Workshop Tutorials for Introductory Physics

Solutions to TI1: **Temperature**

A. Review of ideas in basic physics.

Temperature

We often talk about objects being hot or cold. But hotness or coldness are relative and are not very accurate descriptors. A more accurate way of defining the hotness or coldness of an object is to measure its **temperature**. To illustrate this point, consider what you feel when you step barefooted from a tiled area onto a carpeted area of a floor. The carpet will feel **warmer**, especially on a cold day. Yet common sense should tell you that they are both at the same temperature.

To measure temperature we use a **thermometer**. Thermometers contain some material with a property that is dependent on temperature. For example, the thermometer may contain a liquid such as mercury which expands with increasing temperature and moves up a scale. Many **digital** thermometers have a sensor made of a material whose electrical resistance varies with temperature.

Most importantly, if the thermometer is to read exactly the temperature of an object it must be in thermal **equilibrium** with that object. If two objects are in thermal equilibrium then there is no **nett** flow of thermal energy between them. It is important to leave the thermometer in contact with the object whose temperature is to be measured for a long enough period of time until thermal equilibrium is reached.

We encounter temperature in everyday usage measured on a range of temperature scales. For example the Celsius scale is established by taking two fixed points; zero degrees, the **freezing** point of **water** and 100 degrees, the **boiling** point of water, and dividing the interval between into 100 equal divisions. In physics we use the Kelvin scale. On this scale 0 K equals minus 273.15 ^{o}C; room temperature is **298 K** (often rounded to 300K) on the Kelvin scale.

B. Activity Questions:

1. Thermometers

A liquid in glass thermometer uses the thermal expansion of a liquid to measure temperature. The scale is calibrated to read the temperature as a function of the volume of the liquid. There are also thermometers which use the thermal expansion of a gas, which results in increasing the pressure of the gas if the volume of the gas is fixed. The pressure then tells you the temperature. These are called constant volume gas thermometers.

Digital thermometers use a change in electrical resistance with temperature. There are two types – those that have an increasing resistance with increasing temperature, and those that have a decreasing resistance with increasing temperature. The change in resistance is determined by the material the sensor is made out of.

2. Thermal Expansion of gases

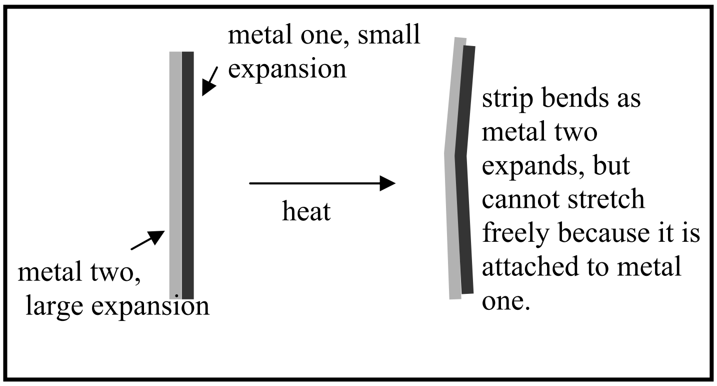
The heat from your hands causes the gas inside the bottle to expand, increasing the pressure inside the bottle. When the force due to the pressure of the gas is greater than the weight of the coin it pops off.

3. Thermal Expansion of liquids

The heat from your hands causes the liquid to expand. As it cools it contracts again. This is how a typical liquid in glass thermometer works.

4. Thermal Expansion of solids - bimetallic strip

The bimetallic strip is made of two metals, one of which expands much more than the other when they are heated. A bi-metallic strip can be used as a sensor because the two metals which make up the strip expand at different rates. When they start to get hot, the strip will bend, and can be used as a switch which either closes or opens a circuit as it bends to or away from a contact. A single strip would expand, but not bend in this way.



C. Qualitative Questions:

1. Measuring temperature.

a. A medical mercury-in-glass thermometer relies on the expansion of mercury up a fine (bore) tube as temperature increases. Digital thermometers, like those found in a car, are more robust and are part of an electrical circuit. The physical property that varies with temperature in most types of digital thermometer is electrical resistance.

b. The mercury in glass thermometer is extremely accurate and so can be used to measure body temperature accurately. Digital thermometers are often used where remote sensing is needed. The electrical signal can be fed into a computer from a remote terminal

c. A thermometer has to be held in the mouth long enough to allow the thermometer to come to thermal equilibrium with your body. When it is inserted it will be at room temperature.

2. A farmer is stringing a wire fence in the middle of the day. He makes it nice and tight so that his cows can't push through it. That night all the wires break.

a. The wires break because they contract and get shorter when they cool off. If the force pulling them is great enough and the change in temperature is large, they will break.

b. Pouring hot water over a jar can make the lid easier to take off. Both the jar and the lid are being heated, but metal expands more than glass for a given temperature increase, so the lid expands more than the jar and loosens. Plastic also has a higher coefficient of expansion than glass, so running hot water over jars with plastic lids works as well as over metal lids.

C. Quantitative question:

You fill your petrol tank with 50 L of petrol [full] in the morning when the temperature is 20^{o}C. The car is left in the Sun and the temperature, in the car, rises to 55^{o}C.

a. We can use $\beta = (\Delta V)/(V\Delta T)$.

We know $\Delta T = 55^oC - 20^oC = 35\ ^oC$, and $\beta = 0.95\text{x}10^{-3}\ C^{-1}$. Rearranging for ΔV gives:

$\Delta V = \beta\, V\, \Delta T = = 0.95 \times 10^{-3}\ C^{-1} \times 50\ l \times 35^oC = 1.7\ l$

b. At 98 ¢/litre, you've wasted 1.7 l × 98 ¢/litre = \$1.63. You've also spilt petrol down the side of the car, which is bad for the paint, and left a flammable, toxic puddle on the ground!

Note that the tank will also expand, but the coefficient of expansion for steel is $\alpha \sim 1 \times 10^{-5}\ C^{-1}$, so the expansion of the tank would be smaller than that of the fuel, and give an overestimate of only around 6 ¢ in the answer to part **b**.