SCIENCE OLYMPIAD 2012/2013 NICHOLS SCRIMMAGE

THERMODYNAMICS

Team: Key **Team Number:**_____

Team Member Names: 1._____

2._____

Instructions: This test contains 23 questions. The points available for each question are indicated. This test is worth a total of 50 points. Show all work where appropriate. Partial credit will be given. Little credit will be given for answers without supporting justification.

Answer all questions on the test paper. If you need more room, you may attach extra paper.

You may not finish the test in the allotted time. Therefore, you are encouraged to complete the questions in any order that you choose.

Part I

1. List the three modes of heat transfer:

   conduction convection radiation

   [3 points]

2. The ideal gas law is valid for gases under low densities, low pressures, and high temperatures relative to critical point properties. [3 points]

3. Write an equation that relates the ideal gas constant, R; the specific heat at constant pressure, c_p, and the specific heat at constant volume, c_v. [1 point]

   $C_P = C_V + R$ (or any algebraic equivalent)

4. An open system does not allow for mass to pass through the boundaries. (TRUE/(FALSE)) [1 point]

5. How many independent, intensive properties are required to completely define the state of a pure, compressible system? 2 [1 point]

6. At the triple point, the solid, liquid, and gas phases coexist in equilibrium. [1 point]

7. According to the Zeroth Law of Thermodynamics, two bodies are in thermal equilibrium if they both have the same
   a. Density
   (b.) Temperature
   c. Pressure
   d. Specific Volume
   e. All of the above [1 point]

8. What type of energy is absorbed or released during a phase change process? [1 point]
   Latent

9. Energy has a tendency to become more ordered. (TRUE (FALSE)) [1 point]

10. Isothermal processes occur at constant temperature. [1 point]

11. Adiabatic processes occur when no heat is gained or lost. [1 point]

12. A reversible process will always have a higher efficiency than an irreversible process ((TRUE) FALSE). [1 point]

13. Reversible processes are real processes that can occur in nature (TRUE (FALSE)). [1 point]

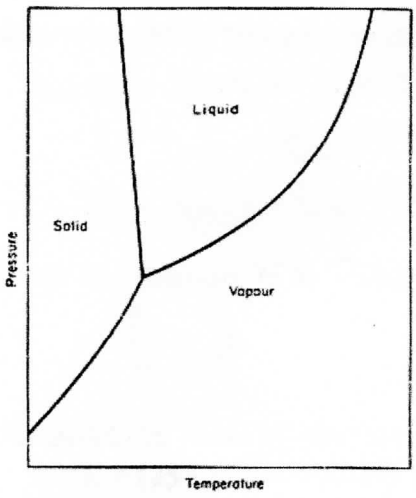
14. An isentropic process occurs under constant entropy. An isentropic process is both adiabatic and reversible. [3 points]

15. At what temperature is the entropy of a pure crystal equal to zero? [1 point]
    Absolute zero (0 K, -273°C, 0 R, -461°F)

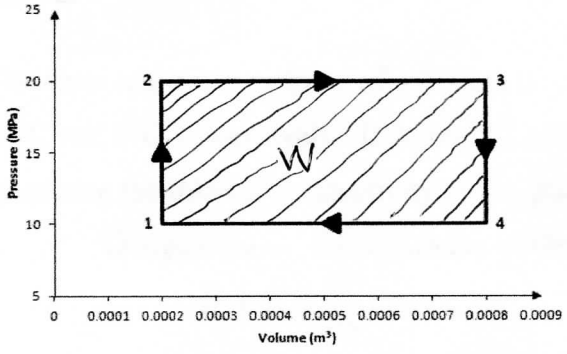
16. The specific heat at constant (PRESSURE) VOLUME) is always higher than the specific heat at constant (PRESSURE (VOLUME)). [2 points]

17. What quantity is conserved in a polytropic process? [1 point]
    PV^n

18. The figure below shows a P-T diagram for a simple substance. As this substance melts, its volume will increase. [1 point]



19. The figure below shows the P-V diagram for an engine.



What type of process occurs between points 1 and 2? Isochoric
(Isovolumetric, Isometric also acceptable) [1 point]

What type of process occurs between points 2 and 3? Isobaric
[1 point]

How much work is done by the engine in one cycle? [3 points]

$W = 10\ MPa \cdot 0.0006\ m^3$

$W = 10 \times 10^6\ Pa \cdot 0.0006\ m^3$

$W = 6000\ J$

$\boxed{W = 6\ kJ}$

20. The gage pressure of an automobile tire is measured to be 210 kPa before a trip and 220 kPa after the trip at a location where the atmospheric pressure is 95 kPa. Assuming the volume of the tire remains constant, and the air temperature before the trip is 25°C, determine the air temperature in the tire after the trip. Assume air is an ideal gas. [4 points]

Determine absolute pressure before + after:

$P_1 = P_{gage,1} + P_{atm} = 210\ kPa + 95 kPa = 305\ kPa$

$P_2 = P_{gage,2} + P_{atm} = 220 kPa + 95 kPa = 315\ kPa$

Since air assumed to be ideal gas and volume constant,

$$\frac{P_1}{T_1} = \frac{P_2}{T_2}$$

Temperatures must be absolute (eg, in Kelvin)

$T_1 = (25+273)\,K = 298\,K$

$$\frac{305\ kPa}{298\ K} = \frac{315\ kPa}{T_2}$$

$T_2 = 307.8\,K$

$\boxed{T_2 = 34.8\,°C}$

21. The inner and outer surfaces of a 0.5-cm-thick, 2-m x 2-m windows glass in winter are 15°C and 6°C, respectively. If 20,000 kJ of heat is lost through the glass in an hour, determine the thermal conductivity of the glass. [5 points]

Temperature distribution varies linearly within glass.

$$Q = kA\frac{\Delta T}{\Delta x}$$

$$Q = 20{,}000\ \frac{kJ}{h} \cdot \frac{1000\ J}{kJ} \cdot \frac{1\ h}{3600\ s} = 5{,}556\ W$$

$$5556\ W = K \cdot 4\ m^2 \cdot \frac{15°C - 6°C}{0.005\ m}$$

$$\boxed{K = 0.77\ \frac{W}{m°C}} \quad \left(\text{or } 0.77\ \frac{W}{mK}\right)$$

22. An insulated rigid tank initially contains 0.7 kg of helium at 27°C and 350 kPa. A paddle wheel with a power rating of 0.015 kW is operated within the tank for 30 minutes. Determine the final temperature of the helium gas. The value of c_v for helium is 3.1156 kJ/kg°C. [5 points]

Amount of work done on system by paddle wheel:

$$W_s = \dot{W}_s \Delta t = 0.015\,kW \cdot 30\,min \left(\frac{60\,s}{1\,min}\right) = 27\,kJ$$

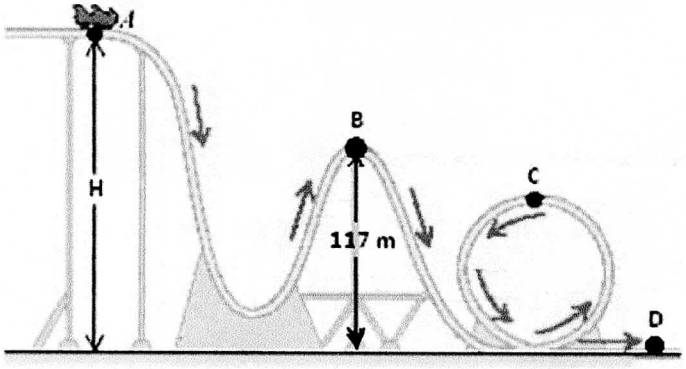
2nd Law: $E_{in} - E_{out} = \Delta E_{system}$

$$W_s = mC_v(T_2 - T_1)$$

$$27\,kJ = 0.7\,kg \cdot 3.1156\,\frac{kJ}{kg\,°C}(T_2 - 27\,°C)$$

$$\boxed{T_2 = 39.4\,°C}$$

23. The figure below shows a roller coaster. The 900-kg car is released from rest at Point A. When the car reaches point B, it has a velocity of 5 m/s.



a. Determine the total energy of the car at Point A. [2 points]

$$E_{total} = PE + KE = mgh + \frac{mv^2}{2}$$

$$E_{total} = 900\,kg \cdot 9.81\,m/s^2 \cdot 117\,m + \frac{900\,kg \cdot (5\,m/s)^2}{2}$$

$$\boxed{E_{total} = 1044\,kJ}$$

b. Assume there are no frictional losses between Points A and B. Determine the height, H, from which the car is released. [2 points]

At top of hill, car is stationary. $\therefore V=0 \rightarrow KE=0$.

So all energy is potential energy.

2^{nd} Law: $E_A = E_B + \cancel{E_{lost,AB}}^{0}$

So $1044 \times 10^3 J = 900\ kg \cdot 9.81\ m/s^2 \cdot H$

$\boxed{H = 118\ m}$

c. When the car travels through the loop, it loses 150 kJ of energy due to friction. Determine the velocity of the car at Point D. [2 points]

At point D, $h=0 \rightarrow PE=0$.

So all energy is kinetic energy.

2^{nd} Law: $E_B = E_D + E_{lost,BD}$

$1044\ kJ = E_D + 150\ kJ$

$E_D = 894\ kJ$

So $894\ kJ = \frac{mv_D^2}{2}$

$894 \times 10^3 J = \frac{900\ kg \cdot v_D^2}{2}$

$\boxed{v_D = 44.6\ m/s}$