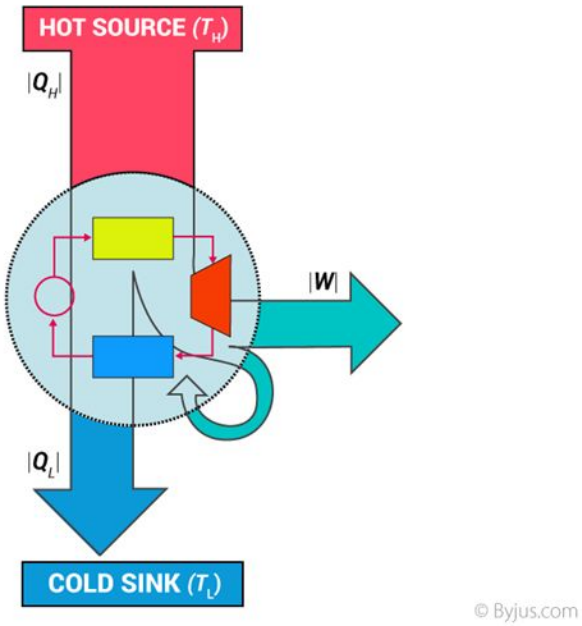
THERMODYNAMICS: Division C Science Olympiad, Round 1 Tryout Test



Student Name:
Student Number:

DIRECTIONS

1. Write the answers that you want graded legibly on the answer sheet provided, as well as your name and student number.
2. If you would like partial credit, show work on calculation questions (credit given for nontrivial progress); if the answer is correct, full credit will be given.
3. Pay attention to significant figures.
4. The test is intentionally short to give time for the lab portion, but nonetheless consists of a mix of easy, medium, and difficult questions. There are about **80 total points** in this test.
5. Good luck!

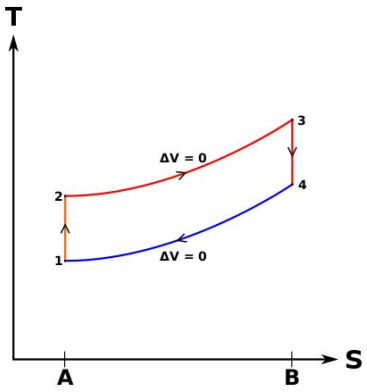
Written Exam

1. There are two small, thermally isolated rooms A and B. The heat capacitances of A and B are 40 and 100 quanta of energy respectively. A and B have 32 and 50 quanta of energy respectively. If the rooms are thermally connected, find in which direction energy will flow on average and explain why. [3]
2. Again, we have two thermally isolated rooms A and B. Now, the heat capacitances of rooms A and B are both 80 quanta of energy. Rooms A and B have 56 and 24 quanta of energy respectively. Find the number of quanta transferred on average when the two rooms are connected and come to thermodynamic equilibrium. [2]
3. Calculate the change in temperature in degrees Fahrenheit when 320 J of heat is applied to 24.5 g of NaCl. The molar heat capacity for NaCl is 50 J/(mol-K). [2]
4. System A has 12 particles and total thermal energy 36 J, while system B has 13 particles and total thermal energy 34 J. If the two systems are allowed to exchange heat, what is the thermal energy of each particle at equilibrium? [1]
5. Around 1850, which two scientists stated both the First and Second Laws of Thermodynamics? [2]
6. Which scientist in 1872 derived an equation that he thought could describe the detailed time development of a gas? [1]
7. What is the specific heat in J/(g-C) of a metal that requires 232 cal to raise its temperature from 23 to 45 degrees Celsius? Assume the mass of the metal is 60 g. [2]
8. At what temperature in Fahrenheit is a reaction with standard enthalpy 14.6 kJ/mol and standard entropy 43.5 J/mol-K at equilibrium? [2]
9. A phase change for a particular substance at constant pressure has an enthalpy change of 43.5 kJ/mol. The change occurs at 77 degrees Fahrenheit. What is the change in entropy in J/mol-K? [2]
10. In a well-insulated vessel, 48.0 g ice at 0.0 degrees Celsius was added to 370 g water at 33 degrees Celsius. What is the equilibrium temperature in Kelvin of the mixture? [2]
11. Which scientist introduced the concept of an ensemble, or the collection of many possible states of a system assigned a certain probability? [1]

12. Name the steps of the Carnot cycle in order (be as specific as possible, i.e. simply compression or expansion will not score). [3]
13. In the 1770s, which scientist developed the explanation of combustion in terms of oxygen? [1]
14. Earth is surrounded by an atmosphere transparent to solar radiation, but can keep and radiate IR heat from the Earth. Suppose that a large amount of black soot enters the atmosphere that can be heated by the Sun directly such that the soot occupies a spherical shell around Earth. When the soot-surrounded Earth reaches equilibrium, it has temperature T(soot). Compute T(soot)/T(normal), where T(normal) is the temperature of the Earth without soot. Assume Earth's albedo is 0.30 and that the Earth and soot are ideal blackbodies. [6]
15. Given the same scenario as in the previous question, find the same ratio if T(normal) is now the temperature of the Earth with no atmosphere. [4]
16. A certain amount of gas is compressed to half of its current value. This process may be isothermal, isobaric, or adiabatic. Rank these three possibilities in decreasing order of the work required from an external agent. [3]
17. Consider a hot balloon in a cold room. Suppose that the balloon is filled with air at 40 degrees C and that the balloon is placed in a room at 30 degrees C. Find the approximate temperature of the air in the balloon after a long time, assuming that the volume of the room is much greater than that of the balloon. [1]
18. What happens to the pressure and temperature of a gas when it passes through a compressor pump in a refrigerator? [1]
19. Suppose that a running, closed refrigerator stays in a room for a long time, such that the temperature of the room is stable. What happens to the temperature of the room after a long time if the refrigerator door was left open? Briefly explain your answer. [2]
20. Ethylene and bromine gas react to form dibromoethane. Find the enthalpy change of the reaction at 25 degrees C, given the following standard enthalpy values. [3]

Bond	Bond Energy (kJ/mol)	Bond	Bond Energy (kJ/mol)
Br – Br	193	Cl – Cl	243
C – C	347	F – F	153
C = C	612	H – Br	368
C ≡ C	820	H – Cl	431
C – Br	276	H – F	565
C – Cl	326	H – H	435
C – F	485	N – H	389
C – H	414	N – N	159
C – O	335	N = N	941
C = O	715	O – H	463

21. Rank aluminum, silver, copper, iron, and lead in increasing order of thermal conductivity. [2]
22. Which law states that the ratio of the thermal to the electrical conductivity of a metal is proportional to the temperature? [2]
23. Derive the mathematical law mentioned in the previous problem classically. [10]
24. Let us approximate the human body as an ideal blackbody. Calculate the radiant exitance from the skin, assuming that the temperature of the skin is 98.6 degrees F. The surface area of the human body is approximately 1.7 square meters. You must give correct units for full credit. [3]
25. In reality, the human body is not exactly an ideal blackbody, but rather has an emissivity of 0.98. Calculate the radiant exitance assuming the same values for temperature and surface area. Again, give units for full credit. [1]
26. Let's go back to the assumption that the human body is an ideal blackbody. Using the values given in the previous two problems, calculate the approximate peak wavelength of emission of the human body in nm. [2]
27. The phase diagram of water is unusual in that the solid-liquid equilibrium line has negative slope. Explain why. [2]
28. In adiabatic processes, the law $PV^{\gamma} = constant$ holds. What is the constant γ for an ideal monatomic gas? For an ideal diatomic gas? [2]
29. The image at right shows a diagram for a four-stroke engine/cycle.
    a. What type of engine/cycle is this? [1]
    b. What do the axes stand for (hence, what is the graph plotting)? [2]
    c. What type of thermodynamic process occurs from 1 to 2? [2]
    d. Which stroke (between which two numbers) is also known as the power stroke? [1]



30. How much heat **in kcal** is required to raise the temperature of 23 g of ice from -10 degrees C to 110 degrees C? [4]