Name and student number:

Group members:

Physics 157 Tutorial 1 – Temperature and Thermal Expansion

In this tutorial, you will get some practice thinking about thermometry and the thermal expansion of materials.

You will work in groups of three or four, but each person should complete their own worksheet to hand in. Your worksheet will be graded for participation credit. You are not required to finish everything on the worksheet. You should show your work.

Ask the TA to come to your group if you are stuck.

Important formulae:

Temperature is proportional to pressure for an ideal gas: T/P = constant

Linear expansion due to temperature change: $\Delta L_{th} = \alpha L \Delta T$

Volume expansion: $\Delta V = \beta V \Delta T$ $\beta = 3\alpha$ for solids

Question 1: A spherical container has a constant volume, is filled with an ideal gas, and has a pressure gauge showing the pressure in the gas. The container is placed in a tub of water and after a long time the pressure gauge shows a pressure of 100 kPa and the water temperature is 50°C. You decide to add some ice to the tub of water. After a long time, the pressure gauge now reads a pressure of 80 kPa. The temperature of the gas in the spherical container is closest to:

- 40°C
- -40°C
- 14°C
- -14°C
- not enough information to tell

$$\frac{P_1}{T_1} = \frac{P_2}{T_2}$$

$$\frac{100}{(50 + 273.15)} = \frac{80}{T_2}$$

$$T_2 = 258.5\,K = -14.6℃$$

Question 2: At a temperature of 20 degrees Celsius, you use a steel ruler to measure the length of a brass rod and find it to be 20.00 cm. What would you measure the length of the brass rod to be using the same ruler if both the rod and the ruler are at a temperature of 270 degrees Celsius?

The coefficients of linear expansion for brass and steel are $\alpha_b = 2.0 \times 10^{-5}\ K^{-1}$ and $\alpha_s = 1.2 \times 10^{-5}\ K^{-1}$, respectively.

- 20.10 cm
- 20.02 cm
- 19.96 cm
- 20.04 cm
- 20.06 cm

The length of the brass rod and the steel ruler will both increase due to thermal expansion as given by

$$L_b = L_{bo}(1 + \alpha_b \Delta T) \quad (1)$$

$$L_s = L_{so}(1 + \alpha_s \Delta T) \quad (2)$$

The length, L_{bm}, measured for the brass rod by using the steel ruler, is given by

$$L_{bm} = \frac{L_b}{L_s} L_{so} \quad (3)$$

Inserting (1) and (2) into (3) gives

$$L_{bm} = \frac{L_{bo}(1+\alpha_b \Delta T)}{L_{so}(1+\alpha_s \Delta T)} L_{so} = L_{bo} \frac{(1+\alpha_b \Delta T)}{(1+\alpha_s \Delta T)} \quad (4)$$

Evaluating this expression for the given parameters gives L_{bm} = 20.04 cm.

Question 3: The length of one side of an aluminum cube is 1.0 m at a temperature of 20°C. The coefficient of linear thermal expansion of aluminum is 13 x 10^{-6} K^{-1}. The change in volume of the cube when it is heated to a temperature of 40°C is closest to:

- 1.3 x 10^{-4} m^3
- 2.6 x 10^{-4} m^3
- 3.9 x 10^{-4} m^3
- 5.2 x 10^{-4} m^3
- 7.8 x 10^{-4} m^3

$$\Delta V = \beta V \Delta T$$
$$\beta = 3\alpha$$
$$\Delta V = 3x13x10^{-6}x1x20 = 7.8x10^{-4}m^3$$

Question 4: To help raise money to buy Mastering Physics codes, you and some friends decide to sell bottles of home-made kombucha in 0.4 L glass bottles for $3.50 each at the Totem Park cafeteria. You have 500 full bottles of kombucha stored at 4.0°C. You are originally planning to sell it chilled, but after attending the first few Physics 157 lectures and looking up the thermal expansion coefficients of kombucha ($\beta_{kombucha}$ = 34.2 x 10^{-5} K^{-1}) and glass (α_{glass} = 5.4 x 10^{-6} K^{-1}), you realize that if you dump out all the kombucha into a big container and then re-fill bottles in the cafeteria (at 26.0°C) to sell warm, you'll make more money. If it costs you $0.50 for each extra glass bottle, how much extra money will you make this way?

Both kombucha and glass expand. The volume of the bottles expands at the same rate as the volume of the glass itself. We have

$$\Delta V_{bottle} = \beta_{glass} V_o \Delta T \qquad (1)$$

where

$$\beta_{glass} = 3\alpha_{glass} \qquad (2)$$

Also:

$$\Delta V_{kombucha} = \beta_{kombucha} V_o \Delta T \qquad (3)$$

Here V_o is 500 x 0.4 L = 200 L for both, and ΔT = 22.0°C.
The excess kombucha at 26.0°C is then:

$$\Delta V_{bottle} - \Delta V_{bottle} = \left(\beta_{kombucha} - 3\alpha_{glass}\right) V_o \Delta T \qquad (4)$$

$$= (32.6x10^{-5}K^{-1}) \cdot 200L \cdot 22K \qquad (5)$$

$$= 1.43\,L \qquad (6)$$

So, you can fill three extra bottles with the extra (with a little left over). This gives you a net excess profit of $3 per bottle, or $9 total extra profit. Good work!