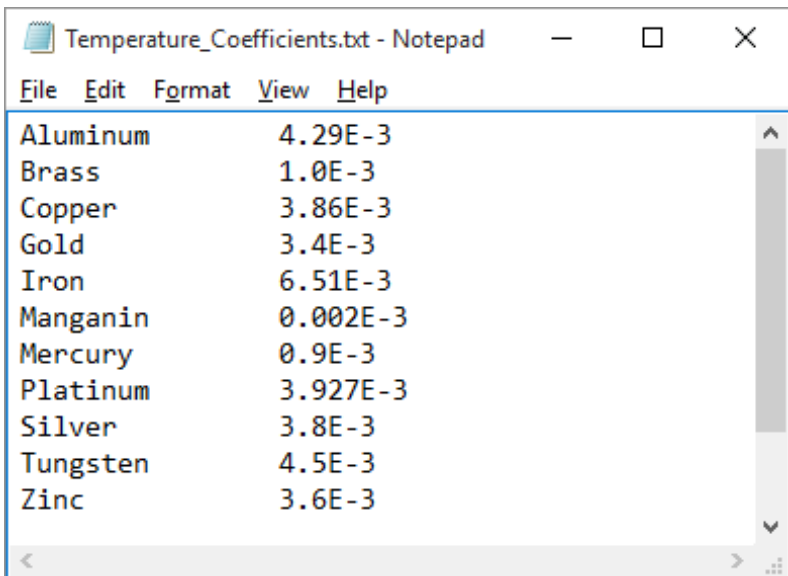
Resistivity_Coefficients.txt - Notepad

Material	Resistivity ($\Omega\cdot\text{m}$)
Aluminum	2.65E-8
Brass	7.5E-8
Copper	1.68E-8
Gold	2.4E-8
Iron	9.71E-8
Manganin	4.82E-7
Mercury	9.8E-7
Platinum	1.06E-7
Silver	1.59E-8
Tungsten	5.6E-8
Zinc	5.5E-8



AWG_Table.txt - Notepad

AWG Size	Wire Diameter (mils)
0	324.9
1	289.3
2	257.6
3	229.4
4	204.3
5	181.9
6	162.0
7	144.3
8	128.5
9	114.4
10	101.9
11	90.74
12	80.81
13	71.96
14	64.08
15	57.07
16	50.82
17	45.26
18	40.30
19	35.89
20	31.96
21	28.46
22	25.35
23	22.60
24	20.10
25	17.90
26	15.94
27	14.20
28	12.64
29	11.26
30	10.03
31	8.928
32	7.950
33	7.080
34	6.305
35	5.615
36	5.000
37	4.453
38	3.965
39	3.531
40	3.145



Temperature_Coefficients.txt - Notepad

Material	Temperature Coefficient ($1/^\circ\text{C}$)
Aluminum	4.29E-3
Brass	1.0E-3
Copper	3.86E-3
Gold	3.4E-3
Iron	6.51E-3
Manganin	0.002E-3
Mercury	0.9E-3
Platinum	3.927E-3
Silver	3.8E-3
Tungsten	4.5E-3
Zinc	3.6E-3

Program Requirements:

1. Write a program that will read the three data files provided above (and on the course website) to find the resistivity, wire diameter, and temperature coefficient in order to calculate the wire resistance. The program should provide the user with two options:

Option 1: Find the resistance of a wire where the user specifies the following:

- Material
- Wire length (in m)
- Wire gauge (0-40)
- Temperature (in °C)

Option 2: Find the resistance of a wire over a range of temperatures (with temperature and resistance values stored in arrays) where the user specifies the following:

- Material
- Wire length (in m)
- Wire gauge (0-40)
- Initial Temperature (in °C)
- Final Temperature (in °C)
- Temperature increment (in °C)

Additionally, if the user selects Option 2, the user should be given two additional choices:

Option 2A: Show a formatted table of Temperature and Resistance values on the screen

Option 2B: Send the temperature and resistance values to a *commas-delimited file* so the file can be opened with Excel to produce a nicely formatted table and a nicely formatted graph of resistance versus temperature. The user should be prompted to enter the name of the output file where the data is to be stored.

2. Use functions for at least the following:
 - a) Calculate resistance
 - b) Convert wire diameter in mils to **area in square meters**
 - c) Convert a string to all lower case letters except for the first letter which should be converted to upper case. For example, if the user enters copper, COPPER, or CoPpEr, it should be converted to Copper.
3. If Option 2 is selected above, use arrays to store the values of temperature and resistance. The arrays should be dimensioned for a max value of 100 points. The actual number of points depends on the initial temperature, final temperature, and temperature increment.
4. The program should check for bad inputs and allow the user to correct the inputs.
5. The program should produce error messages if it can't open any of the three input data files.
6. Allow the user to enter the name of the output data file.
7. Give the user the option of re-running the program.
8. Include printouts of the program, all input data files, all output (commas-delimited) data files, all Excel tables, and all Excel graphs with your program.

(continued)

9. Run the program for the following test cases. Note that Test Cases 1, 2, and 6 correspond to examples provided.

Test Case	Option	Material	Wire length (m)	Wire gauge	Temp (°C)	Initial temp (°C)	Final temp (°C)	Temp increment (°C)
1	1	COPPER	10	24	20			
2	1	copper	10	24	100			
3	1	Gold	2.5	32	50			
4	1	ZINC	0.1	18	150			
5	2A	Copper	100	10		20	200	10
6	2B	Copper	10	24		20	260	20
7	2A	SILVER	25	40		50	250	10
8	2B	ALUMINUM	50	14		0	300	25

Extra Credit Suggestions: (for a maximum of 10 additional points on the program grade)

1. Allow the user to select the units to be used (e.g., wire length could be in cm, ft, or in and temperature could be in °C, °F, or K). The output display should still use wire length in m and temperature in °C. Test the program using inputs that are equivalent to one or more of the test cases specified.
2. Instead of using arrays, use the *vector class* in the Standard Template Library to store the values of temperature and resistance. Determine and specify the vector size after the user enters initial temperature, final temperature, and increment.
3. Instead of using two single-dimensional arrays for temperature and resistance, use a two-dimensional array.
4. Give the user the option of adding additional materials to Resistivity_Coefficients.txt and Temperature_Coefficients.txt by appending the new information to the current files. The materials entered should be commonly used materials with correct coefficients. You can find values for the coefficients online. Run an example (Option 1) using one of the new materials.
5. Use your imagination!