Second Law of Thermodynamics

Heat Engines

Reversible processes (equilibrium processes – quasi-equilibrium processes) – idealised – system always close to being in thermal equilibrium with itself and its surroundings.

Heat engine – device that transforms heat partly into work (mechanical energy) – a working substance undergoes a cyclic process. Any device that transforms heat partly into work or mechanical energy is called a heat engine. Usually a quantity of matter inside the engine (working substance) undergoes addition & subtraction of heat, expansion and compression and sometimes with phase changes.

All heat engines absorb heat $Q_H$ from a source at a relatively high temperature (hot reservoir $T_H$), perform some work and reject some heat at a lower temperature (cold reservoir $T_C$).

First law for a cyclic process

$$\Delta U = 0 = Q - W \implies Q = W$$

The net heat flowing into the engine in a cyclic process equals the net work done by the engine.

For one cycle $Q_H > 0 \quad Q_C < 0$

Net heat absorbed

$$Q = Q_H + Q_C = |Q_H| - |Q_C|$$

Net work done

$$W = Q = Q_H + Q_C = |Q_H| - |Q_C|$$

Thermal efficiency

$$e = W / Q_H = 1 + Q_C / Q_H = 1 - |Q_C| / |Q_H|$$

Internal combustion engine: working substance is air & fuel mixture (in / out)

Steam engine: working substance is water (circulates)
Carnot cycle (maximum efficiency for a heat engine)

For maximum heat engine efficiency – avoid all irreversible processes ⇒ every process that involves heat transfer must be isothermal because heat transfer through a non-zero temperature difference is an irreversible process and energy will be lost from the system that can never be recovered ⇒ any process in which the temperature of the working substance changes must be adiabatic.
1 → 2: **Isothermal compression**, heat $Q_C$ rejected to sink at constant temperature $T_C$.

$$Q_C = -nR\frac{T_C}{V_2} \ln\left(\frac{V_2}{V_1}\right) = nR\frac{T_C}{V_1} \ln\left(\frac{V_1}{V_2}\right)$$

$$\Delta U = 0 \quad \Delta S = -\frac{|Q_C|}{T_C}$$

2 → 3: **Adiabatic compression**, the pressure and temperature both increase without any heat flow taking place.

$$Q = 0 \quad T_CV_2^{\gamma-1} = T_HV_3^{\gamma-1} \quad \Delta U = -W \quad \Delta S = 0$$

$$\left(\frac{V_2}{V_3}\right)^{\gamma-1} = \frac{T_H}{T_C}$$

3 → 4: **Isothermal expansion**, heat $Q_H$ supplied from source at constant temperature $T_H$, the pressure decreases.

$$Q_H = nR\frac{T_H}{V_4} \ln\left(\frac{V_4}{V_3}\right)$$

$$\Delta U = 0 \quad \Delta S = -\frac{|Q_H|}{T_H}$$

4 → 1: **Adiabatic expansion**, the pressure and temperature both decrease until they have their same initial values, no heat flow occurs.

$$Q = 0 \quad T_HV_4^{\gamma-1} = T_CV_1^{\gamma-1} \quad \Delta U = -W \quad \Delta S = 0$$

$$\left(\frac{V_1}{V_4}\right)^{\gamma-1} = \frac{T_H}{T_C}$$

**Efficiency for Carnot Cycle**

$$e_{\text{Carnot}} = \frac{|W|}{|Q_H|} = \frac{|Q_H| - |Q_C|}{|Q_H|} = 1 - \frac{|Q_C|}{|Q_H|}$$

$$e_{\text{Carnot}} = 1 - \frac{nRT_C}{nRT_H} \ln\left(\frac{V_1}{V_2}\right) \quad \frac{V_1}{V_2} = \frac{V_2}{V_3} \quad \Rightarrow \quad \frac{V_1}{V_2} = \frac{V_4}{V_3}$$

$$e_{\text{Carnot}} = 1 - \frac{T_C}{T_H}$$
Alternative proof
\[
\Delta S_{\text{cycle}} = 0 = -\frac{|Q_C|}{T_C} + \frac{|Q_H|}{T_H} + 0 \implies \frac{|Q_C|}{|Q_H|} = \frac{T_C}{T_H}
\]

\[
e_C = \frac{\left|\frac{Q_H}{T_H}\right| - \left|\frac{Q_C}{T_C}\right|}{\left|\frac{Q_H}{T_H}\right|} = 1 - \frac{\left|\frac{Q_C}{Q_H}\right|}{\left|\frac{T_C}{T_H}\right|} = 1 - \frac{T_C}{T_H}
\]

The larger the efficiency, the greater the temperature difference. The efficiency can never be exactly 1 since \(T_C > 0\) K. All Carnot engines operating between the same temperatures have the same efficiency, irrespective of the nature of the working substance.

**Carnot Cycle - Conservation of Energy – Second law of Thermodynamics**

- Second Law of thermodynamics → ideal, reversible heat engines < 100 % efficient in converting work into work.
- Carnot's theorem (Sadi Carnot 1796 – 1832): Conversion of thermal energy into other forms of energy is qualitative different from other kinds of energy conversion. It is easy to convert mechanical energy into internal energy eg, every time we use a car's brakes to stop. It is not so easy to convert internal energy into mechanical energy.
- When the engine takes heat from the hot reservoir at \(T_H\), the working substance must be at \(T_H\), otherwise irreversible heat flow would occur, When the engine discards heat to the cold reservoir at \(T_C\), the engine working substance must be at \(T_C\). During processes when the temperature changes, they must be adiabatic \((Q = 0) \implies \text{Carnot cycle: Two isothermal and two adiabatic processes.}
- Carnot showed that no heat engine operated cyclically between two temperature reservoirs is more efficient than that described by the Carnot cycle.
**Otto cycle – standard petrol engine (4 stroke)**

Idealized model of the thermodynamic processes in a typical car engine. The compression rate is $r = \frac{V_1}{V_2}$. For $r = 8$ and $\gamma = 1.4$ (air) $\Rightarrow e = 56\%$ (ideal engine) $e \sim 35\%$ (real engine). Efficiency increases with larger $r \Rightarrow$ engine operates at higher temperatures $\Rightarrow$ pre-ignition $\Rightarrow$ knocking sound and engine can be damaged.

$T_H$ (peak) $\sim 1800 \, ^\circ\text{C}$  $T_C$ (base) $\sim 50 \, ^\circ\text{C}$  $r \sim 8$  efficiency: ideal $\sim 55 \%$  real $\sim 30 \%$

In practice, the same air does not enter the engine again, but since an equivalent amount of air does enter, we may consider the process as cyclic.

![Otto Cycle Diagram](diagram.png)

5 $\rightarrow$ 1: **inlet stroke** volume increases as piston moves down creating a partial vacuum to aid air/fuel entering cylinder via the open inlet valve.

1 $\rightarrow$ 2: **compression stroke** inlet valve closes piston moves up compressing the air/fuel mixture **adiabatically**.

2 $\rightarrow$ 3: **ignition** – spark plug fires igniting mixture - **constant volume** combustion.

3 $\rightarrow$ 4: **expansion** or **power stroke** – heated gas expands **adiabatically** as the piston is pushed down doing work ($V_{\text{max}} = r \, V_{\text{min}}$).

4 $\rightarrow$ 1 and 1 $\rightarrow$ 5: **Exhaust stroke** – outlet valve opens and mixture expelled at **constant volume** then piston moves up producing a compression at constant pressure, $P_o$ (atmospheric pressure).
**Diesel cycle**

Diesel engines operate at higher temperatures than petrol engines. During the adiabatic compression high temperatures are reached and then fuel is injected fast enough to keep the pressure constant. The injected fuel because of the high temperatures ignites spontaneously without the need for spark plugs.

For $r \approx 18$ and $\gamma = 1.4$ (air) $\Rightarrow e \approx 68\%$ (ideal engine).

Diesel engines – heavier and harder to start, and are more efficient than petrol engines. They need no carburettor or ignition system, but the fuel-injection system requires expensive high-precision machining.

$T_H$ (peak) $\sim 1800 \, ^\circ C$  
$T_C$ (base) $\sim 50 \, ^\circ C$  
$r \sim 18$

ideal efficiency $\sim 65\%$  
real efficiency $\sim 40\%$
5 → 1: **inlet stroke** volume increases as piston moves down creating a partial vacuum to aid air (no fuel) entering cylinder via the open inlet valve.

1 → 2: **compression stroke** inlet valve closes piston moves up compressing the air *adiabatically*. No fuel enters during most of the compression stroke ⇒ no pre-ignition ⇒ larger compression ratio $r \sim 15$ to $20$.

2 → 3: **ignition** – injection of fuel directly into cylinder just fast enough to keep *pressure constant*. High temperature reached: fuel ignites spontaneously; no spark plugs or ignition system, no carburettor, expensive high precision machining for fuel injection.

3 → 4: **expansion** or **power stroke** – heated gas expands *adiabatically* as the piston is pushed down doing work.

4 → 1 and 1 → 5: **Exhaust stroke** – outlet valve opens and mixture expelled at *constant volume* then piston moves up producing a compression at constant pressure, $P_o$ (atmospheric pressure).
Refrigeration Cycle

Refrigerator

\[ Q_C = Q_H - W \]

Air Conditioner

\[ Q_H = W + Q_C \]

Heat Pump

\[ Q_H = W + Q_C \]
The **compressor** compresses the gas (e.g., ammonia). The compressed gas heats up as it is pressurized (orange). The gas represents the working substance, e.g., ammonia, and the compressor driven by an electric motor does work $W$.

The **condenser coils** at the back of the refrigerator let the hot ammonia gas dissipate its heat $Q_H$. The ammonia gas condenses into ammonia liquid (dark blue) at high pressure gas (gas $\rightarrow$ liquid).

The high-pressure ammonia liquid flows through the **expansion valve**. The liquid ammonia immediately boils and vaporizes (light blue), its temperature dropping to about $-35$ °C by the expansion. This makes the inside of the refrigerator cold by absorption of heat $Q_C$ as liquid $\rightarrow$ gas.

The cold ammonia gas enters the **compressor** and the cycle repeats.

A **refrigerator** is a heat engine operating in reverse – it takes heat from a cold place and gives it off at a warmer place, this requires a net input of work.

$$|Q_H| = |Q_C| + |W|$$

Best refrigerator – one that removes the greatest amount of heat $|Q_C|$ from inside the refrigerator for the least expenditure of work $|W| \Rightarrow \text{coefficient of performance, } K$

(higher $K$ value, better the refrigerator)

$$K = \frac{|Q_C|}{|W|} = \frac{|Q_C|}{|Q_H| - |Q_C|}$$

$K = \frac{\text{what we want}}{\text{what we pay for}}$

$K = \frac{\text{extraction of max heat from cold reservoir}}{\text{least amount of work}}$

Refrigerator: working substance – e.g., freon family $\text{CCl}_2\text{F}_2$. 
Because each step in the Carnot cycle is reversible, the entire cycle may be reversed, converting the engine into a refrigerator.

\[ K_{\text{Carnot}} = \frac{T_C}{T_H - T_C} \]

High $K$ value, the better the refrigerator, this is when the temperature difference is small.
Entropy – macroscopic view

Assume a small amount of heat added to a system at a temperature $T$ (measured in K) during a reversible process. Change in entropy of the system is defined to be

$$\Delta S = \Delta Q / T$$

For a large quantity of heat transfer: approximate it by a large number of reversible processes

$$\Delta S = \sum \{ \Delta Q / T \} \rightarrow \int \{ dQ / T \}$$

$\Delta Q > 0$ when heated added to a system
$\Delta Q < 0$ when heated removed from a system
SI unit for entropy J.K$^{-1}$

Irreversible processes - by definition, irreversible processes involve an increase in entropy and $\Delta S$ is calculated by considering reversible processes that would bring the system to the same final state i.e., in calculating changes in entropy we are only interested in the initial and final states of the system, not in the way the system changed.

Law of Nature: part of the energy surrounding us is completely useless - this energy is the energy of the thermal motion of the molecules - it is not possible to simply extract this energy and converting it into useful mechanical work $\Rightarrow$ no perpetual motion machines by just removing heat.

Second Law of Thermodynamics (Closed or isolated system)
- reversible process (system can return to its original state with no net change in the system or surroundings) $\Delta S = 0$
- Irreversible process (e.g., smashing an egg, opening a bottle of perfume, rubbing your hands together) $\Delta S > 0$

The Second Law sets limits on the efficiency of converting thermal energy to work that is independent of the materials used in the process - heat engines can not be 100% efficient in converting heat energy into work- all the energy liberated by burning petrol in a car does NOT go into making the car move. The Second Law enables us to calculate the efficiency of engines.

Cyclic process
A cyclic process is one in which a system goes through certain changes and returns to its original state. The changes may involve heat flowing to or from the system and work being done on or by the system. Examples of such processes occur with a car engine or the human body. Heat flows to the engine from burning petrol or to the body from oxidation of food. In both cases work is done on the surroundings. Schematically these examples might be drawn as
The diagram above indicates that all the energy from the burning petrol or the oxidising food has been transformed to useful work. This is possible on energy conservation considerations, but are there other constraints that prevent it from happening? We use the Second Law and entropy calculations to answer this question.

- Entropy change in engine (cyclic process) = 0
- Entropy change in heat reservoir = \(- \frac{Q}{T}\) (a decrease in entropy because there is a flow of heat from the reservoir).
- Entropy change in surrounding = 0 (there is no heat flow to the surroundings).
- Net entropy change = \(- \frac{Q}{T}\)

The Second Law states that such a decrease of entropy in the universe (system plus reservoir plus surroundings) is impossible. So the above diagram represents an impossible situation and must be amended.

Here, some energy is discharged to a lower temperature reservoir. Only part of the energy from the burning petrol or oxidising food is transformed to useful work.

For one cycle:

First Law \(\Delta U = 0\) and \(Q = Q_H - Q_C\) \(\Rightarrow W = Q_H - Q_C\)

- Entropy change in engine (cyclic process) = 0
- Entropy change in surroundings (only work is done on surroundings) = 0
- Entropy change in hot reservoir = \(- \frac{Q_H}{T_H}\)
- Entropy change in cold reservoir = \( Q_C / T_C \)
- Change in entropy of system = \(- Q_H / T_H + Q_C / T_C\)

As long as \( Q_H / T_H < Q_C / T_C \), useful work can be done on the surroundings while the cyclic process goes on. Note that because \( Q_C \) is smaller than \( Q_H \), \( T_C \) must be smaller than \( T_H \). Both a hot temperature reservoir and a cold temperature reservoir are needed. Most work done on surroundings occurs when \( \Delta S = 0 \) and \( Q_H / T_H = Q_C / T_C \). This gives the maximum efficiency of a heat engine \( e \) as

\[
e = \frac{W}{Q_H} = \frac{(Q_H - Q_C)}{Q_H} = 1 - \frac{Q_C}{Q_H} = 1 - \frac{T_C}{T_H}
\]

For an engine the above represents a **Carnot Cycle** where all processes are reversible.

### Calculating \( \Delta S \)

#### Isothermal Process: \( T \) constant
\[
\Delta S = \int \frac{dQ}{T}
\]
\[
\Delta S = \frac{Q}{T}
\]

In an isothermal expansion, heat \( Q \) must be added to keep \( T \) constant, in a process where \( \Delta T \) is small
\[
\Delta S \approx \frac{Q}{T_{\text{avg}}}
\]
\[
Q = n R \frac{T}{T_{\text{avg}}} \ln\left(\frac{V_f}{V_i}\right)
\]
\[
\Delta S \approx n R \ln\left(\frac{V_f}{V_i}\right)
\]

**For an adiabatic process: \( Q = 0 \)**
\[
Q = 0 \Rightarrow \Delta S = 0
\]

#### Change in entropy object - heating results in an increase in temperature of object with mass \( m \) and specific heat capacity \( c \)
\[
Q = m c \Delta T
\]
\[
\Delta S = \int \frac{dQ}{T} = \int m c \frac{dT}{T} = m c \int \frac{dT}{T}
\]
\[
\Delta S = m c \ln\left(\frac{T_f}{T_i}\right)
\]

#### Change in entropy of an ideal gas for a reversible process
\[
\Delta U = Q - W
\]
process - small steps passing through equilibrium states - reversible
\[
W = p \Delta V
\]
\[
\Delta U = n C_V \Delta T
\]
\[
Q = n C_V \Delta T + p \Delta V
\]
\[
p = n R T / V
\]
\[
\Delta S = \int \frac{dQ}{T} = \int \{ n C_V \frac{dT}{T} + n R \frac{dV}{V} \}
\]
\[
\Delta S = n C_V \ln\left(\frac{T_f}{T_i}\right) + n R \ln\left(\frac{V_f}{V_i}\right)
\]
\[
\Rightarrow \Delta S \text{ depends only on initial and final states - path independent - is a state variable.}
\]
Example 1
A mug of coffee cools from 100 °C to room temperature 20 °C. The mass of the coffee is 0.25 kg and its specific heat capacity may be assumed to be equal to that of water, 4200 J.kg⁻¹.K⁻¹. Calculate the change in entropy of the coffee, of the surroundings and of the coffee plus the surroundings (the "universe").

The entropy of the coffee and of the surroundings will both change. In each case we consider the system of interest (first the coffee, second the surroundings) and look at the corresponding reversible change that takes the system from its initial to its final state. Note well that we are not claiming that the change occurred reversibly, we are just imagining the reversible change so that we can calculate the entropy change in the real situation.

Coffee:  The coffee cools from 100 °C to 20 °C, i.e. from $T_H = 373$ K to $T_C = 293$ K.

The transfer of energy as $\Delta Q$, from the coffee is given by the relation

$$\Delta Q = m c \Delta T,$$

where $m$ is the mass of the coffee, $c$ the specific heat capacity of the coffee and $\Delta T$ the change in temperature of the coffee while in contact with that reservoir.

$$\Delta S = \Sigma \{ m c \Delta T / T \} = \int (m c \, dT/T) = m c \ln (T_C / T_H)$$

$$\Delta S = (0.25)(4200)\ln(293/373) = -253 \, J.K^{-1}$$

Surroundings: These remain at temperature 293 K while an irreversible flow of $m c \Delta T$ occurs. Note that this heat flow is calculated indirectly, in terms of coffee, where data needed for this calculation is available, rather than from values directly associated with the surroundings.

$$\Delta S = \Delta Q / T = (m c \Delta T) / T$$

$$\Delta S = (0.25)(4200)(373 - 293)/293 = 287 \, J.K^{-1}$$

This will be positive, as to be expected since heat flows into the surroundings.

Coffee plus surroundings:

$$\Delta S = \Delta S(\text{coffee}) + \Delta S(\text{surroundings}) = -253 + 287$$

$$\Delta S = 34 \, J.K^{-1}$$

As for all naturally occurring processes the net change in entropy is positive.

Example 2
A stone of mass 1.0 kg is dropped into a lake of water from a height of 3.0 m. Calculate the changes in entropy of the stone and of the lake.

At first sight, this might seem to be a mechanics sum. But there will be an energy transfer: potential energy of the stone to kinetic energy of stone to internal energy of the lake. Changes in entropy are associated with the energy transfers. Because of the size of the lake, its temperature is effectively unchanged. We also assume that there is no difference between the temperatures of the air and the lake, so the temperature of the stone is also unchanged.
Stone:
The initial and final thermal states (internal energy, temperature, volume, etc.) are identical. The corresponding reversible change to be considered is extremely simple - no change. This means that the entropy change of the stone is zero.

The energy that is transferred from the stone to the lake, and is equal to the original potential energy of the stone. The corresponding reversible change is the transfer as heat flow to the lake

\[ \Delta S = \frac{m \cdot g \cdot h}{T} \]

Assume \( T = 300 \text{ K} \), \( m = 1.0 \text{ kg} \), \( g = 10 \text{ m.s}^{-2} \) and \( h = 3.0 \text{ m} \)

\[ \Delta S = \frac{(1.0)(10)(3.0)}{300} = 0.10 \text{ J.K}^{-1} \]

Example 3
A current of 4.0 A passes through a 60 \( \Omega \) resistor in 5 minutes. The resistor is cooled by the continuous passage of fast running water (enough water so that its temperature essentially remains constant). The temperature of the room is 290 K. Calculate the rate of change of entropy of the resistor and the surroundings.

\[ I = 4.0 \text{ A}, \ R = 60 \ \Omega, \ t = 5 \text{ min} = (5)(60) = 300 \text{ s}, \ T = 290 \text{ K} \]

Rate of energy supply = \( I^2 R = (4.0)^2 (60) = 960 \text{ W} \)

When the resistor is cooled by a continuous supply of running water, it remains at room temperature. The thermal state of the resistor is unchanged and there is a flow of heat at a rate of 960 W into the running water. We assume that the water flow is fast enough so that the water temperature is unchanged, so the only thermal effect is the flow of 960 W into the water without changing its temperature

Rate of entropy increase of water = \( \frac{\Delta Q}{T} = \frac{960}{290} = 3.3 \text{ W.K}^{-1} \)
Example 4
Consider two engines, the details of which are given in the following diagrams. For both engines
(a) Calculate the heat flow to the cold reservoir.
(b) The changes in entropy of the hot reservoir, cold reservoir and engine.
(c) Which engine violates the Second Law?
(d) What is the efficiency of the working engine?

<table>
<thead>
<tr>
<th>Engine 1</th>
<th>Engine 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>$T_H = 400$ K</td>
<td>$T_H = 400$ K</td>
</tr>
<tr>
<td>$T_C = 300$ K</td>
<td>$T_C = 300$ K</td>
</tr>
<tr>
<td>$Q_H = 1000$ J</td>
<td>$Q_H = 1000$ J</td>
</tr>
<tr>
<td>$W = 200$ J</td>
<td>$W = 300$ J</td>
</tr>
</tbody>
</table>

| $Q_C = ?$ J | $Q_C = ?$ J |
| $\Delta S = ?$ J.K$^{-1}$ | $\Delta S = ?$ J.K$^{-1}$ |
| $e = ?$ | $e = ?$ |

(a) 
First Law: $\Delta U = Q - W$
$Q = Q_H - Q_C$
Engine - cyclic process $\Delta U = 0 \Rightarrow Q = W \Rightarrow Q_H - Q_C = W$ $\Rightarrow Q_C = Q_H - W$
Engine 1: $Q_C = 1000 - 200 = 800$ J
Engine 2: $Q_C = 1000 - 300 = 700$ J

(b) Change in entropy
$\Delta S = \Delta Q / T$
Surroundings: No heat flows to the surroundings, $\Delta S = 0$
Hot reservoir (heat removed from reservoir): $\Delta S = - Q_H / T_H$
Engines 1 and 2: $\Delta S = - 1000 / 400 = - 2.5$ J.K$^{-1}$
Cold reservoir (heat added to reservoir): $\Delta S = + Q_C / T_C$
Engine 1: $\Delta S = \frac{800}{300} = + 2.7 \text{ J.K}^{-1}$
Engine 2: $\Delta S = \frac{700}{300} = + 2.3 \text{ J.K}^{-1}$
Change in entropy of the engines: $\Delta S = 0 \Leftrightarrow$ undergo continuous cycles
Change in entropy of the "universe":
$\Delta S = \Delta S(\text{hot reservoir}) + \Delta S(\text{cold reservoir}) + \Delta S(\text{surroundings}) + \Delta S(\text{engine})$
Engine 1: $\Delta S = -2.5 + 2.7 + 0 = + 0.2 \text{ J.K}^{-1} > 0 \Rightarrow$ Second Law validated
Engine 2: $\Delta S = -2.5 + 2.3 + 0 = -0.2 \text{ J.K}^{-1} < 0 \Rightarrow$ Second Law not validated
(d) Engine 1 is the working engine;
efficiency, $e = (\text{work out} / \text{energy input}) \times 100$
$e = (200 / 1000)(100) = 20 \%$

Note: The working substance in the engine goes around a cycle, therefore, no change in entropy for the engine.

Example 5
A thermally insulated box is divided by a partition into two compartments, each having a volume $V$. Initially, one compartment contains $n$ moles of an ideal gas at temperature $T$ and the other department is evacuated. We then break the partition and the gas expands to fill both compartments. What is the increase in entropy?

The process is a free expansion, $Q = 0$, $W = 0$ and $\Delta U = 0$ and therefore, because the system is an ideal gas $\Delta T = 0$. The entropy change is not zero even though no heat exchange occurs because the process is not reversible. The change in entropy only depends on the initial and final states and not the process. We can devise a reversible process that has the same end points and hence calculate the change in entropy. We can consider an isothermal expansion from $V$ to $2V$ at a temperature $T$. The gas does work during this expansion and so heat must be supplied to keep the internal energy constant ($\Delta T = 0$).

For an isothermal expansion

$$W = Q = n R T \ln(\frac{V_f}{V_i}) = n R T \ln(2)$$

Thus the change in entropy is

$$\Delta S = Q / T = n R \ln(2)$$
$$\Delta S = (1)(8.315)\ln(2)$$
$$\Delta S = 5.8 \text{ J.K}^{-1}$$