Lab 5 Model Answers

When evaluating your work your values will differ. Check your answers reviewing the method; your process must be the same as these answers, and your calculated values for the mercury and for the water barometer should be close to those of the roof barometer unless your group had reading errors, or lots of water barometer bubbles. Usually, the mercury and roof barometers are the most similar, and the water barometer value is close. **Ask your instructor if you are not sure about any of your answers.**

1. **Calculate the water barometer's station pressure:** *Note, the water height and air temperature values below represent typical answers. Your values will vary with the conditions you experienced when you made your measurements.*

   Water barometer water column height = 9.300 m (record to the mm precision on the measuring tape)
   Water temperature = 19.0 ^{0}C (from the water bucket thermometer, which has 1^{0}C increments.)

   To obtain air pressure P_{air} from the water barometer use:

   $P_{air} = \rho_w \, g \, \Delta Z_w + e^*_{(T)}$

   where: ρ_w = 998.405 kg m^{-3} ← water density at 19.0 ^{0}C, obtained from the Table for the density of water at different temperatures in the lab)

   g = gravity = 9.80665 m s^{-2} ← needed precision for the mercury barometer calculation, use this gravity value for all calculations to increase precision)

   $e^*_{(T)}$ = 22 hPa ←from the Lab 4 saturation vapour pressure curve for water at 19.0 ^{0}C.

   ΔZ_w = 9.300 m ←height of the water column in my water barometer

   P_{air} = (998.405 kg m^{-3})(9.80665 m s^{-2})(9.300 m) + 22 hPa

   P_{air} = 91056.37806 kg m^{-3} m^2 s^{-2} + 22 hPa

$$P_{air} = \left(91056.37806 \frac{\text{kg m}^2}{\text{m}^3 \, s^2}\right) + (22\, hPa)\left(\frac{100\, Pa}{1\, hPa}\right)$$

$$= \left(93256.37806 \frac{\text{kg m}}{\text{m}^2 \, \text{s}^2}\right) + 2200\, Pa$$

$$= (93256.37806\, \text{Pa})\left(\frac{1\,\text{hPa}}{100\,\text{Pa}}\right) = 932.56\, hPa$$

   P_{air} = 932.56 hPa = 933 hPa (adjusted for sig figs)

← But, only pressures in the same units can be added together, so convert both pressure values to the same units. Your final answer should be in hPa.

Know when you have Pascals or hectoPascals. Learn to recognize basic and derived pressure units.

- Pascals (Pa) & hectopascals (hPa) are derived pressure units. Remember 1 hPa = 100 Pa .
- Basic pressure units are kg m^{-1} s^{-2} = 1Pa
  (If not simplified basic units are kg m^{-3} m^2 s^{-2} (or kg m s^{-2} m^{-2} to see these units as force per area)

Why? Pressure is defined as a Force (kg m s^{-2} or Newton - N) per Area (m^2). See coloured circles in the calculation.

Force = mass (kg) x acceleration (m s^{-2})

In the equation, the:

- basic units for pressure = (kg m s^{-2})(m^{-2}) = kg m^{-1} s^{-2}
- derived units for pressure = N m^{-2}
- more derived units for pressure = Pa (Pascals)

2. **Calculate the mercury barometer's station pressure:** Start by doing the temperature and then gravity corrections to your mercury column's height measurement. To do this you need correction multipliers for temperature from the barometer Tables provided in the lab and then follow the process in Fig.5.3.

   My mercury barometer instrument reading = 706.0 mm Hg

   - *determine the temperature correction factor:* (-0.003418)(706.0 mm) = -2.413 mm
   - *calculate the temperature corrected reading:* (706.0 + (- 2.413) mm = 703.6 mm Hg
   - *then determine the gravity correction factor:* (+0.000766)(703.6 mm) = +0.5390 mm
   - *Finally calculate the temperature and gravity corrected barometer reading:*
     (703.6 + 0.5390) mm = 704.14 mm = 0.70414 m ← *This is the corrected height of the mercury column in millimeters and meters.*

   Then convert the temperature and gravity corrected barometer reading (use the value in meters) into hectopascals (hPa) using the Hydrostatic Law. So, the mercury barometer station pressure, P_{air} is:

   $$P_{air} = \rho\, g\, \Delta Z = (13595.1 \text{ kg m}^{-3})(9.80665 \text{ m s}^{-2})(0.70414 \text{ m})$$

   $$= 93877.6 \text{ Pa} = 938.78 \text{ hPa}$$ (adjusted for sig figs)

3. **Compile your answer data**: *Station pressure is the pressure at a location, without adjusting for the location's elevation. In this lab, each pressure was measured by a barometer located at a different elevation. Consequently, some of the calculated pressure differences are caused by elevation (this is why Surface map pressures are adjusted to represent their elevation at sea level).*

Barometer type	Liquid column height	Temperature	Station Pressure
water	9.300 m	19.0 ^{0}C	932.56 hPa = 933 hPa
mercury	706.0 mmHg	21 ^{0}C	938.78 hPa

   If we want to compare our pressure measurements, we must account for and adjust our pressures for the elevation of each barometer.

4. **Comparing water and mercury barometer pressures:** The station pressure values reported in Question 3 (above) are ~6 hPa apart. But, the water and mercury barometers are on different floors. And each floor is about 5 meters high. As pressure decreases with height, the air pressure decreases about 0.5 hPa for every 5 meters of elevation increase.

   We want the water barometer and mercury barometer measurement to appear as if they were taken on the same floor. Given the floor heights (indicated above), we must subtract 0.5 hPa from the water barometer pressure to get the elevation adjusted water barometer result (this allows us to compare the mercury and water barometers.

   Mathematically, the water barometer's pressure, adjusted to the 2nd floor elevation is:

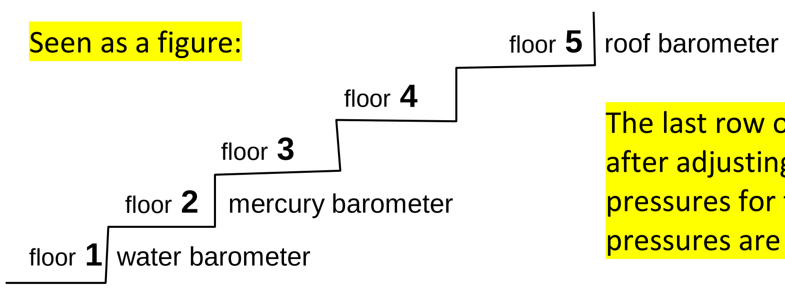
   932.56 hPa – 0.5 hPa = 932.06 hPa = 932 hPa ← *Note: This calculation uses the station pressure before it is rounded; & the final answer is rounded for significant figures.*

   The mercury barometer's pressure (unadjusted, as it is already on the 2nd floor) is: 938.78 hPa . These values are fairly close. *[Alternatively, we could have added 0.5 hPa to the mercury barometer* *reading (i.e. adjusted the mercury barometer's pressure to the values it would be if the mercury barometer was on the first floor; the Question 5 answers show this method.]*

5. **Comparing all 3 pressure values (water, mercury, & roof barometers):**
Similar to methods for previous questions, add the appropriate pressure correction. This will make the higher elevation pressure measurements appear as if they were made on the first floor.

	Water Barometer Pressure	Mercury Barometer Pressure	Roof Barometer Pressure
Station Pressure	932.56 hPa = 933 hPa	938.78 hPa	936.83 hPa
Location of the measurement	1^{st} floor	2^{nd} floor	5^{th} floor
Elevation difference from the first floor	No floors (0 meters or 0 hPa)	1 floor (5 meters or -0.5 hPa)	4 floors (20 meters or -2 hPa)
Elevation corrected pressure [0.5 hPa per floor. Values adjusted as if all the measurements are on the 1st floor]	932.56 hPa = 933 hPa (no change as this measurement was done on the first floor)	939.28 hPa = 939 hPa (938.78 + 0.5) hPa = 939.28 hPa	938.83 hPa = 939 hPa (936.78 + 2) hPa = 938.83 hPa

Seen as a figure:



The last row of the table (above) shows that after adjusting the mercury and roof barometer pressures for their elevation differences, the pressures are very close.

Note: Mercury barometers are used as a reference instrument for calibrating other electronic pressure sensors. The electronic UNBC Wx Stn. pressure sensor is a high quality device that is factory calibrated to be accurate within 0.5 hPa, but this needs checking /re-calibrating against a mercury barometer.

The bigger difference occurs between the water barometer and these two instruments (roof and mercury barometers). The sources of error discussed in question 6 may explain reasons for these differences.

6. **Error Sources:** The water barometer reading is one floor below the mercury barometer reading, so the water barometer should have a higher reading by 0.5 hPa. As this isn't the case, there must be water barometer errors that account for the discrepancy. These are best grouped as: human errors, instrument errors, and method errors.
   - Instrument errors:
     → dissolved gasses in the water came out of the water and lower the height of the water column in the tube resulting in a lower pressure reading
     → precision of the measuring tape
   - Method errors:
     → saturation vapour pressure values are approximated using saturation vapour pressure curves

- → dissolved gas in water cannot be kept in suspension and create bubbles in water column
- → Measuring the height of the water column is challenging as it must be read between the balcony railings /sometimes even between building floors. So, the water column is often viewed from above when a measurement is made, and this under appreciates the true water column's height.

- Human errors specifically affecting the water barometer are:
  - → Not measuring the height of the water column properly – not starting the measuring tape at the water surface; the water column may not have been vertical
  - → Incorrectly reading the temperature of the water: if the water temperature is not accurate, the density and the saturation vapour pressure values are affected
  - → Incorrectly reading table /graphed values, or incorrectly calculating the resulting pressure
  - → if the tube was raised too rapidly more gas escapes from the water, resulting in increased water bubbles in the tube affecting the column height

[Not asked for but consider errors with the other instruments such as:

- Instrument errors
  - → Vaisala (roof-top) barometer loses calibration over time and needs regular maintenance.
- Human errors
  - → Incorrectly reading any pressure sensor (mercury column height, barometer temperature, Vaisala (UNBC Wx Stn.) pressures)
  - → Incorrectly reading / not properly adjusting the mercury barometer (improperly setting the bottom or tope mercury levels)
  - → Incorrectly reading for graph /table values or incorrectly applying correction methods
  - → Forgetting to consider elevation differences for different barometer locations

7. **Other reasons mercury is used as the liquid in barometers:**

- Mercury has a much higher density so it creates a vacuum in the tube eliminating the need to use saturation vapour pressure, and having problems with dissolved gas in the water.
- It requires a much shorter length column (reading are in millimeters), so it is much more convenient to store, use, keep (rather than requiring about 10 meters for a water barometer).