Math Skills Laboratory

Lab 11 MS 4

MATH ACTIVITY

Activity: Solving Problems That Involve Thermal Transducers

MATH SKILLS LAB OBJECTIVES

When you complete these activities, you should be able to do the following:

1. ***Solve problems that involve the selection and use of thermal transducers.***
2. ***Rearrange equations and substitute correct units to solve for an unknown quantity.***

LEARNING PATH

1. ***Read the Math Skills Lab. Give particular attention to the Math Skills Lab Objectives.***
2. ***Work the problems.***

ACTIVITY

Solving Problems That Involve Thermal Transducers

MATERIALS

For this activity, you'll need a pencil, paper and a calculator.

DISCUSSION

In this lab, you'll practice solving problems that involve thermal transducers. The problems are similar to those a technician might meet while troubleshooting a thermal system. They're also the type of problems technicians face when they select thermal transducers for a new system.

Thermal transducers are used in many ways, and there are many different types available. Knowing about transducer characteristics such as ***sensitivity, linearity*** and ***temperature range*** (usually spelled out on the specification sheet) is important. Understanding these characteristics will help you choose the right transducer for the right job.

PRACTICE EXERCISES

Solve the following problems.

Problem 1: The electrical resistance of thermistors (devices constructed of semiconductor materials) ***decreases*** with an ***increase*** in temperature. They're often used in the temperature probes that are part of a solid-state thermometer.

Given: A thermistor probe used with an oral thermometer has the following data on its specifications sheet.

Sensitivity: 30 mV/C°
Linear Accuracy: ±0.1% from 0°C to 100°C
Resistance: 2250 Ω at 25°C
Voltage: 1406 mV at 25°C

Find:

a. The current flowing in the thermistor at 25°C, with voltage and resistance as given on the specification sheet.
b. The resistance of the thermistor when it shows normal body temperature (37°C). (To solve this part, assume that the solid-state thermometer works as a ***constant-current*** device. That means that the voltage and resistance change in step, as the temperature increases or decreases. The current remains at the constant value calculated for Part "a" of this problem.)

Solution:

a. ***Hint:*** Use Ohm's law ($I = V/R$) to find I.
b. ***Hint:***
   1. First, use the data from the specification sheet to find the change in voltage ($\triangle V$) as the temperature increases from 25°C to 37°C. (Think carefully about whether the voltage will increase or decrease.)
   2. Then use the change in voltage ($\triangle V$), the constant current (I) from Part "a," and Ohm's law ($\triangle R = \triangle V/I$) to find the change in resistance ($\triangle R$). (Does the resistance increase or decrease?)

Problem 2: The resistance-temperature detector (RTD) used by industry is a 99.9%-pure platinum wire that's wound around a ceramic or glass core. It's sealed within a glass or ceramic capsule. It works on the principle of change in electrical wire resistance as a function of temperature. For this device as temperature ***rises*** the resistance ***increases.*** (Note that this is opposite from the way a thermistor behaves.)

Given: The plastic extruder—shown in the video making plastic keyring tabs—uses RTD probes in the 0°C to 300°C range. The RTD probes control the temperature of the zone heaters that melt the plastic for extrusion. At a temperature of 0°C, the RTD resistance is 100 Ω. At 200°C, the RTD resistance is 161.5 Ω.

Find:

a. The RTD resistance that the zone-heater control responds to at a temperature of 482°F (250°C). (Assume that the response of the RTD is ***linear*** over the entire temperature range from 0°C to 300°C. This will allow you to plot temperature versus resistance on a graph and read the resistance at 250°C from the curve directly. Use the two data points given above to plot the straight line.)

b. The RTD resistance at 152°C. Remember that the resistance increased from 100 Ω at 0°C to 161.5 Ω at 200°C. That's a difference of 61.5 Ω for a 200-C° temperature range. Remember also that the RTD operates as a ***linear*** device. (Use the graph only to check the ***"Calculations."***)

Solution:

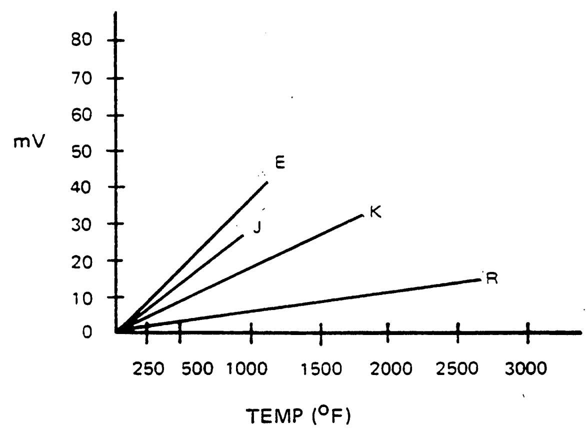
Problem 3: Thermocouples made of unsheathed, beaded-junction, fine wire have many uses in biophysics, metal cutting, scientific instruments, internal combustion engines, calorimetry, thermoelectric cooling and other areas. The voltage and temperature range is determined by the wire material that's used to make the thermocouples. The graph shown gives output voltage (mV) versus junction temperature difference for different thermocouples. The American National Standards Institute (ANSI) symbols for each thermocouple are given below the graph. The table shows maximum service temperatures for various wire sizes of different thermocouple types.

Given: Data in graph and table.

Find:

a. The ***type*** and ***size(s)*** thermocouple to use for a voltage response to temperature change in the 500°F to 1000°F range.
b. The thermocouple to choose for temperatures from 0°F to 2500°F.
c. The sensitivity of a type-E thermocouple (from the graph) in mV/F°.
d. Which type of thermocouple is a good all-around choice and why.

Solution:



MAXIMUM SERVICE TEMPERATURE

Thermocouple	Wire Diameters (in inches)			
Type	0.005	0.015	0.020	0.032
J	600 °F	700 °F	700 °F	900 °F
K	1100	1600	1600	1800
T	400	400	400	500
E	700	800	800	1100
R,S	— —	— —	2642	2642

Problem 4: Given: A certain type thermocouple has a sensitivity (voltage out/temperature difference) of $k = 50\ \mu V/C°$. The voltage generated equals the thermocouple sensitivity times the temperature difference between junctions. (Voltage Out $= k \times \triangle T$)

Find: The voltage generated when the thermocouple junctions are at temperatures of 20°C and 100°C.

Solution:

Problem 5: Given: A solid object expands in size in proportion to its temperature. The new length can be predicted from the following equation:

$$\ell_{final} = \ell_{original}\,(1 + \tau \times \triangle T)$$

where: ℓ = length

τ = the thermal coefficient of linear expansion for a particular material

T = temperature

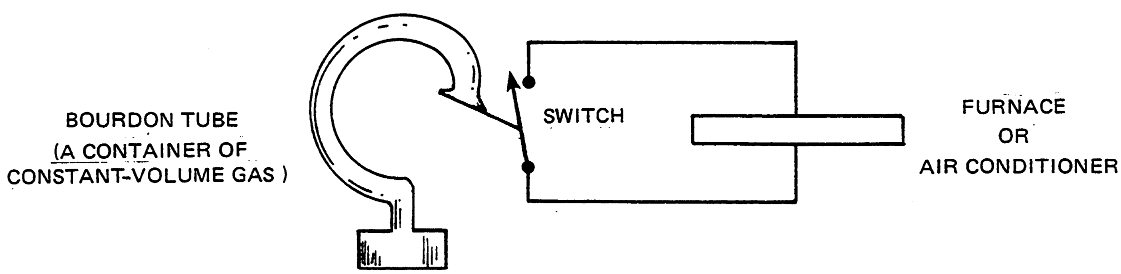
$\triangle T = T_{new} - T_{original}$

Find: The new length of an aluminum rod 20 cm long after it's heated from 20°C to 100°C. The thermal coefficient of linear expansion for aluminum is $25 \times 10^{-6}/C°$, and the original length of the rod is 20 cm at 20°C.

Solution:

Problem 6: Discussion—A "gas thermostat" is a thermal transducer that opens and closes a set of electrical contacts when the pressure of the confined gas reacts to temperature changes.

If a gas is kept in a container at constant volume, and only the pressure and temperature are allowed to vary, the ratio of gas pressure and temperature is a constant (C) expressed by $C = P_1/T_1 = P_2/T_2$. Here, the subscript "1" indicates absolute pressure and temperature in °K in state 1. Subscript "2" indicates the same values in state 2 of the gas. Temperatures in degrees Kelvin (°K) can be found by simply adding 273.15 to the temperature in degrees Celsius. That is, °K = °C + 273.15.



Given: The gas in a constant-volume gas thermostat has a pressure of 120 psi at a temperature of 20°C (state 1).

Find: The pressure of the same gas at 100°C (state 2).

Solution: First, convert temperature in °C to °K. Then use the ratio, $P_1/T_1 = P_2/T_2$, to solve for "P_2."