5 THERMODYNAMICS

THERMODYNAMICS-1

Which of the following are intensive properties?

    I. temperature
    II. pressure
    III. composition
    IV. mass

(A) I only   (B) IV only   (C) I and II   (D) I, II, and III

An intensive property does not depend on the amount of material present. This is true for temperature, pressure, and composition.

The answer is (D).

THERMODYNAMICS-2

How many independent properties are required to completely fix the equilibrium state of a pure gaseous compound?

(A) 0   (B) 1   (C) 2   (D) 3

The number of independently variable properties needed to fix the state of a gaseous compound, f, is given by the Gibbs phase rule.

$$f = n - p + 2$$

In the preceding equation, n is the number of components and p is the number of phases.

For a pure gas,

$$n = p = 1$$
$$f = 1 - 1 + 2$$
$$= 2$$

The answer is (C).

THERMODYNAMICS-3

Which of the following thermodynamic relations is INCORRECT?

(A) $TdS = dU + pdV$ (B) $TdS = dH - Vdp$

(C) $U = Q - W$ (D) $H = U + pV$

$U = Q + W$. Therefore, the relation in option (C) is incorrect.

The answer is (C).

THERMODYNAMICS-4

If air is at a pressure, p, of 135 Pa, and at a temperature, T, of 440K, what is most nearly the specific volume, v? (Air's specific gas constant is $R = 88.81$ J/kg·K, and air can be modeled as an ideal gas.)

(A) 110 m³/kg   (B) 130 m³/kg   (C) 290 m³/kg   (D) 300 m³/kg

$$pv = RT$$

$$v = \frac{RT}{p}$$

$$= \frac{\left(88.81 \ \frac{J}{kg\cdot K}\right)(440K)}{135 \ Pa}$$

$$= 289 \ m^3/kg \quad (290 \ m^3/kg)$$

The answer is (C).

THERMODYNAMICS-5

Which of the following relationships defines enthalpy?
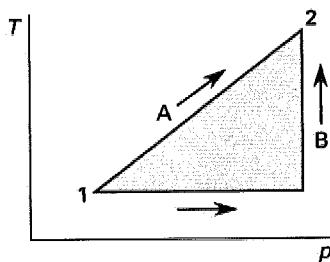
(A) $h = u + \dfrac{p}{T}$ (B) $h = u + pv$ (C) $h = u + \dfrac{p}{v}$ (D) $h = pv + T$

Enthalpy is given by $h = u + pv$.

> The answer is (B).

THERMODYNAMICS-6

In a certain constant mass system, the conditions change from point 1 to point 2. How does the change in enthalpy for path A differ from the enthalpy change for path B in going from point 1 to point 2?

(A) $\Delta H_A > \Delta H_B$

(B) $\Delta H_A = \Delta H_B$

(C) $\Delta H_A < \Delta H_B$

(D) $\Delta H_B \to \infty$

Enthalpy is a state function. Therefore, its value depends only on the initial and final states, and not on the path taken between the two states. Thus, $\Delta H_A = \Delta H_B$.

> The answer is (B).

THERMODYNAMICS-7

Steam at 416 Pa and 166K has a specific volume of 0.41 m³/kg and a specific enthalpy of 29.4 kJ/kg. Find the internal energy per kilogram of steam.

(A) 28.5 kJ/kg   (B) 29.2 kJ/kg   (C) 30.2 kJ/kg   (D) 30.4 kJ/kg

$$h = u + pv$$

$$u = h - pv$$

$$= 29.4 \, \frac{\text{kJ}}{\text{kg}} - (416 \text{ Pa}) \left(0.41 \, \frac{\text{m}^3}{\text{kg}} \right)$$

$$= 29.2 \text{ kJ/kg}$$

The answer is (B).

THERMODYNAMICS-8

Which of the following is true for water at a reference temperature where enthalpy is zero?

(A) Internal energy is negative.
(B) Entropy is nonzero.
(C) Specific volume is zero.
(D) Vapor pressure is zero.

Typically, the saturation temperature (0°C for water) is chosen as the enthalpic reference temperature. At that temperature, the water has a distinct (vapor) pressure and volume. Therefore, options (C) and (D) are false. Although there is no thermodynamic relationship between entropy and enthalpy, the values of enthalpy and entropy are commonly referenced to the same temperature. Thus, by convention, entropy is zero when enthalpy is zero. Therefore, option (B) is also false.

The definition of enthalpy is the sum of internal energy and flow energy.
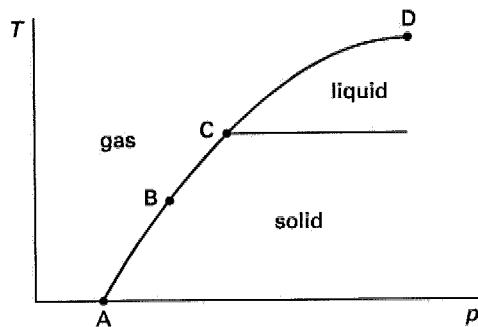
$$h = u + pv$$
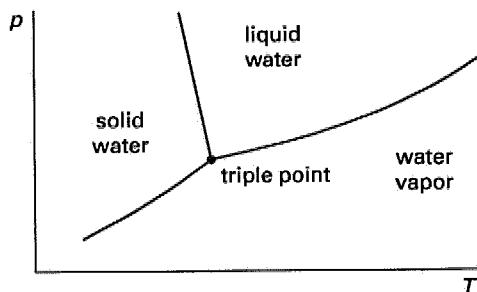
If enthalpy is zero and the flow energy, pv, is nonzero, then the internal energy must be negative.

The answer is (A).

THERMODYNAMICS-9

Which of the following is the triple point for the phase diagram given?


(A) A   (B) B   (C) C   (D) D
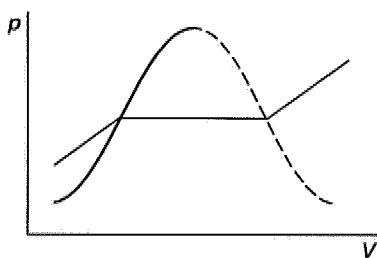
The triple point is the point at which the liquid, solid, and vapor states are all in equilibrium. Therefore, point C is the triple point.

The answer is (C).
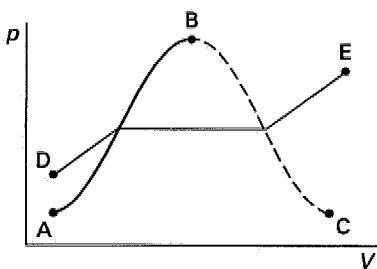
THERMODYNAMICS-10

What does the dashed curve in the figure represent?

(A) the solidus line
(B) an isotherm
(C) the saturated liquid line
(D) the saturated vapor line

The dashed line shown is the saturated vapor line.

AB is the saturated liquid line.
B is the critical point.
BC is the saturated vapor line.
DE represents a possible path of the system when heated.

The answer is (D).

THERMODYNAMICS-11

In an ideal gas mixture of constituents i and j, what is the mole fraction of component i, x_i, equal to?

(A) $\dfrac{T_i}{T_i + T_j}$ (B) $\dfrac{Z_i}{Z_i + Z_j}$ (C) $\dfrac{p_i}{p_i + p_j}$ (D) $\dfrac{m_i}{m_i + m_j}$

For an ideal gas, the mole fraction is equal to the partial pressure fraction.

$$x_i = \frac{p_i}{p_i + p_j}$$

The answer is (C).

THERMODYNAMICS-12

1.36 kg of air are held at 6.89 kPa and 38°C. Given that $R_{air} = 88.89$ J/kg·K, what is most nearly the volume of the container?

(A) 2.2 m³   (B) 3.1 m³   (C) 4.8 m³   (D) 5.5 m³

Use the ideal gas law.

$$T = (38°C + 273°) = 311K$$

$$pV = mRT$$

$$V = \frac{mRT}{p}$$

$$= \frac{(1.36 \text{ kg}) \left(88.89 \; \dfrac{\text{J}}{\text{kg·K}}\right)(311\text{K})}{6890 \text{ Pa}}$$

$$= 5.46 \text{ m}^3 \quad (5.5 \text{ m}^3)$$

The answer is (D).

THERMODYNAMICS-13

The compressibility factor, Z, is used for predicting the behavior of nonideal gases. How is the compressibility factor defined relative to an ideal gas? (Subscript "c" refers to critical value.)

(A) $Z = \dfrac{p}{p_c}$ (B) $Z = \dfrac{pV}{RT}$ (C) $Z = \dfrac{T}{T_c}$ (D) $Z = \left(\dfrac{T}{T_c}\right)\left(\dfrac{p_c}{p}\right)$

For real gases, the compressibility factor, Z, is a dimensionless constant given by $pV = ZRT$. Therefore, $Z = pV/RT$.

The answer is (B).

THERMODYNAMICS-14

On what plane is the Mollier diagram plotted?

(A) p-V (B) p-T (C) h-s (D) s-u

The axes for a Mollier diagram are enthalpy and entropy (h-s).

The answer is (C).

THERMODYNAMICS-15

How is the quality, x, of a liquid-vapor mixture defined?

(A) the fraction of the total volume that is saturated vapor
(B) the fraction of the total volume that is saturated liquid
(C) the fraction of the total mass that is saturated vapor
(D) the fraction of the total mass that is saturated liquid

The quality of the liquid-vapor mixture is defined as the fraction of the total mass that is saturated vapor.

The answer is (C).

THERMODYNAMICS-16

What is the expression for the heat of vaporization?

$$h_g = \text{enthalpy of the saturated vapor}$$

$$h_f = \text{enthalpy of the saturated liquid}$$

(A) $h_g + h_f$ (B) $h_f - h_g$ (C) $h_g - h_f$ (D) $h_g^2 - h_f^2$

The heat of vaporization, h_{fg}, is the difference between the enthalpy of the saturated vapor and the enthalpy of the saturated liquid. Thus, $h_{fg} = h_g - h_f$.

The answer is (C).

THERMODYNAMICS-17

From the steam tables, determine the average specific heat at constant pressure, c_p, of steam at 10 kPa and 45.8°C.

(A) 1.79 kJ/kg·°C   (B) 10.3 kJ/kg·°C   (C) 30.6 kJ/kg·°C   (D) 100 kJ/kg·°C

$$\Delta h = c_p \Delta T$$

$$c_p = \frac{\Delta h}{\Delta T}$$

From the steam tables, for 10 kPa,

at 47.7°C: $h = 2588.1$ kJ/kg
at 43.8°C: $h = 2581.1$ kJ/kg

$$c_p = \frac{2588.1 \text{ kJ/kg} - 2581.1 \text{ kJ/kg}}{47.7°C - 43.8°C}$$

$$= 1.79 \text{ kJ/kg·°C}$$

The answer is (A).

THERMODYNAMICS-18

A 10 m^3 vessel initially contains 5 m^3 of liquid water and 5 m^3 of saturated water vapor at 100 kPa. Calculate the internal energy of the system using the steam tables.

(A) 5×10^5 kJ   (B) 8×10^5 kJ   (C) 1×10^6 kJ   (D) 2×10^6 kJ

From the steam tables,

$$v_f = 0.001043 \text{ m}^3/\text{kg}$$

$$v_g = 1.6940 \text{ m}^3/\text{kg}$$

$$u_f = 417.3 \text{ kJ/kg}$$

$$u_g = 2506 \text{ kJ/kg}$$

$$m_{\text{vap}} = \frac{V_{\text{vap}}}{v_g}$$

$$= \frac{5 \text{ m}^3}{1.694 \dfrac{\text{m}^3}{\text{kg}}}$$

$$= 2.95 \text{ kg}$$

$$m_{\text{liq}} = \frac{V_{\text{liq}}}{v_f}$$

$$= \frac{5 \text{ m}^3}{0.001043 \dfrac{\text{m}^3}{\text{kg}}}$$

$$= 4794 \text{ kg}$$

$$u = u_f m_{\text{liq}} + u_g m_{\text{vap}}$$

$$= \left(417.3 \ \frac{\text{kJ}}{\text{kg}}\right)(4794 \text{ kg}) + \left(2506.1 \ \frac{\text{kJ}}{\text{kg}}\right)(2.95 \text{ kg})$$

$$= 2.01 \times 10^6 \text{ kJ}$$

The answer is (D).

THERMODYNAMICS-19

A vessel with a volume of 1 m³ contains liquid water and water vapor in equilibrium at 600 kPa. The liquid water has a mass of 1 kg. Using the steam tables, determine the approximate mass of the water vapor.

(A) 0.99 kg   (B) 1.6 kg   (C) 1.9 kg   (D) 3.2 kg

From the steam tables at 600 kPa,

$$v_f = 0.001101 \text{ m}^3/\text{kg}$$

$$v_g = 0.3157 \text{ m}^3/\text{kg}$$

$$V_{\text{total}} = m_f v_f + m_g v_g$$

$$m_g = \frac{V_{\text{total}} - m_f v_f}{v_g}$$

$$= \frac{1 \text{ m}^3 - (1 \text{ kg})\left(0.001101 \ \frac{\text{m}^3}{\text{kg}}\right)}{0.3157 \ \frac{\text{m}^3}{\text{kg}}}$$

$$= 3.16 \text{ kg} \quad (3.2 \text{ kg})$$

The answer is (D).

THERMODYNAMICS-20

What is most nearly the entropy of steam at 476 kPa with a quality of 0.6?

(A) 2.4 kJ/kg·K
(B) 3.8 kJ/kg·K
(C) 4.8 kJ/kg·K
(D) 5.7 kJ/kg·K

From the steam tables at 476 kPa,

$$s_f = 1.8418 \text{ kJ/kg·K}$$

$$s_{fg} = 4.9961 \text{ kJ/kg·K}$$

$$s = s_f + x s_{fg}$$

In the preceding equation, x is quality.

$$s = 1.8418 \ \frac{kJ}{kg \cdot K} + (0.6)\left(4.9961 \ \frac{kJ}{kg \cdot K}\right)$$

$$= 4.839 \ kJ/kg \cdot K \quad (4.8 \ kJ/kg \cdot K)$$

The answer is (C).

THERMODYNAMICS-21

If 0.45 kg of steam at 101.3 kPa and 63% quality is heated isentropically, at approximately what pressure will it reach the saturated vapor state?

(A) 15 200 kPa   (B) 16 300 kPa   (C) 17 300 kPa   (D) 17 800 kPa

Use the steam tables.

$$p_1 = 101.3 \ kPa$$

$$s_{f1} = 1.307 \ kJ/kg \cdot K$$

$$s_{fg1} = 6.048 \ kJ/kg \cdot K$$

$$s_1 = s_{f1} + 0.63 s_{fg1}$$

$$= 1.307 \ \frac{kJ}{kg \cdot K} + (0.63)\left(6.048 \ \frac{kJ}{kg \cdot K}\right)$$

$$= 5.117 \ kJ/kg \cdot K$$

Now, find p_2 such that $s_{g2} = 5.117 \ kJ/kg \cdot K$. Interpolating from the steam tables, $p_2 \approx 17\,800$ kPa.

The answer is (D).

THERMODYNAMICS-22

The first law of thermodynamics is based on which of the following principles?

(A) conservation of mass
(B) the enthalpy-entropy relationship
(C) action-reaction
(D) conservation of energy

The first law of thermodynamics is based on the principle of conservation of energy.

> The answer is (D).

THERMODYNAMICS-23

The general energy equation for an open system involves the following five terms.

    I. accumulation of energy

    II. net energy transfer by work (standard sign convention)

    III. net energy transfer by heat (standard sign convention)

    IV. transfer of energy in by mass flow

    V. transfer of energy out by mass flow

Using the standard sign conventions, what is the proper arrangement of these terms for the general energy equation satisfying the first law of thermodynamics?
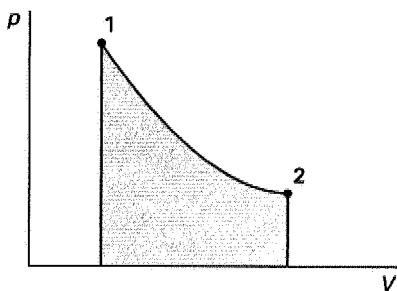
(A) $I = -II + III + IV - V$
(B) $I = II + III + IV + V$
(C) $I = II + III + IV - V$
(D) $I = II - III - IV + V$

The first law of thermodynamics states that the total change in energy (I) is equal to the energy in (IV) minus the energy out (V) minus the work done on the system (II) plus the heat transferred to the system (III). Thus, $I = -II + III + IV - V$.

> The answer is (A).

THERMODYNAMICS-24

In a reversible process, the state of a system changes from state 1 to state 2 as shown on the p-V diagram. What does the shaded area on the diagram represent?

(A) free-energy change
(B) heat transfer
(C) enthalpy change
(D) work done by the system

For a reversible process, the work done by the system is given by the following.

$$W = \int_1^2 p\,dV$$

Therefore, the shaded area represents the work done by the system.

The answer is (D).

THERMODYNAMICS-25

What is the value of the work done for a closed, reversible, isometric system?

(A) zero
(B) positive
(C) negative
(D) positive or negative

$$W = \int p\,dV$$

An isometric system is a system which has a constant volume ($dV = 0$). Therefore, the work done by the system is zero.

> The answer is (A).

THERMODYNAMICS-26

The expansion of a gas through a plug at a high pressure results in a temperature rise, while at lower pressures a temperature drop occurs. The Joule-Thompson coefficient, μ_{JT}, is defined as the ratio of the change in temperature to the change in pressure. The temperature at which μ_{JT} changes from positive to negative is called the inversion temperature. When μ_{JT} is negative, which of the following statements is true?

(A) Gases may be liquified by pressurization.
(B) No liquification is possible.
(C) Only trace liquification is possible.
(D) Liquification can be obtained only with a catalyst.

When $\mu_{JT} < 0$, then $\partial T/\partial p < 0$. Thus, a pressure rise is accompanied by a temperature drop. Therefore, a gas may be liquified by pressurization.

> The answer is (A).

THERMODYNAMICS-27

A 5 m^3 vessel initially contains 50 kg of liquid water and saturated water vapor at a total internal energy of 27 300 kJ. Calculate the heat requirement to vaporize all of the liquid.

(A) 100 000 kJ   (B) 200 000 kJ   (C) 300 000 kJ   (D) 400 000 kJ

An expression for the first law of thermodynamics is

$$Q = U_2 - U_1$$
$$U_1 = 27\,300 \text{ kJ}$$

Find U_2 in the steam tables at 100% vapor. $v_g = 5$ m^3/50 kg = 0.10 m^3/kg.

The final state is at $p = 2.00$ MPa and $u_g = 2600$ kJ/kg.

$$U_2 = mu_g$$

$$= \left(2600 \ \frac{kJ}{kg}\right)(50 \text{ kg})$$

$$= 130\,000 \text{ kJ}$$

$$Q = 130\,000 \text{ kJ} - 27\,300 \text{ kJ}$$

$$= 103\,000 \text{ kJ} \quad (100\,000 \text{ kJ})$$

The answer is (A).

THERMODYNAMICS-28

What is most nearly the change in internal energy of 2.27 kg of oxygen gas when the temperature changes from 38°C to 49°C? ($c_v = 0.658$ kJ/kg·K)

(A) 16 kJ   (B) 420 kJ   (C) 470 kJ   (D) 630 kJ

$$\Delta U = mc_v\Delta T$$

$$\Delta T = 49°C - 38°C$$

$$= 11°C$$

$$\Delta U = (2.27 \text{ kg})\left(0.658 \ \frac{kJ}{kg\cdot K}\right)(11°C)$$

$$= 16.4 \text{ kJ} \quad (16 \text{ kJ})$$

The answer is (A).

THERMODYNAMICS-29

Water (specific heat $c_v = 4.2$ kJ/kg·K) is being heated by a 1500 W heater. What is most nearly the temperature rate of change for 1 kg of water?

(A) 0.043K/s   (B) 0.18K/s   (C) 0.36K/s   (D) 1.5K/s

$$\dot{Q} = mc_v(\dot{\Delta T})$$

$$\dot{\Delta T} = \frac{\dot{Q}}{mc_v}$$

$$= \frac{1500 \text{ W}}{(1 \text{ kg})\left(4200 \ \frac{\text{J}}{\text{kg·K}}\right)}$$

$$= 0.357\text{K/s} \quad (0.36\text{K/s})$$

The answer is (C).

THERMODYNAMICS-30

1 kg of water ($c_v = 4.2$ kJ/kg·K) is heated by 316 kJ of energy. What is most nearly the change in temperature?

(A) 18K   (B) 71K   (C) 74K   (D) 75K

$$mc_v\Delta T = Q$$

$$\Delta T = \frac{Q}{mc_v}$$

$$= \frac{316 \text{ kJ}}{(1 \text{ kg})\left(4.2 \ \frac{\text{kJ}}{\text{kg·K}}\right)}$$

$$= 75.2\text{K} \quad (75\text{K})$$

The answer is (D).

THERMODYNAMICS-31

What is most nearly the change in enthalpy per kg of nitrogen gas as its temperature changes from 260°C to 93°C (c_p = 1.04 kJ/kg·K)?

(A) −200 kJ   (B) −170 kJ   (C) 110 kJ   (D) 170 kJ

$$\Delta h = c_p \Delta T$$

$$= \left(1.04 \ \frac{kJ}{kg\cdot K}\right)(93°C - 260°C)$$

$$= -173.7 \ kJ \quad (-170 \ kJ)$$

The answer is (B).

THERMODYNAMICS-32

Calculate the change in enthalpy as 1 kg of nitrogen is heated from 1000K to 1500K, assuming the nitrogen is an ideal gas at a constant pressure. The temperature-dependent specific heat of nitrogen is

$$C_p = 39.06 - 512.79T^{-1.5} + 1072.7T^{-2} - 820.4T^{-3}$$

(C_p is in kJ/kmol·K, and T is in K.)

(A) 600 kJ   (B) 700 kJ   (C) 800 kJ   (D) 900 kJ

$$C_p \equiv \left(\frac{\partial H}{\partial T}\right)_p$$

$$\partial H = C_p \partial T$$

$$= \int C_p dT$$

$$= \int_{1000}^{1500} \left(39.06 - 512.79T^{-1.5} + 1072.7T^{-2} - 820.4T^{-3}\right) dT$$

$$= \left| \left(39.06T + 1025.6T^{-0.5} + 1072.7T^{-1} + 410.2T^{-2}\right) \right|_{1000}^{1500}$$

$$= 58\,617 \ \frac{kJ}{kmol} - 39\,094 \ \frac{kJ}{kmol}$$

$$= 19\,523 \ kJ/kmol$$

$$\Delta H_{total} = m\Delta h = m\left(\frac{\Delta H}{MW}\right) = \left(19\,523\ \frac{kJ}{kmol}\right)(1\ kg)\left(\frac{1\ kmol}{28\ kg}\right)$$

$$= 697.3\ kJ \quad (700\ kJ)$$

The answer is (B).

THERMODYNAMICS-33

What is most nearly the resulting pressure when 400 g of air at 103.6 kPa and 93°C is heated at constant volume to 427°C?

(A) 160 kPa   (B) 200 kPa   (C) 250 kPa   (D) 480 kPa

$$\frac{T_1}{p_1} = \frac{T_2}{p_2}$$

$$p_2 = \frac{p_1 T_2}{T_1}$$

$$= \frac{(103.6\ kPa)(427°C + 273°)}{93°C + 273°}$$

$$= 198\ kPa \quad (200\ kPa)$$

The answer is (B).

THERMODYNAMICS-34

Approximately how much power is required to isothermally compress 23 m³/min of air from 101.5 kPa to 828.5 kPa?

(A) 64 kW   (B) 82 kW   (C) 92 kW   (D) 98 kW

For an isothermal process,

$$W = -p_1 V_1 \ln \frac{p_1}{p_2}$$

$$= p_1 V_1 \ln \frac{p_2}{p_1}$$

$$= (101.5\ kPa)(23\ m^3) \ln \left(\frac{828.5\ kPa}{101.5\ kPa}\right)$$

$$= 4901\ kJ$$

$$P = \frac{dW}{dt}$$

$$= \frac{4901 \text{ kJ}}{60 \text{ s}}$$

$$= 81.7 \text{ kW} \quad (82 \text{ kW})$$

The answer is (B).

THERMODYNAMICS–35

What is most nearly the work done by a system in which 1 kmol of water completely evaporates at 100°C and 1 atm constant pressure?

(A) 1000 kJ   (B) 2100 kJ   (C) 2500 kJ   (D) 3100 kJ

$$p = (1 \text{ atm}) \left(101.3 \ \frac{\text{kPa}}{\text{atm}} \right) = 101.3 \text{ kPa}$$

From the steam tables,

$$v_f = 0.001\,044 \text{ m}^3/\text{kg}$$

$$v_g = 1.673 \text{ m}^3/\text{kg}$$

The molecular weight of water is

$$MW_{H_2 0} = 18.016 \text{ kg/kmol}$$

$$V_1 = v_f MW_{H_2 0} m$$

$$= \left(0.001\,044 \ \frac{\text{m}^3}{\text{kg}} \right) \left(18.016 \ \frac{\text{kg}}{\text{kmol}} \right) (1 \text{ kmol})$$

$$= 0.01881 \text{ m}^3$$

$$V_2 = v_g MW_{H_2 0} m$$

$$= \left(1.673 \ \frac{\text{m}^3}{\text{kg}} \right) \left(18.016 \ \frac{\text{kg}}{\text{kmol}} \right) (1 \text{ kmol})$$

$$= 30.141 \text{ m}^3$$

$$W = \int_1^2 p\,dV$$

$$= p(V_2 - V_1)$$

$$W = (101\,300 \text{ Pa})(30.141 \text{ m}^3 - 0.018\,81 \text{ m}^3)$$

$$= 3.05 \times 10^6 \text{ J} \quad (3100 \text{ kJ})$$

The answer is (D).

THERMODYNAMICS-36

5 mol of water vapor at 100°C and 1 atm pressure are compressed isobarically to form liquid at 100°C. The process is reversible, and the ideal gas laws apply. What is most nearly the initial volume of the vapor?

(A) 120 L   (B) 130 L   (C) 140 L   (D) 150 L

Use the ideal gas law.

$$pV = nR^*T$$

$$V = \frac{nR^*T}{p}$$

$$= \frac{(5 \text{ mol})\left(0.0821 \frac{\text{atm·L}}{\text{mol·K}}\right)(100°C + 273°)}{1 \text{ atm}}$$

$$= 153 \text{ L} \quad (150 \text{ L})$$

The answer is (D).

THERMODYNAMICS-37

5 kmol of water vapor at 100°C and 1 atm pressure are compressed isobarically from an initial volume of 153 L to form liquid at 100°C. The process is reversible, and the ideal gas laws apply. What is most nearly the work done on the system?

(A) 6.0 kJ   (B) 6.2 kJ   (C) 6.0 MJ   (D) 6.2 MJ

$$W = -p(V_2 - V_1)$$

From the steam tables,

$$v_f = 0.001\,044 \text{ m}^3/\text{kg}$$

$$\text{MW}_{\text{H}_2\text{O}} = 18.016 \text{ kg/kmol}$$

$$V_1 = (153 \text{ L}) \left(0.001 \ \frac{\text{m}^3}{\text{L}} \right)$$

$$= 0.153 \text{ m}^3$$

$$V_2 = n\text{MW}_{\text{H}_2\text{O}}v_f$$

$$= (5 \text{ kmol}) \left(18.016 \ \frac{\text{kg}}{\text{kmol}} \right) \left(0.001\,044 \ \frac{\text{m}^3}{\text{kg}} \right)$$

$$= 0.094 \text{ m}^3$$

$$W = -p\Delta V = -(101\,325 \text{ Pa}) \left(0.094 \text{ m}^3 - 0.153 \text{ m}^3 \right)$$

$$= 5978 \text{ J} \quad (6.0 \text{ kJ})$$

The answer is (A).

THERMODYNAMICS–38

5 kmol of water vapor at 100°C and 1 atm pressure are compressed isobarically to form liquid at 100°C. The process is reversible, and the ideal gas laws apply. The heat of vaporization is 2257 kJ/kg. What is most nearly the heat required for condensation for the amount of water given?

(A) −200 MJ   (B) −140 MJ   (C) 200 MJ   (D) 410 MJ

$$h_{fg} = 2257 \text{ kJ/kg}$$

$$Q = \Delta H$$

$$= m(-h_{fg}) = nM(-h_{fg})$$

$$= (5 \text{ kmol}) \left(18.016 \ \frac{\text{kg}}{\text{kmol}} \right) \left(-2257 \ \frac{\text{kJ}}{\text{kg}} \right)$$

$$= -203.3 \text{ MJ} \quad (-200 \text{ MJ})$$

The answer is (A).

THERMODYNAMICS-39

What is the equation for the work done by a constant temperature system?

(A) $W = mRT \ln(V_2 - V_1)$

(B) $W = mR(T_2 - T_1) \ln \dfrac{V_2}{V_1}$

(C) $W = mRT \ln \dfrac{V_2}{V_1}$

(D) $W = mRT \ln \dfrac{p_2}{p_1}$

$$W = \int_1^2 pdV$$

$$p = \frac{mRT}{V}$$

$$W = \int_1^2 \frac{mRT}{V} dV$$

$$= mRT \ln V \Big|_1^2$$

$$W = mRT \ln \frac{V_2}{V_1}$$

The answer is (C).

THERMODYNAMICS-40

20 g of oxygen gas (O_2) are compressed at a constant temperature of 30°C to 5% of their original volume. What work is done on the system?

(A) 820 cal   (B) 920 cal   (C) 950 cal   (D) 1120 cal

$$W = -\int_{V_1}^{V_2} pdV \qquad \begin{bmatrix} \text{negative to get work} \\ \text{done on system} \end{bmatrix}$$

$$= -mRT \ln \frac{V_2}{V_1}$$

$$R = \frac{R^*}{MW} = \frac{1.98 \; \dfrac{\text{cal}}{\text{mol·K}}}{32 \; \dfrac{\text{g}}{\text{mol}}}$$

$$= 0.0619 \; \text{cal/g·K}$$

$$T = 30°C + 273° = 303K$$

$$W = -(20\text{ g})\left(0.0619\ \frac{\text{cal}}{\text{g·K}}\right)(303K)\ln\left(\frac{5\%}{100\%}\right)$$

$$= 1124\text{ cal}\quad(1120\text{ cal})$$

The answer is (D).

THERMODYNAMICS-41

Helium ($R^* = 0.6403$ kJ/kg·K) is compressed isothermally from 101.3 kPa and 20°C. The compression ratio is 4. What is most nearly the work done by the gas?

(A) −320 kJ/kg   (B) −260 kJ/kg   (C) 170 kJ/kg   (D) 180 kJ/kg
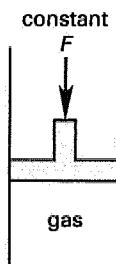
$$W = \int_1^2 p\,dV$$

$$= RT\ln\frac{V_2}{V_1}$$

$$= \left(0.6403\ \frac{\text{kJ}}{\text{kg·K}}\right)(293K)\ln\frac{1}{4}$$

$$= -260\text{ kJ/kg}$$

The answer is (B).

THERMODYNAMICS-42

Gas is enclosed in a cylinder with a weighted piston as the top boundary. The gas is heated and expands from a volume of 0.04 m³ to 0.10 m³ at a constant pressure of 200 kPa. Calculate the work done by the system.

(A) 8.0 kJ   (B) 10 kJ   (C) 12 kJ   (D) 14 kJ

At constant pressure,

$$W = \int_1^2 pdV$$

$$= p(V_2 - V_1)$$

$$= (200\,000 \text{ Pa})(0.10 \text{ m}^3 - 0.04 \text{ m}^3)$$

$$= 12\,000 \text{ J} \quad (12 \text{ kJ})$$

The answer is (C).

THERMODYNAMICS–43

A piston-cylinder system contains a gas that expands under a constant pressure of 57 kPa. If the piston is displaced 0.3 m during the process, and the piston diameter is 0.6 m, what is the work done by the gas on the piston?

(A) 2.4 kJ   (B) 3.2 kJ   (C) 3.4 kJ   (D) 4.8 kJ

The work is done at constant pressure.

$$W = \int_1^2 pdV$$

$$= p\Delta V$$

$$\Delta V = A\Delta L$$

$$= \pi(0.3 \text{ m})^2(0.3 \text{ m})$$

$$= 0.085 \text{ m}^3$$

$$W = (57 \text{ kPa})(0.085 \text{ m}^3)$$

$$= 4.8 \text{ kJ}$$

The answer is (D).

THERMODYNAMICS-44

Gas is enclosed in a cylinder with a weighted piston as the top boundary. The gas is heated and expands from a volume of 0.04 m^3 to 0.10 m^3. The pressure varies such that pV is constant, and the initial pressure is 200 kPa. What is most nearly the work done by the system?

(A) 6.8 kJ   (B) 7.3 kJ   (C) 10 kJ   (D) 12 kJ

The work done by the system on the piston is given as follows.

$$W = \int_1^2 p\,dV$$

$$p_2 = \frac{p_1 V_1}{V_2}$$

$$W = p_1 V_1 \int_1^2 \frac{dV}{V}$$

$$= p_1 V_1 \ln \frac{V_2}{V_1}$$

$$= (200\,000 \text{ Pa})(0.04 \text{ m}^3) \ln \left(\frac{0.10 \text{ m}^3}{0.04 \text{ m}^3} \right)$$

$$= 7330 \text{ J} \quad (7.3 \text{ kJ})$$

The answer is (B).

THERMODYNAMICS-45

Steam flows into a turbine at a rate of 10 kg/s, and 10 kW of heat are lost from the turbine. Ignoring elevation and kinetic energy effects, what is most nearly the power output from the turbine?

	inlet conditions	exit conditions
pressure	2.0 MPa	0.1 MPa
temperature	350°C	–
quality	–	100%

(A) 4000 kW   (B) 4400 kW   (C) 4600 kW   (D) 5000 kW

Use the first law of thermodynamics.

$$P = \dot{W}$$

$$= \dot{m}(h_i - h_e) + Q$$

From the steam tables,

$$h_i = 3137.0 \text{ kJ/kg}$$

$$h_e = 2675.5 \text{ kJ/kg}$$

$$\dot{W} = \left(10 \; \frac{\text{kg}}{\text{s}}\right)\left(3137.0 \; \frac{\text{kJ}}{\text{kg}} - 2675.5 \; \frac{\text{kJ}}{\text{kg}}\right) - 10 \text{ kW}$$

$$= 4605 \text{ kW} \quad (4600 \text{ kW})$$

The answer is (C).

THERMODYNAMICS-46

How does an adiabatic process compare to an isentropic process?

(A) adiabatic: heat transfer $= 0$; isentropic: heat transfer $\neq 0$
(B) adiabatic: heat transfer $\neq 0$; isentropic: heat transfer $= 0$
(C) adiabatic: reversible; isentropic: not reversible
(D) both: heat transfer $= 0$; isentropic: reversible

An adiabatic process is one in which there is no heat flow. It is not necessarily reversible. An isentropic process has no heat flow and is reversible.

The answer is (D).

THERMODYNAMICS-47

What is true about the polytropic exponent, n, for a perfect gas undergoing an isobaric process?

(A) $n > 0$ (B) $n < 0$ (C) $n \to \infty$ (D) $n = 0$

For an isobaric process,

$$p_1 = p_2 \qquad\qquad \text{[I]}$$

For a polytropic process,

$$p_1 V_1^n = p_2 V_2^n \qquad\qquad \text{[II]}$$

Equation I can be derived from II only if $n = 0$.

The answer is (D).

THERMODYNAMICS-48

In an isentropic compression, $p_1 = 2.14\ \text{N/cm}^2$, $p_2 = 4.28\ \text{N/cm}^2$, $V_1 = 164\ \text{cm}^3$, and the ratio of specific heats is $k = 1.4$. What is most nearly the value of V_2?

(A) 18 cm^3 (B) 21 cm^3 (C) 23 cm^3 (D) 100 cm^3

For an isentropic process,

$$\frac{p_1}{p_2} = \left(\frac{V_2}{V_1}\right)^k$$

$$V_2 = V_1 \left(\frac{p_1}{p_2}\right)^{1/k}$$

$$= (164\ \text{cm}^3) \left(\frac{2.14\ \dfrac{\text{N}}{\text{cm}^2}}{4.28\ \dfrac{\text{N}}{\text{cm}^2}}\right)^{1/1.4}$$

$$= 99.96\ \text{cm}^3 \quad (100\ \text{cm}^3)$$

The answer is (D).

THERMODYNAMICS-49

In an adiabatic, isentropic process, $p_1 = 4.28$ N/cm^2, $p_2 = 6.42$ N/cm^2, and $T_1 = 388$K. The ratio of specific heats is 1.4. What is most nearly the value of T_2?

(A) 270K   (B) 390K   (C) 430K   (D) 440K

For an isentropic process,

$$T_2 = T_1 \left(\frac{p_2}{p_1}\right)^{(k-1)/k}$$

$$= (388\text{K}) \left(\frac{6.42 \dfrac{\text{N}}{\text{cm}^2}}{4.28 \dfrac{\text{N}}{\text{cm}^2}}\right)^{(1.4-1)/1.4}$$

$$= 436\text{K} \quad (440\text{K})$$

> The answer is (D).

THERMODYNAMICS-50

Air undergoes an isentropic compression from 0.31 N/cm^2 to 3.87 N/cm^2. If the initial temperature is 20°C and the final temperature is 327.5°C, what is most nearly the work done by the gas?

(A) −320 kJ/kg   (B) −220 kJ/kg   (C) 120 kJ/kg   (D) 230 kJ/kg

For air,

$$c_v = 0.718 \text{ kJ/kg·K}$$

$$W = c_v(T_1 - T_2)$$

$$= \left(0.718 \frac{\text{kJ}}{\text{kg·K}}\right)(20°\text{C} - 327.5°\text{C})$$

$$= -221 \text{ kJ/kg} \quad (-220 \text{ kJ/kg})$$

> The answer is (B).

THERMODYNAMICS-51

Nitrogen is expanded isentropically. Its temperature changes from 600K to 288K. Find the pressure ratio (p_1/p_2).

(A) 11   (B) 13   (C) 16   (D) 22

For an isentropic process,

$$\frac{p_1}{p_2} = \left(\frac{T_1}{T_2}\right)^{k/(k-1)}$$

$$k = 1.4$$

$$\frac{p_1}{p_2} = \left(\frac{600\text{K}}{288\text{K}}\right)^{1.4/(1.4-1)}$$

$$= 13$$

The answer is (B).

THERMODYNAMICS-52

Nitrogen is expanded isentropically. Its temperature changes from 327°C to 15°C. The volumetric ratio is $V_2/V_1 = 6.22$, and the specific gas content for nitrogen is 0.1017 kJ/kg·K. What is most nearly the work done by the gas?

(A) −80 kJ/kg   (B) −13 kJ/kg   (C) 19 kJ/kg   (D) 79 kJ/kg

For an isentropic process,

$$k = 1.4$$
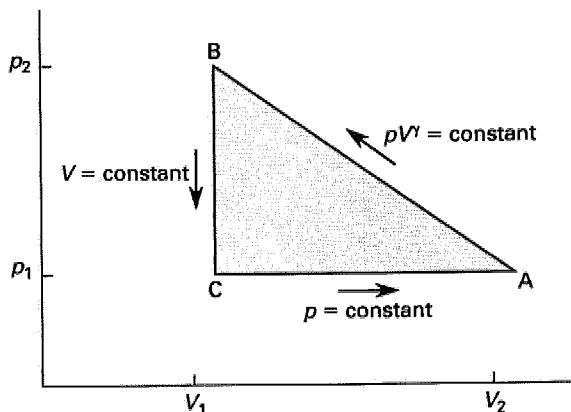
$$W = \frac{R(T_1 - T_2)}{k - 1}$$

$$= \frac{\left(0.1017\ \frac{\text{kJ}}{\text{kg·K}}\right)(327°\text{C} - 15°\text{C})}{0.4}$$

$$= 79.3\ \text{kJ/kg} \quad (79\ \text{kJ/kg})$$

The answer is (D).

THERMODYNAMICS-53

For the cycle shown, what is the work done on the system?

(A) 0
(B) area enclosed by the cycle in T-V space
(C) $R(T_B - T_C)$
(D) area enclosed by the cycle in p-V space

$$W = \oint p\,dV$$

$$= W_A^B - W_C^A$$

$$= \frac{R(T_B - T_A)}{k-1} - \frac{R(T_A - T_C)}{k-1}$$

$$= \left(\frac{R}{k-1}\right)(T_B + T_C - 2T_A)$$

Thus, options (A), (B), and (C) are incorrect. However, $\oint p\,dV$ is the area enclosed in p-V space. Therefore, option (D) is correct.

The answer is (D).

THERMODYNAMICS-54

An isobaric steam generating process starts with saturated liquid at 143 kPa. The change in entropy is equal to the initial entropy. Not all of the liquid is vaporized. What is most nearly the change in enthalpy during the process?

(A) 110 kJ/kg   (B) 270 kJ/kg   (C) 410 kJ/kg   (D) 540 kJ/kg

$$\Delta h = x h_{fg}$$

In the preceding equation, x is quality.

$$h_{fg} = 2230 \text{ kJ/kg}$$

$$s_{\text{initial}} = s_f$$

$$= 1.4185 \text{ kJ/kg·K} \quad [\text{at } 143 \text{ kPa}]$$

$$s_{\text{final}} = s_{\text{initial}} + \Delta s$$

$$= 2s_{\text{initial}}$$

$$= (2) \left(1.4185 \frac{\text{kJ}}{\text{kg·K}} \right)$$

$$= 2.837 \text{ kJ/kg·K}$$

$$= s_f + x s_{fg}$$

$$x = \frac{s_{\text{final}} - s_f}{s_{fg}}$$

$$= \frac{2.837 \dfrac{\text{kJ}}{\text{kg·K}} - 1.4185 \dfrac{\text{kJ}}{\text{kg·K}}}{5.8202 \dfrac{\text{kJ}}{\text{kg·K}}}$$

$$= 0.244$$

$$\Delta h = x h_{fg} = (0.244) \left(2230 \frac{\text{kJ}}{\text{kg}} \right)$$

$$= 544.1 \text{ kJ/kg} \quad (540 \text{ kJ/kg})$$

The answer is (D).

THERMODYNAMICS–55

A cylinder and piston arrangement contains saturated water vapor at 110°C. The vapor is compressed in a reversible adiabatic process until the pressure is 1.6 MPa. What is most nearly the work done by the system?

(A) −640 kJ/kg   (B) −510 kJ/kg   (C) −430 kJ/kg   (D) −330 kJ/kg

Use the first law of thermodynamics.

$$Q = U_1 - U_2 + W$$

$$= 0$$

$$W = U_1 - U_2$$

State 1 is specified. Because the process is reversible and adiabatic, $s_1 = s_2$. Thus, it is possible to find state 2. To do so, use the steam tables.

$$\text{at } 110°C: \quad s_1 = 7.2387 \text{ kJ/kg·K}$$

$$u_1 = 2518.1 \text{ kJ/kg}$$

$$\text{at } 1.6 \text{ MPa}: \quad s_2 = 7.2374 \text{ kJ/kg·K}$$

$$u_2 = 2950.1 \text{ kJ/kg}$$

$$T_2 = 400°C$$

$$W = 2518.1 \text{ kJ/kg} - 2950.1 \text{ kJ/kg}$$

$$= -432 \text{ kJ/kg} \quad (-430 \text{ kJ/kg})$$

The answer is (C).

THERMODYNAMICS-56

During an adiabatic, internally reversible process, what is true about the change in entropy?

(A) It is always zero.
(B) It is always less than zero.
(C) It is always greater than zero.
(D) It is infinite.

Since there is no heat flow, an adiabatic, reversible process has a zero change in entropy.

The answer is (A).

THERMODYNAMICS-57

For an irreversible process, what is true about the total change in entropy of the system and surroundings?

(A) $dS = \infty$ (B) $dS = 0$ (C) $dS > 0$ (D) $dS < 0$

For an irreversible process,

$$dS = dS_{\text{system}} + dS_{\text{surroundings}} > 0$$

The answer is (C).

THERMODYNAMICS-58

For which type of process is the equation $dQ = TdS$ valid?

(A) irreversible   (B) isothermal   (C) reversible   (D) isobaric

$$TdS = dH - Vdp$$
$$dH = dU + pdV + Vdp$$
$$TdS = dU + pdV$$
$$pdV = dW$$
$$TdS = dU + dW$$

The first law of thermodynamics is

$$dQ = dU + dW$$

Therefore,

$$dQ = TdS \quad \text{[for a reversible process]}$$

The answer is (C).

THERMODYNAMICS-59

Which of the following is true for any process?
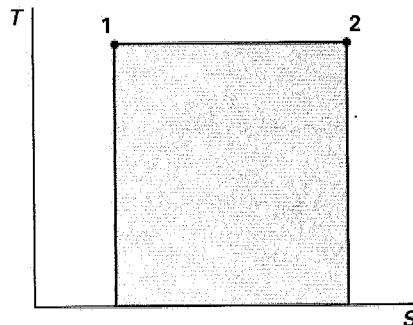
(A) $\Delta S_{\text{surroundings}} + \Delta S_{\text{system}} \geq 0$
(B) $\Delta S_{\text{surroundings}} + \Delta S_{\text{system}} \leq 0$
(C) $\Delta S_{\text{surroundings}} + \Delta S_{\text{system}} < 0$
(D) $\Delta S_{\text{surroundings}} + \Delta S_{\text{system}} > 0$

The total entropy either increases or, for a reversible process, remains the same. Therefore, the total change in entropy is always greater than or equal to zero.

> The answer is (A).

THERMODYNAMICS-60

In a reversible process, the state of a system changes from state 1 to state 2, as shown on the T-S diagram. What does the shaded area of the diagram represent?

(A) free-energy change
(B) heat transfer
(C) enthalpy change
(D) work

For a reversible process, $Q = \int T dS$. Thus, the shaded area represents the heat transfer.

> The answer is (B).

THERMODYNAMICS-61

Helium is compressed isothermally from 14.7 psia and 68°F. The compression ratio is 4. What is most nearly the change in entropy of the gas, given that the specific gas constant is $R_{He} = 0.6411$ kJ/kg·K?

(A) −0.97 kJ/kg·K   (B) −0.89 kJ/kg·K
           (C) 0.45 kJ/kg·K   (D) 0.89 kJ/kg·K

For an isothermal process,

$$\Delta s = R_{He} \ln \frac{V_2}{V_1}$$

$$= \left(0.6411 \ \frac{kJ}{kg \cdot K} \right) \ln \frac{1}{4}$$

$$= -0.889 \ kJ/kg \cdot K \quad (-0.89 \ kJ/kg \cdot K)$$

The answer is (B).

THERMODYNAMICS-62

For an ideal gas, what is most nearly the specific molar entropy change during an isothermal process in which the pressure changes from 200 kPa to 150 kPa?

(A) 2.0 J/mol·K   (B) 2.4 J/mol·K

    (C) 2.8 J/mol·K   (D) 3.1 J/mol·K

For an ideal gas,

$$\Delta S = c_p \ln \frac{T_2}{T_1} - R^* \ln \frac{p_2}{p_1}$$
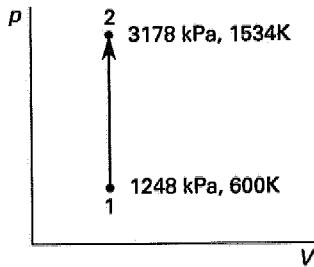
For an isothermal process,

$$T_1 = T_2$$

$$\ln \frac{T_2}{T_1} = 0$$

$$\Delta S = -R^* \ln \frac{p_2}{p_1}$$

$$= \left(-8.314 \ \frac{J}{mol \cdot K} \right) \ln \left(\frac{150 \ kPa}{200 \ kPa} \right)$$

$$= 2.39 \ J/mol \cdot K \quad (2.4 \ J/mol \cdot K)$$

The answer is (B).

THERMODYNAMICS-63

In the $p\text{-}V$ diagram shown, heat addition occurs between points 1 and 2. Given that $c_v = 0.434$ kJ/kg·K, what is most nearly the entropy produced during this step?

(A) -0.41 kJ/kg·K   (B) -0.23 kJ/kg·K

(C) 0.23 kJ/kg·K   (D) 0.41 kJ/kg·K

$$\Delta s = c_v \ln \frac{T_2}{T_1} + R \ln \frac{V_2}{V_1}$$

$$V_2 = V_1$$

$$\Delta s = c_v \ln \frac{T_2}{T_1}$$

$$= \left(0.434 \; \frac{\text{kJ}}{\text{kg·K}} \right) \ln \left(\frac{1534\text{K}}{600\text{K}} \right)$$

$$= 0.407 \; \text{kJ/kg·K} \quad (0.41 \; \text{kJ/kg·K})$$

The answer is (D).

THERMODYNAMICS-64

200 g of water are heated from 5°C to 100°C and vaporized at a constant pressure. The heat of vaporization of water at 100°C is 539.2 cal/g. The heat capacity at constant pressure, c_p, is 1.0 cal/g·K. What is most nearly the total change in entropy?

(A) 250 cal/K   (B) 300 cal/K   (C) 350 cal/K   (D) 400 cal/K

$$T_1 = 5°C + 273° = 278K$$

$$T_2 = 100°C + 273° = 373K$$

$$\Delta S = \Delta S_{\text{heat}} + \Delta S_{\text{vaporization}}$$

$$\Delta s_{\text{heat}} = s_2 - s_1$$

$$= \int_{T_1}^{T_2} \frac{c_p}{T} dT - R \ln \frac{p_2}{p_1}$$

$$p_1 = p_2$$

$$\Delta s_{\text{heat}} = \int_{T_1}^{T_2} \frac{c_p}{T} dT$$

$$= c_p \ln \frac{T_2}{T_1}$$

$$= \left(1 \ \frac{\text{cal}}{\text{g·K}}\right) \ln \left(\frac{373K}{278K}\right)$$

$$= 0.2940 \ \text{cal/g·K}$$

$$\Delta S_{\text{heat}} = m\Delta s_{\text{heat}}$$

$$= (200 \ \text{g}) \left(0.2940 \ \frac{\text{cal}}{\text{g·K}}\right)$$

$$= 58.8 \ \text{cal/K}$$

$$\Delta s_{\text{vaporization}} = \frac{Q}{T} = \frac{h_{fg}}{T_{\text{vap}}}$$

$$= \frac{539.2 \ \dfrac{\text{cal}}{\text{g}}}{373K}$$

$$= 1.446 \ \text{cal/g·K}$$

$$\Delta S_{\text{vaporization}} = m\Delta s_{\text{vaporization}}$$

$$= (200 \ \text{g}) \left(1.446 \ \frac{\text{cal}}{\text{g·K}}\right)$$

$$= 289.2 \ \text{cal/K}$$

$$\Delta S = 58.5 \ \frac{\text{cal}}{\text{K}} + 289.2 \ \frac{\text{cal}}{\text{K}}$$

$$= 348 \ \text{cal/K} \quad (350 \ \text{cal/K})$$
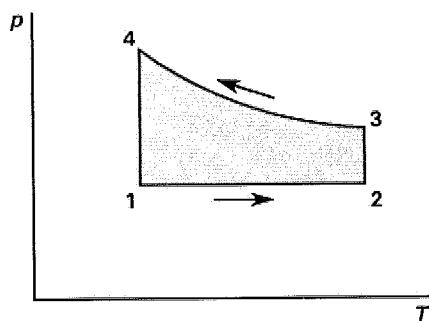
The answer is (C).

6 POWER CYCLES

POWER CYCLES-1

What kind of process occurs between points 3 and 4?

(A) isentropic
(B) isobaric
(C) isothermal
(D) There is insufficient information to determine the process type.

The process between points 3 and 4 is indeterminate. All that can be said about the process is that it is neither isobaric nor isothermal.

> The answer is (D).

POWER CYCLES-2

Which of the following thermodynamic cycles is the most efficient?
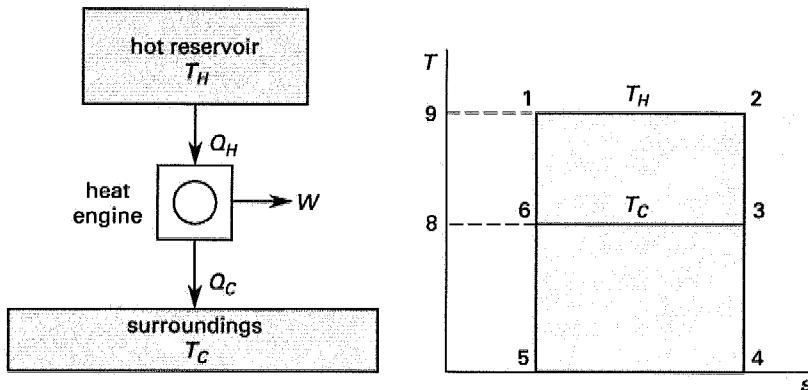
(A) Brayton
(B) Rankine
(C) Carnot
(D) combined Brayton-Rankine

> No cycle is more efficient than the Carnot cycle, because it is completely reversible.

> The answer is (C).

POWER CYCLES-3

For the reversible heat engine shown, which area on the corresponding T-S diagram represents the work done by the system?

(A) work $= 0$ (B) 1-2-4-5   (C) 6-3-4-5   (D) 1-2-3-6

> Use the first law of thermodynamics.

$$\begin{aligned} W &= Q_H - Q_C \\ &= T_H \Delta S - T_C \Delta S \\ &= (1 - 2 - 4 - 5) - (3 - 4 - 5 - 6) \\ &= 1 - 2 - 3 - 6 \end{aligned}$$
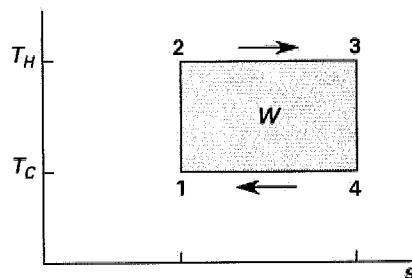
> The answer is (D).

POWER CYCLES-4

The ideal reversible Carnot cycle involves several basic processes. What type of processes are they?

(A) all adiabatic
(B) all isentropic
(C) two adiabatic and two isentropic
(D) two isothermal and two isentropic
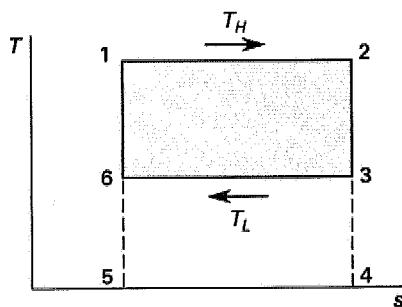
By definition, a Carnot cycle consists of two isothermal processes and two isentropic processes.

The answer is (D).

POWER CYCLES-5

An ideal reversible Carnot cycle is represented on the T-S diagram shown. The efficiency of the cycle is represented by which of the following ratios of areas?

(A) $\dfrac{1-2-3-6}{1-2-4-5}$

(B) $\dfrac{1-2-4-5}{1-2-3-6}$

(C) $\dfrac{3-4-5-6}{1-2-4-5}$

(D) $\dfrac{1-2-4-5}{3-4-5-6}$
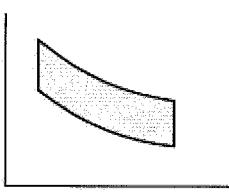
The efficiency, η, is defined as follows.
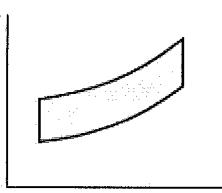
$$\eta = \frac{W_{net}}{Q_H}$$

$$W_{net} = Q_{net}$$

$$= 1 - 2 - 3 - 6$$

$$Q_H = 1 - 2 - 4 - 5$$

$$\eta = \frac{1 - 2 - 3 - 6}{1 - 2 - 4 - 5}$$
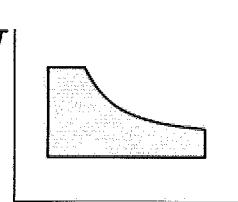
The answer is (A).
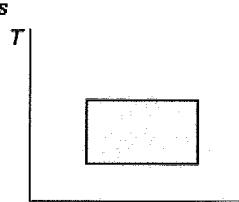
POWER CYCLES-6

Which of the following T-S diagrams may be that of a Carnot cycle?
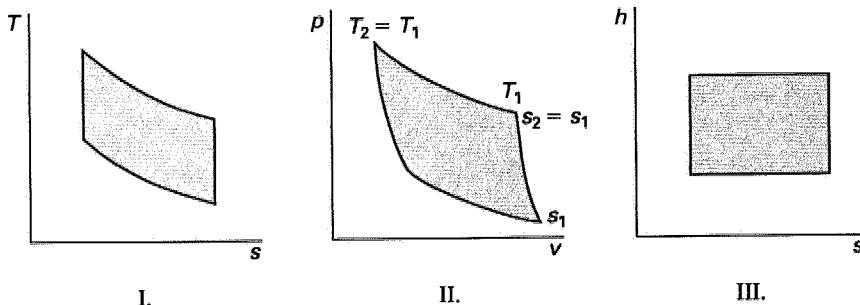
A Carnot cycle has two isothermal processes (horizontal lines on a T-S diagram) and two isentropic processes (vertical lines on a T-S diagram). The only diagram that has both of these properties is the diagram represented in option (D).

The answer is (D).

POWER CYCLES-7

Which of the following is/are representations of a Carnot cycle?

I.   II.   III.
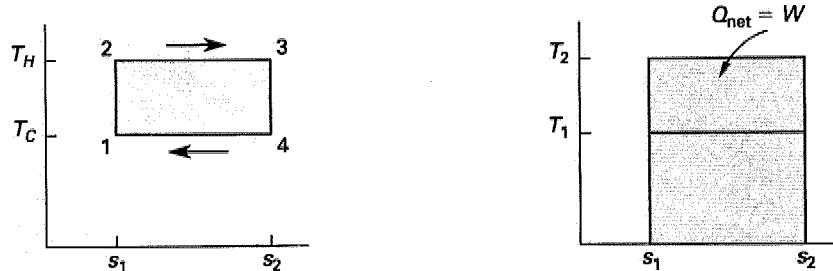
(A) I only   (B) II only   (C) I and II   (D) II and III

A Carnot cycle has two isentropic processes and two isothermal processes. Diagram I has two isentropic processes, but no isothermal processes. Diagram II has two isentropic processes and two isothermal processes. When h is constant, T is constant. Diagram III also has two isentropic processes and two isothermal processes. Thus, II and III both represent a Carnot cycle.

The answer is (D).

POWER CYCLES-8

Consider the T-S diagram of a Carnot cycle in the figure. What is the amount of total work done in one cycle?
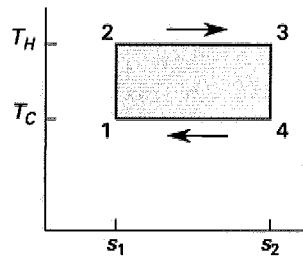
(A) $(S_2 - S_1)(T_2 - T_1)$ (B) $(S_2 - S_1)T_2$

     (C) $(S_1 - S_2)T_1$ (D) $(S_2 - S_1)T_2 - T_1$

$$W = Q_{net} - \Delta U$$

$$= Q_H - Q_C - 0$$

$$= T_H \Delta S_H - T_C \Delta S_C$$

$$= T_2(S_2 - S_1) - T_1(S_2 - S_1)$$

$$= (S_2 - S_1)(T_2 - T_1)$$
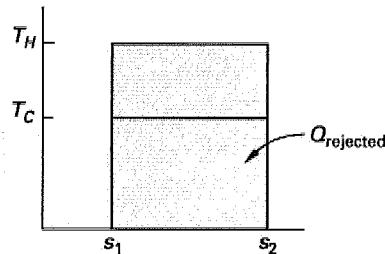
The answer is (A).

POWER CYCLES-9

Consider the T-S diagram of a Carnot cycle shown. What amount of heat is rejected to the surroundings?

(A) $T_H(S_3 - S_2)$ (B) $T_H(S_2 - S_1)$

(C) $T_C(S_3 - S_2)$ (D) $T_C(S_2 - S_1)$

The rejected heat is equal to the area under the lower branch of the cycle.

$$Q_{rejected} = T_C(S_2 - S_1)$$
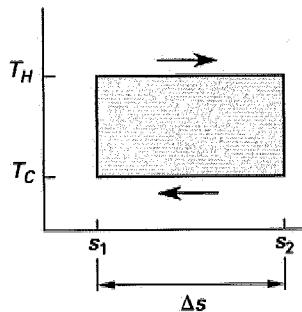
The answer is (D).

POWER CYCLES-10

What is the temperature difference of the cycle if the entropy difference is ΔS and the work done is W?

(A) $W - \Delta S$ 　　(B) $\dfrac{W}{\Delta S}$ 　　(C) $\dfrac{\Delta S}{W}$ 　　(D) $W(\Delta S)$

In the figure, the work done, W, is represented by the shaded area.


$$W = (\Delta T)(\Delta S)$$
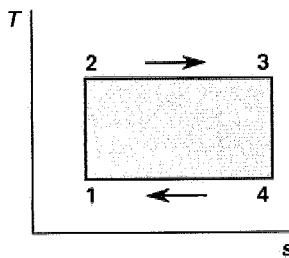
Rearranging,

$$\Delta T = \frac{W}{\Delta S}$$

The answer is (B).

POWER CYCLES-11

In the Carnot cycle shown, the net amount of heat put into the system is equal to the total amount of work done by the system. However, it cannot be stated that the heat put into the system between states 1 and 2 is equal to the work done between states 1 and 2. What is the reason for this?
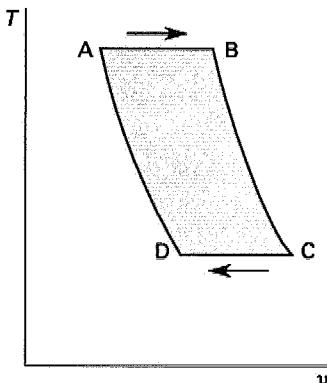
(A) The process is adiabatic.

(B) The process is not adiabatic.

(C) The second law states that the amount of energy put into the system is equal to the amount taken out of the system.

(D) The first law states that $dQ = dU + dW$. Since $dU \neq 0$, $dQ \neq dW$.

The first law states that $dQ = dU + dW$. Between states 1 and 2, $\Delta U \neq 0$. Therefore, $dQ_{12} \neq dW_{12}$.

> The answer is (D).

POWER CYCLES-12

For the Carnot cycle shown, helium is the gas used with a specific heat ratio, k, of 5/3. Given that $V_B/V_A = 2$ and $T_A/T_D = 1.9$, calculate p_C/p_A.

(A) 0.0633   (B) 0.100   (C) 0.180   (D) 0.262

$$\frac{T_A}{T_D} = \frac{T_B}{T_C} = 1.9$$

For a constant temperature,

$$\frac{p_B}{p_A} = \frac{V_A}{V_B} = 1/2$$

For a Carnot cycle, stage B to C is isentropic. The relation for ideal gases undergoing a constant entropy process is

$$\frac{p_C}{p_B} = \left(\frac{T_C}{T_B}\right)^{k/(k-1)}$$

$$\frac{p_C}{p_A} = \left(\frac{p_C}{p_B}\right)\left(\frac{p_B}{p_A}\right)$$

$$= \left(\frac{1}{1.9}\right)^{5/2}\left(\frac{1}{2}\right)$$

$$= 0.100$$

The answer is (B).

POWER CYCLES-13

A Carnot engine operates between 444K and 555K. What is its thermal efficiency?

(A) 20%   (B) 30%   (C) 40%   (D) 50%

$$\eta_t = 1 - \frac{T_C}{T_H}$$

$$= 1 - \frac{800K}{1000K}$$

$$= 0.2 \quad (20\%)$$

The answer is (A).

POWER CYCLES-14

For a heat engine operating between two temperatures $(T_2 > T_1)$, what is the maximum efficiency attainable?

(A) $1 - \frac{T_2}{T_1}$ (B) $1 - \frac{T_1}{T_2}$ (C) $\frac{T_1}{T_2}$ (D) $1 - \left(\frac{T_1}{T_2}\right)^k$

The maximum efficiency attainable is the Carnot efficiency.

$$\eta = \frac{W}{Q_{in}}$$

$$= \frac{Q_{in} - Q_{out}}{Q_{in}}$$

$$\eta_{Carnot} = 1 - \frac{T_1}{T_2}$$

The answer is (B).

POWER CYCLES-15

Which of the following is NOT an advantage of a superheated, closed Rankine cycle over an open Rankine cycle?

(A) increased efficiency
(B) increased turbine work output
(C) increased turbine life
(D) increased boiler life

Option (D) is not an advantage because a superheated Rankine cycle has higher boiler heat temperatures that decrease boiler life.

The answer is (D).

POWER CYCLES-16

Which of the following statements regarding Rankine cycles is FALSE?
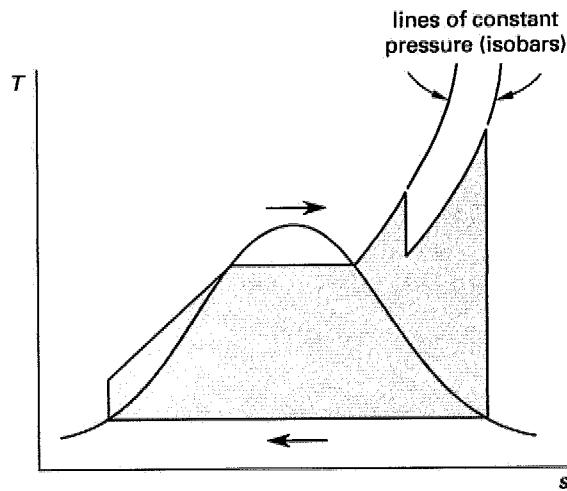
(A) Use of a condensible vapor in the cycle increases the efficiency of the cycle.

(B) The temperatures at which energy is transferred to and from the working liquid are less separated than in a Carnot cycle.

(C) Superheating increases the efficiency of a Rankine cycle.

(D) In practical terms, the susceptibility of the engine materials to corrosion is not a key limitation on the operating efficiency.

Corrosion is a principal limitation on the use of higher temperatures
for this type of engine. Thus, the susceptibility of engine materials
to corrosion does limit operating efficiency.

> The answer is (D).

POWER CYCLES-17

What type of power cycle does the following diagram illustrate?
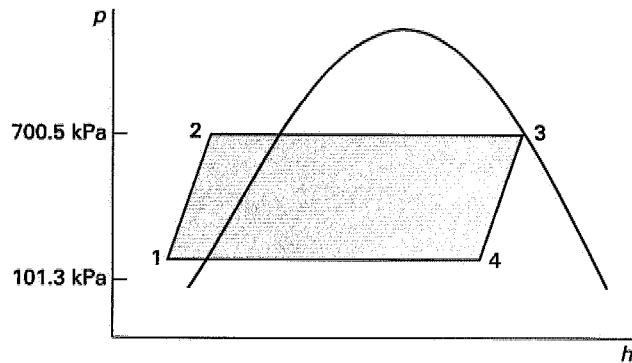
(A) a Carnot cycle
(B) an idealized Rankine cycle with superheat and reheat
(C) an idealized diesel cycle
(D) an idealized Stirling cycle

The diagram shows an idealized Rankine cycle with reheat.

> The answer is (B).

POWER CYCLES-18

For the steam Rankine cycle shown, determine the approximate enthalpy at state 3.

(A) 2000 kJ/kg   (B) 2500 kJ/kg

        (C) 2680 kJ/kg   (D) 2760 kJ/kg
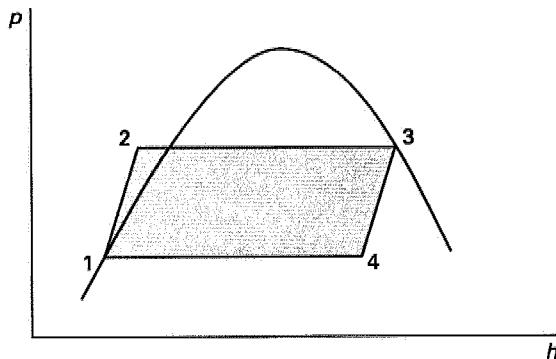
State 3 is saturated steam at 700.5 kPa. From the steam tables,

$$h_3 = h_g$$

$$= 2763.5 \text{ kJ/kg} \quad (2760 \text{ kJ/kg})$$

The answer is (D).

POWER CYCLES–19

In a Rankine cycle, state 3 is saturated steam at 1.398 MPa. Assuming that the turbine is isentropic and $p_4 = 101.35$ kPa, find the approximate enthalpy at state 4.

(A) 420 kJ/kg   (B) 2260 kJ/kg   (C) 2350 kJ/kg   (D) 2680 kJ/kg

$$p_3 = 1.398 \text{ MPa}$$

From the steam tables,

$$s_3 = s_g$$
$$= 6.4698 \text{ kJ/kg·K}$$
$$s_4 = s_3$$
$$= 6.4698 \text{ kJ/kg·K}$$
$$s_4 = s_f + x s_{fg}$$
$$= 1.3069 \; \frac{\text{kJ}}{\text{kg·K}} + x \left(6.0480 \; \frac{\text{kJ}}{\text{kg·K}} \right)$$

Rearrange to solve for quality x.
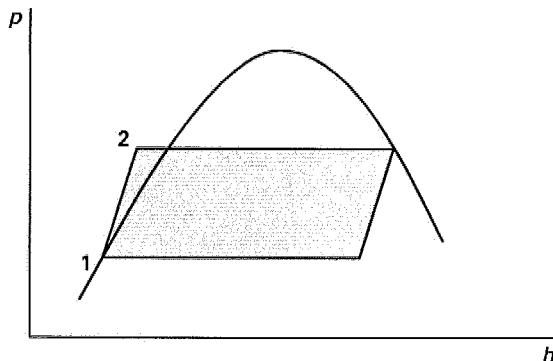
$$x = \frac{s_4 - s_f}{s_{fg}} = \frac{6.4698 \; \dfrac{\text{kJ}}{\text{kg·K}} - 1.3069 \; \dfrac{\text{kJ}}{\text{kg·K}}}{6.0480 \; \dfrac{\text{kJ}}{\text{kg·K}}}$$

$$= 0.854$$

$$h_4 = h_f + x h_{fg}$$

$$= 419.04 \ \frac{kJ}{kg} + (0.854) \left(2257.0 \ \frac{kJ}{kg} \right)$$

$$= 2346.5 \ kJ/kg \quad (2350 \ kJ/kg)$$

The answer is (C).

POWER CYCLES–20

In a steam Rankine cycle, state 1 is saturated liquid at 101.35 kPa. State 2 is high-pressure liquid at 0.7005 MPa. Approximately how much work is required to pump 0.45 kg of water from state 1 to state 2?

(A) 125 kJ   (B) 136 J   (C) 280 J   (D) 19.5 kJ

$$p_1 = 101.35 \ kPa$$

$$v_f = 0.001 \, 044 \ m^3/kg$$

$$W = m(h_2 - h_1)$$

$$= m v \Delta p$$

$$= (0.45 \ kg) \left(1.044 \times 10^{-3} \ \frac{m^3}{kg} \right) (700.5 \ kPa - 101.35 \ kPa) \left(1000 \ \frac{Pa}{kPa} \right)$$
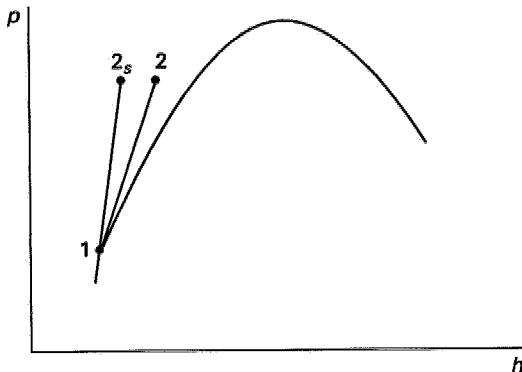
$$= 281.5 \ J \quad (280 \ J)$$

Note: State 2 is not a saturated state.

The answer is (C).

POWER CYCLES-21

In a steam Rankine cycle, saturated liquid at 101.35 kPa is pumped to 1.398 MPa. If the pump were isentropic, the enthalpy of state 2 would be 420.2 kJ/kg. The isentropic efficiency of the pump is 60%. What is most nearly the enthalpy of state 2?

(A) 252.1 kJ/kg   (B) 417.5 kJ/kg   (C) 418.9 kJ/kg   (D) 421.0 kJ/kg

$$\eta = \frac{W_s}{W}$$

$$= \frac{m\Delta h_s}{m\Delta h}$$

$$= \frac{\Delta h_s}{\Delta h}$$

$$= \frac{(h_2 - h_1)_s}{h_2 - h_1}$$

$$h_2 - h_1 = \frac{(h_2 - h_1)_s}{\eta}$$

$$h_2 = h_1 + \frac{(h_2 - h_1)_s}{\eta}$$
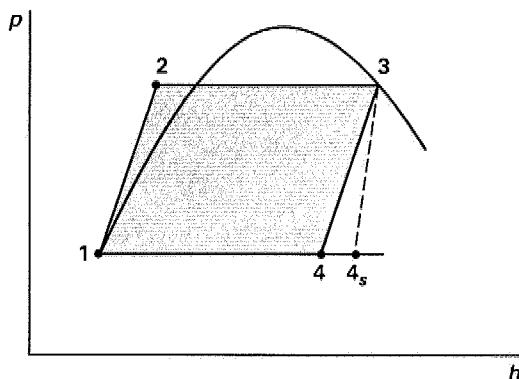
From the steam tables,

$$h_1 = 419.04 \text{ kJ/kg}$$

$$h_2 = 419.04 \ \frac{\text{kJ}}{\text{kg}} + \frac{420.2 \ \frac{\text{kJ}}{\text{kg}} - 419.04 \ \frac{\text{kJ}}{\text{kg}}}{0.6}$$

$$= 421.0 \text{ kJ/kg}$$

The answer is (D).

POWER CYCLES-22

Steam in a Rankine cycle is expanded from a 1.398 MPa saturated vapor state to 0.1433 MPa. The turbine has an efficiency of 0.8. What is most nearly the enthalpy of state 4?

(A) 2233 kJ/kg   (B) 2294 kJ/kg   (C) 2393 kJ/kg   (D) 2476 kJ/kg

Call the isentropic state 4_s.

$$p_3 = 1.398 \text{ MPa} \quad [\text{saturated vapor}]$$

$$s_3 = s_{f,4s} + x s_{fg,4s}$$

$$6.4698 \; \frac{\text{kJ}}{\text{kg·K}} = 1.4185 \; \frac{\text{kJ}}{\text{kg·K}} + x \left(5.8202 \; \frac{\text{kJ}}{\text{kg·K}} \right)$$

$$x = 0.8679$$

$$h_{4s} = h_{h,4s} + x h_{fg,4s}$$

$$= 461.30 \; \frac{\text{kJ}}{\text{kg}} + (0.8679) \left(2230.2 \; \frac{\text{kJ}}{\text{kg}} \right)$$

$$= 2396.89 \text{ kJ/kg}$$

$$\eta = \frac{h_s - h_4}{h_3 - h_{4s}}$$

$$h_4 = h_3 - \eta(h_3 - h_{4s})$$

$$= 2790.0 \; \frac{\text{kJ}}{\text{kg}} - (0.8) \left(2790.0 \; \frac{\text{kJ}}{\text{kg}} - 2396.89 \; \frac{\text{kJ}}{\text{kg}} \right)$$

$$= 2476 \text{ kJ/kg}$$

The answer is (D).

POWER CYCLES-23

Which of the following sets of reversible processes describes an ideal Otto cycle?
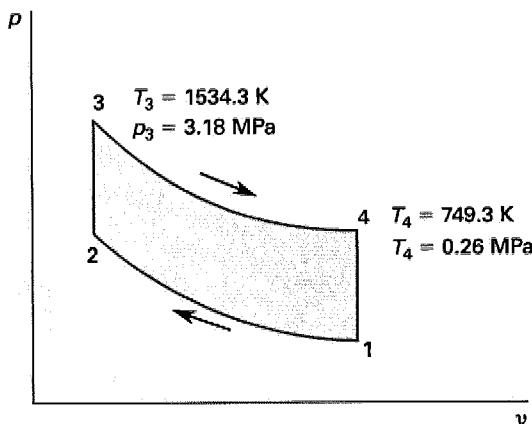
    I. adiabatic compression, constant volume heat addition, adiabatic expansion, constant volume heat rejection

    II. isothermal compression, isobaric heat addition, isothermal expansion, isobaric heat rejection

(A) I only
(B) II only
(C) I and II in succession
(D) II and I in succession

An Otto cycle is defined by the set of reversible processes in I.

> The answer is (A).

POWER CYCLES-24

In the power stroke (3 to 4) of the ideal Otto cycle shown, what is the entropy change?
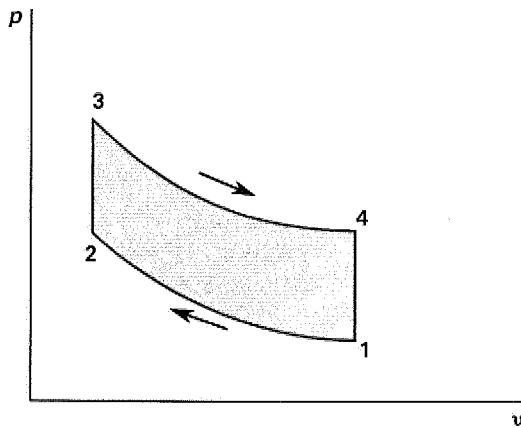
(A) -0.536 kJ/kg·K   (B) 0.00 kJ/kg·K

      (C) 0.536 kJ/kg·K   (D) 0.749 kJ/kg·K

In the ideal Otto cycle, the expansion process is reversible and adiabatic (isentropic). For an isentropic process, $\Delta S = 0$.

The answer is (B).

POWER CYCLES-25

The compression ratio of an ideal air Otto cycle is 6:1. p_1 is 101.35 kPa, and T_1 is 20°C. What is the temperature at state 2?

(A) 159.4°C
(B) 332.6°C
(C) 600.0°C
(D) 600.0K

The process from state 1 to state 2 is an isentropic compression, with $k = 1.4$ for air.

$$\frac{p_2}{p_1} = \left(\frac{V_1}{V_2}\right)^k$$

$$= (6)^{1.4}$$

$$p_2 = p_1(6)^{1.4}$$

$$= (101.35 \text{ kPa})(6)^{1.4}$$

$$= 1245.19 \text{ kPa}$$

$$\frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{k-1}$$

$$= (6)^{1.4-1}$$

$$T_2 = T_1(6)^{0.4}$$

$$= (20°C + 273°)(6)^{0.4}$$

$$= 599.97K \quad (600.0K)$$

The answer is (D).

POWER CYCLES-26

What is the ideal efficiency of an Otto cycle with a compression ratio of 6:1? The gas used is air.

(A) 0.167   (B) 0.191   (C) 0.488   (D) 0.512

By definition,

$$\eta = 1 - r^{1-k}$$

In this equation, r is the compression ratio.

For air,

$$k = 1.4$$
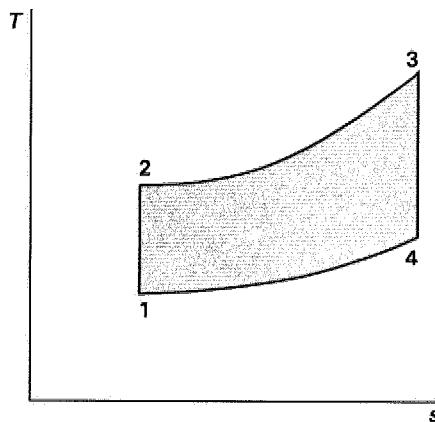
$$\eta = 1 - (6)^{1-1.4}$$

$$= 0.512$$

The answer is (D).

POWER CYCLES-27

The cycle shown in the diagram can be described as follows.

The process from 1 to 2 is adiabatic, isentropic compression.

The process from 2 to 3 is isobaric heat addition.

The process from 3 to 4 is adiabatic, isentropic expansion.

The process from 4 to 1 is constant volume heat rejection.

Which of the following is the name of this cycle?

(A) Otto   (B) Carnot   (C) diesel   (D) Rankine

The cycle described above is a diesel cycle.

The answer is (C).

POWER CYCLES-28

A device produces 37.5 J per power stroke. There is one power stroke per revolution. Approximate the power output, P_{out}, if the device is run at 45 rpm.

(A) 4.7 W   (B) 14 W   (C) 28 W   (D) 280 W

$$P_{out} = \frac{W}{t}$$

$$= \left(37.5 \; \frac{J}{power \; stroke}\right) \left(1 \; \frac{power \; stroke}{revolution}\right) \left(45 \; \frac{revolutions}{min}\right) \left(\frac{1 \; min}{60 \; s}\right)$$

$$= 28.125 \; W \quad (28 \; W)$$

The answer is (C).

POWER CYCLES-29

A steam generator produces saturated steam at 700.5 kPa from saturated liquid at 101.35 kPa. If the heat source is a bath at 171°C that provides 1860.8 kJ/kg, which of the following is true?

(A) The device violates the first law of thermodynamics only.
(B) The device violates the second law of thermodynamics only.
(C) The device violates both the first and second laws of thermodynamics.
(D) No thermodynamic laws are violated.

For the heat output,

$$\Delta Q = h_2 - h_1$$
$$= 2763.5 \ \frac{kJ}{kg} - 419.04 \ \frac{kJ}{kg}$$
$$= 2344.5 \ kJ/kg$$

However, it is given that the heat input is 1860.8 kJ/kg. This would mean that the heat output is greater than the heat input. Therefore, the first law of thermodynamics is violated.

$$\Delta s = s_2 - s_1 - \frac{Q}{T}$$
$$= \left(6.7078 \ \frac{kJ}{kg \cdot K} - 1.3069 \ \frac{kJ}{kg \cdot K} \right) - \frac{1860.8 \ \frac{kJ}{kg}}{171°C + 273K}$$
$$= 5.4009 \ \frac{kJ}{kg \cdot K} - 4.1910 \ \frac{kJ}{kg \cdot K}$$
$$= 1.2099 \ kJ/kg \cdot K$$

Since $\Delta s > 0$, the second law of thermodynamics is not violated.

> The answer is (A).

POWER CYCLES-30

A device that is meant to extract power from waste process steam starts with steam of 75% quality at 700.5 kPa. The exit conditions of the steam are 70% quality at 101.35 kPa. Which of the following statements are true?

(A) This device violates the first law of thermodynamics.
(B) This device violates the second law of thermodynamics.
(C) The device generates positive net power.
(D) The device generates no net power.

$$W = -(h_{\text{final}} - h_{\text{initial}})$$
$$h = h_f + x h_{fg}$$

h_f and h_{fg} can be found in the steam tables.

$$h_{\text{final}} = 419.04 \ \frac{\text{kJ}}{\text{kg}} + (0.7) \left(2257.0 \ \frac{\text{kJ}}{\text{kg}} \right)$$
$$= 1998.94 \ \text{kJ/kg}$$

$$h_{\text{initial}} = 697.34 \ \frac{\text{kJ}}{\text{kg}} + (0.75) \left(2066.2 \ \frac{\text{kJ}}{\text{kg}} \right)$$
$$= 2246.99 \ \text{kJ/kg}$$

$$W = h_{\text{initial}} - h_{\text{final}}$$
$$= 2246.99 \ \frac{\text{kJ}}{\text{kg}} - 1998.94 \ \frac{\text{kJ}}{\text{kg}}$$
$$= 248.05 \ \text{kJ/kg}$$

Thus, the device generates positive net power, and the first law of thermodynamics is not violated.

$$\Delta s = s_{\text{final}} - s_{\text{initial}}$$
$$s = s_f + x s_{fg}$$

s_f and s_{fg} can be found in the steam tables.

$$s_{\text{final}} = 1.3069 \ \frac{\text{kJ}}{\text{kg·K}} + (0.7) \left(6.0480 \ \frac{\text{kJ}}{\text{kg·K}} \right)$$
$$= 5.5405 \ \text{kJ/kg·K}$$

$$s_{\text{initial}} = 1.9925 \ \frac{\text{kJ}}{\text{kg·K}} + (0.75) \left(4.7153 \ \frac{\text{kJ}}{\text{kg·K}} \right)$$
$$= 5.5290 \ \text{kJ/kg·K}$$

$$\Delta s = 5.5405 \ \frac{\text{kJ}}{\text{kg·K}} - 5.5290 \ \frac{\text{kJ}}{\text{kg·K}}$$
$$= 0.0115 \ \text{kJ/kg·K}$$

Since $\Delta s > 0$, the second law of thermodynamics is not violated. Therefore, options (A), (B), and (D) are all false. Only option (C) is true.

The answer is (C).

POWER CYCLES-31

An engineer devises a scheme for extracting some power from waste process steam. The engineer claims that the steam enters the device at 700.5 kPa and quality 75%, and the steam exits at 101.35 kPa and 65% quality. Which of the following statements are true?

    I. The device produces 316 kJ/kg of work.

    II. The device violates the second law of thermodynamics.

    III. The device violates the first law of thermodynamics.

(A) I only   (B) II only   (C) III only   (D) I and II

$$h = h_f + xh_{fg}$$

h_f and h_{fg} can be found in the steam tables.

$$h_{\text{initial}} = 697.34 \ \frac{\text{kJ}}{\text{kg}} + (0.75) \left(2066.2 \ \frac{\text{kJ}}{\text{kg}} \right)$$

$$= 2246.99 \text{ kJ/kg}$$

$$h_{\text{final}} = 419.04 \ \frac{\text{kJ}}{\text{kg}} + (0.65) \left(2257.0 \ \frac{\text{kJ}}{\text{kg}} \right)$$

$$= 1886.09 \text{ kJ/kg}$$

$$W = 2246.99 \ \frac{\text{kJ}}{\text{kg}} - 1886.09 \ \frac{\text{kJ}}{\text{kg}}$$

$$= 360.9 \text{ kJ/kg}$$

Thus, the device produces 316 kJ/kg of work without violating the first law of thermodynamics.

$$\Delta s = s_{\text{final}} - s_{\text{initial}}$$

$$s = s_f + xs_{fg}$$

s_f and s_{fg} can be found in the steam tables.

$$s_{\text{initial}} = 1.9925 \ \frac{\text{kJ}}{\text{kg·K}} + (0.75) \left(4.7153 \ \frac{\text{kJ}}{\text{kg·K}} \right)$$

$$= 5.529 \text{ kJ/kg·K}$$

$$s_{\text{final}} = 1.3069 \ \frac{\text{kJ}}{\text{kg·K}} + (0.65) \, (6.0480 \text{ kg·K})$$

$$= 5.2381 \text{ kJ/kg·K}$$

$$\Delta s = 5.2381 \ \frac{\text{kJ}}{\text{kg·K}} - 5.529 \ \frac{\text{kJ}}{\text{kg·K}}$$

$$= -0.2909 \text{ kJ/kg·K}$$

Since $\Delta s < 0$, the device violates the second law of thermodynamics. Thus, I and II are true, but III is false.

> The answer is (D).

POWER CYCLES-32

An engine burns a liter of fuel each 12 min. The fuel has a specific gravity of 0.8 and a heating value of 45 MJ/kg. The engine has an efficiency of 25%. What is most nearly the brake horsepower of the engine?

(A) 12.5 hp   (B) 15.6 hp   (C) 16.8 hp   (D) 21.0 hp

The fuel flow rate is

$$Q = \left(\frac{1 \text{ L}}{12 \text{ min}}\right)\left(\frac{1 \text{ m}^3}{1000 \text{ L}}\right)\left(\frac{1 \text{ min}}{60 \text{ s}}\right)$$
$$= 1.39 \times 10^{-6} \text{ m}^3/\text{s}$$

For the power input to the engine,

$$P_i = \dot{m}(\text{heating value})$$
$$= \rho Q(\text{heating value})$$
$$= (0.8)\left(1000 \ \frac{\text{kg}}{\text{m}^3}\right)\left(1.389 \times 10^{-6} \ \frac{\text{m}^3}{\text{s}}\right)\left(45 \ \frac{\text{MJ}}{\text{kg}}\right)$$
$$= 0.0500 \text{ MJ/s} \quad (50.0 \text{ kW})$$

For the power output (actual power),
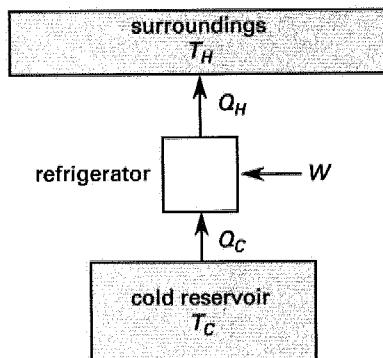
$$P_{\text{out}} = \eta P_i$$
$$= (0.25)(50.0 \text{ kW})\left(\frac{1 \text{ hp}}{0.746 \text{ kW}}\right)$$
$$= 16.8 \text{ hp}$$

> The answer is (C).

POWER CYCLES-33

A Carnot refrigerator operates between two reservoirs. One reservoir is at a higher temperature, T_H, and the other is at a cooler temperature, T_C. What is the coefficient of performance, COP, of the refrigerator?

(A) $T_H - \dfrac{T_C}{T_H}$ (B) $1 - \dfrac{T_C}{T_H}$ (C) $\dfrac{T_H}{T_C} - T_C$ (D) $\dfrac{T_C}{T_H - T_C}$

$$\begin{aligned}
\text{COP} &= \frac{Q_C}{W} \\[2mm]
&= \frac{Q_C}{Q_H - Q_C} \\[2mm]
&= \frac{T_C}{T_H - T_C}
\end{aligned}$$

The answer is (D).

POWER CYCLES-34

A refrigeration system produces 348.9 kJ/kg of cooling. In order to have a rating of 1 ton of refrigeration, what must be the mass flow rate of the vapor? (1 ton of refrigeration = 12.66 MJ/hr, approximately the rate required to freeze 2000 lbm of ice in a day.)

(A) 0.998 kg/hr   (B) 6.800 kg/hr   (C) 36.29 kg/hr   (D) 163.3 kg/hr

refrigeration rate $= \dot{m}$(cooling capacity)

Therefore, the mass flow rate, $\dot{m}$, is

$$\dot{m} = \frac{\text{refrigeration rate}}{\text{cooling capacity}}$$

$$= \frac{12.66 \; \frac{\text{MJ}}{\text{hr}}}{348.9 \; \frac{\text{kJ}}{\text{kg}}}$$

$$= 36.29 \text{ kg/hr}$$

The answer is (C).

POWER CYCLES–35

What is the ideal compression ratio of an Otto cycle that uses air as the gas and has an efficiency of 50%?

(A) 4.3:1   (B) 5.0:1   (C) 5.7:1   (D) 6.2:1

By definition,

$$\eta_{\text{Otto}} = 1 - r^{1-k}$$

r is the compression ratio.

$$k_{\text{air}} = 1.4$$

$$r = (1 - \eta_{\text{Otto}})^{1/1-k}$$

$$= (1 - 0.5)^{1/-0.4}$$

$$= 5.7$$

Therefore, the ratio is 5.7:1.

The answer is (C).