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. Define *thermodynamics.*

2. Define a *closed system*.

3. Define an *isolated system*.

4. State the *first law of thermodynamics.*

5. 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. Describe the equation $W = P\Delta V$.

7. Describe the equation $\Delta U = \frac{3}{2}Nk_{\mathrm{B}}\Delta T = \frac{3}{2}nR\Delta T$.

8. Define *thermal equilibrium.*

9. State the *zeroth law of thermodynamics.*

10. 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.

11. Define *entropy* S. Units?

12. Describe the equation $\Delta S = \frac{\Delta Q}{T}$.

13. 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?

14. Describe the equation $S = k_{\mathrm{B}} \ln \Omega$.

15. State the *second law of thermodynamics.*

16. State the *Clausius version* of the *second law of thermodynamics.*

17. State the *Kelvin version* of the *second law of thermodynamics.*

18. State the *arrow of time* and *entropy* in terms of the *second law of thermodynamics*.

19. State the *third law of thermodynamics.*

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

21. Define *heat engine* and *heat pump.*

22. **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.

23. 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?

c. Is the *Carnot cycle* efficient?