$$dS = dS_{th,rev} + dS_{th,irr} + dS_m = \frac{đQ}{T_B} + \frac{đQ\ \delta T_{neq}}{T_{eq}\ T_B} + \frac{đW^i_{irr}}{T_{eq}} \qquad \text{(IIIB-30)}$$

Only the irreversible terms contribute to production. The reversible term has no effect on the entropy of the universe.

Example 8. Show that $dS_{th,rev}$ does not contribute to the increase of the entropy of the universe.

To demonstrate this result we apply eqn. IIIB-30 to both the system and the surroundings and substitute into the second law, eqn. IIIB-5.

$$dS_{univ} = dS_{sys} + dS_{surr} = \left(\frac{đQ}{T_B} + \frac{đQ\ \delta T_{neq}}{T_{eq}\ T_B} + \frac{đW^i_{irr}}{T_{eq}}\right)_{sys} + \left(\frac{đQ}{T_B} + \frac{đQ\ \delta T_{neq}}{T_{eq}\ T_B} + \frac{đW^i_{irr}}{T_{eq}}\right)_{surr} \geq 0$$

Heat that enters the system leaves the surroundings, $đQ_{sys} = -đQ_{surr}$, and by definition, the boundary temperatures are the same in both terms, $T_{B,sys} = T_{B,surr}$. We see that

$$dS_{th,rev}\Big|_{sys} + dS_{th,rev}\Big|_{surr} = \frac{đQ}{T_B}\Big|_{sys} + \frac{đQ}{T_B}\Big|_{surr} = 0$$

and

$$dS_{univ} = (dS_{th,irr} + dS_m)_{sys} + (dS_{th,irr} + dS_m)_{surr}$$

$$dS_{univ} = \left(\frac{đQ\ \delta T_{neq}}{T_{eq}\ T_B} + \frac{đW^i_{irr}}{T_{eq}}\right)_{sys} + \left(\frac{đQ\ \delta T_{neq}}{T_{eq}\ T_B} + \frac{đW^i_{irr}}{T_{eq}}\right)_{surr}$$

The preceding example demonstrates that production originates in both the system and the surroundings due to thermal and mechanical irreversibility. If there is no production within the system the process is said to be "internally reversible." A reversible process is one in which there is no production in either the system or the surroundings, that is, $\Delta S_{univ} = 0$.

Like mechanical irreversibility, thermal irreversibility deteriorates performance. We have suggested a thermodynamic design principle—*an optimum design is one that accomplishes given objectives and results in the minimum increase (or rate of increase) in the entropy of the universe.* The validity of this premise, as it relates to thermal irreversibilities, will be expanded by the consideration of thermal engines, Unit IVB, and heat exchangers, Unit IVC.

Example 9. A styrofoam ice chest has an inside and outside wall temperature of 32°F and 80°F, respectively. The insulatory value and thickness of wall are such that heat enters the cooler at a rate of 10 BTU/hr per square foot of surface area. Taking a square foot of the wall as the system, determine its rate of reversible and irreversible (continued)

Ans. 9. $$dS_{th} = \frac{đQ}{T_{eq}} = \frac{đQ}{T_B}\frac{T_B}{T_{eq}} = \frac{đQ}{T_{eq}T_B}(T_{eq} + \delta T_{neq})$$