Question 1:

Idea:
Water is circulating through a closed system of pipes in a two-floor apartment. On the first floor, the water has a gauge pressure of 3.4×10^5Pa and a speed of 2.1 m/s. However, on the second floor, which is 4.0m higher, the speed of the water is 3.7m/s. The speeds are different because the pipe diameters are different. What is the gauge pressure of the water on the second floor?

Setup & solution

Here well need to use the Bernoulli equation and solve for P_2:

$$P_1 + \frac{1}{2}\rho v_1^2 + \rho g h_1 = P_2 + \frac{1}{2}\rho v_2^2 + \rho g h_2 \implies P_2 = P_1 + \frac{1}{2}\rho(v_1^2 - v_2^2) + \rho g(h_1 - h_2)$$

Plugging in numbers:

$$P_2 = (3.4\times10^5 \text{ Pa})+\frac{1}{2}(1000 \text{ kg/m}^3)((2.1 \text{ m/s})^2-(3.7 \text{ m/s})^2)+(1000 \text{ kg/m}^3)(9.81 \text{ m/s}^2)(0\text{m}-4\text{m}) = \boxed{296{,}120 \text{ Pa}}$$

Question 2

Because of differing measurement systems, every person should know how some basic information on temperature scales. Answer the following:

- **(a)** You're talking to your friend from India on the phone and they tell you its 4°C in New York City. **Without using a calculator** estimate what the temperature is in Fahrenheit. (you might need to do this one day in conversation)
- **(b)** Repeat (a) using a calculator
- **(c)** As of science in 2019, it is impossible for any observable matter to reach something called **absolute zero** ($T_k = 0$), what is this temperature in Fahrenheit?

Setup & solution

(a) The equation between Fahrenheit and Celsius is very straightforward expect the 9/5 part. Luckily 9/5 is roughly 2 so we just approximate it:

$$T_F \approx 2 * T_c + 32 \implies T_F \approx 2(4°C) + 32 = \boxed{40°C}$$

(b) Doing this calculation in the calculator"

$$T_F = \frac{9}{5} * T_c + 32 \implies T_F = \frac{9}{5}(4°C) + 32 = \boxed{39.2°C}$$

Which is really close with the approximation value!

(c) Absolute zero is when $T_K = 0$ so we need to convert between kelvin and Celsius, then from Celsius to Fahrenheit:

$$T_K = T_C + 273.15 \implies T_C = -273.15°C$$

$$T_F = \frac{9}{5} * T_c + 32 \implies T_F = \frac{9}{5}(-273.15°C) + 32 = \boxed{\text{-459.67}°F}$$

Question 3

A steel bridge is built in several segments, each 20 m long. The gap between segments is 4 cm at 18°C. What is the maximum temperature that the bridge can manage before buckling?

Setup & solution

Since we have segments thermally expanding, they technically expand in all three dimensions, but only one of those dimensions has the segments expanding into one another. So this is a **linear** thermal expansion problem where we solve for temperature when the segments touch (because any more expansion after the touching point is where they start to buckle). The last thing to note is that **each segment** will expand, meaning we need to consider only when they cover **half** the gap distance.

$$\Delta L = \alpha L_0 \Delta T = \alpha L_0 (T_f - T_0) \implies T_f = \frac{\Delta L}{\alpha L_0} + T_0 = \frac{(0.04m/2)}{(12 \times 10^{-6} \frac{m}{mK})(20m)} + (18°C) \approx \boxed{101.3\ °C}$$

Note: It's okay to use Celsius in the equation because if we converted them, the conversion factor cancels out. So either Celsius or Kelvin is fine here.

Question 4

The roof tiles of Van Allen are square and are often seen bent upward at the perimeter toward the sky (see figure below). They are seen to fit snug against one another with one side faced toward the sun and the other face against the lower temperature roof.

- **(a)** Offer a possible explanation as to why the tiles curve upward
- **(b)** If the dimensions of the tiles when brand new are (0.91m by 0.91m by 1.5cm) what is their volume?
- **(c)** The average daily temperature change in Iowa City is about 13°. If the tiles have a specific heat of $4 \times 10^{-5} \frac{J}{kgK}$, what is total change in volume of the top half of the tiles?

Setup & solution

(a) One face of the tiles are facing the sun while the other are not, which means one half of the tiles is getting hotter than the other half. So the sun-side half will expand faster than the lower half, thus the top half expands outward (and upward) and since it has nowhere to go it must go upwards!

(b) The tiles are square so:

$$V = \ell * w * h = \frac{1}{2}(0.91) * (0.91) * (0.015m) = \boxed{0.00621075 \ \ \mathrm{m}^3}$$

(c) Using the volume thermal expansion rate:

$$\Delta V = \beta V_0 \Delta T = (4 \times 10^{-5}\ \mathrm{K}^{-1})(0.00621075\ \mathrm{m}^3)(13K) = \boxed{3.22959\ \times 10^{-6}\ \mathrm{m}^3}$$

Question 5

A snow maker at a resort pumps 130 kg of lake water per minute and sprays it into the air above a ski run. The water droplets freeze in the air and fall to the ground, forming a layer of snow. If all the water pumped into the air turns into snow, and the snow cools to the ambient air temperature of -7.0C, how much heat does the snow-making process release each minute given the following:

$T_0 = 12.0°\text{C}$ (initial temperature of lake water)

$c_w = 2.00 \times 10^3 \text{J}/(\text{kg C})$ (specific heat of lake water)

$L_f = 3.33 \times 10^5 \text{J}/\text{kg}$ (latent het of fusion water)

Assume the temperature in the lake water is and use for the specific heat capacity of snow.(be careful of signs)

Idea:
When water freezes into ice/snow it needs to release heat i.e. remove heat from the system in order to cool down. The amount of heat needed to heat up/cool down a substance from an initial temperature is given by $Q = mc\Delta T$, but in order for the substance to undergo a phase change (water $\leftrightarrow$ ice) we need to lose $Q = mL_f$ amount of heat, where L_f is a constant called the latent heat of fusion. The final piece of information we need to understand is that **water** undergoes a phase change at 0°C. But that doesn't mean you suddenly get ice once the water is 0°C, that just means we cannot make the water go any lower in temperature before turning it into ice. To turn it into ice we need then to take the 0°C water and further remove $Q = mL_f$ amount of heat to turn all "m" amount of water to ice. The mathematics for this aren't too bad, but the concepts are the real meat of the problem.

Setup & solution

We find the amount of heat the water releases to go to 0°C:

$$Q = mc\Delta T \implies Q = (130 \text{ kg})(2 \times 10^3 \text{ J/kg}^\circ C)(0K - 12K) = -3,120,000J$$

Now we find the amount of energy needed to turn all the 0° water into ice:

$$Q = mL_f \implies Q = (-)(130 \text{ kg})(3.33 \times 10^5 \text{ J/kg}) = -43,290,000J$$

Next is to find the ice/snow heat loss required to get the snow to -7°C:

$$Q = mc\Delta T \implies Q = (130 \text{ kg})(2.09 \times 10^3 \text{ J/kg}^\circ C)(-7K - 0K) = -1,901,900J$$

The final step is to add up how much total energy we need to lose in order to achieve our final product:

$$Q_{total} = -3,120,000 - 43,290,000 - 1,901,900 = \boxed{\text{-48,311,900 J}} \text{ or } \boxed{-4.83 \times 10^7\text{J}}$$