Thermodynamics

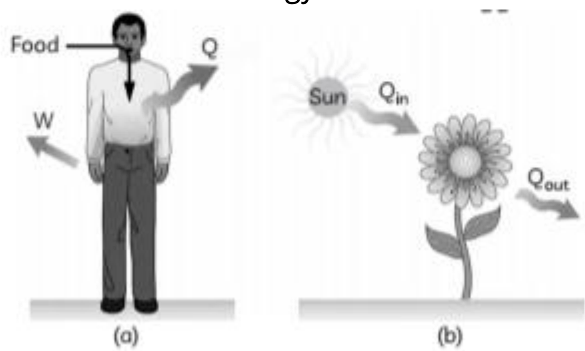
Case Study Based Questions

Read the following passages and answer the questions that follow:

1. The first law of thermodynamics simply states that energy can be neither created nor destroyed (conservation of energy). Thus, power generation processes and energy sources involve the conversion of energy from one form to another, rather than the creation of energy from nothing. Thus, the energy of the universe is constant. However, energy can be transferred from one part of the universe to another. To work out thermodynamic problems we will need to isolate a certain portion of the universe, the system, from the remainder of the universe, the surroundings.

ΔU-Q-W+food energy

ΔU Stored food energy



(A) It's a hot summer day, and your air conditioning system isn't working. You have a working refrigerator and an ice chest full of ice in your kitchen. Which should you open and which should you leave open to effectively cool the room?

(B) Can a gas be liquefied at any temperature by the increase of pressure alone?

(C) State the first law of thermodynamics.

Ans. (A) The high-temperature reservoir for your kitchen refrigerator is the air in the kitchen. If the refrigerator door were left open, energy would be drawn from the air in the kitchen passed through the refrigeration system and transferred right back into the air. The result would be that the kitchen would become warmer, due to the addition of the energy coming in by electricity to run the refrigeration system. If the ice chest were opened, energy in the air would enter the ice, raising its temperature and causing it to melt. The transfer of energy from the air would cause its temperature to drop. Thus, it would be more effective to open the ice chest.

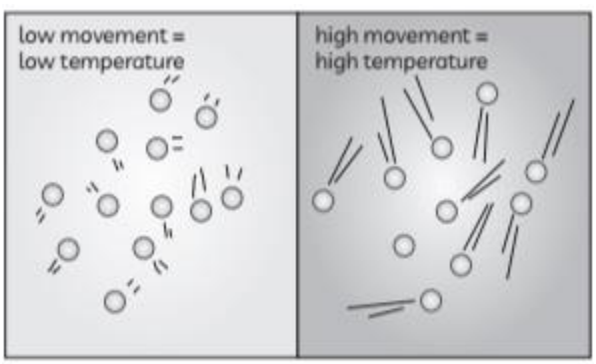
(B) No, a gas can be liquefied by pressure alone, only when the temperature of the gas is below its critical temperature.

(C) If some quantity of heat is supplied to a system capable of doing work. Then the quantity of heat absorbed by the system
is equal to the sum of the increase in the internal energy of the system and the external work done by the system.

8Q = SU+SW

or Q = W + AU

2. Water's high specific heat is a result of hydrogen bonds. The molecules must vibrate in order to raise the temperature of the water due to the multitude of joined hydrogen bonds. Because there are so many hydrogen bonds, it takes more energy to break the water molecules by vibrating them. Similarly, it takes some time for hot water to cool down. Temperature drops as heat are dissipated, and the vibrational movement of water molecules slows. The heat emitted compensates for the cooling effect of heat loss from liquid water.



Heat can be transferred from one place to another by three different methods. These are conduction, convection and radiation. Solids are usually heated by the process of conduction. Liquid and gases are heated by the process of convection. The process of radiation requires no medium. Conduction and convection are slow processess while radiation is a very fast process.

(A) Which of the following processes depends on gravity?

(a) Conduction

(b) Convection
(c) Radiation
(d) None of these

(B) Woolen cloths keep the body warm because wool:
(a) is a bad conductor
(b) increases the temperature
(c) decreases the temperature
(d) generates heat energy

(C) On a cold morning, a metal surface will feel colder to touch than a wooden surface because:
(a) metal has a high specific heat
(b) metal has a high thermal conductivity
(c) metal has a low specific heat
(d) metal has a low thermal conducting

(D) Earth receive heat from the sun by the method of:
(a) conduction
(b) convection
(c) radiation
(d) all of these

(E) A slab consists of two portions of different materials of the same thickness and having the thermal conductivities K_1 and K_2. The equivalent thermal conducting of the slab is:
(a) $K_1 + K_2$
(b) $\frac{K_1 K_2}{K_1 + K_2}$
(c) $\frac{2K_1 K_2}{K_1 + K_2}$
(d) $\sqrt{K_1 + K_2}$

Ans. (A) (b) Convection
Explanation: Convection occurs when heated lighter particles move upwards and colder heavier particles move downwards to their respective positions. This is determined by weight, and thus by gravity.
(B) (a) is a bad conductor
Explanation: Woolen cloths keep the body warm because it is a poor conductor of heat. As a result, the body stays warm.
(C) (b) metal has high a thermal conductivity

Explanation: The metal has a high thermal conductivity, which means it conducts heat more quickly. Metal is also a good heat conductor. As a result, it absorbs your body heat as you touch it, causing your body temperature to drop and you to feel cold when you touch a piece of metal.

(D) (c) radiation

Explanation: The majority of the energy received by the earth's surface is in short wavelengths. Incoming solar radiation, also known as insolation, is the energy received by the Earth.

(E)

(c) $\frac{2K_1K_2}{K_1+K_2}$

Explanation: The thermal rate for the firstconductor is given as,

$$\frac{H_1}{t} = \frac{K_1A(T-T_1)}{L}$$

The thermal rate for the second conductor is given as,

$$\frac{H_2}{t} = \frac{K_2A(T_2-T)}{L}$$

Since they are counted in series,

$$H_1 = H_2$$

$$K(T-T_1) = K_2(T_2-T)$$

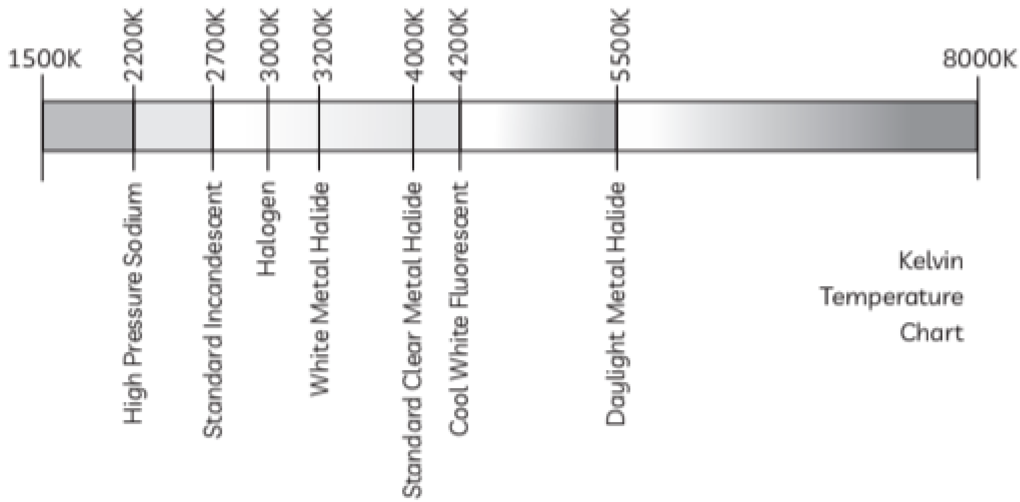
Let K be the equivalent conductance

Hence,

$$\frac{KA(T_2-T_1)}{2L} = \frac{K_1A(T-T_1)}{L} + \frac{K_2A(T_2-T)}{L}$$

$$K = \frac{2K_1K_2}{K_1+K_2}$$

3. Carnot cycle is particularly significant for a number of reasons. This cycle serves as a useful representation of a reversible steam power plant and refrigerator or heat pump model. However, it is also crucial from a theoretical standpoint since it helped formulate a crucial part of the second law of thermodynamics. Finally, it is possible to define an absolute temperature scale using



(A) Find the efficiency of the Carnot engine that operates between two reservoirs at temperatures of 1000 K and 330 K respectively and if the engine absorbs 5000 J of heat from the hot reservoir in a cycle, how much heat is ejected to the cool reservoir?
(B) Compare different thermodynamic processes.
(C) Mention two important results given by Carnot.

Ans. (A) For ideal gas, all Carnot engines operating between the same two temperatures have the same efficiency and given as $e_c =$
$1-T_CT_H = 1-330 \times 1000 = 0.670 = 67.0\%$.

$$Q_{out}Q_{in} = T_cT_H,$$
$$Q_{out} \times 5000 = 330 \times 1000$$
$$Q_{out} = 0.330 \times 5000 J$$
$$= 1650 J$$

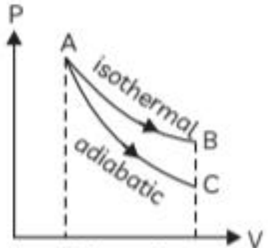
(B) An adiabat, is steeper than an isothermal i.e., the slope of an adiabatic is greater than the slope of an isothermal.

Slope of isothermal $\left(\frac{dP}{dV}\right) = \frac{P}{V}$

the second law of thermodynamics and only two reservoirs, which is really independent of any material used to measure temperature. The Kelvin (or absolute) temperature scale was considered a "Universal" scale because every constant volume gas thermometer containing dilute gas gave rise to the same absolute scale, irrespective of the type of gas involved and defined as T=273.16K (PPtr) where Ptr is the pressure of any dilute constant volume gas thermometer and P is the pressure of same thermometer at T.

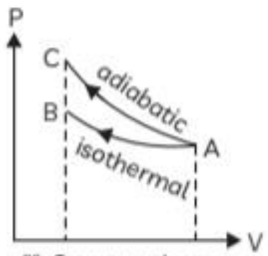
Slope of adiabatic $\left(\frac{dP}{dV}\right) = -\gamma \frac{P}{V}$

Slope of an adiabatic process = y * (slope of the isothermal process)
In expansion, the adiabatic curve lies below the Isothermal



(i) Expansions

In compression, the adiabatic curve lies above isothermal



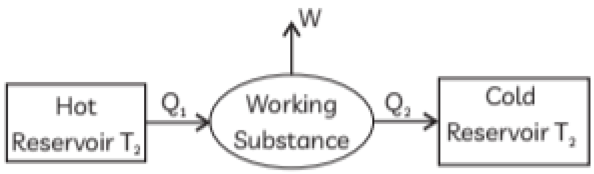
(ii) Compressions

(C) No engine can have efficiency more than that of the Carnot engine and the efficiency of the Carnot engine is independent of the nature of the working substance.

4. A heat engine is a device by which a system is made to undergo a cyclic process that results in the conversion of heat into work. Basically, a heat engine consists of (i) a hot reservation maintained at a higher temperature T1 (ii) a cold reservation maintained at a lower temperature T2 and (iii) a working substance. If in one cycle of its operation the system draws,

Q1 heat from the hot reservoir does W work and releases Q2 heat to the cold reservoir than

Efficiency of engine, $\eta_1 = \frac{W}{Q_1} = \frac{Q_1 - Q_2}{Q_1} = 1 - \frac{Q_2}{Q_1}$



(A) The area enclosed by a Carnot cycle represents:

(a) heat absorbed

(b) heat released

(c) amount of work done

(d) none of these

(B) A reversible heat engine 'A' operates between 223°C and 123°C. The efficiency of the engine is:

(a) 15%

(b) 20%

(c) 25%

(d) 30%

(C) Another reversible engine 'B' operates between temperatures 123° and T°C and has an efficiency 30%. The value of 'T' will be:

(a) 19.8°C

(b) 10°C

(c) 280°C

(d) 320°C

(D) Even the Carnot engine cannot give 100% efficiency, because we cannot:

(a) prevent radiation

(b) find ideal source

(c) eliminate friction

(d) reach absolute zero temperature

(E) The efficiency of Carnot engine does not depends on:

(a) temperature of source

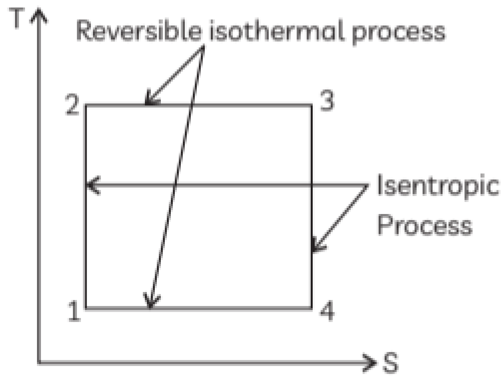
(b) temperature of sink

(c) nature of working substance

(d) temperature difference of source and sink temperature

Ans. (A) (c) amount of work done

Explanation: Carnot cycle consists of two reversible isothermal and two isentropic process.



Carnot cycle is one of the best-known reversible cycles. The Carnot cycle is composed of four reversible processes.

• Reversible Isothermal Expansion (process 1-2)
• Reversible adiabatic expansion (Process 2-3)
• Reversible isothermal compression (process 3-4)
• Reversible adiabatic compression (process 4-1)

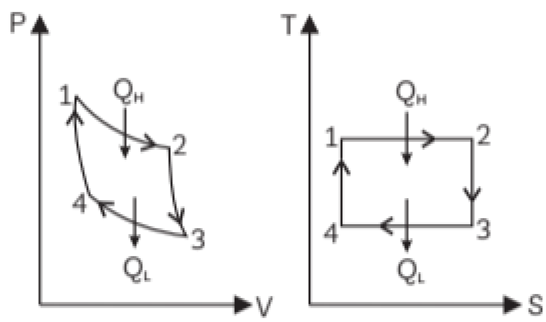


Fig. P-V and T-S diagrams of Carnot Cycle

:: We know that

work done (W) = PΔV

The area under the PV diagram

represents the work done.

(B) (b) 20%

Explanation: Using the relation for efficiency of Carnot's engine

$$\eta = \frac{T_1 - T_2}{T_1}$$

$$= \frac{396 - 496}{396}$$

$$= \frac{-100}{396}$$

$$= \frac{-100}{396} \times 100$$

$$= 20.155\% \simeq 20\%$$

(C) (a) 19.8°C

Explanation: We know that: Efficiency of Carnot Engine,

$$\eta = \frac{T_1 - T_2}{T_1}$$

$$30\% = 1 - \frac{T_2}{T_1}$$

$$\Rightarrow \quad 0.3 = 1 - \frac{123 + 273}{T + 273}$$

$$\Rightarrow \quad 0.7 = \frac{123 + 273}{T + 273}$$

$$\Rightarrow 0.7\,(T + 273) = 123 + 273$$

$$\Rightarrow \quad T = 292.8$$

$$K = 19.8°C$$

(D) (d) reach absolute zero temperature

Explanation: Even the Carnot engine is not 100% efficient. 100% efficiency (n=1) requires that Q_2 be equal to 0, which indicates that all of the heat from the source has been turned to work. The term "temperature of sink" refers to a negative temperature that is larger than unity on an absolute scale.

(E) (d) temperature difference of source and sink temperature

Explanation: The efficiency of the cycle

is given as $\eta = 1 - \frac{T_2}{T_1}$. Here T_1 is the

temperature of the source and T_2 is the temperature of the sink.

If the difference between temperature of the source and the sink is increased (ie., temperature of source increase or temperature of sink decreases), the $\frac{T_2}{T_1}$

value decreases and thus efficiency increases.