6.27 Air in a piston–cylinder assembly and modeled as an ideal gas undergoes two internally reversible processes in series from state 1, where $T_1 = 290$ K, $p_1 = 1$ bar.

**Process 1–2:** Compression to $p_2 = 5$ bar during which $pV^{1.19} = constant$.

**Process 2–3:** Isentropic expansion to $p_3 = 1$ bar.

(a) Sketch the two processes in series on $T$–$s$ coordinates.
(b) Determine the temperature at state 2, in K.
(c) Determine the net work, in kJ/kg.
The integral of Eq. 6.18 can be expressed in terms of $s^\circ$ as follows

$$\int_{T_1}^{T_2} \frac{c_p}{T} dT = \int_{T_1}^{T_2} \frac{c_p}{T} dT - \int_{T_1}^{T_1} \frac{c_p}{T} dT$$

$$= s^\circ(T_2) - s^\circ(T_1)$$

Thus, Eq. 6.18 can be written as

$$s(T_2, p_2) - s(T_1, p_1) = s^\circ(T_2) - s^\circ(T_1) - R \ln \frac{p_2}{p_1}$$  \hspace{1cm} (6.20a)
6.37 Answer the following true or false. Explain.

(a) A process that violates the second law of thermodynamics violates the first law of thermodynamics.
(b) When a net amount of work is done on a closed system undergoing an internally reversible process, a net heat transfer of energy from the system also occurs.
(c) One corollary of the second law of thermodynamics states that the change in entropy of a closed system must be greater than zero or equal to zero.
(d) A closed system can experience an increase in entropy only when irreversibilities are present within the system during the process.
(e) Entropy is produced in every internally reversible process of a closed system.
(f) In an adiabatic and internally reversible process of a closed system, the entropy remains constant.
(g) The energy of an isolated system must remain constant, but the entropy can only decrease.
6.7.1 Interpreting the Closed System Entropy Balance

If the end states are fixed, the entropy change on the left side of Eq. 6.24 can be evaluated independently of the details of the process. However, the two terms on the right side depend explicitly on the nature of the process and cannot be determined solely from knowledge of the end states. The first term on the right side of Eq. 6.24 is associated with heat transfer to or from the system during the process. This term can be interpreted as the entropy transfer accompanying heat transfer. The direction of entropy transfer is the same as the direction of the heat transfer, and the same sign convention applies as for heat transfer: A positive value means that entropy is transferred into the system, and a negative value means that entropy is transferred out. When there is no heat transfer, there is no entropy transfer.

The entropy change of a system is not accounted for solely by the entropy transfer, but is due in part to the second term on the right side of Eq. 6.24 denoted by $\sigma$. The term $\sigma$ is positive when internal irreversibilities are present during the process and vanishes when no internal irreversibilities are present. This can be described by saying that entropy is produced (or generated) within the system by the action of irreversibilities.

The second law of thermodynamics can be interpreted as requiring that entropy is produced by irreversibilities and conserved only in the limit as irreversibilities are reduced to zero. Since $\sigma$ measures the effect of irreversibilities present within the system during a process, its value depends on the nature of the process and not solely on the end states. Entropy production is not a property.
When applying the entropy balance to a closed system, it is essential to remember the requirements imposed by the second law on entropy production: The second law requires that entropy \emph{production} be positive, or zero, in value

\[
\sigma: \begin{cases}
> 0 & \text{irreversibilities present within the system} \\
= 0 & \text{no irreversibilities present within the system}
\end{cases}
\]  
(6.26)

The value of the entropy production cannot be negative. In contrast, the \emph{change} in entropy of the system may be positive, negative, or zero:

\[
S_2 - S_1: \begin{cases}
> 0 \\
= 0 \\
< 0
\end{cases}
\]  
(6.27)

Like other properties, entropy change for a process between two specified states can be determined without knowledge of the details of the process.
Air contained in a rigid, insulated tank fitted with a paddle wheel, initially at 300 K, 2 bar, and a volume of 2 m³, is stirred until its temperature is 500 K. Assuming the ideal gas model for the air, and ignoring kinetic and potential energy, determine (a) the final pressure, in bar, (b) the work, in kJ, and (c) the amount of entropy produced, in kJ/K. Solve using

(a) data from Table A-22.
(b) constant \( c_v \) read from Table A-20 at 400 K.

Compare the results of parts (a) and (b).
Three kilograms of Refrigerant 134a initially a saturated vapor at 20°C expand to 3.2 bar, 20°C. During this process, the temperature of the refrigerant departs by no more than 0.01°C from 20°C. Determine the maximum theoretical heat transfer to the refrigerant during the process, in kJ.