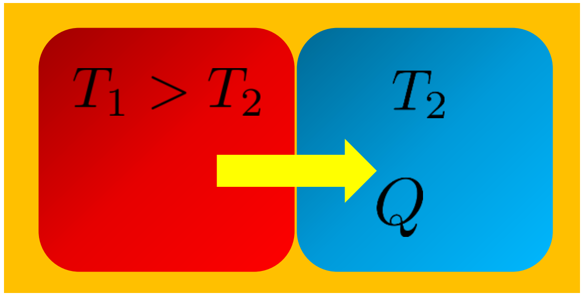
20-2: Why Does Heat Flow from Hot to Cold?



Now that we have a description of what heat is, we should ask: **"why does heat <u>spontaneously</u> only go from high temperature to low temperature?"**

We never see it going the other way . . <u>on its own</u>.

At this point, we have seen no physical law that would prevent the reverse from happening. **What makes a process Irreversible, i.e. going only one way in time?**

An **irreversible process** is a process for which a backwards running movie shows something that is physically impossible . . or at least, never observed.

Motion of particles at the microscopic level is reversible.

But motion in the macroscopic world is irreversible.

Maybe the ball can absorb thermal energy from the surrounding air and convert it into kinetic energy? That would not violate The First Law. Let's try this in a problem.

Whiteboard Problem: 20-7

The air in a room is at T = 20°C and P = 1 atm and the dimensions of the room are 2 m X 2 m X 2 m. A 1.0 kg ball is at rest on the floor of this room. The air is 80% N_2 and 20% O_2 (i.e. all diatomic).

a) **How much thermal energy is in the air in the room? (LC)**
   (There are many ways to do this calculation, some will take a lot of time; but there's one real easy way. Think ***$PV = nRT$*** *and* ***$E_{th} = nC_VT$*** *, and recall HW 20.28)*

b) **Suppose some of this thermal energy could be conveyed to the ball to spontaneously launch it from the floor to a height of 1.0 m? Since energy is conserved, this would not violate the First Law. By how much would the air temperature have to decrease to convey this much energy to the ball? (LC)**

c) **You should be getting a very small change in temperature. So small, that it might not be measurable . . . and *yet have you ever seen this happen? (LC)***

- This process does not violate the **First Law of Thermodynamics**; i.e. energy is conserved – the KE for the ball comes from the thermal energy in the air.
- It does, however, violate the **Second Law of Thermodynamics**.
- Oddly, the **Second Law** doesn't say that it will never happen – **instead, it says that the process is <u>exceedingly unlikely</u> to happen**.

The Second Law of Thermodynamics

In Chapters 20 & 21, your author gives **TEN** different and distinct statements of the **Second Law of Thermodynamics**!

Most General (What is Entropy?)

Second law, formal statement The entropy of an isolated system (or group of systems) never decreases. The entropy either increases, until the system reaches equilibrium, or, if the system began in equilibrium, stays the same.

Direction of Spontaneous Heat Flow

Second law, informal statement #1 When two systems at different temperatures interact, heat energy is transferred spontaneously from the hotter to the colder system, never from the colder to the hotter.

Second law, informal statement #2 The time direction in which the entropy of an isolated macroscopic system increases is "the future."

First law Energy is conserved; that is, $\Delta E_{th} = W + Q$.

Second law Most macroscopic processes are irreversible. In particular, heat energy is transferred spontaneously from a hotter to a colder system but never from a colder system to a hotter system.

Second law, informal statement #3 There are no perfect refrigerators with coefficient of performance $K = \infty$.

Second law, informal statement #4 There are no perfect heat engines with efficiency $\eta = 1$.

Second law, informal statement #5 No heat engine operating between reservoirs at temperatures T_H and T_C can be more efficient than a perfectly reversible engine operating between these temperatures.

Second law, informal statement #6 No refrigerator operating between reservoirs at temperatures T_H and T_C can have a coefficient of performance larger than that of a perfectly reversible refrigerator operating between these temperatures.

Most Useful (we'll use these in Chap 21)

Second law, informal statement #7 No heat engine operating between energy reservoirs at temperatures T_H and T_C can exceed the Carnot efficiency

$$\eta_{Carnot} = 1 - \frac{T_C}{T_H}$$

Second law, informal statement #8 No refrigerator operating between energy reservoirs at temperatures T_H and T_C can exceed the Carnot coefficient of performance

$$K_{Carnot} = \frac{T_C}{T_H - T_C}$$

What is Entropy?

Entropy, S, is a macroscopic state variable like P, V, T, & E_{th}:

Macroscopically: $$\Delta S = S_f - S_i = \int_i^f \left(\frac{\text{đ}Q}{T}\right)_{\text{reversible path}}$$

Do not write these equations down – we aren't going to use them!

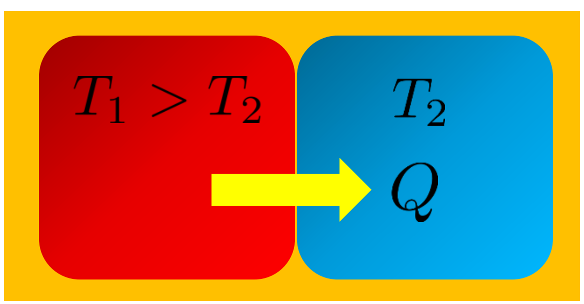
Microscopically: $$S = k_B \log W$$

Where W is the number of ways that the state can be realized.

In the microscopic case, we see that **Entropy is a measure of how ordered or disordered the system is**. There are only a few ways that an ordered state can be realized (i.e. W is *small, so low Entropy*), but there are many ways that a disordered state can be realized *(i.e. W is large, so high Entropy)*.

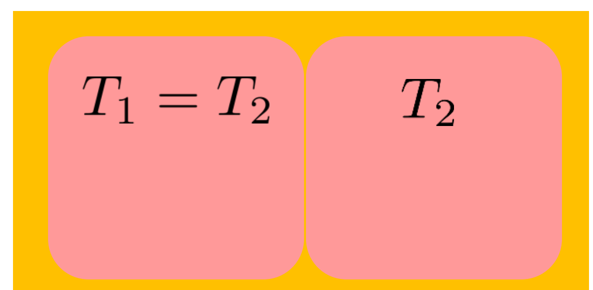
The **Second Law** says that a system or a group of systems will always tend to a state of higher Entropy; i.e. a state of more disorder. *(e.g. consider my garage)*

Ordered, Low Entropy



Heat flows in the direction that will increase the entropy

Disordered, Higher Entropy



Here's a very nice explanation by Brian Green

(arrow is an active link)

(we also saw a nice discussion of this in The Story of Energy video)