Worksheet: Adiabatic gas expansion between two tanks

Name(s) ______________________________

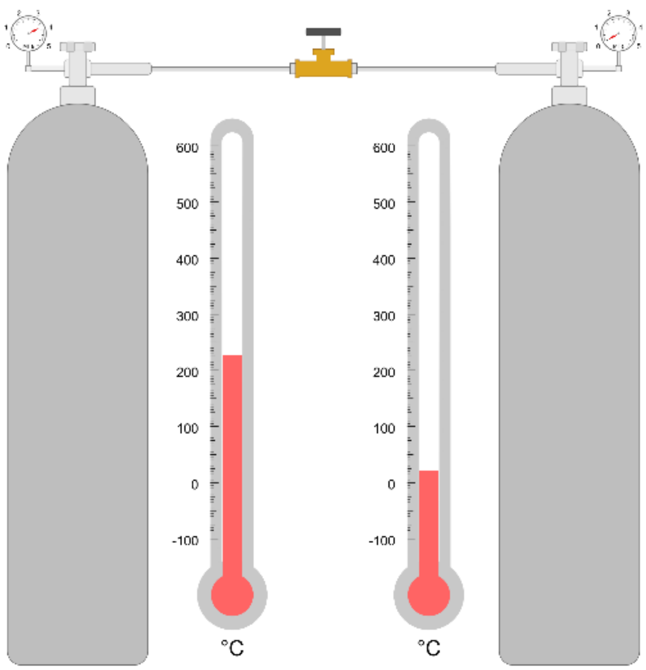
In this experiment, an ideal gas at high pressure in a tank expands adiabatically into a second tank that is under vacuum by opening a valve between the two tanks. The valve closes as soon as the pressure equalizes between the two tanks.

Student learning objectives

1. Be able to apply the ideal gas law.
2. Be able to do energy balances on a closed system.
3. Be able to do energy balances on an open system.
4. Be able to do mass balances.

Experimental Diagram

An insulated line that contains a valve connects the two tanks. Each tank has a valve, a pressure gauge, and a temperature sensor.



Assumptions

- The tanks and the line connecting them are well insulated.
- The volumes of the valves and the line connecting the tanks are insignificant.
- Gas expansion is fast so heat transfer from the gas to the tanks is insignificant, and thus the heat capacity of the tank material can be ignored.
- The gas is ideal, and it has a constant heat capacity C_P of 30. J/ (mol K) and $C_V = C_P - R$.

Questions to answer before beginning the experiment

1. If the two tanks are the same volume and the initial temperature in the first tank is 400 K, is the final temperature in the first tank greater than, less than, or equal to 400 K? Explain.

2. If the two tanks are the same volume and the initial temperature in the first tank is 400 K, is the final temperature in the second tank greater than, less than, or equal to 400 K? Explain.

3. If the two tanks are the same volume and the initial pressure in the first tank is 20 bar, is the final pressure in the system greater than, less than, or equal to 10 bar? Explain.

4. If the two tanks are the same volume and the initial pressure in the first tank is 20 bar, and the initial temperature is 400 K, is the final average temperature of the two tanks greater than, less than, or equal to 400 K? Explain.

5. If the two tanks are the same volume, is the final number of moles larger in the first or second tank. Why?

Run the experiment

1. Set the initial conditions in the first tank and record them (with units).

   T_{1i} = ____________ P_{1i} = _______________ V_1 = ________________

2. Use the ideal gas law to calculate the number of moles in the first tank initially.

   n_{1i} = ________________

3. Set the volume of the second tank, which is under vacuum, and record it.

   V_2 = ___________

3. Open the valves on the two tanks, then open the valve connecting the tanks. When the tank pressure in the first tank stops decreasing and equals the pressure in the second tank, close the valve. Record the pressure.

   $P_{1f} = P_{2f} =$ ___________

4. Record the temperatures in the two tanks.

   $T_{1f} =$ _________ $T_{2f} =$_________

5. Use the ideal gas law to determine the number of moles in each tank.

   $n_{1f} =$ _________ $n_{2f} =$ ___________

   Total number of moles = $n_{1f} + n_{2f} =$ _________

6. How close is the final total moles to the initial number of moles in the first tank?

   Percent difference ___________

7. Calculate the final average temperature $T_{average}$ of the system from an internal energy balance.

$$(n_{1f} + n_2)C_V\left(T_{average} - T_{ref}\right) = n_{1f}C_V\left(T_{1f} - T_{ref}\right) + n_2C_V\left(T_{2f} - T_{ref}\right)$$

   and a mass balance $\left(n_{1f} + n_2\right) = n_{i1}$

   Note that $T_{average}$ should equal T_i because an internal energy balance on the system can also be written as:

$$n_{1i}C_V\left(T_{1i} - T_{ref}\right) = n_{1f}C_V\left(T_{1f} - T_{ref}\right) + n_2C_V\left(T_{2f} - T_{ref}\right)$$

   where

   n_{1i} = initial number of moles in first tank

   C_V = constant volume heat capacity of gas

   T_{1i} = initial temperature in tank 1

   T_{ref} = reference temperature (pick any convenient value)

T_{1f} = final temperature in tank 1

n_{1f} = final number of moles in tank 1

n_2 = final number of moles in tank 2

T_{2f} = final temperature in tank 2

8. How close is the final average temperature to the initial temperature in tank 1?

   Percent difference ___________ Why?

9. How close is the final pressure to the pressure expected if the expansion were conducted isothermally?

   Percent difference ___________ Why?

10. Calculate the final temperature expected in the first tank if the final number of moles in the first tank had expanded adiabatically and reversibly using this equation:

$$\frac{T_{1f}}{T_{1i}} = \left(\frac{P_{1f}}{P_{1i}}\right)^{R/C_P}$$

where

P_{1f} = final pressure in tank 1

P_{1i} = initial pressure in tank 1

Temperature calculated for adiabatic reversible expansion _____________

How close is the final temperature in the first tank to that expected for reversible adiabatic expansion?

Percent difference ___________ Why?

Questions to answer

1. Why did the temperature in the first tank increase/decrease?

2. Why did the temperature in the second tank increase above the initial temperature in the first tank?

3. Did the specific entropy in the first tank increase, decrease, or stay the same? Why?

4. What are sources of error in the measurements?

4. If this experiment were conducted in the laboratory, what might cause the measured pressure and temperatures calculated be different from the values calculated above?

5. What safety measures would you employ if making this measurement in the laboratory?