Name: ______________________

Class: ______________________

Due Date: ______________________

B.4 Thermodynamics

Additional HL Understandings

- The first law of thermodynamics, as given by $Q = \Delta U + W$, results from the application of conservation of energy to a closed system and relates the internal energy of a system to the transfer of energy as heat and as work.
- The work done by or on a closed system as given by $W = P\Delta V$ when its boundaries are changed can be described in terms of pressure and changes of volume of the system.
- The change in internal energy, as given by $\Delta U = \frac{3}{2}nR\Delta T = \frac{3}{2}Nk_{\mathrm{B}}\Delta T$, of a system is related to the change of its temperature.
- Entropy S is a thermodynamic quantity that relates to the degree of disorder of the particles in a system.
- Entropy can be determined in terms of macroscopic quantities such as thermal energy and temperature as given as $\Delta S = \frac{\Delta Q}{T}$ and also in terms of the properties of individual particles of the system as given by $S = k_{\mathrm{B}} \ln \Omega$ where k_B is the Boltzmann constant and Ω is the number of possible microstates of the system.
- The second law of thermodynamics refers to the change in entropy of an isolated system and sets constraints on possible physical processes and on the overall evolution of the system.
- Processes in real isolated systems are almost always irreversible and consequently the entropy of a real isolated system always increases.
- The entropy of a non-isolated system can decrease locally, but this is compromised by an equal or greater increase of the entropy of the surroundings.
- Isovolumetric, isobaric, isothermal, and adiabatic processes are obtained by keeping one variable fixed.
- Adiabatic processes in monatomic ideal gases can be modeled by the equation as given by $PV^{\frac{5}{3}} = \text{constant}$.
- Cyclic gas processes are used to run heat engines.
- A heat engine can respond to different cycles and is characterized by its efficiency as given by $\eta = \frac{\text{useful work}}{\text{input energy}}$.

- The Carnot cycle sets a limit for the efficiency of a heat engine at the temperatures of its heat reservoirs as given by $\eta_{\text{carnot}} = 1 - \frac{T_{\text{c}}}{T_{\text{h}}}$.

Additional HL Equations

$Q = \Delta U + W$

$W = P\Delta V$

$\Delta U = \frac{3}{2}nR\Delta T = \frac{3}{2}Nk_{\text{B}}\Delta T$

$\Delta S = \frac{\Delta Q}{T}$

$S = k_{\text{B}} \ln \Omega$

$PV^{\frac{5}{3}} = \text{constant}$

$\eta = \frac{\text{useful work}}{\text{input energy}}$

$\eta_{\text{carnot}} = 1 - \frac{T_{\text{c}}}{T_{\text{h}}}$

The solutions can be found on the YouTube channel Go Physics Go:

https://www.youtube.com/@gophysicsgo/playlists

Part 1: Use your favorite sources to answer the following questions

1. C: Define *thermodynamics.*

2. C: Define a *closed system*.

3. C: Define an *isolated system*.

4. C: State the *first law of thermodynamics.*

5. C: Consider a system filled with an ideal gas and the equation for the law of conservation of energy $Q = \Delta U + W$.

   a. Define ΔU. What is the meaning if $\Delta U > 0$ Joules? $\Delta U = 0$ Joules? $\Delta U < 0$ Joules?

b. Define W. What is the meaning if $W > 0$ Joules? $W = 0$ Joules? $W < 0$ Joules?

c. Define Q. What is the meaning if $Q > 0$ Joules? $Q = 0$ Joules? $Q < 0$ Joules?

6. E: 8.42×10^3 J of heat is given to a closed system while the system does 4.37×10^3 J of work. What is the change in internal energy of the system during this process?

7. E: A closed system absorbs 2.33×10^3 J and at the same time 1.24×10^3 J of work is done on it. What is the change in internal energy of the system during this process?

8. E: 9.97×10^3 J is removed from a gas held at a constant volume. What is the change in internal energy of the system during this process?

9. E: 246 J of thermal energy is used to compress a gas while its internal energy increases by 122 J. Determine the amount of energy leaving the system.

10. E: In a slow isothermal compression 3.45×10^4 J of work is done on an ideal gas. Determine the work done on the gas.

11. E: During a slow isothermal expansion 3.45×10^4 J of work is done by an ideal gas. Determine the work done by the gas.

12. C: Describe the equation $W = P\Delta V$.

13.E: An ideal gas in a piston is compressed from an initial volume of 1.87×10^{-1} m^3 to a final volume of 1.03×10^{-1} m^3 at a constant pressure of 4.04×10^5 Pa. The initial temperature of the ideal gas, before expansion, is 406 K. Determine the work done on the ideal gas and the final temperature of the ideal gas.

14.E: An ideal gas in a piston is expanded from an initial volume of 9.87×10^{-1} m^3 to a final volume of 1.23×10^0 m^3 at a constant pressure of 3.03×10^5 Pa. The initial temperature of the ideal gas, before expansion, is 398 K. Determine the work done by the ideal gas and the final temperature of the ideal gas.

15.C: Describe the equation $\Delta U = \frac{3}{2} N k_\mathrm{B} \Delta T = \frac{3}{2} n R \Delta T$.

16.C: Define *thermal equilibrium.*

17.C: State the *zeroth law of thermodynamics.*

18.C: What does the area under a *pressure-volume curve* tell us?

a. Define *isothermal process.* Draw three *isothermal processes (isotherms)* on a *pressure vs. volume* graph.

b. Define *isobaric process*. Draw an *isobaric process* on a *pressure vs. volume graph*.

c. Define *isochoric/isovolumetric process*. Draw an *isochoric/isovolumetric* process on a *pressure vs. volume* diagram.

d. Define *adiabatic process*. Draw an *adiabatic process* on a *pressure vs. volume* graph.

19.E: A gas does 1.00×10^3 J of work while a closed system expands adiabatically. Determine the change in internal energy.

20.E: 1.23×10^3 J of work is done on a closed system during an adiabatic compression. Determine the change in internal energy.

21.C: Define *entropy* S. Units?

22.C: Describe the equation $\Delta S = \frac{\Delta Q}{T}$.

23.C: The change in entropy S of a system is defined as $\Delta S = \frac{\Delta Q}{T}$.

a. What can we do to make ΔS positive?

b. What can we do to make ΔS negative?

24.E: A cup of hot chocolate at a temperature of 90.0°C is in a room with an ambient temperature of 23.0°C. If the temperature of the hot chocolate and room do not change and 1.97×10^3 J of energy flows out of the hot chocolate to the room then determine the change in entropy.

25.E: Two large cubes filled with water are separated by a thin thermally conducting metal plate. The temperature of the water in cube 1 is 82.0°C and the temperature of the water in cube 2 is 39.0°C. Determine the change in entropy of the whole system if heat flows between the plate at 249 Joules per second.

26.E: 400. g of ice at 0.00°C melts to water at a constant temperature. The latent heat of fusion of H_2O is $3.34 \times 10^5 \ \frac{\mathrm{J}}{\mathrm{kg}}$. Determine the change in entropy.

27.E: 500. g of water at 0.00°C freezes to ice at a constant temperature. The latent heat of fusion of $\mathrm{H_2O}$ is $3.34 \times 10^5\ \frac{\mathrm{J}}{\mathrm{kg}}$. Determine the change in entropy.

28.E: 600. g of boiling water at 100.°C vaporizes to steam at a constant temperature. The latent heat of vaporization of $\mathrm{H_2O}$ is $2.26 \times 10^6\ \frac{\mathrm{J}}{\mathrm{kg}}$. Determine the change in entropy.

29.E: 800. g of steam at 100.°C condenses to water at a constant temperature. The latent heat of vaporization of $\mathrm{H_2O}$ is $2.26 \times 10^6\ \frac{\mathrm{J}}{\mathrm{kg}}$. Determine the change in entropy.

30.E: A piston is slowly compressed so the temperature of the ideal gas inside it remains at 40.0°C. 748 J of work is done on the gas. Determine the change in entropy of the gas.

31.E: A piston is slowly expanded so the temperature of the ideal gas inside it remains at 68.3°C. 498 J of work is done by the gas. Determine the change in entropy of the gas.

32.C: Describe the equation $S = k_\mathrm{B} \ln \Omega$.

33.E: Determine the entropy of a system which has 7.53×10^{45} microstates.

34.C: State the *second law of thermodynamics.*

35.C: State the *Clausius version* of the *second law of thermodynamics.*

36.C: State the *Kelvin version* of the *second law of thermodynamics.*

37.C: State the *arrow of time* and *entropy* in terms of the *second law of thermodynamics*.

38.C: State the *third law of thermodynamics.*

39.C: Describe the equation $PV^{\frac{5}{3}} = \text{constant}$.

40.E: An ideal gas is initially held at a pressure of 1.23×10^4 Pa, a volume of 9.06×10^{-1} m^3, and a temperature of 348 K. The ideal gas then expands adiabatically to a new volume of 1.00×10^1 m^3. Determine the final pressure and final temperature of the ideal gas.

41.E: An ideal gas is initially held at a pressure of 7.65×10^4 Pa, a volume of 9.63×10^{-1} m^3, and a temperature of 388 K. The ideal gas then compresses adiabatically to a new volume of 8.28×10^{-1} m^3. Determine the final pressure and final temperature of the ideal gas.

42.E: In an adiabatic process the volume of a piston increases from $145\ \text{cm}^3$ to $194\ \text{cm}^3$. By which factor does the pressure change?

43.E: In an adiabatic process the pressure of a piston increases from 3.03×10^5 Pa to 7.07×10^5 Pa. By which factor does the volume change?

44.C: Define *heat engine* and *heat pump.*

45.C: **Use a pencil!** Carefully and clearly draw the *Carnot cycle*. Label the vertical axis and the horizontal axis. Label the adiabatic processes and isothermal processes.

46.C: In general the efficiency of an engine is $\eta = \frac{\text{useful work}}{\text{input energy}}$. For a *Carnot engine* $\eta_{\text{carnot}} = 1 - \frac{T_{\text{cold}}}{T_{\text{hot}}}$.

a. Is the *Carnot cycle* a fast or slow process?

b. Is the *Carnot cycle* realistic?

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c. Is the *Carnot cycle* efficient?

47.E: Calculate the efficiency of a Carnot engine operating between the following temperatures.

a. 123°C and 23.0°C

b. 223°C and 123°C

c. 323°C and 223°C

48.E: Suppose you have 12 two-sided fair unbiased coins. You throw them all up and count the number of heads and number of tails. You want to determine the number of arrangements to land one head, two heads, three heads, etc. and also its probability. Complete the table below:

Number of Heads	Number of Arrangements	Probability
0		
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		