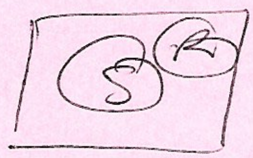
Ch. 8 KK <u>Heat & Work</u> 4/14/21

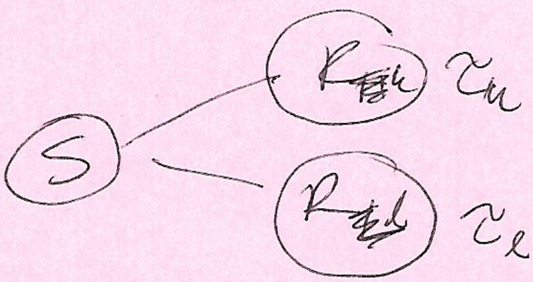
This is perhaps what you expected to learn about in a thermodynamics class. I am going to cover it so that your friends in engineering don't tell you that you didn't learn anything in this class.

In Ch. 9 we will look at what your chemistry friends learned in their class.

Before we considered the following:



Now:



Thermodynamics started with the heat engines during the industrial revolution in the 19th century. There was an important economic incentive to understanding the topic in order to design and build more efficient engines. It was science at the time.

In science, if you know what you are doing, you should NOT be doing it.

In engineering, if you <u>DON'T</u> know what you are doing, you should <u>NOT</u> be doing it.

-Richard Hamming

But this is less 1-D than it looks. You can't discover things without engineering or invent new technology without science.

KK: The most important physical process in a modern energy-intensive civilization is the conversion of heat into work.

How do you convert petroleum or coal into electricity? Geothermic? Nuclear?

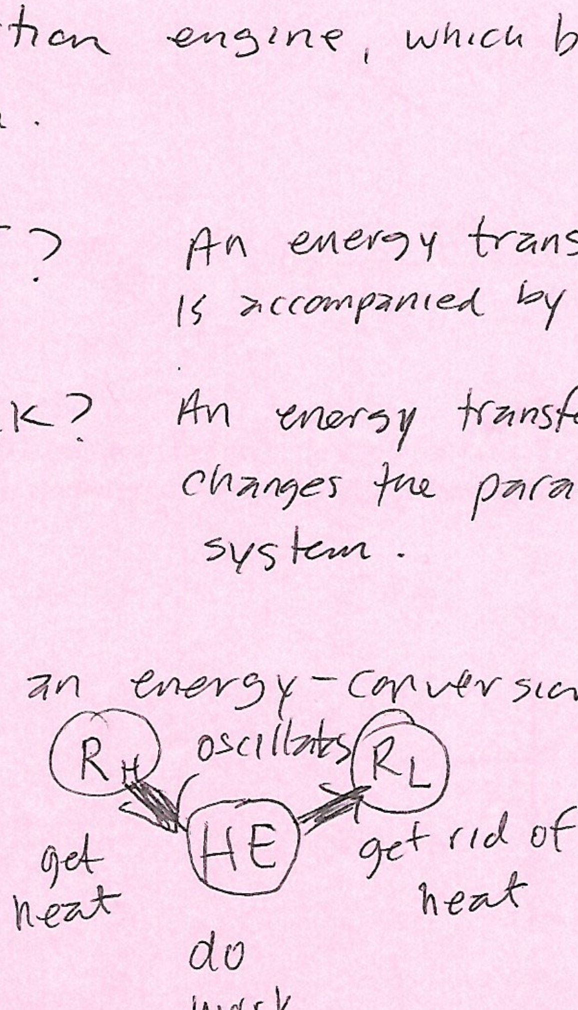
Are other sources of energy usable? Mechanical? Why our fixation with electricity?

The conversion of ~~#~~ heat into work is achieved by the internal combustion engine, which brough the Industrial revolution.

What is HEAT? An energy transfer that is accompanied by entropy change

WHAT IS WORK? An energy transfer that changes the parameters of the system.

A Heat Engine is an energy-conversion device that operates in cycles



closed-cycle is common

1st Law of thermodynamics

$$\text{đ}W = dU - \text{đ}Q = dU - \tau d\sigma$$ KK Eq. 8.3

the work and heat derivative symbol includes a horizontal bar đ. It is not mandatory, but it does remind the reader that W and Q are not state functions, like U, τ and σ are. has energy, entropy

does work, gets heat

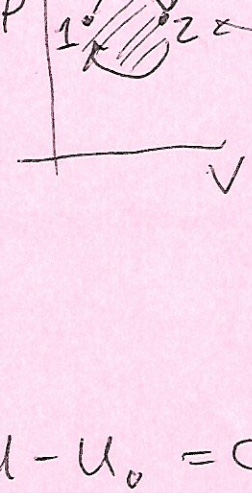
Definition $\quad \text{đ}Q \equiv \tau d\sigma$ ← number

↑ energy

How come?

The two extremes are pure work $(d\sigma = 0)$ so $\text{đ}W = dU$ and pure heat $dU = \tau d\sigma$ so $\text{đ}W = 0$.

A closed cycle system has at least two volume/pressure points



The work per cycle is marked

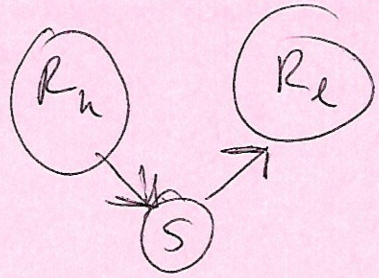
If you look at initial and final, V is the same, so work done is zero! But work was done. so

cycle

$\oint dU = U - U_0 = 0$. For the ideal gas in the engine, but, $\oint dW = 0$ is useless, so you use the đ to represent the whole cycle, $\oint \text{đ}W \neq 0$.

The origin of thermodynamics is the empirical discovery that not all the heat that you add to a system can be converted to useful work.

This is fundamental.



Heat flows from high to low, system (engine) does work

The ingredients of the ideal engine are:

- Engine in contact with either reservoir
- It is closed-cycle, so it returns to initial state
- Reversible (move system adiabatically) isentropic always in equilibrium

KK ~~Eq 8.4~~
Eq. 8.4

Heat withdrawn from R_h is $\quad dQ = \tau_h d\sigma$

$$\Delta Q = \tau_h \Delta\sigma \qquad Q_h = \tau_h \Delta\sigma$$

Heat dispersed to R_l is $\quad dQ = \tau_l d\sigma$

$$\Delta Q = \tau_l \Delta\sigma \qquad Q_l = \tau_l \Delta\sigma$$

Since the system is reversible, $\Delta\sigma$ is the same for both

Entropy lost by R_h is the entropy gained by R_l.

IS R_H REALLY LOSING ENTROPY? YES.

Since the system is closed-cycle, $\oint dU = 0 = \Delta U$

~~From 1st law of thermodynamics,~~ $\cancel{dW = dU - \tau d\sigma} = Q_h - Q_l$

$\cancel{W = \tau_h - \tau_l}$

A perfectly efficient engine converts all the heat it took in into work, the efficiency (eta)

$$\eta = \frac{W}{Q_h}$$

What are we really simulating with ~~[illegible]~~ R_e?

As soon as the ~~[illegible]~~ engine takes the heat and expands, doing work, it loses energy to its environment, and it can't be used for work. This heat is lost at a lower temperature. Since $\Delta U = 0$, $W = Q_h - Q_l$ KK Eq. 8.6

$$\eta = \frac{Q_h - Q_l}{Q_h} = 1 - \frac{Q_l}{Q_h} = 1 - \frac{\tau_l \cancel{\Delta\sigma}}{\tau_h \cancel{\Delta\sigma}} = 1 - \tau_l/\tau_h$$ KK Eq. 8.7

This is typically known as η_c (for Carnot)

This is the 2nd law of thermo, discovered empirically

Some observations: The only way $\eta = 100\%$ is if $\tau_l = 0$

POSSIBLE IN REAL LIFE?

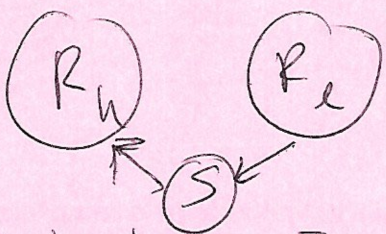
So $\eta < 1$ even in ideal case!

Change in entropy $\Delta\sigma \geq 0 = \sigma_h - \sigma_l$

POSSIBLE IN REAL LIFE?

This construction is very simple, and very abstract, but pretty powerful. You are at a temperature higher than your environment and you do work. You are a heat engine. You produce an entropy differential. You disperse heat. This goes back to the first forum.

Consider the case:



Heat flows from low to high: Equations for heat engine are reversible, so we can reuse them.

WHAT IS THIS ?

Coefficient of refrigerator performance $\gamma_c = \dfrac{Q_l}{W}$ KK Eq. 8.13

we want the work to be low so that we don't have to pay too much and Q_l to be high, we remove a lot of heat.

KK Eq. 8.12

$$W = Q_h - Q_l = \tau_h \sigma - \tau_l \sigma \Rightarrow \left(\frac{\tau_h}{\tau_l} - 1\right) Q_l$$

$$\text{so } \gamma = \frac{Q_l}{W} = \frac{Q_l}{Q_l\left(\frac{\tau_h}{\tau_l} - 1\right)} = \frac{1}{\frac{\tau_h}{\tau_l} - \frac{1}{1}} = \frac{1}{\frac{\tau_h - \tau_l}{\tau_l}} = \frac{\tau_l}{\tau_h - \tau_l}$$

$$\gamma = \frac{\tau_l}{\Delta \tau}$$ High if $\Delta\tau$ is small

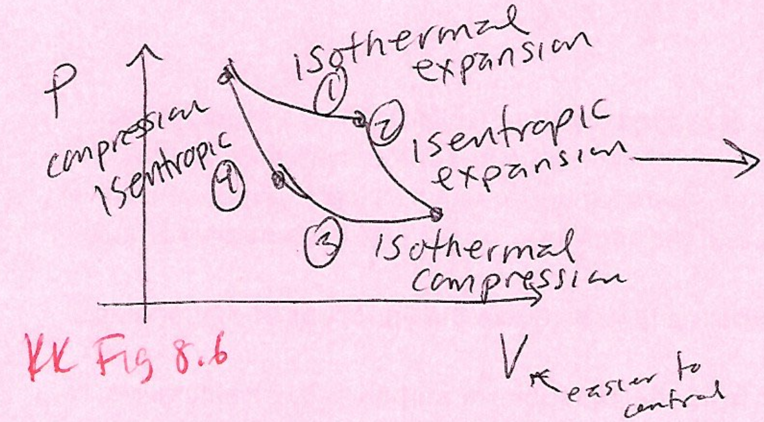
KK Eq. 8.13

How does an air conditioner work?

Fan pulls air in forcing it to exchange energy with water, high heat capacity, it deposits heat on the water, Cold air flushes in.

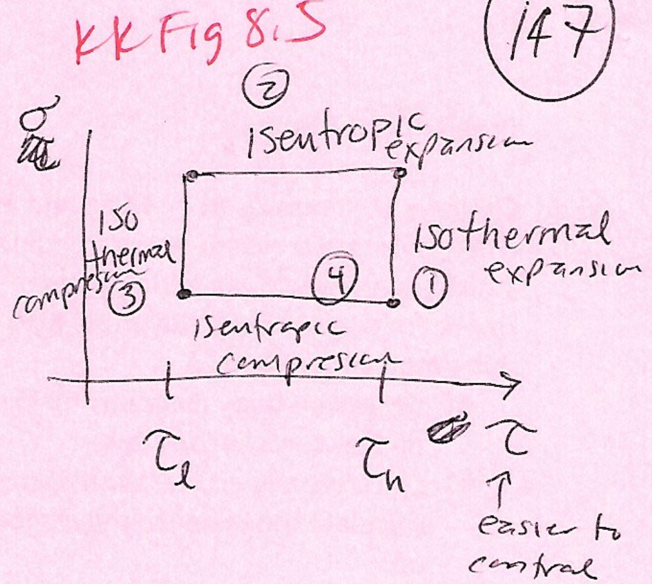
CONSIDER COLD AIR AND HOT AIR MOVING AT THE SAME SPEED - WHY IS ONE COLD AND THE OTHER HOT?

Carnot revisited:



KK Fig 8.6

KK Fig 8.5



Pressure and Volume are <u>conjugate</u> variables, one intensive, one extensive

These variables multiplied give you an energy

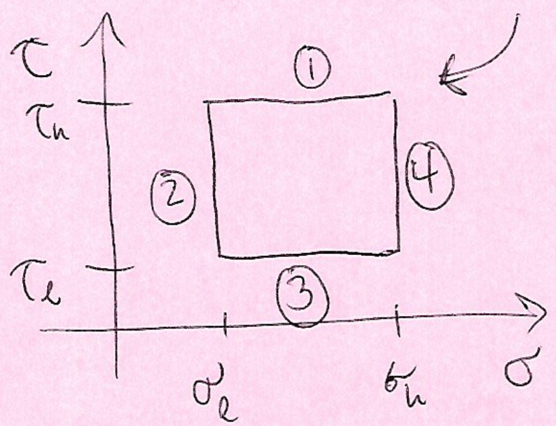
☆ $P = \frac{F}{A}$, $PV = \frac{F \cdot V}{A} = F \cdot x = W$ units of Joules

☆ $\tau\sigma = J \times \text{number} = \text{Joules}$

In conventional units, $T \cdot k_B = K \cdot J/K = \text{Joules}$

☆ $\mu N = J \times \text{number} = \text{Joules}$

$W = (\tau_h - \tau_l)(\sigma_h - \sigma_l)$



$$\oint dU = 0$$

$$W = \oint \tau \, d\sigma = \tau_h \Delta\sigma - \tau_l \Delta\sigma$$

$$= (\tau_h - \tau_l)\Delta\sigma$$

~~Remember isothermal: $PV = N\tau$ so, $W = \int P\,dV = \int \frac{N\tau}{V} dV = N\tau \ln\left(\frac{V_f}{V_i}\right)$~~

~~isentropic: $V\tau^{3/2}$ = constant so $PV^{5/3}$ = constant~~