Answer on Question #65269 –Physics - Molecular Physics - Thermodynamics

Condition:

Question 01:
2.0g of Nitrogen gas is at 270C in a fixed volume. If 20% of its total internal energy is due to rotation what is the average velocity of nitrogen molecules?
What will be the temperature 2.0 g of Helium gas in a fixed volume if the average velocity of its molecules is 20 m/s ?
Plot schematic of Cv v/s T curve based for nitrogen and helium gas based on Kinetic theory.

Question 02:
200g of melting ice is introduced to a huge lake at 270C. Find the total entropy change of ice-lake system.
200g of melting ice is introduced to a huge lake at 0.20C. Find the total entropy change of ice-lake system.
Can you draw any conclusion based on result? (Hint: tends to reversible, irreversible etc)

Solution:

Question 01:

Nitrogen gas is diatomic gas so N_2 has 5 degrees of freedomso total internal energy is$U = \frac{5}{2}kT * N$, where k is Boltzmann constant (k=1.38×10−23 J/K), T=270C = 543 K, N is quantity of molecules.

$N = \frac{m}{M} N_A$, where m=2.0g , M is molar mass(Molecular Weight):

$M(N_2) = 28 \, \frac{g}{mol}$, $N_A$is Avogadro constant ($N_A = 6{,}023 * 10^{23} mol^{-1}$).

$$N = \frac{2}{28} * 6{,}023 * 10^{23} = 0{,}43 * 10^{23} = 4{,}3 * 10^{22}$$

$$U = \frac{5}{2} * 1{,}38 * 10^{-23} * 543 * 4{,}3 * 10^{22} = 805{,}54\, J$$

If 20% of its total internal energy is due to rotationthen 80% is the average energy of motion:

$$E = 0{,}8 * 805{,}54 = 644{,}4 \; J$$

On theotherhand: $= N * E_0$, where N is quantity of molecules and E_0 is kinetic energy of one molecule.

$$E_0 = \frac{E}{N} = \frac{644{,}4}{4{,}3 * 10^{22}} = 149{,}86 * 10^{-22} = 1{,}5 * 10^{-20}\, J$$

On theotherhand: $E_0 = m_0 \frac{V^2}{2}$, where V is the average velocity, m_0 - molecular mass:

$$m_0 = 28 * 1{,}66 * 10^{-27} = 4{,}65 * 10^{-26} \; kg$$

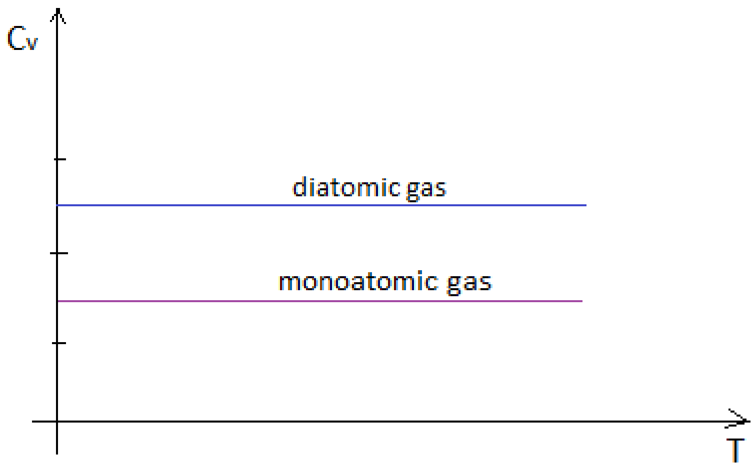
$$V = (\frac{2E_0}{m_0})^{1/2} = \left(\frac{2*1{,}5*10^{-20}}{4{,}65*10^{-26}}\right)^{1/2} = (0{,}645*10^6)^{1/2} = 0{,}803*10^3 \frac{m}{s} = 803 \frac{m}{s}$$

Helium gas is monoatomic gas so $E_0 = \frac{3}{2}kT = m_0\frac{V^2}{2} \rightarrow T = m_0\frac{V^2}{3k}$

$$m_0 = 4*1{,}66*10^{-27} = 6{,}64*10^{-27}\ kg$$

$$T = 6{,}64*10^{-27} * \frac{20^2}{3*1{,}38*10^{-23}} = 641{,}5*10^{-4}\ K = 0{,}064\ K = -273{,}086\ C$$

$$C_v = \frac{\delta Q}{\delta T} = \frac{\delta U}{\delta T} \rightarrow C_v(N_2) = \frac{\delta(\frac{5}{2}kT)}{\delta T} = \frac{5}{2}k\ ;\ C_v(He) = \frac{\delta(\frac{3}{2}kT)}{\delta T} = \frac{3}{2}k$$



Question 02:

a) Ice->water->steam:

Heat of fusion for ice: q=335 kJ/kg. Warmthwhichisnecessaryforicethawing: $Q = q*m = 335*0{,}2 = 67\ kJ$.

$$\Delta S_1 = \frac{Q}{T_0} = \frac{67}{273} = 0{,}245\ \frac{kJ}{K} = 245\ \frac{J}{K}$$

Heat capacity for water: c=4,187 kJ/kg*K. Warmthwhichisnecessaryforheatingwaterfrom$T_0 =$ 0C (273K) to T=100C (373 K):

$$Q = c*m*(T-T_0) = 4{,}187*0{,}2*100 = 83{,}74\ kJ$$

$$\Delta S_2 = Q * ln\frac{T}{T_0} = 83{,}74 * \ln\left(\frac{373}{273}\right) = 25959\frac{J}{K}$$

Heat ofvaporization for water: L=2260 kJ/kg. Warmth which is necessary for water vaporization$Q = Lm = 2260 * 0{,}2 = 452\ kJ$.

$$\Delta S_3 = \frac{Q}{T} = \frac{452}{373} = 1211{,}8\ \frac{J}{K}$$

Heat capacity for steam: c=2 kJ/kg*K. Warmthwhichisnecessaryforheatingsteamfrom$T =$ 100C (373K) to T_1=270C (543 K):

$$Q = c * m * (T_1 - T) = 2 * 0{,}2 * 170 = 68\ kJ$$

$$\Delta S_4 = Q * ln\frac{T_1}{T} = 68 * \ln\left(\frac{543}{373}\right) = 29172\ \frac{J}{K}$$

$\Delta S = 245 + 25959 + 1211{,}8 + 29172 = 56587{,}8\ \frac{J}{K}$ - entropy change for ice.

Thelakeloseswarmth: Q=-(67+83,74+452+543)=-1145,74 kJ. But temperature of the *large* lake is a constantsoentropy change for lake: $\Delta S = \frac{Q}{T} = \frac{-1145{,}74}{543} = -2110\ \frac{J}{K}$

The total entropy change of ice-lake system:$\Delta S = 56587{,}8\ + (-2110) = 54477{,}8\frac{J}{K}$

b) Heat of fusion for ice: q=335 kJ/kg. Warmthwhichisnecessaryforicethawing: $Q = q * m = 335 * 0{,}2 = 67\ kJ$.$\Delta S_1 = \frac{Q}{T_0} = \frac{67}{273} = 0{,}245\ \frac{kJ}{K} = 245\ \frac{J}{K}$

Heat capacity for water: c=4,187 kJ/kg*K.WarmthwhichisnecessaryforheatingwaterfromT_0 =0C (273K) to T=0,2C (273,2 K): $Q = c * m * (T - T_0) = 4{,}187 * 0{,}2 * 0{,}2 = 0{,}167\ kJ$

$$\Delta S_2 = Q * ln\frac{T}{T_0} = 0{,}167 * \ln\left(\frac{273{,}2}{273}\right) = 0{,}12\ J/K$$

$\Delta S = \Delta S_1 + \Delta S_2 = 245{,}12\frac{J}{K}$ - entropy change for ice.

Thelakeloseswarmth: Q=-(67+0,12)=-67,12 kJ. But temperature of the *large* lake is a constantsoentropy change for lake: $\Delta S = \frac{Q}{T} = \frac{-67{,}12}{273{,}2} = -245{,}68\frac{J}{K}$

The total entropy change of ice-lake system:$\Delta S = 245{,}12 + (-245{,}68) = -0{,}56\frac{J}{K}$

If we don't take in attention of heating of waterthenthe total entropy change of ice-lake systemis 0$\frac{J}{K}$.

The total entropy of an isolated system always increases over time therefore it is irreversible process.

Answer:

Question 01: average velocity of nitrogen moleculesis $803\ \frac{m}{s}$; temperature of Helium gas is $0{,}064\ K = -273{,}086\ C$

Question 02: The total entropy change of ice-lake system is$54477{,}8\ \frac{J}{K}$and $0\ \frac{J}{K}$