Worksheet: Adiabatic gas expansion between two tanks

Name(s) _____

In this experiment, an ideal gas at high pressure in a tank expands into a second tank that is under vacuum by opening a valve between the two tanks. The expansion is adiabatic. The valve is closed 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 pressure gauge and a temperature sensor.
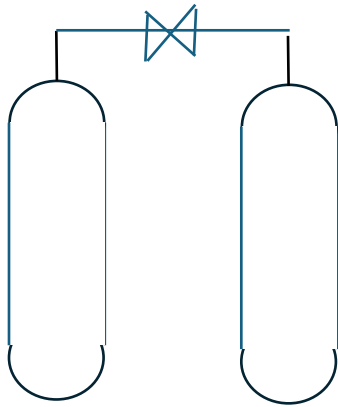
Assumptions

The tanks and the line connecting them are well insulated.

The volume of valve and the line connecting the tanks is insignificant.

The heat capacity of the tank material is zero.

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

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?

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?

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 20 bar?

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?

Start the experiment

Record the initial conditions (with units) in the first tank.

    Temperature _____

    Pressure _____

    Volume _____

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

    Moles _____

The second tank is under vacuum. Record its volume.

    Volume _____

Open the valve. When the tank pressure in the first tank stops decreasing and equals the pressure in the second tank, close the valve. Record the pressure.

    Pressure _____

Record the temperatures in the two tanks.

    Temperature tank 1 _____

    Temperature tank 2 _____

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

    Moles in tank 1 _____

    Moles in tank 2 _____

    Total number of moles _____

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

    Percent difference _____

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

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

Note that since $(n_{1f} + n_2) = n_{i1}$

then $T_{average} = T_{1i}$

because an internal energy balance on the system is:

$$n_{1i}C_V(T_{1i} - T_{ref}) = n_{1f}C_V(T_{1f} - T_{ref}) + n_2 C_V(T_{2f} - T_{ref})$$

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

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

     Percent difference _____

Why?

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

     Percent difference _____

Why?

Calculate the final temperature expected in the first tank if the final number of moles in the first tank 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} = initial pressure in tank 1

P_{1i} = final pressure in tank 1

Temperature calculated for adiabatic reversible expansion _____

How close is the final temperature measured to that expected for reversible adiabatic expansion?

    Percent difference _____

Why?

Questions to answer

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

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

3. What are possible 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?