## PROBLEM 5.5 (Contd.)

process of the cycle and the same amount of energy is removed from the cold reservoir in the second process of the cycle, this reservoir experiences no net change in its condition. The power cycle enclosed within the combined system also undergoes a cycle. Accordingly, the combined system undergoes a cycle in which work $W_{cycle}$ is produced while exchanging energy by heat transfer with a single reservoir (the hot reservoir). Such a cycle violates the Kelvin-Planck statement of the second law, and thus is impossible. It follows that one, or both, of the processes making up the cycle executed by the combined system must be impossible. However, as the first process involving the power cycle can occur, it is the second process that must be impossible: energy Q <u>cannot</u> be transferred from the cold to the hot reservoir without other effects. By definition, then, the transfer of energy Q by conduction from the hot to the cold reservoir is irreversible.

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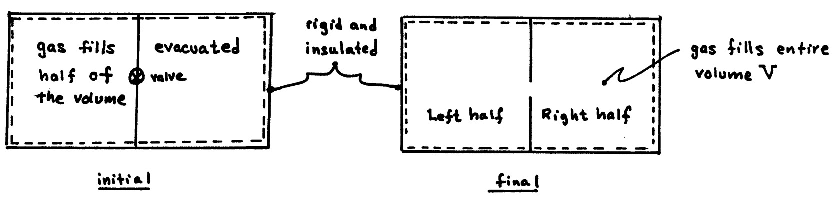
## PROBLEM 5.6

<u>KNOWN</u>: When an interconnecting valve is opened, a gas expands from one half of a tank to the other half which is initially evacuated.

<u>FIND</u>: Using the Kelvin-Planck statement of the second law, show that such a process is irreversible.

<u>SCHEMATIC & GIVEN DATA</u>:




<u>ASSUMPTIONS</u>: (1) The system shown in the accompanying figure undergoes a process in which the gas expands spontaneously to fill the entire volume V. (2) During the process Q = W = 0. (3) The initial and final states are equilibrium states. There is no change in kinetic or potential energy between these states. (4) A turbine and a thermal reservoir are available for use in demonstrating that the process is irreversible.

<u>ANALYSIS</u>: The object in this proof by contradiction is to devise a system that undergoes a power cycle while the system communicates thermally with a single reservoir, thereby violating the Kelvin-Planck statement of the second law.

Before considering such a system, note that an energy balance for the spontaneous process is

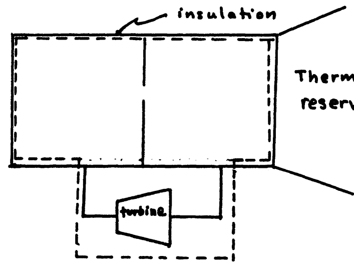
$$U_{final} - U_{initial} = \cancel{Q}^{0} - \cancel{W}^{0}$$

where assumptions 2 and 3 have been used. Accordingly,

$$U_{final} = U_{initial}$$

That is, the internal energy of the system does not change in the free expansion.

As shown in the figure below, modify the system to include a turbine and introduce a thermal reservoir in the surroundings (assumption 4).




Starting with the gas filling the entire volume V, let the modified system undergo a cycle consisting of three processes.

<u>Process 1</u>. Let the reverse of the free expansion occur without any other effects. That is, the gas passes spontaneously from the right half of the tank until it fills only the left half. (This would be possible only if the process described in assumption 1 were reversible.)

<u>Process 2</u>. Let part of the gas expand through the turbine into the right half of the tank until the pressure in both halves is the same. In expanding through the turbine the gas does work so that its internal energy is decreased: $U < U_{initial}$.

<u>Process 3</u>. Remove part of the tank insulation and add energy by heat transfer from the thermal reservoir until the internal energy of the gas is restored to its initial value. Thus, a cycle is completed.

The net result of this cycle is to draw energy from a single reservoir by heat transfer and produce an equivalent amount of work. Such a cycle violates the Kelvin-Planck statement of the second law, and thus is impossible. Since both the heating of the gas by the reservoir (process 3) and the development of work as gas passes through the turbine (process 2) are possible, it can be concluded that it is process 1 that is impossible. Since process 1 is the reverse of the original free expansion, it follows that the original process is irreversible.