PHYS 1200 Physics of Everyday Experience

Review questions and exercises for Lecture 19 (T-4)

1. Heat is added to a substance and it undergoes a change in phase. Is there a temperature change associated with this process?
2. What factors affect the change in phase of a substance?
3. State the first law of thermodynamics.
4. What general physical principle is contained in the first law of thermodynamics?
5. Describe the essential processes that occur in a heat engine.
6. A heat engine is operated in a cycle. What is the change in the internal energy of the working substance over one cycle?
7. A heat engine operating in a cycle absorbs an amount of heat Q_H from a heat source, performs an amount of work W, and discards an amount of heat Q_C to a cold source. According to the first law of thermodynamics, how are these quantities related?
8. Give the Kelvin and Clausius statements of the second law of thermodynamics.
9. In terms of order and disorder what does the second law of thermodynamics state?
10. 1000 J of heat are absorbed by a gas while the gas expands and performs 700 J of work. What is the change in the internal energy of the gas in this process?
11. A gas has an initial amount of internal energy $U_0 = 100{,}000$ J. It then undergoes a process in which it absorbs 10,000 J of heat while expanding and performing 15,000 J of work. How much internal energy does it have at the end of the process?
12. A gas absorbs 500 J of heat energy while doing work. If the internal energy of the gas decreased by 1000 J in this process, how much work was performed by the gas?
13. An engine operating in a cycle absorbs 5000 J of heat from a heat source and performs 2000 J of work. How much heat was discarded in this cycle and what is the efficiency of this engine?
14. An engine operating in a cycle absorbs 15,000 J of heat and discards 10,000 J to a cold reservoir. How much work is done by this engine and what is its efficiency?

Answers and solutions:

1. When heat is added to a substance and a phase change occurs, there is no change in the temperature of the substance.

2. The phase of a substance depends on both the temperature and pressure.

3. If an amount of heat Q is absorbed by a system and the system performs an amount of work W, the internal energy of the system changes by an amount $\Delta U = Q - W$.

4. The first law of thermodynamics is essentially a statement of conservation of energy.

5. In a heat engine that operates in a cycle heat is taken into the system from a heat reservoir, work is performed, and the excess heat that was not used to perform work is discarded to a low temperature reservoir. The system is always returned to its initial state. $\Delta U = Q - W = 10,000\,J - 15,000\,J = -5000\,J$.

6. By definition, a cyclic process is one in which the system is always brought back to its initial state so over the cycle there is no change in the internal energy.

7. For a cyclic heat engine, the first law of thermodynamics requires that $\Delta U = 0 = Q_{NET} - W$, where $Q_{NET} = Q_H - Q_{C.}$ Therefore, the work performed by the engine each cycle is

   $W = Q_{NET} = Q_H - Q_C$.

8. (*Kelvin*) It is impossible to have a heat engine that is 100 % efficient. Not all of the heat taken in by the engine can be converted to work. (*Clausius*) In a spontaneous process, heat flows from a hot to a cold substance Work must be done to move heat from a cold to a hot substance.

9. In any spontaneous process, a system proceeds from a state of order to disorder.

NOTE: Exercises 10, 11, and 12 involve thermodynamic processes, not cyclic heat engines. In a non-cyclic process $\Delta U \neq 0$, necessarily. Exercises 13 and 14 involve cyclic heat engines in which $\Delta U = 0$.

10. $\Delta U = Q - W = 1000\,J - 700\,J = +300\,J$. The internal energy *increases* by <u>300 J</u>

11. $\Delta U = Q - W = 10,000\,J - 15,000\,J = -5000\,J$. The internal energy of the system decreases by 5000 J. Since the initial value of the internal energy was U_0 = 100,000 J, the final value of its internal energy will be U_f = 100,000 J – 5000 J = 95,000 J.

12. $\Delta U = Q - W \rightarrow -1000\,J = 500\,J - W \rightarrow W = 1500\,J.$

13. $W = Q_H - Q_C \rightarrow 2000\,J = 5000\,J - Q_C \rightarrow Q_C = 3000\,J.$

$$engine\ efficiency = \frac{W}{Q_H} = \frac{2000\,J}{5000\,J} = \frac{2}{5} = 0.40\ or\ 40\%.$$

14. $W = Q_H - Q_C = 15,000\,J - 10,000\,J = 5000\,J.$

$$engine\ efficiency = \frac{W}{Q_H} = \frac{5000\,J}{15,000\,J} = \frac{1}{3} = 0.33,\ or\ 33\%.$$