4.1 REVERSIBLE PROCESSES

The examination of reversible cyclic processes, such as the Carnot cycle, led Clausius to the discovery of the property of entropy. Therefore, let us recall some of the important features of a Carnot engine cycle. We found that in a Carnot engine, heat Q_H absorbed by the ideal gas at temperature T_H and heat Q_C released at the lower temperature T_C are in the same proportion as the temperatures expressed in the absolute scale.

$$\frac{Q_H}{Q_C} = \frac{T_H}{T_C} \tag{4.1}$$

Using a positive sign for an energy entering the system and a negative for the energy leaving the system, we obtain the following over a cycle.

$$\frac{Q_H}{-Q_C} = \frac{T_H}{T_C} \tag{4.2}$$

Rearranging this equation, we find the following relation for the heat exchange of the Carnot engine with the environment over a cycle.

$$\frac{Q_H}{T_H} + \frac{Q_C}{T_C} = 0. \tag{4.3}$$

Using the summation sign, we can rewrite this result more compactly

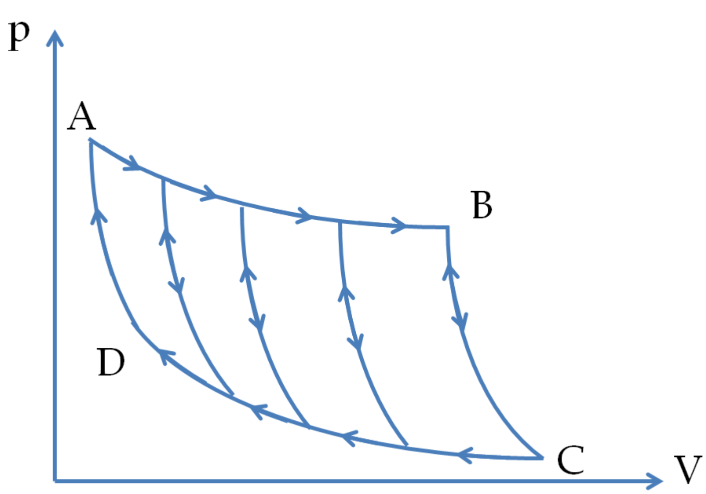

Figure 4.1: Any Carnot cycle can be broken up into multiple Carnot subcycles as shown here. The larger cycle is just a sum of the smaller cycles indicated. This process can be continued ad-infinitum.

as follow.

$$\sum \frac{Q}{T} = 0 \quad \text{(Carnot cycle)} \tag{4.4}$$

where Q is the heat entering the system from the environment at temperature T. In this equation, Q is positive for heat raising the energy of the system and negative for heat lowering the energy of the system. Any Carnot cycle can be broken up into infinitely many smaller Carnot sub-cycles as shown in Fig. 4.1. Thinking of the entire cyclic process as made up of infinitesimal steps, one can write Eq. 4.4 as an integral.

$$\boxed{\oint \frac{dQ}{T} = 0 \quad \text{(Carnot cycle)}} \tag{4.5}$$

By an ingenious argument presented at the end of this chapter, Clausius proved that the following inequality will hold true for any arbitrary cyclic process.

$$\oint \frac{dQ}{T} \leq 0 \quad \text{(All cycle processes in nature)} \tag{4.6}$$

This inequality is called **Clausius's inequality**. Inequality 4.6 is yet another way of expressing second law of thermodynamics. If the equality holds, then the process is called a **reversible process**. If the equality does not hold then the process is called an **irreversible process**.