Name: Group member names:
Student number:

Physics 157 Tutorial – week of September 17th

In this tutorial, you will get some practice with some of the main ideas from last week's lectures: temperature scales, the constant volume gas thermometer, and thermal expansion of materials. One of the main goals is to help you learn to solve problems where you need to take into account thermal expansion of different materials – these are important for practical applications and also show up on your homework due next week. **Work in groups of three or four, but hand in your own worksheet,** to be graded for participation credit. You are not required to finish everything on the worksheet. Show your work.

Question 1: A 200 liter tank of nitrogen gas is at 1.00 atm pressure at 20°C. Approximately what is its pressure at 40°C?

A) 0.50 atm B) 0.93 atm C) 1.07 atm D) 2.00 atm

Your TA will ask this as a clicker question.

Pressure at fixed volume is proportional to Kelvin temperature.

So: $\frac{P_2}{P_1} = \frac{T_2}{T_1} = \frac{313}{293} \approx 1.07$ Thus $P_2 = 1.07 \cdot P_1$
$= 1.07$ atm

Question 2: At 20°C, a spherical steel ball has diameter 1.001cm and sits on a 1.000cm wide circular hole in a copper plate, not quite fitting through. If the ball and plate are heated together, at roughly what temperature will the ball fall through the plate? ($\alpha_{steel} = 1.2 \times 10^{-5}\ K^{-1}$ and $\alpha_{copper} = 1.7 \times 10^{-5}\ K^{-1}$)

A) 40°C B) 100°C C) 200°C D) 220°C E) 280°C

Your TA will ask this as a clicker question. See the hint on page 4 if you are stuck.

We need the change in hole diameter ΔL_{hole} to be larger than the change in ball diameter ΔL_{ball} by 0.001cm. The hole expands in proportion to the expansion in material. We have:

$$\Delta L_{hole} = \alpha_c \cdot (L_{hole})_0 \cdot \Delta T$$
$$\Delta L_{ball} = \alpha_s \cdot (L_{ball})_0 \cdot \Delta T$$

So we need $\Delta L_{hole} - \Delta L_{ball} = (\alpha_c L_{hole} - \alpha_s L_{ball}) \cdot \Delta T = 0.001$cm

$\Rightarrow 0.5 \times 10^{-5} K^{-1} \cdot 1\text{cm} \cdot \Delta T = 0.001\text{cm} \Rightarrow \Delta T \approx 200°C.$

So the ball will fall through at 220°C.

Question 3: To help raise money to buy Mastering Physics codes, you and some friends decide to sell bottles of home-made kombucha in 0.4L 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 \times 10^{-5}\ K^{-1}$) and glass ($\alpha_{glass} = 5.4 \times 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?

See the hints on page 4 if you are stuck.

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

$\Delta V_{bottles} = \beta_{glass} V_0 \cdot \Delta T$ where $\beta_{glass} = 3\alpha_{glass}$.

Also: $\Delta V_{kombucha} = \beta_{kombucha} \cdot V_0 \cdot \Delta T$.

Here V_0 is $500 \times 0.4L = 200L$ for both, and $\Delta T = 22°C$.

The excess kombucha at 26°C is then:

$$\Delta V_{kombucha} - \Delta V_{bottles} = (\beta_{kombucha} - 3\alpha_{glass}) \cdot V_0 \cdot \Delta T$$
$$= (32.6 \times 10^{-5} K^{-1}) \cdot 200L \cdot 22K$$
$$= 1.43\ L$$ (with a little left over)

So you can fill three extra bottles with the extra 1. This gives you a net excess profit of $3 per bottle, or $9 total extra profit. Good work!

Question 4: Wendy runs a YouTube channel where she posts videos in which she floats various things on a pool of mercury. She has 487,214 subscribers, but that is not relevant to this question. Wendy doesn't like it that her pool of mercury changes depth due to thermal expansion of the mercury and the container, so she hires you to build a rectangular container out of some material so that the depth of the mercury is the same regardless of temperature. What coefficient of linear expansion α does such a material need to have? ($\beta_{mercury} = 18 \times 10^{-5}\ K^{-1}$)

See the hints on page 4 if you are stuck.

The volume V of the mercury is related to the depth d and the container area A by: $V = d \cdot A$. If the depth remains constant, we must then have:

$$\Delta V = d \cdot \Delta A \quad (*)$$

Also $\Delta V = \beta_{mercury} \cdot V_0 \cdot \Delta T$, while for a material with linear expansion coefficient α, we have $\Delta A = (2\alpha) \cdot A_0 \cdot \Delta T$. The relation $(*)$ then gives

$$\beta_{mercury} \cdot V_0 \cdot \Delta T = d \cdot (2\alpha) A_0 \cdot \Delta T = 2\alpha \cdot V_0 \cdot \Delta T$$

Solving for α, we have:

$$\alpha = \frac{\beta_{mercury}}{2} = 9 \times 10^{-5}\ K^{-1}$$

Hints: wait until you are stuck before using the hints, then try them one at a time.

For each hint, write the missing letters in the blank spaces, in order. For example: putting p,y,c,t,r,l in __h__si__s __uto__ia__ in gives “physics tutorial”

Hint for question 2:

missing letters: t, m, t, r, c, g, w, c, d, r, d, t, r, c

Hint: For a __te__mpera__tu__r__e __c__han__g__e ΔT, ho__w__ mu__c__h does the __d__iffe__r__ence in __d__iame__t__e__r__ __c__hange?

Hint 1 for question 3:

missing letters: h, m, c, v, m, b, l, s, c, g, x, n, g, a

__h__ow __m__u__c__h will the __v__olu__m__e of the __b__ott__l__e__s__ __c__han__g__e due to the e__x__pa__n__sion of __g__l__a__ss?

Hint 2 for question 3:

Missing letters: m, n, x, r, b, l, f, x, e, v, l, e, k, b, a

How __m__a__n__y e__x__t__r__a __b__ott__l__es can you __f__ill with the e__x__c__e__ss __v__o__l__um__e__ of __k__om__b__uch__a__?

Hint for question 4:

Missing letters: d, t, c, g, h, g, v, m, m, u, y, d, p, h, g, a, a, f, m

Assuming the __d__ep__t__h doesn’t __c__han__g__e, write a formula for the c__h__an__g__e in __v__olu__m__e of the __m__erc__u__r__y__ in terms of the __d__e__p__th and the c__h__an__g__e in __a__re__a__ of the __f__ra__m__e?