Exploring the World of Science

Inaugural University of Michigan
Science Olympiad Invitational Tournament

Thermodynamics

Test length: 20-25 Minutes

Team number: _____
School name: _____
Student names: _____

Instructions: Show work for all problems. Partial credit will be given on problems with work to support it.

For any historical names, please list first and last name. All gases can be assumed to be ideal.

1. The Carnot cycle is a theoretical thermodynamic cycle consisting of four steps.

   What was the full name of the man who defined the Carnot cycle?

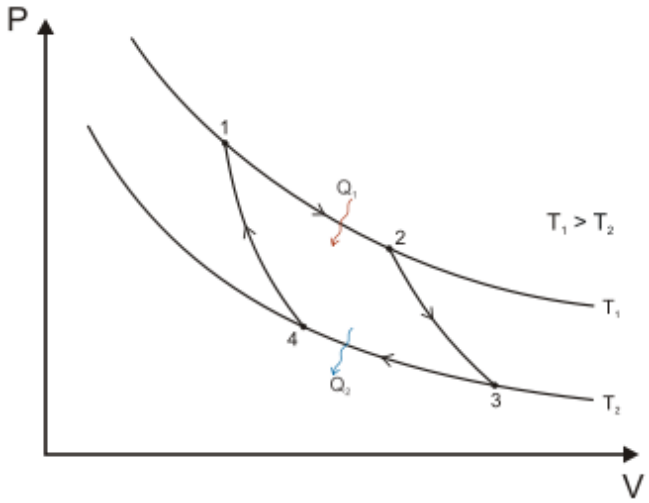
2. Label each of the steps of the Carnot Cycle with regards to reversibility and the type of process (e.g. irreversible isothermal, reversible isobaric…)

   1-2: _____ _____ expansion

   2-3: _____ _____ expansion

   3-4: _____ _____ compression

   4-1: _____ _____ compression



3. Oxygen has a boiling point of 162.37°R. What is the boiling point in the following units?

   a. °F

   b. °C

   c. K

4. You want some Nutella and look at the nutrition content. On the label, it states that the serving size of Nutella is 2 tbsps, providing 200 Cal.

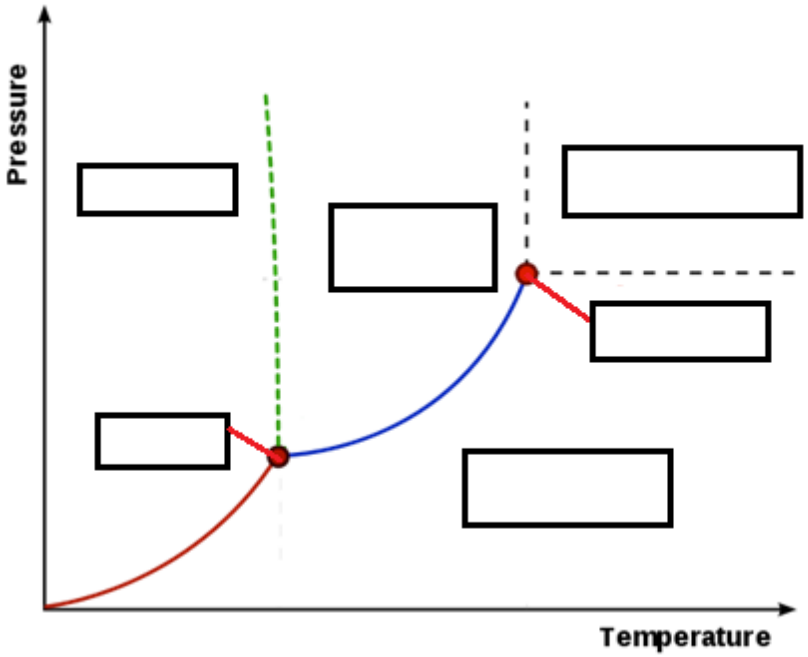
   a. How many calories is one serving size of Nutella?

   b. How many joules of energy is this?

5. A process in which there is no generation of entropy is a(n) _____ process. The term entropy was first introduced by _____ in the early 1850s.

6. Absolute zero is defined as _____ K. Though the concept of absolute zero was defined before his time, who determined the value of absolute zero? _____

7. Label the following phase diagram. Indicate the point at which three phases can coexist.



8. The ideal gas law is the equation of state of an ideal gas.
   a. The ideal gas law is most applicable at **high/low** (circle one) temperatures and **high/low** (circle one) pressures.

   b. Explain why.

9. What is a state variable? List two examples of state variables.

10. What is the third law of thermodynamics? What is the full name of the person who developed this law?

11. What is the difference between heat capacity and specific heat?

12. After doing all these thermodynamics problems, you decide you want a refreshing lemonade. You have 3 ice cubes in your lemonade, with each ice cube being 30 mL. How much energy (in kJ) would it take to melt the 3 ice cubes at 0°C? L_{ice} = 334 J/g ρ = 0.917 g/mL

13. Considering the example above:
    a. After the ice is added, the entropy of the lemonade **decreases/increases** (circle one).
    b. After the ice is added, the entropy of the total universe **decreases/increases** (circle one).
    c. What thermodynamic law explains this behavior?

14. Helium at 300K and 1 atm has an internal energy of 3800 J/mol and molar volume of 24.63 L/mol. Calculate the specific enthalpy of helium (in J/g) at these conditions. MW_{He} = 4.002 g/mol

15. A piston-cylinder device contains 5 moles of some gas. This device features a frictionless and perfect seal. The gas is heated 15°C, causing the piston to move. Assume a constant pressure of 1 atm.
    a. What is the work done by the gas in joules?

    b. Is this work positive or negative, what does this mean?

16. Within the steam engine of a locomotive, the temperature of the steam coming out of the boiler is 350°C which then condenses in a reservoir of 105°C.

a. What is the Carnot efficiency of this engine?

b. Why is the Carnot efficiency the maximum efficiency an engine between two temperature reservoirs can achieve?

17. A power plant produces 600 MW of energy with an input of 1900MW of fuel with the rest going into waste heat. Assume 25% of the waste heat goes into the air, and 75% of the waste heat is removed by cooling water.

a. What is the efficiency of this plant?

b. Assuming the cooling water is only allowed to rise in temperature by 10°C, what flow rate would be required (m^3/hr)?

18. The wall of a pizza oven is made of two layers. The first layer is made of 20 cm of concrete (k=0.13 W/m*K) and the second layer is made of 20 cm of firebrick (k=1.10 W/m*K). The temperature of the inner wall is 900°F (480°C). The safety standard for pizza ovens requires the outside temperature to be 60°C before insulation must be applied. Assuming an energy transfer rate of q = 200W, does this current configuration require any additional insulation? Assume an area of 1 m^2.