Thermal Expansion

Name: Terence Henriod

Partner’s Name: .

TA’s Name: Justin Wojdula

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**Objective**: The coefficients of linear thermal expansion will be found for copper, aluminum, and steel. This will be accomplished by heating metal rods of these materials with steam, and recording the length and electrical resistance measurements of the rods before and directly after heating. The proportionality of electrical resistance and temperature will be used to determine the change in temperature of the rods. This data will then be used to find the coefficients of linear thermal expansion. Because these materials are isotropic, finding the length expansion coefficient should produce the same result for the general coefficient.

**Theory**

Thermal energy is the vibrational kinetic energy of particles. As a particle gains more thermal energy, its vibration becomes more rapid and forceful. When particles vibrate faster, they push more forcefully on each other and the walls of their container and will either occupy a larger area than they would normally with less energy, or exert a higher pressure on the walls of their container if the container is unyielding; whatever may be the case. This freedom they gain with energy, of course, is with respect to the current state of matter they occupy: solid and liquid states only allow for small amounts of increased freedom, while gases either disperse more quickly to occupy a container or exert increased pressure on the walls of the container. The obligatory measure of the average thermal/kinetic energy of the particles in a body of material is temperature.

Of particular interest to this experiment is the discussion of increasing temperature in solid objects. With increased temperature and the particles of a solid object vibrating more quickly, the particles are still held relatively tightly by the forces binding them together as a solid; thus crystalline arrangements are maintained. However, the particles are harder to hold together due to this increased vibrational energy, and the crystalline structure is somewhat degraded as the particles are forced apart. As the particles push apart from one another, they create more separation between themselves, and at the scale of the entire object this can be observed as expansion: the object will grow in volume with increased temperature.

In general, the changes in dimensions of an object are proportional to the change in an object’s temperature (provided that a phase change does not occur and the change in temperature is relatively small), as modeled by the following equation:

[1]

where ΔX and X are the change in the dimension of the object being and the original value of that dimension being observed in meters, α is the coefficient of linear expansion for the material in inverse Kelvin, and ΔT is the change in temperature of the object measured in Kelvin.

How the object expands depends on the molecular structure of the material. Some materials, such as asymmetrical crystals, will expand in different dimensions at different rates. In these cases, the material may have a different coefficient α for each axis. There is a class of materials that are known as isotropic, whose molecular structure is such that thermal expansion occurs at the same rate along all axes. Because these materials will be easier to work with, we will be using such materials in our experiment; though it should be noted that because we are only measuring length expansion, we could probably use other materials as well and simply state that we will only be defining the coefficient of thermal expansion for one axis.

It should also be noted, that just as different materials are easier to heat or cool than others (in terms of specific heat or heat capacity measures), different materials will expand or contract at different rates than other materials; coefficients of thermal expansion are not universal.

Because change in temperature will be measured indirectly, through the use of evaluating electrical resistance, it will be important to discuss electrical theory as well as thermodynamic theory.

Electrical current is the flow of electrons through a material. Conductive materials are usually considered such because electrons encounter little resistance as they flow through the material, and this is due to orderly crystalline structures and arrangements of the constituent molecules. This orderly arrangement allows for electrons to flow through the material easily, encountering little resistance as they do not need to navigate a disorderly path past the constituent molecules (or nuclei of the constituent atoms), thus avoiding collisions. An insulator inhibits the flow of electrons because its structure presents resistance to the flow of electrons. However, as mentioned earlier, as a material is heated, its orderly structure may degrade somewhat, thus presenting more resistance to electron flow. It should be noted that electrical flow can cause this heating, but for the purposed of this experiment, the heating of the material will be done externally. By measuring the electrical resistance of a material, we can determine its temperature:

[2]

where R is the observed resistance in ohms, R0 is the resistance of the material at 0˚ C, β is the temperature coefficient of resistance for the material, and T is the observed temperature of the material. While we will not be using this equation directly, we will be referring for a table that pairs resistance and temperature values for an intermediate material for the experiment.

**Procedure**

This experiment requires the following materials: a thermal expansion apparatus for holding and heating metal rods, three metal tubes: copper, aluminum, and steel; a foam insulator, thermoplastic tubing, a steam generator, banana plug patch cords, a voltmeter for measuring electrical resistance, a meter stick for measuring the length of the rods, and a wooden block or wedge to prop up the thermal expansion apparatus.

The following procedure will be repeated for each rod.

First the length of the rod/tube will be measured with the meter stick and recorded. Then the tube will be mounted into the thermal expansion apparatus, fixed so that one end is secured against the spring arm of the dial gauge (used to make precise length measurements). The other end will be fitted to the THERMISTOR lug, and the foam insulator will be placed over the lug. Then the patch cords will be used to connect the voltmeter to the THERMISTOR, and the initial resistance will be measured and recorded. Next, the steam generator will be attached to the tube at the end opposite the dial gauge via the tubing. The block/wedge will be used to prop the apparatus up on one end so that if any steam condenses, the water will drain out. The dial gauge will then be zeroed. Finally, the steam generator is turned on, and the tube is warmed until the resistance reading on the voltmeter stabilizes. The change in length is obtained from the dial gauge, the resistance of the THERMISTOR is obtained from the multimeter, and these observations are recorded. The observations are then used to compute the coefficient of linear thermal expansion for the material of the metal tube. The THERMISTOR resistance-temperature conversion table is used to find the change in temperature.