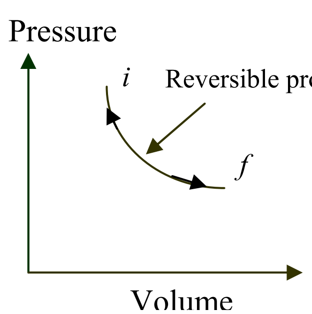
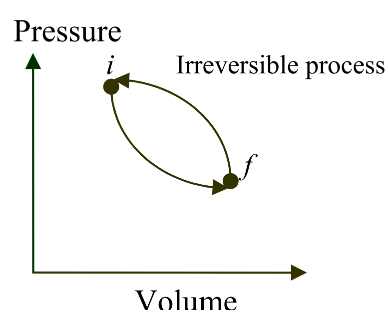
Chapter 6
Second Law of Thermodynamics

The first law of thermodynamics is an energy conservation statement. It determines whether or not a process can take place energetically. It does not tell in which direction the process can go, even that they are energetically possible. For examples: A rock will fall if you lift it up and then let go, and never come back to your hand by itself. Hot frying pans loose heat and cool down when taken off the stove. Air in a high-pressure tire leaks out from even a small hole in its side to the lower pressure atmosphere, and never sees the reverse process. Ice cubes gains heat and melt in a warm room. Second law of thermodynamics is based on human experience. It doesn't come from complicated theory and equations and will tell you why some process will be forbidden although they are energetically possible. This why we have to define the reversibility and irreversibility of a process.

- A **reversible** change (or process) is one in which the values of P, V, T, and U are well defined during the change. If the process is reversed, then P, V, T, and U will take on the same values in reverse order. To be reversible, a process must usually be slow (quasi-statically), and the system must be close to equilibrium during the entire change.
- A process is **irreversible** if the system and its surroundings can not be returned to their initial states, which is the common case in nature.





Second law of Thermodynamics: Many equivalent statements could be specified for the second law of thermodynamics. One of them, due to Claussius and states

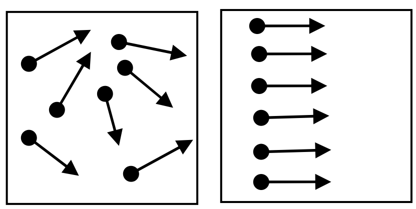
"*Heat can not be transferred from a cold reservoir to a warm one without doing work*", or in another words

"*heat will not flow spontaneously from a colder to a hotter temperature*".

See the animation:

http://www.colorado.edu/physics/2000/bec/what_is_it.html

Entropy (S, $[S]$ = J/K) is a quantity used to measure the degree of **disorder (or randomness)** of a system. Irreversible processes such as spontaneous flow of heat from a hotter to a colder body without the production of useful work always increase the entropy of an isolated system and of the universe.



1. It is a state function of the system like pressure, volume, temperature and energy), i.e. it depend only on the initial and final state of a system and not on how it reach that states That is, a system has definite entropy just as it has a definite internal energy U.
2. The entropy of a system increases when heat flows into the system and decreases when heat flows out.
3. When heat dQ_r enters (or removed from) a system at absolute temperature T, the change in entropy, dS, is defined by the ratio

$$\boxed{dS \equiv \frac{|dQ_r|}{T}}$$

provided the system changes in a reversible way. The change in entropy of a system moving reversible between two equilibrium states i and f is given by:

$$\Delta S = \int_i^f dS = \int_{\underbrace{i}_{\text{arbitrary reversible path}}}^{f} \frac{dQ_r}{T} = S_f - S_i$$

This implies that for an irreversible processes between equilibrium states i and f, the entropy change is evaluated using the last equation, and any

convenient reversible path which connects *i* to *f*; the result is of course path dependent.
For thermodynamic processes**:**

$$\Delta S_{\text{system}} + \Delta S_{\text{surrounding}} \equiv \Delta S_{\text{universe}}$$

and the second law of thermodynamics is formulated as the principle of increasing of entropy. This is:

$$\boxed{\Delta S_{\text{universe}} \geq 0}$$

where the equality applies to reversible process only. For natural process (irreversible) processes one can say"

"*Natural processes starting in an equilibrium state and ending in another proceed in such a direction the entropy of the universe increases*"

Cyclic ($dU = 0$)

$$\boxed{\Delta S = \int_i^f \frac{dQ_r}{T} = 0} \qquad \text{(Claussius' theorem)}$$

Adiabatic ($dQ = 0$)

$$dQ = 0 \qquad \Rightarrow \qquad \boxed{\Delta S = \int_i^f \frac{dQ_r}{T} = 0}$$

Changing Phase ($dT = 0$ but T = constant)

$$dQ = mL_v\,(or\ \ mL_f\,) \quad \Rightarrow \quad \boxed{\Delta S = \frac{dQ}{T}}.$$

Same Phase (e.g. **liquid**)

$$dQ = mc\Delta T \quad \Rightarrow \quad \boxed{\Delta S = mc\int_i^f \frac{dT}{T} = mc\ \ln(\frac{T_f}{T_i})}$$

Same Phase (e.g. **gases**)

$$dQ = \begin{cases} nc_p\Delta T \quad \Rightarrow \Delta S = \boxed{nc_p\int_i^f \frac{dT}{T} = nc_p \ln(\frac{T_f}{T_i})} & \text{(constant pressure)} \\ nc_v\Delta T \quad \Rightarrow \Delta S = \boxed{nc_v\int_i^f \frac{dT}{T} = nc_v \ln(\frac{T_f}{T_i})} & \text{(constant volume)} \end{cases}$$

Isothermal process ($\Delta U = \Delta T = 0$) hence

$$dQ = dW = P\Delta V = nRT\frac{\Delta V}{V} \quad \Rightarrow \quad \boxed{\Delta S = nR\int_i^f \frac{dV}{V} = nR\ln(\frac{V_f}{V_i})}$$

Heat transfer between two masses defined as (m_1,c_1,T_1) and (m_2,c_2,T_2)

$$\Delta S = m_1c_1\ln(\frac{T_f}{T_1}) + m_2c_2\ln(\frac{T_f}{T_2})$$

where T_f is the equilibrium temperature.

➔ How much does the entropy increase in the following cases?

a) 18-gram ice cube at 0 °C is changed to water at 0 °C . [L_f= 3.33×10^5 J/kg]

✓ $$dS_1 \equiv \frac{dQ_r}{T} = \frac{mL_f}{T} = \frac{0.018\times(3.33\times10^5)}{273+0} = \underline{22.0\text{ J/K}}$$

b) 18-gram of water at 0 °C is changed to water at 100 °C . [c(water) = 4186 J/(kg.K)]

✓ $$dS_2 = mc\ln(\frac{T_f}{T_i}) = 0.018\times4186\times\ln(\frac{273+100}{273+0}) = \underline{23.52\text{ J/K}}$$

c) 18-gram of water at 100 °C is changed to steam at 100 °C . [L_v= 22.6×10^5 J/kg]

✓ $$dS_3 = \frac{dQ_r}{T} = \frac{mL_v}{T} = \frac{0.018\times(22.6\times10^5)}{273+0} = \underline{109.1\text{ J/K}}$$

d) 18-gram ice cube at 0 °C is changed to steam at 100 °C.

✓ $$dS = dS_1 + dS_2 + dS_3 = \underline{154.6\text{ J/K}}$$

➔ Two moles of an ideal monatomic gas undergo a reversible isothermal expansion from 0.1 m³ to 0.5 m³ at a temperature of 20 °C. What is the change in entropy of the gas?

✓ $$\Delta S = nR\int_i^f \frac{dV}{V} = nR\ln(\frac{V_f}{V_i}) = 2\times 8.314\times \ln(\frac{0.5}{0.1}) = \underline{26.7\text{ J/K}}$$

➔ One mole of an ideal monatomic gas is heated quasi-statically at constant volume from 100 K to 105 K. What is the change in entropy of the gas?

✓ $$\Delta S = nC_v\int_i^f \frac{dT}{T} = nC_v\ln(\frac{T_f}{T}) = 1\times\frac{3}{2}\times 8.314\times\ln(\frac{105}{100}) \approx \underline{0.61\text{ J/K}}$$

✓ Or one can use the following approximate method,

$$\Delta S = \frac{dQ}{T} = nRC_v\frac{105\text{-}100}{102.5} = 1(\frac{3}{2}\times 8.314)\frac{5}{102.5} \approx \underline{0.61\text{ J/K}}$$

➔ If 200 g of water at 20 °C is mixed with 300 g of water at 75 °C, find:
a- the final equilibrium temperature of the mixture and

✓ First, calculate the heat lost by 300 g and the heat gained by the 200 g,

$$Q\,(\text{lost by 300 g}) = Q_1 = 300C_{water}\left(T_f - 75\right)$$

$$Q\,(\text{gained by 200 g}) = Q_2 = 200C_{water}\left(T_f - 20\right)$$

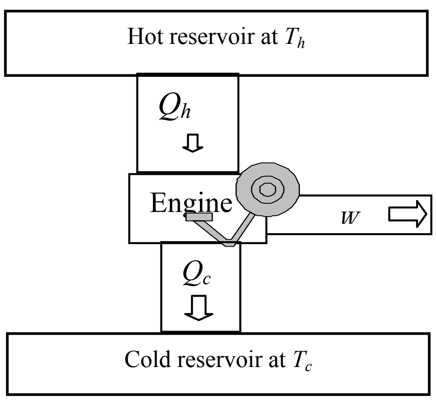
Use the fact that $Q_1 + Q_2 = 0$, one can solve and find $T_f = 53.0\ ^{o}\text{C}$.

b- the change in entropy of the system.

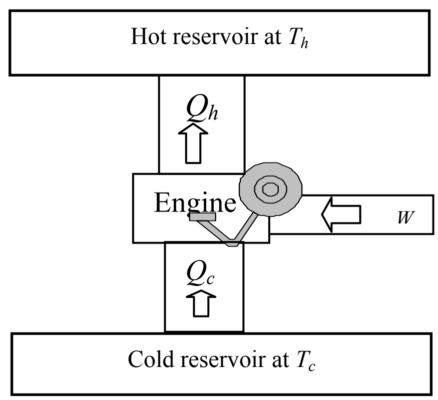
$$\Delta \text{S} = 300C_{water}\ln(\frac{53+273}{75+273}) + 300C_{water}\ln(\frac{53+273}{20+273})$$

$$= (-82.010 + 89.35)\ \frac{\text{J}}{\text{K}} = 7.34\ \frac{\text{J}}{\text{K}}$$

Heat engine: any device that works in a cycle, extracting (or absorbing or takes in) heat, Q_h, from a hot reservoir doing work (*W*), and exhausting (or rejected or expelled) remaining heat, Q_c, into a cold reservoir. Q_c makes the pollutions of our environment.



Heat engine



Refrigerator

The efficiency (e) of the heat engine is given by:

$$e = \frac{\text{Energy we get}}{\text{Energy we pay for}} = \frac{W}{Q_h} = \frac{|Q_h| - |Q_c|}{|Q_h|}$$

The power is

$$P \text{ [Watt]} = \frac{W \text{ [Joule]}}{t \text{ [Seconds]}} \quad \Rightarrow \quad e = \frac{W/t}{Q_h/t} = \frac{P}{Q_h/t}$$

➔ An automobile engine operates with an overall efficiency of 20%. How many gallons of gasoline are wasted for each 10 gallons burned?

✓
$$e = \frac{W}{Q_h} = \frac{|Q_h| - |Q_c|}{|Q_h|}$$
$$\Rightarrow 0.2 = \frac{10 - |Q_c|}{10} \quad \Rightarrow \quad |Q_c| = \underline{8 \text{ gallons}}$$

➔ An engine absorbs 1600 J from a hot reservoir and expels 1000 J to a cold reservoir in each cycle.

a. What is the efficiency, e, of the engine?

✓
$$e = \frac{W}{Q_h} = \frac{|Q_h| - |Q_c|}{|Q_h|} = \frac{1600 - 1000}{1600} = \underline{0.375} \text{ or } \underline{37.5\%}$$

b. How much work is done, W, in each cycle?

✓
$$W = Q_h - Q_c = 1600 - 1000 = \underline{600 \text{ J}}.$$

c. What is the power output of the engine if each cycle lasts for 0.3 s?

✓
$$P = \frac{W}{t} = \frac{600 \text{ J}}{0.3 \text{ s}} = \underline{2000 \text{ Watt}}.$$

Carnot cycle: is the most efficient cycle possible for a heat engine. An engine that operates in accordance to this cycle between a hot reservoir, T_h, and a cold reservoir, T_h, has the ratio $\frac{|Q_h|}{|Q_c|} = \frac{T_h}{T_c}$ and the maximum efficiency

$$e = \frac{T_h - T_c}{T_h}$$

NOTE THAT: **Kelvin Temperature must be used in the above equations**.

➔ A Carnot engine has a power output, *P*, of 200 W and operates between two reservoirs at 27 $^{\mathrm{o}}\mathrm{C}$ and 327 $^{\mathrm{o}}\mathrm{C}$.

a- Find the maximum efficiency of the engine

✓ $$e = \frac{T_h - T_c}{T_h} = \frac{(273+327)-(273+27)}{(273+327)} = \frac{300}{600} = 0.5$$

b- How much energy is absorbed per hour?

✓ Use the efficiency in the form:

$$e = \frac{W/t}{Q_h/t} = \frac{P}{Q_h/t} \quad \Rightarrow \quad \frac{Q_h}{t} = \frac{P}{e} = \frac{200}{0.5} = 400 \text{ Watt.}$$

For one hour,

$$Q_h = (4.0\times10^2 \text{ J/s})(3600 \text{ s}) = 1.44\times10^6 \text{ J.}$$

c- How much heat energy is rejected per hour?

✓ You can use: $$Q_c = Q_h - W = Q_h - Pt$$

$$= 1.44\times10^6 \text{ J} - (2\times10^2 \text{ W})(3600 \text{ s}) = 7.2\times10^5 \text{ J.}$$

✓ Or you can use: $$Q_c = Q_h(\frac{T_h}{T_c})$$

$$= 1.44\times10^6(\frac{300}{600}) = 7.2\times10^5 \text{ J}$$

➔ A heat engine operating between 200 °C and 80 °C achieves 20% of the maximum possible efficiency.

a. What is the maximum possible efficiency?

✓ $$e_{\max} = e_{\text{Carnot}} = \frac{T_h - T_c}{T_h} = \frac{353-473}{353} = 0.254$$

b. What is the actual efficiency?

✓ $$e_{actual} = 0.2\times e_{\max} = 0.2\times0.254 = 0.051$$

c. What energy input will enable the engine to perform 10^4 J of work?

$\Rightarrow$ $$e_{\text{actual}} = \frac{W}{Q_h} \quad \Rightarrow \quad Q_h = \frac{W}{e_{\text{actual}}} = \frac{10^4}{0.051} = 1.97\times10^5 \text{ J.}$$

Heat pumps and Refrigerator: A heat pump, or refrigerator, is a device that moves heat from a reservoir at a low temperature, Q_c, to one at higher temperature, Q_h. Mechanical work, *W*, must be supplied to the heat pump in order to accomplish this.

The coefficient of performance (COP) of a **<u>refrigerator</u>** is defined by:

$$COP = \frac{\text{what we want}}{\text{what we pay for}} = \frac{|Q_c|}{W} = \frac{|Q_c|}{|Q_h| - |Q_c|} = \frac{T_c}{T_h - T_c}$$

The coefficient of performance (COP) of a **<u>heat pump</u>** is defined by:

$$COP(\text{heat pump}) = \frac{1}{e} = \frac{|Q_h|}{W} = \frac{|Q_h|}{|Q_h| - |Q_c|} = \frac{T_h}{T_h - T_c}$$

➔ What is the coefficient of performance of a heat pump that brings heat from the outdoors at - 3.0 ^{o}C into + 22 ^{o}C house? (Hint: the heat pump does work, *W*, which is also available to heat the house.)

✓
$$COP(\text{heat pump}) = \frac{T_h}{T_h - T_c}$$
$$= \frac{(273+22)}{(273+22)-(273-3)} = \frac{295}{25} = 11.8$$

True-False Questions

1- Liquid water has less entropy than ice.
2- The entropy of a system can never decrease.
3- Crystals are less disordered than gases
4- The most efficient cyclic process is the Carnot cycle. T
5- A refrigerator (heat pump) is a heat engine working in reverse. T
6- It is impossible to construct a heat engine which does work without rejecting some heat to a cold reservoir. T
7- Entropy is a quantity used to measure the degree of disorder in a system. T
8- The total entropy decreases for any system that undergoes an irreversible process. F
9- The total entropy of a system increases only if it absorbs heat. F
10- No heat engine has higher efficiency than Carnot efficiency. T
11- The efficiency of the ideal engine should be greater than one. F
12- No change in entropy for a system goes in reversible cyclic process. T
13- If the steam is condensed, its entropy will decrease. T
14- The coefficient of performance of refrigerator should be less than one. F
15- Isolated systems tend toward disorder and entropy is a measure of this disorder. T
16- The entropy of the universe decreases in any process. F
17- The efficiency of heat engines can be 100%. F
18- Heat engines can have efficiency higher than Carnot engine working between the same two temperatures. F
19- To calculate the efficiency of ideal engine the temperature should be in Celsius. F
20- The thermal efficiency of an ideal engine can be = 1.0. F
21- For any process the change in entropy of a closed system < 0. F

Supplementary Problems

- One mole of an ideal monatomic gas is heated quasi-statically at constant volume from 100 K to 105 K. What is the change in entropy of the gas?

(a) 0.18 J/K.
(b) 0.26 J/K.
(c)@ 0.61 J/K.
(d) 1.03 J/K.
(e) 1.39 J/K.

- Suppose that 10 kg of water at 50 ^{o}C is mixed with an equal amount of water at 10 ^{o}C. When thermal equilibrium is reached, what is the change in entropy of the mixture?

(a) 250 J/K
(b) 130 J/K
(c) 246 J/K
(d) 551 J/K
(e)@ 183 J/K

- Five moles of an ideal diatomic gas (Cp = 7R/2) is taken through an isovolumetric process. If the final pressure is five times the initial pressure, what is the change in entropy of the gas?

(a) 234 J/K
(b) -234 J/K
(c) -167 J/K
(d)@ 167 J/K
(e) -151 J/K

- Find the change in entropy when 100 g of ice at 0 ^{o}C is heated slowly to 80 ^{o}C.

(a) 85 cal/K
(b) 25 cal/K
(c) 62 cal/K
(d) 12 cal/K
(e)@ 55 cal/K

- The left-hand side of the container shown in Figure 2 contains 5 moles of nitrogen gas, in thermal equilibrium with the right hand side, which contains 3 moles of hydrogen gas. The two sides are separated by a partition, and the container is insulated. After the partition is broken, what is the change in entropy of the system?

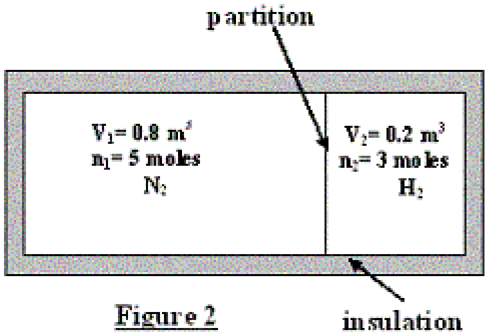


Figure 2

(a) 34 J/K
(b) 58 J/K
(c) zero
(d) 12 J/K
(e)@ 49 J/K

- A container holds 240 g of water at 8 $^{\circ}C$. The container is placed in a refrigerator maintained at - 5 $^{\circ}C$. Calculate the change in entropy of the water after it is in thermal equilibrium with the refrigerator.

(a) 331 J/K
(b)@ -331 J/K
(c) -254 J/K
(d) -172 J/K
(e) 254 J/K

- A 10 kg piece of ice at 0 $^{\circ}C$ is changed slowly and reversibly to water at 70 $^{\circ}C$. What is the change in entropy of the Ice?

(a) -2.2×10^4 J/K.
(b) 6.5×10^4 J/K.
(c)@ 2.2×10^4 J/K.
(d) -6.5×10^4 J/K.
(e) -3.4×10^4 J/K.

- Consider 5 moles of an isolated ideal gas initially at a pressure P1 and volume V1. The gas expands freely to a final pressure P2 and volume V2. If the entropy change during this process is 16.6 J/K, then the ratio of the final pressure to the initial pressure is:

(a)@ 0.67
(b) 3.0
(c) 0.33
(d) 0.50
(e) 1.5

- When an ideal gas is subjected to a reversible adiabatic compression process, which one of the following statements is TRUE:

(a) The gas rejects heat.
(b) No work is done on the gas.
(c)@ The entropy of the gas does not change.
(d) The gas absorbs heat.
(e) The internal energy of the gas does not change.

- What is the change in entropy of 200-g of water as its temperature increases from 0 ^{o}C to 50 ^{o}C.

(a) 2.55×10^{3} J/K.
(b)@ 1.41×10^{2} J/K.
(c) 4.19×10^{3} J/K.
(d) 0.35×10^{3} J/K.
(e) 3.35×10^{3} J/K.

- 50.0 g of water at 15.0 ^{o}C are converted slowly into ice at - 15.0 ^{o}C. What is the change of entropy of water?

(a) - 17.5 J/K
(b) + 83.4 J/K
(c)@ - 78.5 J/K
(d) + 78.5 J/K
(e) - 83.4 J/K

- An ideal monatomic gas is confined to a cylinder by a piston. The piston is slowly pushed in so that the gas temperature remains at 27 C^o . During the compression, 750 J of work is done on the gas. The change in the entropy of the gas is:

(a) 3.0 J/K.
(b)@ - 2.5 J/K.
(c) 2.5 J/K.
(d) Zero.
(e) - 3.0 J/K.

- One mole of an ideal monatomic gas expands at constant pressure to three times its initial volume. What is the change of entropy of the gas in this process ?

(a)@ + 22.8 J/K
(b) + 9.13 J/K
(c) - 22.8 J/K
(d) - 13.7 J/K
(e) + 13.7 J/K

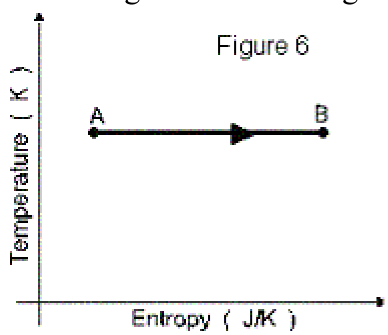
- The change in entropy is zero for

(a) reversible processes during which no work is done.
(b) reversible isothermal processes.
(c) reversible isobaric processes.
(d) all adiabatic processes.
(e)@ reversible adiabatic processes.

- A 4.0-kg piece of iron at 800 K is dropped into a lake whose temperature is 280 K. Assume that the lake is so large that its temperature rise is negligible. Find the change in the entropy of the lake. [specific heat of iron = 0.11 kcal/kg.K].

(a) - 0.20 kcal/K
(b) + 0.20 kcal/K
(c)@ + 0.82 kcal/K
(d) zero
(e) - 0.82 kcal/K

- A sample of an ideal monatomic gas undergoes the reversible process A to B displayed in the T-S diagram shown in figure 6. The process is :



(a) a change of phase.
(b) an isothermal compression.
(c) a constant-volume process.
(d)@ an isothermal expansion.
(e) a free expansion.

- Five moles of an ideal gas undergo a reversible isothermal compression from volume V to volume V/2 at temperature 30 ^{o}C. What is the change in the entropy of the gas?

(a) 29 J/K.
(b) -81 J/K.
(c)@ -29 J/K.
(d) -18 J/K.
(e) 18 J/K.

- Which of the following statements is correct?

(a) For an adiabatic process the change in entropy is negative if it is done irreversibly.
(b) The efficiency of a Carnot engine is 100%.
(c) For an isothermal expansion the change in entropy of an ideal gas is zero.
(d) A Carnot engine does not reject any heat as waste.
(e)@ For an adiabatic process the change in entropy is zero if it is done reversibly.

- One mole of a monatomic ideal gas is taken from an initial state (i) to a final state (f) as shown in figure 1. Calculate the change in entropy of the gas for this process.

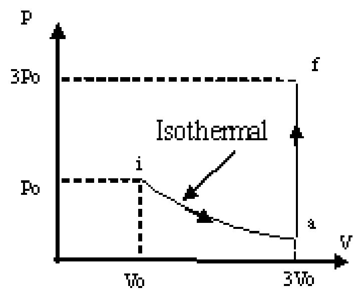


Figure 1

(a) 1.25 J/K.
(b)@ 36.5 J/K.
(c) 11.2 J/K.
(d) 22.5 J/K.
(e) 25.0 J/K.

- You mix two samples of water, A and B. Sample A is 100 g at 20 ^{o}C and sample B is also 100 g but at 80 ^{o}C. Calculate the change in the entropy of sample B.

(a) 8.9 cal/K.
(b) 9.7 cal/K
(c) - 9.7 cal/K.
(d) zero.
(e)@ - 8.9 cal/K.

- Five moles of an ideal monatomic gas are allowed to expand isobarically. The initial volume is 20.0 cm^3 and the final volume is 100 cm^3. Find the change in entropy of the gas.

(a) 67.0 J/K
(b) 100 J/K
(c) 152 J/K
(d) 52.0 J/K
(e)@ 167 J/K

- 10.0 kg of water at zero ^{o}C are mixed with 10.0 kg of water at 100 ^{o}C. The specific heat of water is 4.19 kJ/kg.K. The total change in entropy of the system is

(a)@ 1.02 kJ/K
(b) 6.03 kJ/K
(c) 7.05 kJ/K
(d) 13.1 kJ/K
(e) zero

- One mole of an ideal gas undergoes an isothermal expansion in which its volume increases to five times its initial value. What is the change of entropy of the gas in this process?

(a) 12.5 J/K
(b) 4010 J/K
(c) 20.1 J/K
(d)@ 13.4 J/K
(e) zero

- Two moles of an ideal gas undergo an adiabatic free expansion from an initial volume of 0.6 L to 1.3 L. Calculate the change in entropy of gas.

(a) -12.9 J/K.
(b) -5.3 J/K.
(c) 16.6 J/K.
(d)@ 12.9 J/K.
(e) zero.

$$\boxed{\begin{aligned}\Delta S &= nR\ln\left(\frac{V_f}{V_i}\right) = 2.0\times 8.31\ln\left(\frac{1.3}{0.6}\right)\\ &= \underline{12.85\ \frac{\text{J}}{\text{K}}}\end{aligned}}$$

- System A (one kilogram of ice at 0 ^{o}C) is added to system B (one kilogram of water at 100 ^{o}C) in an insulator container. Calculate the total change in entropy of system A.

(a) Infinite.
(b) 6.00 kJ/K.
(c) -1.41 kJ/K.
(d)@ 1.36 kJ/K.
(e) 1.20 kJ/K.

- A 5.00-kg block of copper is at 296 K. If it is heated such that its entropy increases by 1.07 kJ/K, what is the final temperature? [The specific heat of copper is 386 J/(kg*K)]

(a) 760 K.
(b) 273 K.
(c) 310 K.
(d)@ 515 K.
(e) 100 K.

$$\Delta S = mc\ln\left(\frac{T_f}{T_i}\right) \Rightarrow 1.07\times10^3 = 5\times386\ln\left(\frac{T_f}{296}\right)$$
$$\Rightarrow T_f = 296e^{0.55} = \underline{515\text{ K}}.$$

- Which of the following statements are CORRECT:
  1. Two objects are in thermal equilibrium if they have the same temperature.
  2. In an isothermal process, the work done by an ideal gas is equal to the heat energy
  3. In an adiabatic process, no heat enters or leaves the system.
  4. The thermal efficiency of an ideal engine can be = 1.0.
  5. For any process the change in entropy of a closed system < 0.

(a)@ 1, 2, and 3.
(b) 3 and 5.
(c) 4 and 5.
(d) 1, 2 and 5.
(e) 1 and 4.

- Which of the following statements are WRONG:
  1. The efficiency of the ideal engine is greater than one.
  2. The change in entropy is zero for reversible isothermal processes.
  3. In cyclic processes, the change in entropy is zero.
  4. If steam is condensed, its entropy will decrease.
  5. If ice is melted, its entropy will decrease.

(a) 1, 2 and 4.
(b)@ 1, 2 and 5.
(c) 2, 3 and 4.
(d) 1, 3 and 5.
(e) 1, 2 and 3.

- Which of the following statements are true?
  - (I) Temperatures that differ by $10\ C^{o}$ must differ by $18\ F^{o}$.
  - (II) $0\ ^{o}C$ is the lowest temperature that one can reach.
  - (III) Heat conduction refers to the transfer of thermal energy between objects in contact.
  - (IV) The entropy of a system never decreases.
  - (V) Heat is a form of energy.

(a)@ I, III, and V.
(b) II, III, and V.
(c) I, III, and IV.
(d) I, II, and IV.
(e) II, III, and IV.

- An ideal heat pump is used to absorb heat from the outside air at -10 ^{o}C and transfers it into a house at a temperature of 30 ^{o}C. What is the heat energy transferred into the house if 5.0 kJ of work is done on the heat pump?

(a) 20 kJ
(b) 76 kJ
(c) 18 kJ
(d) 12 kJ
(e)@ 38 kJ

- Which one of the following statements is WRONG?

(a)@ The entropy of the universe remains constant in all processes.
(b) Perfect engines do not exist because they violate the second law of thermodynamics.
(c) No real engine is more efficient than Carnot engine.
(d) In an isolated system, the entropy increases for a irreversible process and remains constant for a reversible process.
(e) The change in entropy of a system depends only on the initial and final states.

- One mole of an ideal monatomic gas ($C_v = 3R/2$)is taken through the cycle shown in Figure 1. If $T_a = 590$ K, $T_b = 450$ K and $T_c = 300$ K, calculate the efficiency of an engine operating in this cycle.

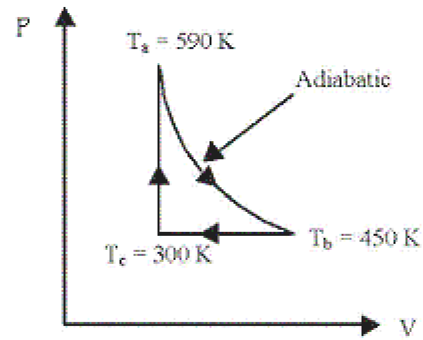
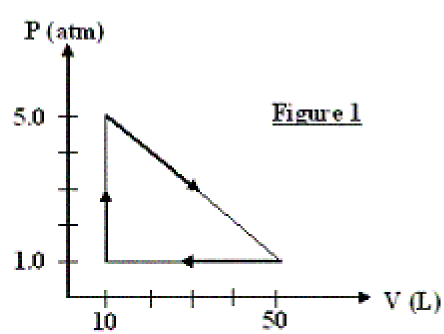


Figure 1

(a) 0.45
(b) 0.28
(c) 0.08
(d) 0.55
(e)@ 0.14

- A heat engine has a monatomic gas as the working substance and its operating cycle is shown by the P-V diagram in Figure 1. In one cycle, 18.2 kJ of heat energy is absorbed by the engine. Find the efficiency of the heat engine.



(a) 0.31
(b) 0.25
(c) 0.55
(d) 0.22
(e)@ 0.44

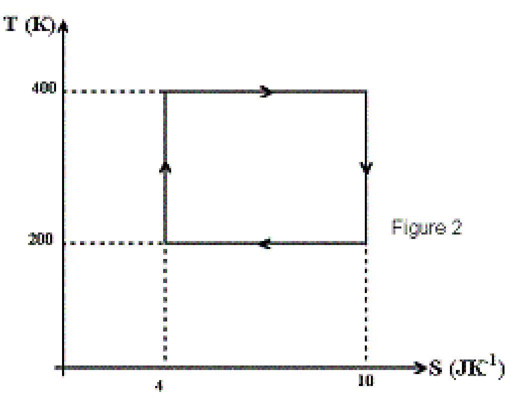
- A Carnot engine whose low temperature reservoir is at 7 ^{o}C has an efficiency of 50%. It is desired to increase the efficiency to 70%. By how many degrees should the temperature of the high temperature reservoir be increased while the cold reservoir remains at the same temperature?

(a) 742 K
(b) 560 K
(c)@ 373 K
(d) 280 K
(e) 434 K

- A heat engine absorbs 8.71×10^{3} J per cycle from a hot reservoir with an efficiency of 25% and executes 3.15 cycles per second. What is the power output of the heat engine?

(a) 1.91×10^{3} W.
(b) 1.58×10^{5} W.
(c) 1.11×10^{5} W.
(d) 3.15×10^{3} W.
(e)@ 6.86×10^{3} W.

- One mole of an ideal gas is taken through the cycle shown in the T-S diagram of figure (2). Calculate the efficiency of the cycle.



(a) 0.60.
(b) 0.82.
(c) 0.46.
(d) 0.20.
(e)@ 0.50.

- An ideal engine absorbs heat at 527 ^{o}C and rejects heat at 127 ^{o}C. If it has to produce useful mechanical work at the rate of 750 Watts, it must absorb heat at the rate of:

(a) 2250 Watts.
(b) 527 Watts.
(c) 750 Watts.
(d) 375 Watts.
(e)@ 1500 Watts.

- Specify the CORRECT statement:

(a) The entropy of the universe decreases in any process.
(b) To calculate the efficiency of ideal engine the temperature should be in Celsius.
(c) Heat engines can have efficiency higher than Carnot engine working between the same two temperatures.
(d) The efficiency of heat engines can be 100%.
(e)@ Isolated systems tend toward disorder and entropy is a measure of this disorder.

- An ideal engine, whose low-temperature reservoir is at 27 ^{o}C, has an efficiency of 20%. By how much should the temperature of the high-temperature reservoir be increased to increase the efficiency to 50%?

(a) 20 K.
(b)@ 225 K.
(c) 975 K.
(d) 88 K.
(e) 300 K.

- An ideal heat engine has a power output of 200 W. The engine operates between two reservoirs at 300 K and 600 K. How much energy is absorbed per hour?

(a) 6.31×10^{3} J.
(b)@ 1.44×10^{6} J.
(c) 1.93×10^{5} J.
(d) 1.92×10^{6} J.
(e) 5.46×10^{6} J.

- A Carnot heat engine operates between two reservoirs whose temperatures are 27 ^{o}C and 127 ^{o}C. If we want to double the efficiency of the heat engine, what should be the temperature of the hot reservoir? Assume the temperature of the cold reservoir is kept constant.

(a)@ 600 K
(b) 1200 K
(c) 800 K
(d) 1500 K
(e) 900 K

- One mole of an ideal gas is taken through the reversible cycle shown in figure 1, with Q_1 = 6.0 kJ, Q_2 = 30 kJ, Q_3 = 18 kJ and Q_4 = 10 kJ. What is the efficiency of this cycle ?

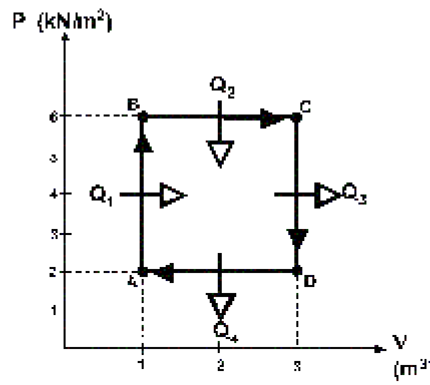


Figure 1

(a) 0.54
(b) 0.44
(c)@ 0.22
(d) 0.33
(e) 0.29

- A Carnot heat engine absorbs 70.0 kJ as heat and expels 55.0 kJ as heat in each cycle. If the low-temperature reservoir is at 120 ^{o}C, find the temperature of the high-temperature reservoir.

(a) 35.8 ^{o}C
(b) 393 ^{o}C
(c) 153 ^{o}C
(d)@ 227 ^{o}C
(e) 450 ^{o}C

- A heat engine operates between 600 K and 300 K. In each cycle it takes 100 J from the hot reservoir, loses 25 J to the cold reservoir, and does 75 J of work. This heat engine violates:

(a) The first law but not the second law of the thermodynamics.
(b)@ The second law but not the first law of thermodynamics.
(c) Neither the first law nor the second law.
(d) Conservation of energy.
(e) Both, the first law and the second law of thermodynamics.

- One mole of a diatomic ideal gas is taken through the cycle shown in Figure 2. Process b->c is adiabatic, $P_a = 0.3$ atm, $P_b = 3.0$ atm, $V_b = 1.0\times10^{-3}$ m^3, and $V_c = 4.0\times V_b$. What is the efficiency of the cycle?

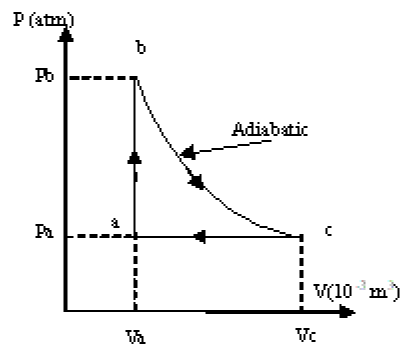


Figure 2

(a) 74%.
(b)@ 53%.
(c) 34%.
(d) 28%.
(e) 12%.

- A Carnot engine has an efficiency of 20%. It operates between two constant-temperature reservoirs differing in temperature by 70.0 K. What is the temperature of the HOT reservoir?

(a)@ 350 K.
(b) 280 K.
(c) 400 K.
(d) 300 K.
(e) 70 K.

➢ A heat engine operates in a Carnot cycle between reservoirs of temperatures 127 ^{o}C and 727 ^{o}C. It is found that 20 J of heat is expelled to the cold reservoir in every cycle. What is the work done per cycle?

(a) 40 J
(b) 20 J
(c) 50 J
(d)@ 30 J
(e) 10 J

➢ An 8.0-MW electric power plant has an efficiency of 30 %. It loses its waste heat to the environment. How much heat is lost to the environment per second?

(a) 23 MJ
(b) 5.6 MJ
(c) 2.4 MJ
(d)@ 19 MJ
(e) 8.0 MJ

➢ A car engine delivers 8.6 kJ of work per cycle. If its efficiency is 30%, find the energy lost by the engine per cycle.
(a) 24 kJ.
(b)@ 20 kJ.
(c) 8.6 kJ.
(d) 26 kJ.
(e) 14 kJ.

➢ A heat engine has a thermal efficiency of 20%. It runs 2 revolutions per second and delivers 80 W. For each cycle find the heat discharged to the cold reservoir.

(a) 40 W.
(b) 61 W.
(c) 200 W.
(d) 121 W.
(e)@ 160 W.

$$\boxed{\begin{gathered} W\ \text{(per cycle)} = \frac{80}{2} = 40\ \text{J}, \quad Q_H = \frac{W}{\varepsilon} = \frac{40}{0.2} = 200\ \text{J} \\ |Q_C| = |Q_H| - W = 200 - 40 = \underline{160\ \text{J}} \end{gathered}}$$

➢ Which one of the following statements is WRONG?

(a) A refrigerator is a heat engine working in reverse.
(b) The most efficient cyclic process is the Carnot cycle.
(c)@ The total entropy decreases for any system that undergoes an irreversible process.
(d) Entropy is a quantity used to measure the degree of disorder in a system.
(e) It is impossible to construct a heat engine which does work without rejecting some heat to a cold reservoir.

➢ Which one of the following statements is WRONG?

(a) No heat engine has higher efficiency than Carnot efficiency.
(b) Thermal energy cannot be transferred spontaneously from a cold object to a hot object.
(c) After a system has gone through a reversible cyclic process, its total entropy does not change.
(d) A heat pump works like a heat engine in reverse.
(e)@ The total entropy of a system increases only if it absorbs heat.

➢ What is the coefficient of performance of a refrigerator that absorbs 40 cal/cycle at low temperature and expels 51 cal/cycle at high temperature?

(a) 4.6.
(b) 0.22.
(c) 2.3.
(d)@ 3.6.
(e) 0.28.

➢ An ideal refregerator has a coefficient of performance (COP) of 5. If the temperature inside the freezer is - 20 ^{o}C, what is the temperature at which heat is rejected?

(a) -20 ^{o}C
(b)@ 31 ^{o}C
(c) -45 ^{o}C
(d) 20 ^{o}C
(e) 36 ^{o}C

- Which one of the following statements is WRONG?

(a) No heat engine has higher efficiency than Carnot efficiency.
(b) A refrigerator works like a heat engine in reverse.
(c) Thermal energy cannot be transferred spontaneously from a cold object to a hot object.
(d)@ The total entropy of a system increases only if it absorbs heat.
(e) After a system has gone through a reversible cyclic process, its total entropy does not change.

- What is the coefficient of performance of an ideal refrigerator if the temperatures of the two reservoirs are $10\ ^{\circ}\mathrm{C}$ and $27\ ^{\circ}\mathrm{C}$.

(a)@ 7.1
(b) 1.5
(c) 0.5
(d) 8.0
(e) 6.5

- A Carnot refrigerator has a coefficient of performance equal to 6. If the refrigerator expels 80 J of heat to a hot reservoir in each cycle, find the heat absorbed from the cold reservoir.

(a) 21 J.
(b) 15 J.
(c) 30 J.
(d) 5 J.
(e)@ 69 J.

- A Carnot refrigerator has a coefficient of performance equal to 5. The refrigerator absorbs 120 J of heat from a cold reservoir in each cycle. How much heat is expelled to the hot reservoir?

(a) 720 J
(b) 480 J
(c) 600 J
(d)@ 144 J
(e) 125 J

- What mass of water at 0 ^{o}C can a freezer make into ice cubes in one hour, if the coefficient of performance of the refrigerator is 3.0 and the power input is 0.2 Kilowatt?

(a) 0.4 kg.
(b) 1.9 kg.
(c) 3.0 kg.
(d) 9.2 kg.
(e)@ 6.5 kg.

- During one cycle, a Carnot refrigerator does 200 J of work to remove 600 J from its cold compartment. How much energy per cycle is exhausted to the kitchen as heat?

(a)@ 800 J.
(b) 200 J.
(c) 225 J.
(d) 600 J.
(e) 450 J.
