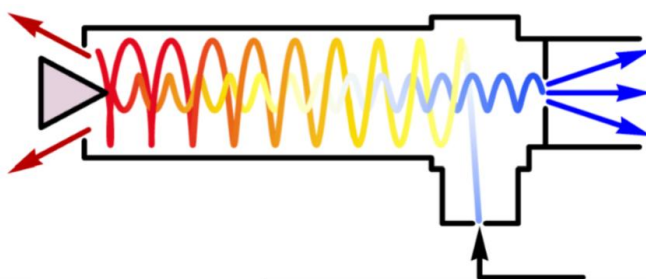


Worksheet: Ranque-Hilsch Vortex Tube

Name(s): _____

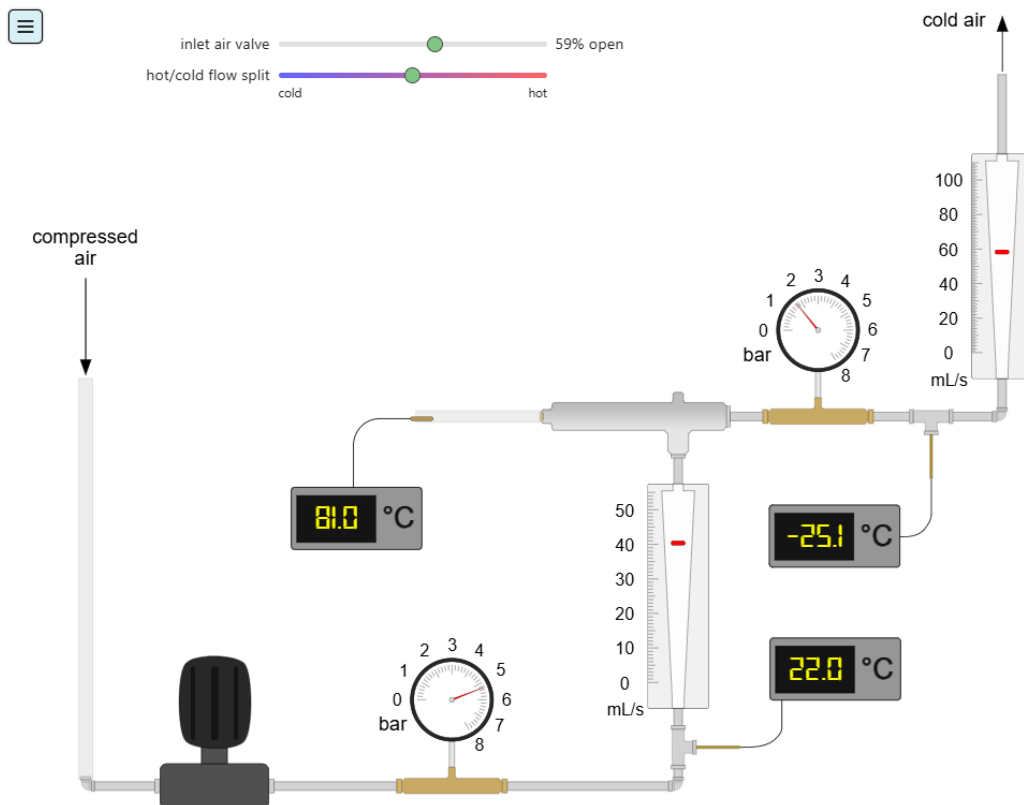
Higher-pressure, room-temperature air is fed to a Ranque-Hilsch vortex tube, which splits the air into hot and cold streams at lower pressure. The fraction of the air that goes to the cold side (or hot side) affects how cold the low temperature side is (or how hot the high-temperature side is). The blue in the figure represents colder temperatures and the red represents hotter temperatures.



Student Learning Objectives

1. Use the ideal gas law to determine molar flow rates.
2. Apply the first law of thermodynamics to a steady-state system.
3. Apply the second law of thermodynamics to a steady-state system.

Equipment



Questions to answer before running the experiment:

1. Is it physically possible to split a room-temperature stream into a hot and cold stream?
2. Does the total entropy of the system increase, decrease, or not change? Explain why.
3. What are advantages and disadvantages of using a vortex tube over a typical refrigeration system?
4. If more air flows to the hot side of the tube, do you expect the high temperature to increase or decrease? Why?

Running the experiment:

1. Use the slider to open the valve to flow compressed air to the vortex tube and to adjust the flow rate split between the hot and cold sides.
2. Wait for the system to equilibrate and then record the pressures (the pressure gauges read absolute pressure), temperatures, and flow rates in Table 1. Note that the rotameter flow rates are read from the top of the float. The hot-side pressure is 1.0 bar.
3. Repeat these measurements for a range of feed pressures and for various openings of the valve on the high temperature outlet. Record values in Table 1.

Table 1

Expt. #	Feed temperature (°C)	Feed pressure (bar)	Feed flow rate (mL/s)	Cold-side temperature (°C)	Cold-side pressure (bar)	Cold-side flow rate (mL/s)	hot-side temperature (°C)	Hot-side pressure (bar)
1								1.0
2								1.0
3								1.0
4								1.0
5								1.0
6								1.0
7								1.0
8								1.0

After the experiments:

For each experiment, use the ideal gas law to calculate the molar flow rates for the feed \dot{n}_f and the cold stream \dot{n}_c and record in Table 2.

Use the \dot{n}_f and \dot{n}_c values and material balances to calculate the hot stream molar flow rates \dot{n}_h and record in Table 2. A spreadsheet might simplify the calculations.

Calculate the two terms in the energy balance for the change in energy of the hot and cold streams. Use a heat capacity of 29.1 J/(mol K).

Add the two terms together. Do they add to zero?

where T_f = feed temperature (K); T_c = cold temperature (K) T_h = hot temperature (K)

P_f = feed pressure (bar) P_h = hot side pressure (bar)

P_c = cold side pressure (bar) C_p = constant pressure heat capacity (J/(mol K))

Table 2

Expt. #	\dot{n}_f (mol/s)	\dot{n}_c (mol/s)	\dot{n}_h (mol/s)	$\dot{n}_c C_p (T_c - T_f)$ (J/s)	$\dot{n}_h C_p (T_h - T_f)$ (J/s)	Add 2 energy terms
1						
2						
3						
4						
5						
6						
7						
8						

Calculate the change in entropy for the hot and cold streams and record in Table 3.

Table 3

Expt. #	\dot{n}_c (mol/s)	\dot{n}_h (mol/s)	$\dot{n}_c \left[C_p \ln \left(\frac{T_f}{T_c} \right) + R \ln \left(\frac{P_f}{P_c} \right) \right]$ [J/(K s)]	$\dot{n}_h \left[C_p \ln \left(\frac{T_f}{T_h} \right) + R \ln \left(\frac{P_f}{P_h} \right) \right]$ [J/(K s)]	Add 2 entropy terms
1					
2					
3					
4					
5					
6					
7					
8					

Is the total entropy change positive?

Questions to answer

1. What is the entropy change of the surroundings? Why?
2. What experimental aspect was ignored in applying the first law to this system?
3. What safety precautions would you observe in carrying out this experiment in the laboratory?

Reference

S. Subudhi and M. Sen, "Review of Ranque–Hilsch Vortex Tube Experiments Using Air," Renewable and Sustainable Energy Reviews, 52, 2015 pp. 172–178. [doi:10.1016/j.rser.2015.07.103](https://doi.org/10.1016/j.rser.2015.07.103).