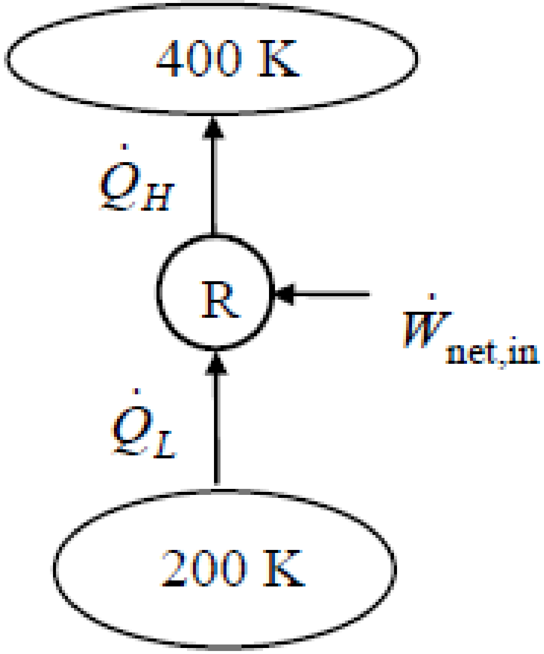
# EXAMPLE 1

- A refrigerator shown in figure below uses 10 kW of power, rejects 14 kW of heat, and has a high-temperature energy reservoir at 400 K and a low-temperature energy reservoir at 200 K.
  - What is the rate of cooling produced by this refrigerator?
  - Calculate the total rate of entropy change
  - Is this refrigerator completely reversible?



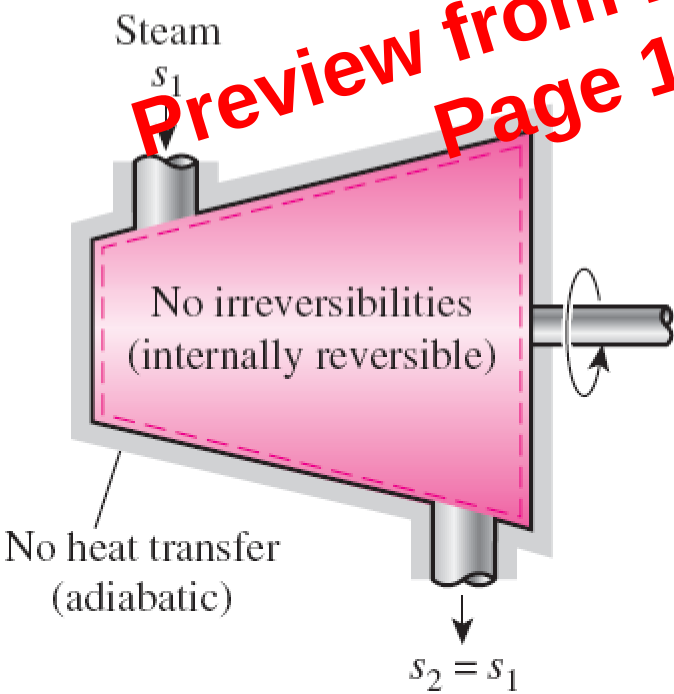


# ISENTROPIC PROCESSES

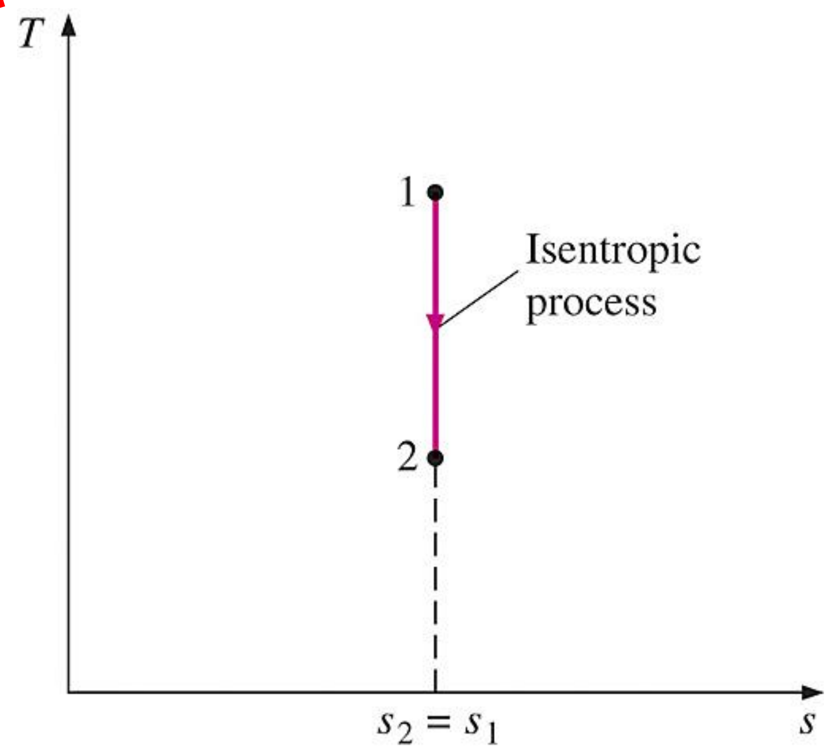
A process during which the entropy remains constant is called an **isentropic process**.



$$\Delta s = 0 \quad \text{or} \quad s_2 = s_1 \ (\text{kJ/kg} \cdot \text{K})$$

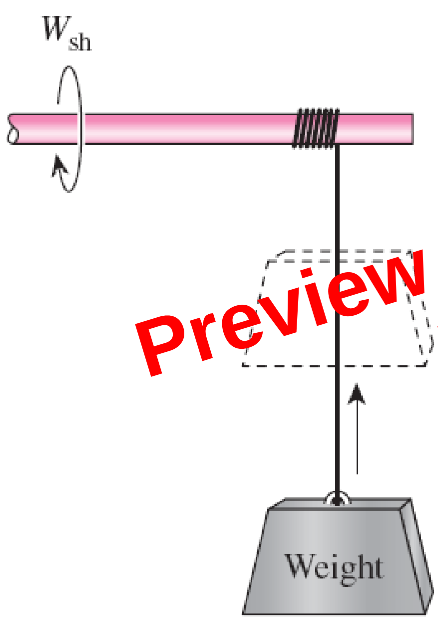



During an internally reversible, adiabatic (isentropic) process, the entropy remains constant.

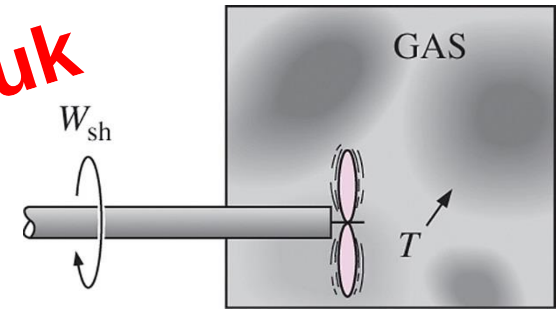



The isentropic process appears as a *vertical* line segment on a *T-s* diagram.

# WHAT IS ENTROPY?



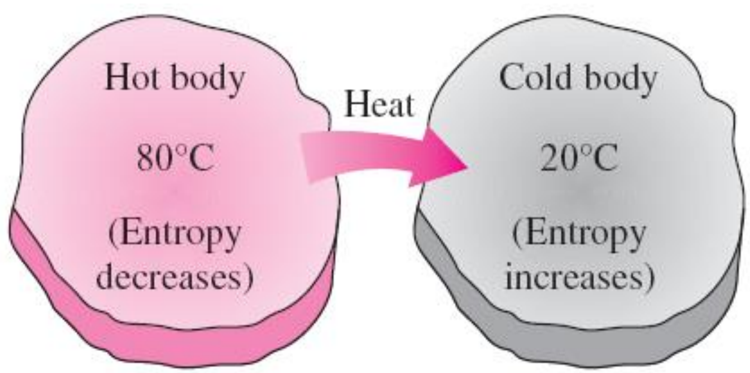





The paddle-wheel work done on a gas increases the level of disorder (entropy) of the gas, and thus energy is degraded during this process.

In the absence of friction, raising a weight by a rotating shaft does not create any disorder (entropy), and thus energy is not degraded during this process.

**FIGURE 7–26**
The use of entropy (disorganization, uncertainty) is not limited to thermodynamics.




During a heat transfer process, the net entropy increases. (The increase in the entropy of the cold body more than offsets the decrease in the entropy of the hot body.)

# THE ENTROPY CHANGE OF IDEAL GASES



From the first *T ds* relation

$$ds = \frac{du}{T} + \frac{P\,dv}{T} \qquad du = c_v\,dT \qquad P = RT/v$$

$$ds = c_v\frac{dT}{T} + R\frac{dv}{v}$$

$$s_2 - s_1 = \int_1^2 c_v(T)\frac{dT}{T} + R\ln\frac{v_2}{v_1}$$

From the second *T ds* relation

$$ds = \frac{dh}{T} - \frac{v\,dP}{T}$$

$$dh = c_p\,dT \qquad v = RT/P$$

$$s_2 - s_1 = \int_1^2 c_p(T)\frac{dT}{T} - R\ln\frac{P_2}{P_1}$$

$$Pv = RT$$
$$du = C_v\,dT$$
$$dh = C_p\,dT$$

A broadcast from channel IG.

# ISENTROPIC PROCESSES OF IDEAL GASES

## Constant Specific Heats (Approximate Analysis)



$$s_2 - s_1 = c_{v,\text{avg}} \ln \frac{T_2}{T_1} + R \ln \frac{v_2}{v_1}$$

Setting this eq. equal to zero, we get

$$\ln \frac{T_2}{T_1} = -\frac{R}{c_v} \ln \frac{v_2}{v_1}$$

$$\ln \frac{T_2}{T_1} = \ln \left(\frac{v_1}{v_2}\right)^{R/c_v}$$

$R = c_p - c_v$, $k = c_p/c_v$
and thus $R/c_v = k - 1$

$$\left(\frac{T_2}{T_1}\right)_{s=\text{const.}} = \left(\frac{v_1}{v_2}\right)^{k-1}$$

$$\left(\frac{T_2}{T_1}\right)_{s=\text{const.}} = \left(\frac{P_2}{P_1}\right)^{(k-1)/k} \qquad \left(\frac{P_2}{P_1}\right)_{s=\text{const.}} = \left(\frac{v_1}{v_2}\right)^{k}$$

$$\left(\frac{T_2}{T_1}\right)_{s=\text{const.}} = \left(\frac{P_2}{P_1}\right)^{(k-1)/k} = \left(\frac{v_1}{v_2}\right)^{k-1}$$

Valid for
*ideal gas
*isentropic process
*constant specific heats

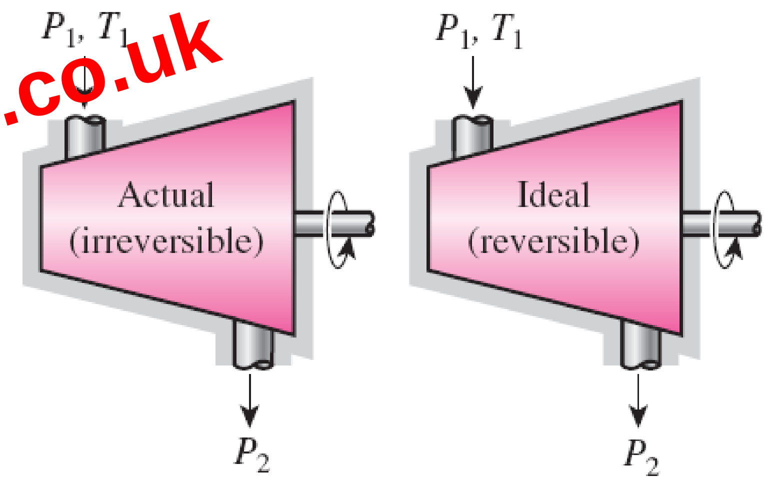
The isentropic relations of ideal gases are valid for the isentropic processes of ideal gases only.

$$Tv^{k-1} = \text{constant}$$
$$TP^{(1-k)/k} = \text{constant}$$
$$Pv^{k} = \text{constant}$$

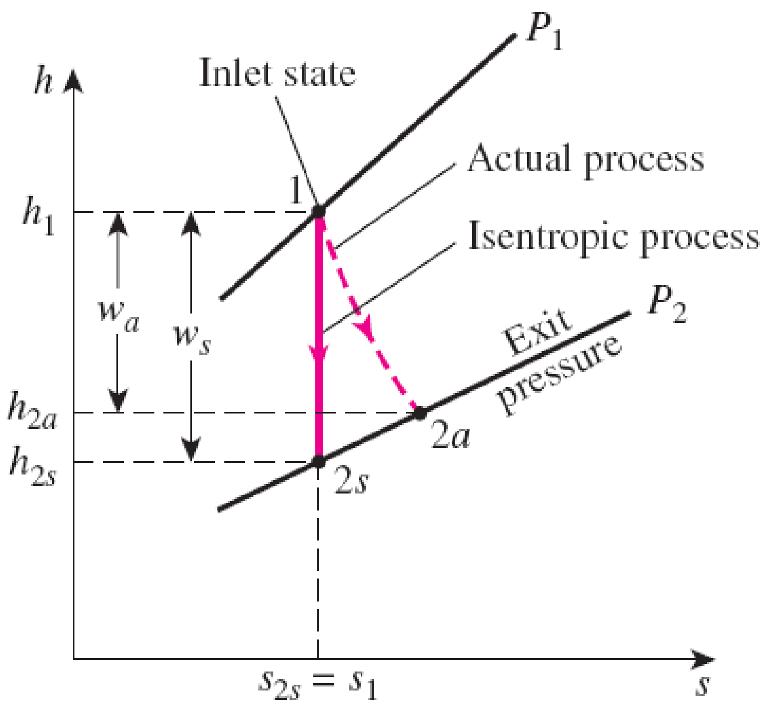
# ISENTROPIC EFFICIENCIES OF STEADY-FLOW DEVICES



The isentropic process involves no irreversibilities and serves as the ideal process for **adiabatic devices**.




## Isentropic Efficiency of Turbines




$$\eta_T = \frac{\text{Actual turbine work}}{\text{Isentropic turbine work}} = \frac{w_a}{w_s}$$

$$\eta_T \cong \frac{h_1 - h_{2a}}{h_1 - h_{2s}}$$

The *h-s* diagram for the actual and isentropic processes of an adiabatic turbine.

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# ENTROPY GENERATED WHEN A HOT BLOCK IS DROPPED IN A LAKE

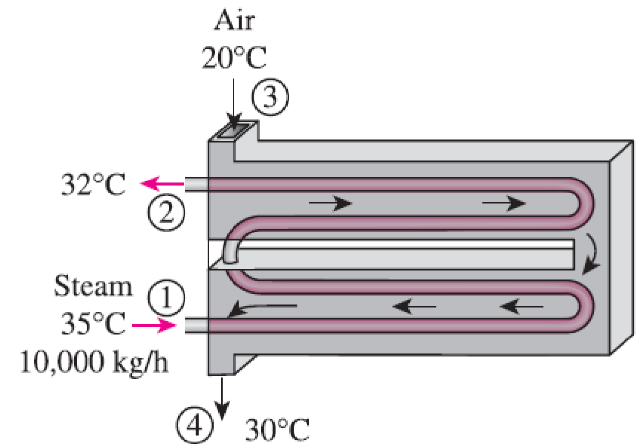

$$\underbrace{S_{in} - S_{out}}_{\text{Net entropy transfer by heat and mass}} + \underbrace{S_{gen}}_{\text{Entropy generation}} = \underbrace{\Delta S_{system}}_{\text{Change in entropy}}$$

$$-\frac{Q_{out}}{T_b} + S_{gen} = \Delta S_{system}$$

or $$S_{gen} = \Delta S_{total} = \Delta S_{system} + \Delta S_{lake}$$



*Entropy Generation in a Heat Exchanger*




$$\underbrace{\dot{S}_{in} - \dot{S}_{out}}_{\text{Rate of net entropy transfer by heat and mass}} + \underbrace{\dot{S}_{gen}}_{\text{Rate of entropy generation}} = \underbrace{\Delta \dot{S}_{system}}_{\text{Rate of change in entropy}} \rightarrow 0 \text{ (steady)}$$

$$\dot{m}_{steam} s_1 + \dot{m}_{air} s_3 - \dot{m}_{steam} s_2 - \dot{m}_{air} s_4 + \dot{S}_{gen} = 0$$

$$\dot{S}_{gen} = \dot{m}_{steam}(s_2 - s_1) + \dot{m}_{air}(s_4 - s_3)$$