

Toward Corruption

The progress of science is marked by the transformation of the qualitative into the quantitative. In this way not only do notions become turned into theories and lay themselves open to precise investigation, but the logical development of the notion becomes, in a sense, automated. Once a notion has been assembled mathematically, then its implications can be teased out in a rational, systematic way. Now, we have promised that this account of the Second Law will be nonmathematical, but that does not mean we cannot introduce a quantitative concept. Indeed, we have already met several, temperature and energy among them. Now is the time to do the same thing for spontaneity.

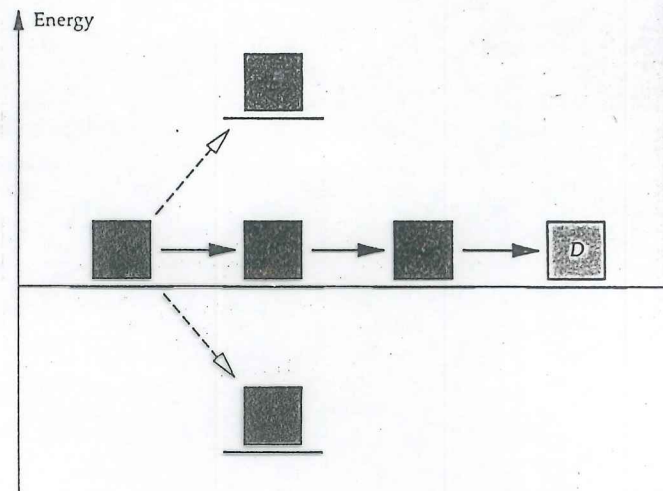
* The idea behind the next move can be described as follows. The Zeroth Law of thermodynamics refers to the thermal equilibrium between objects ("objects," the things at the center of our attention, are normally referred to as systems in thermodynamics, and we shall use that term from now on). Thermal equilibrium exists when system A is put in thermal contact with system B, but no net flow of energy occurs. In order to express this condition, we need to introduce the idea of the temperature of a system, which we define as meaning that if A and B happen to have the same temperature, then we know without further ado that they are in thermal equilibrium with each other. That is, the Zeroth Law gives us a reason to introduce a "new" property of a system, so that we can easily decide whether or not that system would be in thermal equilibrium with any other system if they were in contact.

* The First Law gives us a reason to carry out a similar procedure, but now one that leads to the idea of "energy." We may be interested in what states a system can reach if we heat it or do work on it. We can assess whether a particular state is accessible from the starting condition by introducing the concept of energy. If the new state differs in energy from the initial state by an amount that is different from the quantity of work or heating that we are doing, then we know at once, from the First Law, that that state cannot be reached: we have to do more or less work, or more or less heating, in order to bring the energy up to the appropriate value. The energy of a system is therefore a property we can use for deciding whether a particular state is accessible (see figure on next page).

This suggests that there may be a property of systems that could be introduced to accommodate what the Second Law is telling us. Such a property would tell us, essentially at a glance, not whether one state of the system is accessible from the other (that is the job of the energy acting through the First Law), but whether it is spontaneously accessible. That is, there ought to be a property that can act as the signpost of natural, sponta-



An isolated system may in principle change its state to any other of the same energy (the four colored boxes in the horizontal row), but the First Law forbids it to change to states of different energy (the brown-tinted boxes).



neous change, change that may occur without the need for our technology to intrude into the system in order to drive it.

* There is such a property. It is the entropy of the system, perhaps the most famous and awe-inspiring thermodynamic property of all. Awe-inspiring it may be: but the awe should not be misplaced. The awe for entropy should be reserved for its power, not for its difficulty. The fact that in everyday discourse "entropy" is a word far less common than "energy" admittedly makes it less familiar, but that does not mean that it stands for a more difficult concept. In fact, I shall argue (and in the next chapter hope to demonstrate) that the entropy of a system is a simpler property to grasp than its energy! The exposure of the simplicity of entropy, however, has to await our encounter with atoms. Entropy is difficult only when we remain on the surface of appearances, as we do now.

Entropy

We are now going to build a working definition of entropy, using the information we already have at our disposal. The First Law instructs us to think about the energy of a system that is free from all external influences; that is, the constancy of energy refers to the energy of an *isolated system*, a system into which we cannot penetrate with heat or with work, and which for brevity we shall refer to as the *universe* (see figure on facing page). Similarly, the entropy we define will also refer to an isolated system, which we shall call the universe. Such names reflect the hubris of thermodynamics: later we shall see to what extent the "universe" is truly the Universe.

TERMODINAMIKAREN BIGARREN PRINTZIPIOA

* 1. ZADIKO ASIMETRIA

6.1, 6.6

6.5

6.7

• Atkins

- LANA/BEROA ; BEROA/LANA TRANSFORMAZIO-MOTAK
- ZIKLOAK ETA MOTORE TERMIKOAK : MOTOREAK, HOSKAILUAK, PUNTAK, ETEKINAK, EFIZIENTZIAK
- BIGARREN PRINTZIPIOAREN ENUNTZIATUA
 - CLAUSIUS-EN ENUNTZIATUA
 - KELVIN/PLANCK-EN ENUNTZIATUA
- BIGARREN PRINTZIPIOAREKIN LOTURIK DAGOEN ALDAGAI TERMODINAMIKOA

} BALIOKIDETASUNA

7.1

* ITZULGARRITASUNA / ITZULEZINTASUNA

7.2

7.3

7.4

7.5

7.6

* BIGARREN PRINTZIPIOAREN ONDORIOAK

- 1 - 1. ZADIKO BEREZKO PROZESUAK ITZULEZINAK DIRA (ADIBIDEAK)
 - ITZULGARRITASUNERAKO BALDINTZAK
 - ONDORIOEKIN SEGITEKO BI METODO:

AXIOMATIKOA : CARATHÉODORY-REN ENUNTZIATUA

7.7

7.8

7.9

7.10, 7.11

8.1

8.2

8.3

8.4

2

3

4

5 (2')

- GAINAZAL ADIABATIKO ITZULGARRIEN EXISTENTZIA
- δQ -REN FAKTORE INTEGRATZAILA : ESANGURA FISIKOA
- KELVIN TEMPERATURA-ESKALA

KELVIN TEMPERATURA-ESKALA = GAS IDEALAREN

- ENTROPIA FUNTZIOAREN EXISTENTZIA

adibideak
kalkulua

TEKNIKOA : KELVIN, PLANCK-EN METODOA

8.5

8.6

4

5 (2')

- CARNOT-EN ZIKLOA
- CARNOT MOTOREAREN ETEKINAK : SISTEMAREKIKO MENPEKOTASUNIKETZ BALIOKIDETASUNA
- KELVIN TEMPERATURA-ESKALA
- CLAUSIUS-EN TEOREMA : ENTROPIA FUNTZIOAREN EXISTENTZIA

8.8

* ENTROPIA-FUNTZIOAREN PRINTZIPIOA

- BIGARREN PRINTZIPIOAREN FURMUZAZIO BERRIA

8.9

8.10

8.11 (2.p)

* LAN MAXIMOAREN TEOREMA

- ERABIL DAITEKEEN ENERGIA

+ C. 4. GAIA : 4.5 1-1
4.7 C2

4.1
4.2
4.3
4.4

IZADIKO ASIMETRIA (EXPERIENTZIAREN ARABERA)

(i) - LANA $\rightarrow$ BEROA TRANSFORMAZIO-MOTAK (EDOZEIN LAN-MOTA)

ADIBIDEA

EZAUGARRIAK : (1) - % 100

(2) - SISTEMAREN ESPERA ALDATU GABE

(3) - BEHIN ETA BERRIRO ("AD INFINITUM")

ALDIBEREAN

(ii) - BEROA $\rightarrow$ LANA TRANSFORMAZIO-MOTAK (EDOZEIN LAN-MOTA)

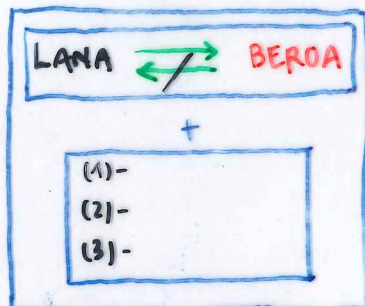
ADIBIDEA

EZAUGARRIAK : (1) - % 100

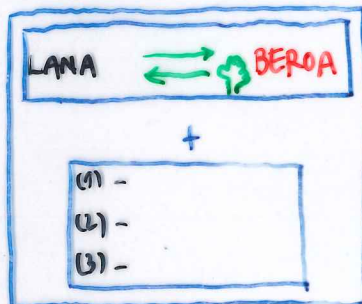
(2) - SISTEMAREN ESPERA ALDATU GABE

(3) - BEHIN ETA BERRIRO ("AD INFINITUM")

ERINEZKOR
ALDIBEREAN



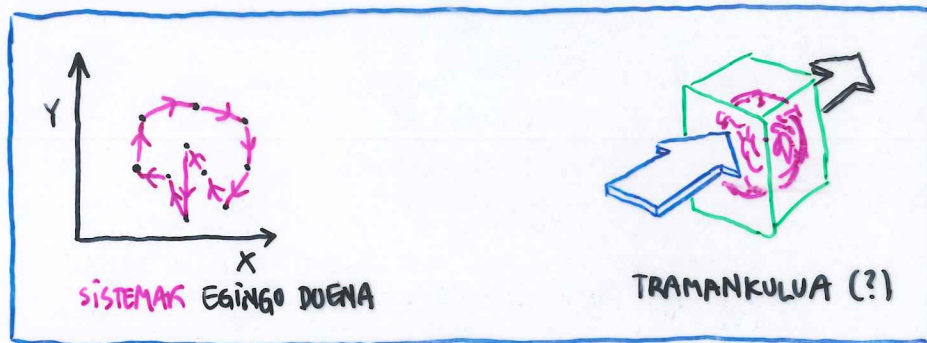
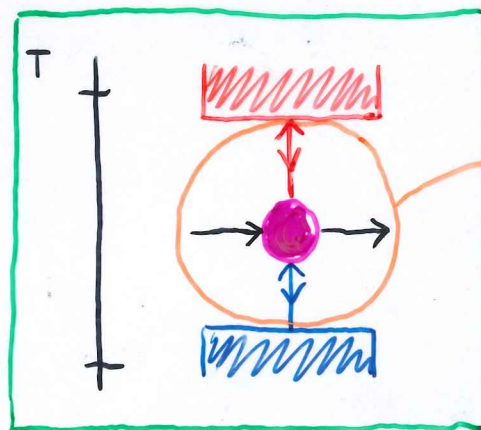
ASIMETRIA!!



SIMETRIA!!

$\hookrightarrow$ $\equiv$ INGURUNEAREKIN LOTU
(ALDIBEREAN HIRURAK LOTURAKO
MOTOREAK BEHAR DIRA)

ZIKLOAK ETA MAKINA TERMIKOAK

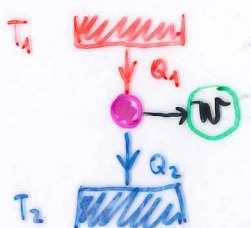


LEHENENGO PRINTEZIOA

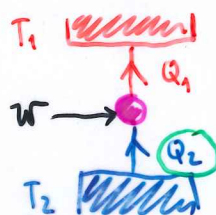
$$Q = \Delta U - W \quad \Delta U = 0$$

$$Q = -W$$

MOTORE TERMIKOA

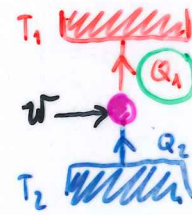


HOTZAILUA



$$|Q_1| - |Q_2| = |W|$$

BERO-PUNPA



$$\eta = \frac{|W|}{|Q_1|} = \frac{|Q_1| - |Q_2|}{|Q_1|} = 1 - \frac{|Q_2|}{|Q_1|}$$

$$\epsilon_h = \frac{|Q_1|}{|W|} = \frac{|Q_1|}{|Q_1| - |Q_2|} = \frac{1}{\frac{|Q_2|}{|Q_1|} - 1}$$

$$\epsilon_p = \frac{|Q_2|}{|W|} = \frac{|Q_2|}{|Q_1| - |Q_2|} = \frac{1}{1 - \frac{|Q_2|}{|Q_1|}}$$

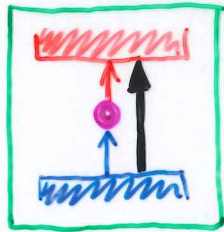
Adierazpena modu

$$\epsilon_p = \frac{|Q_2|}{|W|} = \frac{|Q_2|}{|Q_1| - |Q_2|}$$

TERMODINAMIKAREN BIGARREN PRINTZPIOAREN ENUNTZIATUAK

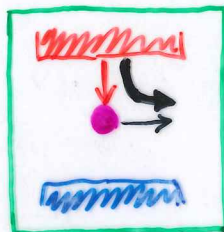
(1)- CLAUSIUS-EN ENUNTZIATUA (DENOK EZAGUTU DUGUNA)

EZ DAGO PROZESURIK ZEINAREN **ONDORIO BAKARRA*** GORPUTZ HOTZETIK GORPUTZ BERURAKO BERO-TRANSFERENTZIA DEN



(2)- KELVIN/PLANCK-EN ENUNTZIATUA (MOTOREAK BEHAR DIRA)

EZ DAGO PROZESURIK ZEINAREN **ONDORIO BAKARRA*** GORPUTZ BEROTIK HARTUTAKO BERO GUZTIA LAN BIHURTZEAREN DEN



ASIMETRIA BERAREN BI (BADAHO GERTAGORRIK) AURPEGIAK
BADAHO BESTE ENUNTZIATURIK

* "... BESTE INOLAKO ERAGINIK GABE."

"... BESTE SISTEMAREN BATEAN ERAGINIK IZAN GABE."

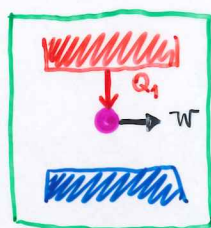
"... ESKUARTU GABE."

BIGARREN PRINTZPIOAREKIN LOTURIK DAGOEN ALDAGAI TERMODINAMIKOA: ENTROPIA

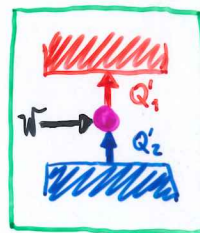
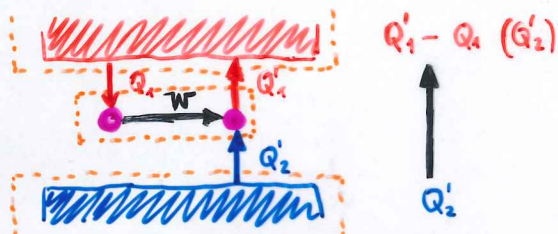
S

ENUNTZIATUEN ARTEKO BALIOKIDETASUNA : $C \Leftrightarrow K/P$

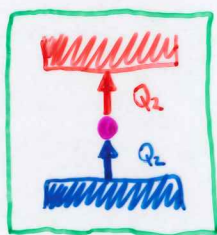
(i) $(C \Rightarrow K/P) \Rightarrow \boxed{Ez K/P \Rightarrow Ez C}$



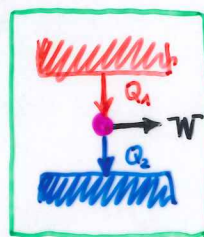
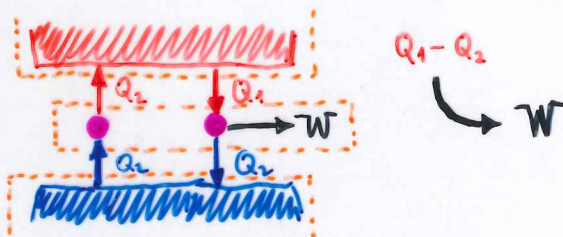
+



(ii) $(K/P \Rightarrow C) \Rightarrow \boxed{Ez C \Rightarrow Ez K/P}$

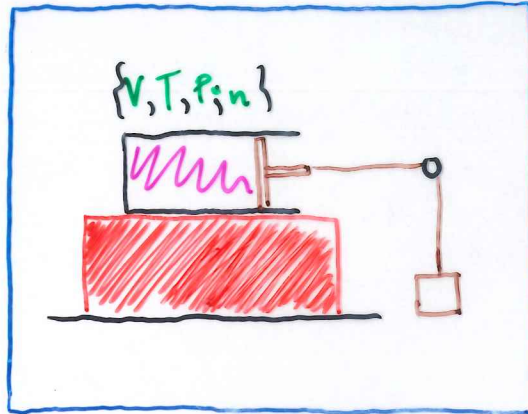


+



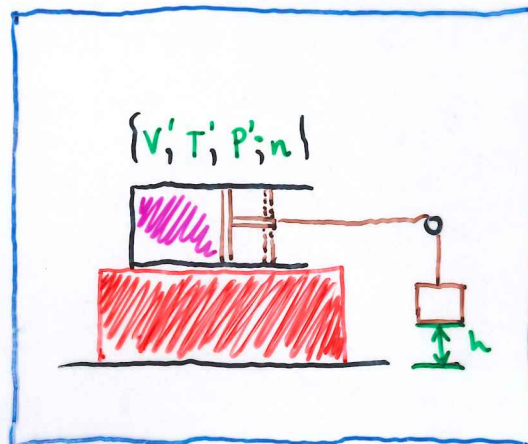
ITZULGARITASUNA/ ITZULEZINTASUNA

(i)



HASIERAKO OREKA-EGOKIA

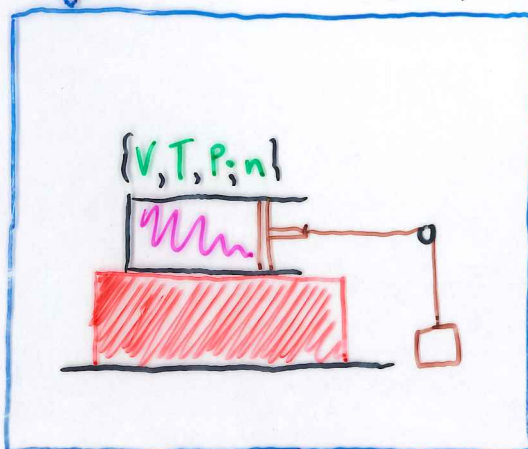
(f)



BUKARA KO OREKA-EGOKIA

SISTEMAK : ENERGIA
BERO-ITURRIAK : BEROA
LAN-FOKOAK : LANA

(i)



BESTE INOLAKO
ERAGINIK IRAN GABE!!

KONEXIOK GABE!!

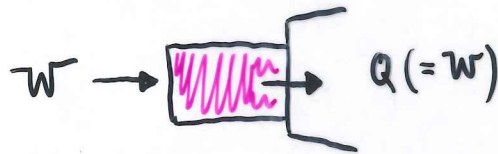
?? GABE!!

$-\Delta U, -Q, -W$

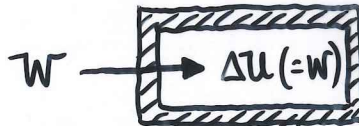
$\Delta U, Q, W$

BIGARREN PRINTZÍPIOAREN ONDORIOAK :

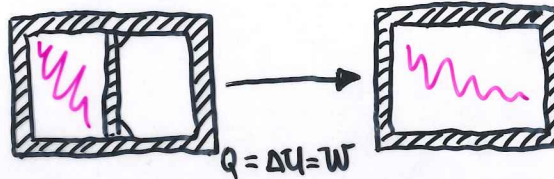
(1) - IZADIKO **BEREZKO** PROZESUAK ("PROZESU ESPONTANEOAK") ITZULEZINAK DIRA.



BERO-TITARRIAREN BARNE-ENERGIA



SISTEMAREN BARNE-ENERGIA



ESPANTATIA ASKEA



BERO-KONDUKZIOA

ITZUGARRITASUNERAKO * BALDINTZAK :

- (a) EZ DAGO OREKA TERMODINAMIKORIK
- (b) ENERGIA - BARREIAPENA (DISIPAZIOA)

PROZESU ITZUGARRIA

$\Leftrightarrow$

{ KUASIESTATIKOA
BARREIAPENIK GABEKOA

METODO AXIOMATIKOA

CARATHEODORY-REN ENUNTZIATUA

EDOZEIN SISTEMAREN, EDOZEIN OREKA-EGOKERAREN INGURUAN,
PROZESU ADIABATIKO ITZULGARRIEN BIDEZ LOTU EZIN DIREN
OREKA-EGOKERAK DAUDE


EZ (ADIABATIKO ITZULGARRI)

(2) - GAINAZAL ADIABATIKO ITZULGARRIEN EXISTENTZIA : (GAIEN EXISTENTZIA)

(i) - OSAGAIA BAKARRERAKO SISTEMA :

$$\{t, Y, X\} \Rightarrow f(t, Y, X) = 0 \Rightarrow Y = Y(t, X)$$

$$\delta Q = dU - \delta W$$
$$\delta W = Y dX$$

$$\delta Q = dU - Y dX$$
$$dU = \left(\frac{\partial U}{\partial t}\right)_X dt + \left(\frac{\partial U}{\partial X}\right)_t dX$$

$$\delta Q = \left(\frac{\partial U}{\partial t}\right)_X dt + \left[\left(\frac{\partial U}{\partial X}\right)_t - Y\right] dX$$

$$\delta Q = 0$$

$$\left(\frac{\partial U}{\partial t}\right)_X dt + \left[\left(\frac{\partial U}{\partial X}\right)_t - Y\right] dX = 0$$

$$\left(\frac{\partial U}{\partial t}\right)_X dt = \left[Y - \left(\frac{\partial U}{\partial X}\right)_t\right] dX$$

$$\left[\frac{dt}{dX}\right] = \left[\frac{Y - \left(\frac{\partial U}{\partial X}\right)_t}{\left(\frac{\partial U}{\partial t}\right)_X}\right]$$

$$\sigma = \sigma(t, X) = Kt$$

inorkin :

lehenguz printzipiaren
adierazpena prozesu
itzulgarriaren kasuan.
eta anuekoetan ?

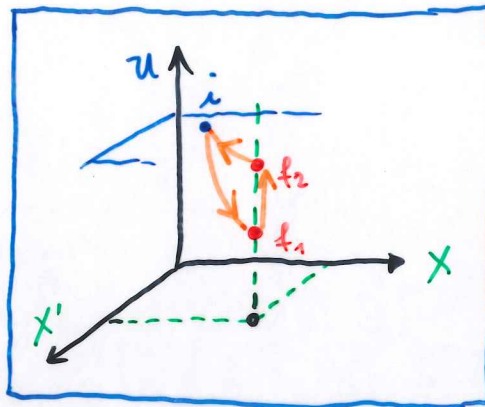
(ii) ALDAGAI ANITZEKO SISTEMA :

$$\{t, Y, X, Y', X'\} \rightarrow f(t, Y, X) = 0 \Rightarrow Y = Y(t, X)$$

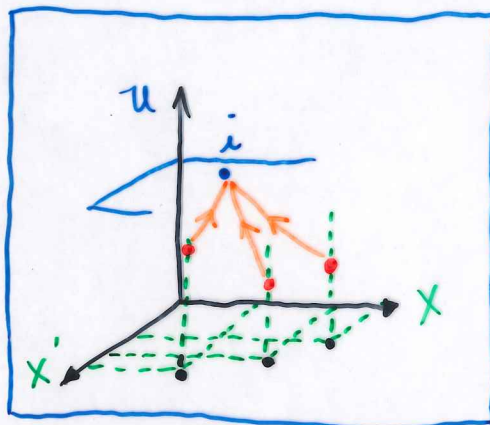
$$f'(t, Y', X') = 0 \Rightarrow Y' = Y'(t, X')$$

$$t = t(u, X, X', Y, Y')$$

$$\delta Q = dU - Y dX - Y' dX'$$



EZINEZKOA !!!



$$\sigma = \sigma(t, X, X') = Kt$$

$$\sigma = \sigma(t, X, X')$$

GAINAZAL ADIABATIKO ITZULGARRIA

(3) δQ - REN FAKTORE INTEGRATEAILEA (2. INDORIOAREN ONDORIOA)

$$\delta Q = dU - Ydx - Y'dx' \quad \left\{ \begin{array}{l} u = u(t, x, x') \\ Y = Y(t, x, x') \\ Y' = Y'(t, x, x') \end{array} \right\}$$

$$\sigma = \sigma(t, x, x') \Rightarrow t = t(\sigma, x, x')$$

$$\delta Q = \left(\frac{\partial u}{\partial \sigma} \right)_{x, x'} d\sigma + \left[\left(\frac{\partial u}{\partial x} \right)_{\sigma, x'} - Y \right] dx + \left[\left(\frac{\partial u}{\partial x'} \right)_{\sigma, x} - Y' \right] dx'$$

$$(i) \quad d\sigma = dx = 0 \\ dx' \neq 0$$

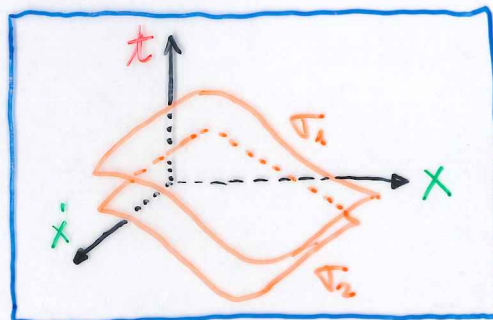
$$(ii) \quad d\sigma = dx' = 0 \\ dx \neq 0$$

$$\delta Q = \left(\frac{\partial u}{\partial \sigma} \right)_{x, x'} d\sigma$$

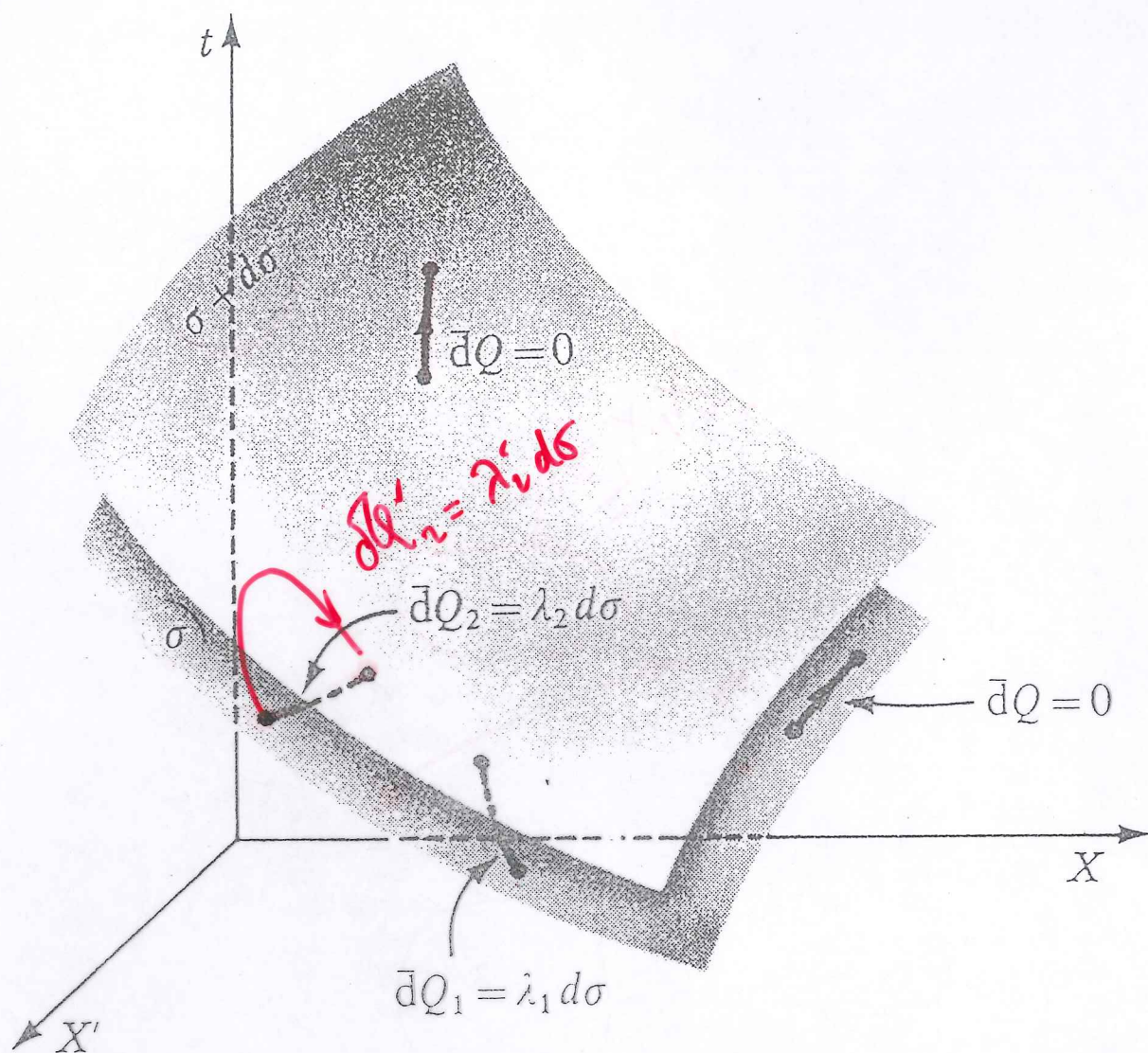
$$\lambda \equiv \left(\frac{\partial u}{\partial \sigma} \right)_{x, x'}$$

$$\delta Q = \lambda d\sigma$$

$$\lambda = \lambda(\sigma, x, x')$$



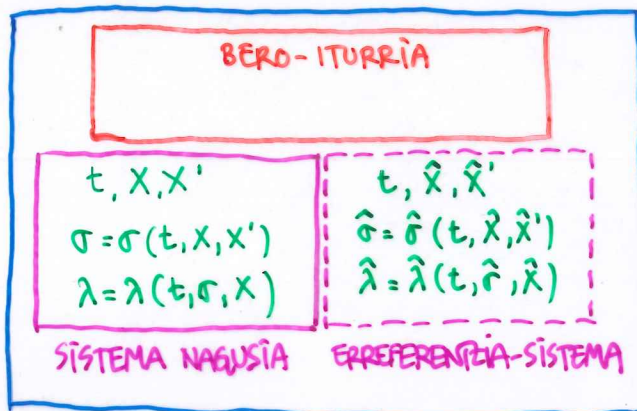
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FAKTORE INTEGRATZAILEAREN ESANGURA FISIKOA

ALDAGAI INDEPENDENTEAK
GAINAZAL ADIABATIKO ITZ.
FAKTORE INTEGRATZAILEA



SISTEMA KONPOSATUA

$$(t, X, X', \hat{X}, \hat{X}') \rightarrow \{t, \sigma, X, \hat{\sigma}, \hat{X}\}$$

$$\bar{\sigma} = \bar{\sigma}(t, \sigma, X, \hat{\sigma}, \hat{X})$$

$$\bar{\lambda} = \bar{\lambda}(t, \sigma, X, \hat{\sigma}, \hat{X})$$

$$\delta \bar{Q} = \delta Q + \delta \hat{Q}$$

$$\bar{\lambda} d\bar{\sigma} = \lambda d\sigma + \hat{\lambda} d\hat{\sigma}$$

$$d\bar{\sigma} = \frac{\lambda}{\bar{\lambda}} d\sigma + \frac{\hat{\lambda}}{\bar{\lambda}} d\hat{\sigma}$$

$$\bar{\sigma} \rightarrow \bar{\sigma} + d\bar{\sigma}$$

$$d\bar{\sigma} = \left(\frac{\partial \bar{\sigma}}{\partial t}\right)_{\sigma, X, \hat{\sigma}, \hat{X}} dt + \left(\frac{\partial \bar{\sigma}}{\partial \sigma}\right)_{t, X, \hat{\sigma}, \hat{X}} d\sigma + \left(\frac{\partial \bar{\sigma}}{\partial X}\right)_{t, \sigma, \hat{\sigma}, \hat{X}} dX + \left(\frac{\partial \bar{\sigma}}{\partial \hat{\sigma}}\right)_{t, X, \sigma, \hat{X}} d\hat{\sigma} + \left(\frac{\partial \bar{\sigma}}{\partial \hat{X}}\right)_{t, \sigma, X, \hat{\sigma}} d\hat{X}$$

$$\delta Q = \lambda d\sigma \Rightarrow \delta Q = \phi(t) f(\sigma) d\sigma$$

- FAKTORE INTEGRATZAILEA (SISTEMA)
- TEMPERATURAREN FUNTzioA SOILIK
- FUNTzio UNIBERTSALA

(1)

$$\delta \bar{Q} = \delta Q + \delta \hat{Q}$$

$$\delta Q = \lambda d\sigma$$

adiversionen overkomme

$$\bar{\lambda} d\bar{\sigma} = \delta \bar{Q} = \lambda d\sigma + \hat{\lambda} d\hat{\sigma}$$

$$d\bar{\sigma} = \frac{\lambda}{\bar{\lambda}} d\sigma + \frac{\hat{\lambda}}{\bar{\lambda}} d\hat{\sigma}$$

$$\Rightarrow \bar{\sigma} = \bar{\sigma}(\sigma, \hat{\sigma}) \Rightarrow d\bar{\sigma} = \left(\frac{\partial \bar{\sigma}}{\partial \sigma}\right)_{\hat{\sigma}} d\sigma + \left(\frac{\partial \bar{\sigma}}{\partial \hat{\sigma}}\right)_{\sigma} d\hat{\sigma} \Rightarrow \left\{ \begin{array}{l} \left(\frac{\partial \bar{\sigma}}{\partial \sigma}\right)_{\hat{\sigma}} = \frac{\lambda}{\bar{\lambda}} \\ \left(\frac{\partial \bar{\sigma}}{\partial \hat{\sigma}}\right)_{\sigma} = \frac{\hat{\lambda}}{\bar{\lambda}} \end{array} \right\} = \left. \begin{array}{l} = g_1(\sigma, \hat{\sigma}) \\ = g_2(\sigma, \hat{\sigma}) \end{array} \right\}$$

(2)

$$\bar{\sigma} = \bar{\sigma}(t, \sigma, \hat{\sigma}, x, \hat{x})$$

$$d\bar{\sigma} = \left(\frac{\partial \bar{\sigma}}{\partial t}\right)_{\sigma, \hat{\sigma}, x, \hat{x}} dt + \left(\frac{\partial \bar{\sigma}}{\partial \sigma}\right)_{t, \hat{\sigma}, x, \hat{x}} d\sigma + \left(\frac{\partial \bar{\sigma}}{\partial \hat{\sigma}}\right)_{t, \sigma, x, \hat{x}} d\hat{\sigma} + \left(\frac{\partial \bar{\sigma}}{\partial x}\right)_{t, \sigma, \hat{\sigma}, \hat{x}} dx + \left(\frac{\partial \bar{\sigma}}{\partial \hat{x}}\right)_{t, \sigma, \hat{\sigma}, x} d\hat{x}$$

haverik alderafu

ondurisa

$$\left(\frac{\partial \bar{\sigma}}{\partial t}\right)_{\sigma, \hat{\sigma}, x, \hat{x}} = \left(\frac{\partial \bar{\sigma}}{\partial x}\right)_{t, \sigma, \hat{\sigma}, \hat{x}} = \left(\frac{\partial \bar{\sigma}}{\partial \hat{x}}\right)_{t, \sigma, \hat{\sigma}, x} = 0$$

$$d\bar{\sigma} = \left(\frac{\partial \bar{\sigma}}{\partial \sigma}\right)_{t, \hat{\sigma}, x, \hat{x}} d\sigma + \left(\frac{\partial \bar{\sigma}}{\partial \hat{\sigma}}\right)_{t, \sigma, x, \hat{x}} d\hat{\sigma} \Rightarrow \left(\frac{\partial \bar{\sigma}}{\partial \sigma}\right)_{t, \hat{\sigma}, x, \hat{x}} = f_1(t, \sigma, \hat{\sigma}, x, \hat{x}) ; \left(\frac{\partial \bar{\sigma}}{\partial \hat{\sigma}}\right)_{t, \sigma, x, \hat{x}} = f_2(t, \sigma, \hat{\sigma}, x, \hat{x})$$

haverik dua alderafu ka
ditiyammak
mendikis tasawuk
etapufuta

$$\left. \begin{array}{l} \bar{\lambda} = \bar{\lambda}(t, \sigma, \hat{\sigma}, x, \hat{x}) \\ \lambda = \lambda(t, \sigma, x) \\ \hat{\lambda} = \hat{\lambda}(t, \hat{\sigma}, \hat{x}) \end{array} \right\}$$

$$\frac{\lambda}{\bar{\lambda}} = \frac{\lambda(t, \sigma, x)}{\bar{\lambda}(t, \sigma, \hat{\sigma}, x, \hat{x})} = g_1(\sigma, \hat{\sigma})$$

$$\frac{\hat{\lambda}}{\bar{\lambda}} = \frac{\hat{\lambda}(t, \hat{\sigma}, \hat{x})}{\bar{\lambda}(t, \sigma, \hat{\sigma}, x, \hat{x})} = g_2(\sigma, \hat{\sigma})$$

$$\bar{\lambda}(t, \sigma, \hat{\sigma}, x, \hat{x}) \rightarrow \bar{\lambda}(t, \sigma, \hat{\sigma}, x) \text{ ①}$$

$$\begin{array}{l} \bar{\lambda}(t, \sigma, \hat{\sigma}, x) \rightarrow \bar{\lambda}(t, \sigma, \hat{\sigma}) \text{ ②} \\ \hat{\lambda}(t, \hat{\sigma}, \hat{x}) \rightarrow \hat{\lambda}(t, \hat{\sigma}) \text{ ③} \end{array}$$

alderafu ondurisa

$$\lambda(t, \sigma, x) \rightarrow \lambda(t, \sigma) \text{ ④}$$

$$\frac{\lambda}{\bar{\lambda}} = \frac{\lambda(t, \sigma)}{\bar{\lambda}(t, \sigma, \hat{\sigma})} = g_1(\sigma, \hat{\sigma})$$

$$\frac{\hat{\lambda}}{\bar{\lambda}} = \frac{\hat{\lambda}(t, \hat{\sigma})}{\bar{\lambda}(t, \sigma, \hat{\sigma})} = g_2(\sigma, \hat{\sigma})$$

$$\lambda(t, \sigma) = \phi(t) f_1(\sigma)$$

$$\bar{\lambda}(t, \sigma, \hat{\sigma}) = \phi(t) f_1(\sigma, \hat{\sigma})$$

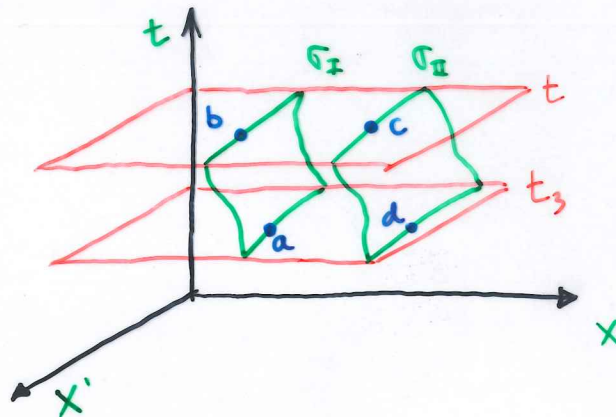
$$\hat{\lambda}(t, \hat{\sigma}) = \phi(t) f_2(\hat{\sigma})$$

$$\bar{\lambda}(t, \sigma, \hat{\sigma}) = \phi(t) f_1(\sigma, \hat{\sigma})$$

regitu...

(4) - KELVIN TEMPERATURA - ESKALA

SISTEMA $\{t, X, X'\}$ (SISTEMA EDOZEIN (ZAN DAITEKE))



$$Q = \phi(t) \int_{\sigma_I}^{\sigma_{II}} f(\sigma) d\sigma$$

$$\frac{Q}{Q_3} = \frac{\phi(t)}{\phi(t_3)} = \frac{Q \text{ TRANSFERITU DEN } t \text{ TEMPERATURAREN FUNTIOA}}{Q_3 \text{ TRANSFERITU DEN } t_3 \text{ TEMPERATURAREN FUNTIOA BERBERA}}$$

↓
EZ DAGO SISTEMA (SISTEMAREN ERAGARRIRIK) $\Rightarrow \phi(t) \propto T \Rightarrow$ TEMPERATURA ABSOLUTUA

$$\frac{Q(\{\sigma_I \rightarrow \sigma_{II}\}, T)}{Q_3(\{\sigma_I \rightarrow \sigma_{II}\}, T_3)} = \frac{T}{T_3}$$

$$T = 273.16 \left[\frac{Q}{Q_{PH}} \right] K$$

ZERO ABSOLUTUA... ?

KELVIN TEMPERATURA - ESKALA $\iff$ GAS IDEALAREN TEMPERATURA - ESKALA

↓ KELVIN TEMPERATURA
GAS-TERMOMETROA ERABILITZ NEURQU

(5) ENTROPIA FUNTzioAREN EXISTENTZIA

$$\delta Q = \lambda d\sigma$$

$$\lambda = \phi(t) f(\sigma)$$

$$\delta Q = \phi(t) f(\sigma) d\sigma$$

$$\frac{Q'}{Q} = \frac{T'}{T} \rightsquigarrow \frac{\delta Q'}{\delta Q} = \frac{T'}{T} \rightsquigarrow T = k \phi(t)$$

$$\frac{\delta Q}{T} = \frac{1}{k} f(\sigma) d\sigma$$

$$dS = \frac{\delta Q_{1g}}{T}$$

FISIKOKI ZER DEN
ZER EQIN BEHAR DEN

$$S_f - S_i = \int_i^f \frac{\delta Q_{1g}}{T}$$

$$\oint_{1g} \frac{\delta Q}{T} = 0$$

CLAUSIUS-EN TEOREMA

LABURBILDUMA

$$\delta Q = dU - \delta W$$

LEHENENGO PRINTZÍPIOA PROZESU IRIBERGARIAN

$$(\delta Q)_{ig} = (dU - \delta W)_{ig}$$

ALDAGAI TERMODINAMIKOEN FUNTzioAN

$$\frac{(\delta Q)_{ig}}{T}$$

ZATIKETA

$$\int [ds = \frac{(\delta Q)_{ig}}{T}]$$

INTEGRATzioA

FORMULAZIOZ ALDATZEAN, METODOA BESTE BAT IZANGO DA.

ADIBIDEA : GAS IDEALARI DAGOKION ENTROPIA

$$dS = \frac{\delta Q_{ig}}{dT}$$

$$(i) (a) \Delta S = \int \frac{\delta Q_{ig}}{T} = \int \frac{1}{T} [C_p dT - V dp] = \int \frac{C_p}{T} dT - \int \frac{V}{T} dp$$

$$\Delta S \equiv S - S_r = C_p \ln \frac{T}{T_r} - nR \ln \frac{P}{P_r}$$

$$S = C_p \ln T - nR \ln P + \{S_r - C_p \ln T_r + nR \ln P_r\}$$

$$S = C_p \ln T - nR \ln P + S_0$$

$$(b) dS = \frac{1}{T} C_p dT - \frac{1}{P} nR dp \leadsto$$

$$S = \int \frac{C_p}{T} dT - nR \ln P + S_0$$

$$(ii) (a) \Delta S = \int \frac{\delta Q_{ig}}{T} = \int \frac{1}{T} [C_v dT + P dV] = \int \frac{C_v}{T} dT + \int \frac{P}{T} dV$$

$$\Delta S \equiv S - S_r = C_v \ln \frac{T}{T_r} + nR \ln \frac{V}{V_r}$$

$$S = C_v \ln T + nR \ln V + \{S_r + C_v \ln T_r + nR \ln V_r\}$$

$$S = C_v \ln T + nR \ln V + S_0$$

$$(b) dS = \frac{1}{T} C_v dT + \frac{1}{V} nR dV \leadsto$$

$$S = \int \frac{C_v}{T} dT + nR \ln V + S_0$$

$$\left. \begin{aligned} dS &= \frac{\delta Q_{16}}{T} \\ \delta Q_{16} &= dU - \delta W \end{aligned} \right\} ds = \frac{dU - \delta W}{T}$$

aniketa $\rightarrow$

- aldagaiak (T, p) ; (T, V) ; (p, V) sistema hidentafikazaren kasuan, itxia (2 arkatasmu-gradu)
 (T, X) ; (T, Y) ; (Y, X) beste edozein sistemaren kasuan (2 arkatasmu-gradu)

- materia haurerako } aldagai independenteen sata aukeratu
 amaietarako }

- sistema berrak informazioa:

- egoera-erakusketak : - termikoa
 - mekanikoa (besten)

- koefiziente esperimentalak :- $(C_p, C_v, \alpha, \kappa_T)$

- denak eta ditz independenteak : $C_p - C_v = \frac{TV\alpha^2}{\kappa_T}$

- (T, V)	$\delta Q = C_v dT + \frac{C_p - C_v}{V\alpha} dV$	$\Rightarrow$	$dS = \frac{\delta Q}{T} = \frac{C_v}{T} dT + \frac{C_p - C_v}{TV\alpha} dV$	$\Rightarrow S = S(T, V) \Rightarrow$	$\begin{cases} \left(\frac{\partial S}{\partial T}\right)_V = \frac{C_v}{T} \\ \left(\frac{\partial S}{\partial V}\right)_T = \frac{C_p - C_v}{TV\alpha} \end{cases}$
- (p, V)	$\delta Q = \frac{C_p}{V\alpha} dV + \frac{\kappa_T}{\alpha} C_v dp$	$\Rightarrow$	$dS = \frac{\delta Q}{T} = \frac{C_p}{TV\alpha} dV + \frac{\kappa_T}{\alpha} \frac{C_v}{T} dp$	$\Rightarrow S = S(V, p) \Rightarrow$	$\begin{cases} \left(\frac{\partial S}{\partial V}\right)_p = \frac{C_p}{TV\alpha} \\ \left(\frac{\partial S}{\partial p}\right)_V = \frac{\kappa_T C_v}{\alpha T} \end{cases}$
- (p, T)	$\delta Q = C_p dT + \frac{\kappa_T}{\alpha} (C_v - C_p) dp$	$\Rightarrow$	$dS = \frac{\delta Q}{T} = \frac{C_p}{T} dT + \frac{\kappa_T}{T\alpha} (C_v - C_p) dp$	$\Rightarrow S = S(T, p) \Rightarrow$	$\begin{cases} \left(\frac{\partial S}{\partial T}\right)_p = \frac{C_p}{T} \\ \left(\frac{\partial S}{\partial p}\right)_T = \frac{\kappa_T}{\alpha T} (C_v - C_p) \end{cases}$

* Gaurko ikolatu emari behar du

* atzeratzea

$$\delta Q = dU - \delta W$$

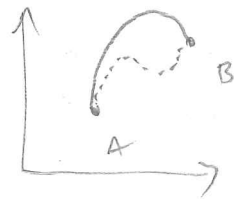
Lehenengo printzipioaren adierazpena bota prozesu itzulgarria kanon

$$(\delta Q)_{1g} = \left(\frac{\delta Q_{1g}}{T} \right)_{1g} \rightarrow \text{aldeari termodinamika menpe}$$

$$\frac{\delta Q_{1g}}{T} \rightarrow \text{temperatura erabiltzen dugu}$$

$$\left(\frac{\delta Q_{1g}}{T} \right) \rightarrow \text{integratze berriz}$$

* erabiltzen prozesuak dS baina kontatu modua: prozesu itzulgarria zehar



ΔS_{AB} funtzioa

ΔS_{AB} kontatu = prozesu itzulgarria erabiltzen dugu konstante berriz

$$dS = \frac{\delta Q_{1g}}{T}$$

$\frac{\delta Q}{T} = ?$ baina atzeratzea dS

Itzulgarria $dS = \frac{\delta Q_{1g}}{T} \Rightarrow dS = 0$ $S = kT$

adibidez $\delta Q_{1g} = 0$

$$C_v = T \left(\frac{\partial S}{\partial T} \right)_V \rightarrow \text{Lehenengo printzipioaren abiaketa}$$

$$\delta Q = dU - \delta W$$

$$C_p = T \left(\frac{\partial S}{\partial T} \right)_P$$

$$T dS = dU - \delta W$$

$$dS = \frac{1}{T} [dU - \delta W]$$

$$S = S(T, V) \Rightarrow \left[dS = \left(\frac{\partial S}{\partial T} \right)_V dT + \left(\frac{\partial S}{\partial V} \right)_T dV \right] T \Big|_P$$

$$S = S(T, P) \Rightarrow$$

$$dS = \frac{1}{T} [dU - Y dX]$$

Lehenengo printzipioa modura eta erabiltzen dugu: prozesu itzulgarria erabiltzen dugu

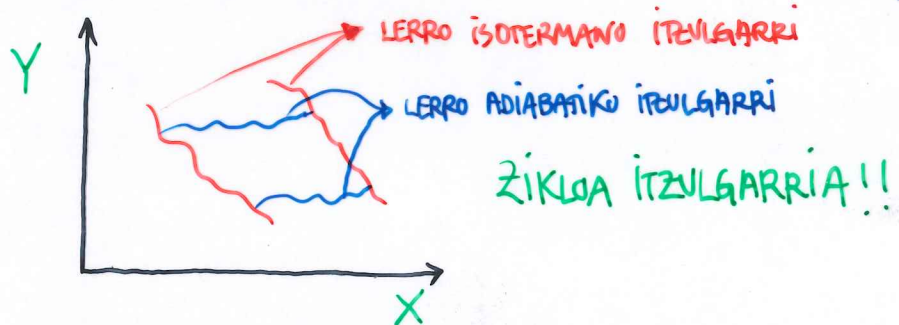
METODO TEKNIKOA

* CARNOT-EN ZIKLOA:

BI LERRO ISOTERMANO ITZULGARRIZ
 BI LERRO ADIABATIKO ITZULGARRIZ } OSATURIKO ZIKLOA
 EDOZEIN SISTEMAREN KASUAN

$$S = S(Y, X)$$

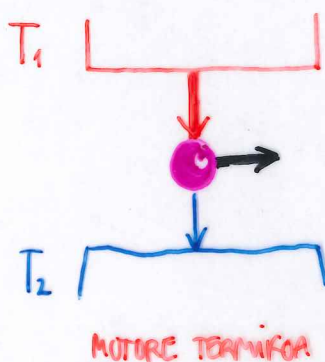
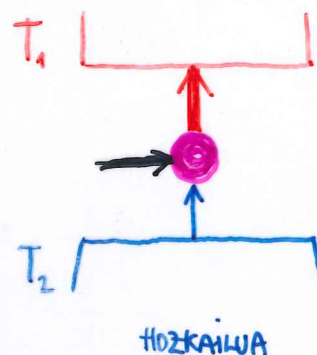
SISTEMA



DEFINIZIOAREN ONDORIOZ:

ZURGATUTAKO BEROA, GOI-TENPERATURAN DAGEN BERO-ITURRITIK
 KANPORANTAKO BEROA, BEHE-TENPERATURAN DAGEN BERO-ITURRIRA }
 BI BERO-ITURRI BAINO EZ DAGO

* CARNOT-EN MOTOREA ETA HOZKAILUA

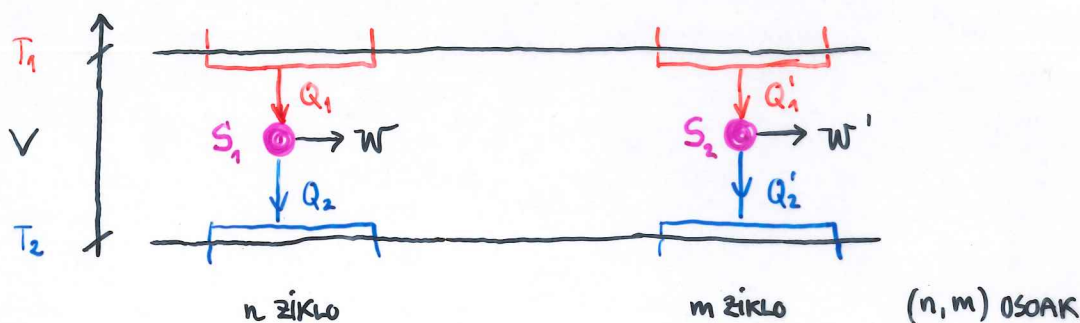


* CARNOT-EN ZIKLOAREN ADIERAZPIDE GRAFIKOA T/S DIAGRAMAN

+ ETEKINAREN ADIERAZPENA

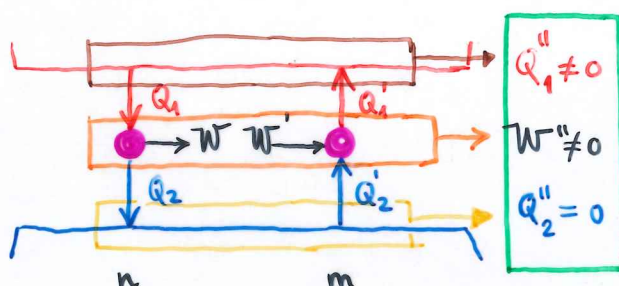
(1) - CARNOT-EN MOTOREAREN ETEKINAK EZ DAUKA SISTEMAREKIKO MENPEKOTASUNIK

$\left[\left(-\frac{Q_2}{Q_1} \right) \right]$ ADIERAZPENAK BALIO KONSTANTEA DAUKA (T_1, T_2) BIKOTEA FINKATUZ GERO



$$n|Q_2| = m|Q'_2| \quad \left\{ nQ_2 + mQ'_2 = 0 \right\} \quad \text{HAUXE DA EGİN DUGUN AUKERA}$$

- MIHIZTATUKO DITUGU, (n, m) ZIKLO BAKARRA, KONTRAKO ZEINUAREKIN



ZIKLO BAKAR OSOARI LEHENENGU PRINTZIPIOA APLIKATUKO DUGU:

$$nQ_1 + mQ'_1 = \Delta U - W'' \quad \Delta U = 0 \text{ ZIKLOA BAITA}$$

$$nQ_1 + mQ'_1 = -W''$$

$$nQ_1 + mQ'_1 > 0 \quad \text{EZINEZKOA !!} \quad 2. \text{PRINTZIPIOAREN AURKA}$$

$$nQ_1 + mQ'_1 \leq 0$$

ZIKLOA ALDERANETUZ GERO: ITZULGARRIA BAITA ...

$$nQ_1 + mQ'_1 \geq 0$$

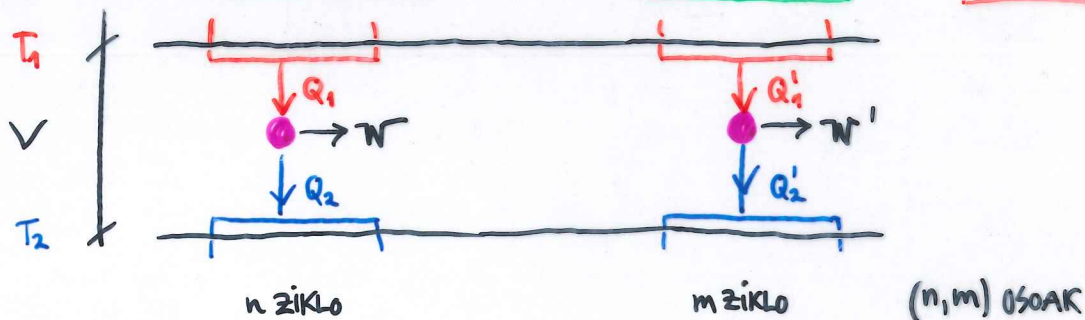
$$nQ_1 + mQ'_1 = 0$$

$$nQ_2 + mQ'_2 = 0 \text{ HIPOTESIS}$$

$$\frac{Q_2}{Q_1} = \frac{Q'_2}{Q'_1}$$

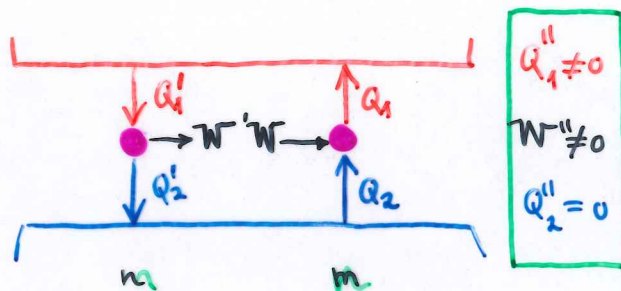
(2) - CARNOT-EN MOTOREAK FINKATURIKO TEMPERATUREN ARTEKO ETEKIN MAXIMOA

$$\eta = \frac{|W|}{|Q_1|} = \frac{|Q_1| - |Q_2|}{|Q_1|} \Rightarrow \boxed{\eta_C = 1 - \frac{|Q_2|}{|Q_1|}} > \boxed{\eta^* = 1 - \frac{|Q_2'|}{|Q_1'|}} \Rightarrow \boxed{\frac{|Q_2|}{|Q_1|} \leq \frac{|Q_2'|}{|Q_1'|}}$$



$$n |Q_2| = m |Q_2'| \quad \left\{ n Q_2 + m Q_2' = 0 \right\} \quad \text{HAUKE DA EGIN DUGUN AUKERA}$$

- MITIIZTATUKO DITUQU, (n, m) ZIKLO BAKARRA, CARNOT-EN MOTOREARI BUELTA



ZIKLO BAKAR OSOARI LEHENENGO PRINTZÍPIOA APLIKATUKO DITUQU:

$$n Q_1 + m Q_1' = \Delta U - W'' \quad \Delta U = 0 \text{ zikloa baita}$$

$$n_1 Q_1 + m Q_1' = -W''$$

$$n_1 Q_1 + m Q_1' > 0$$

EZINEZKOA !! 2. PRINTZÍPIOAREN KO.

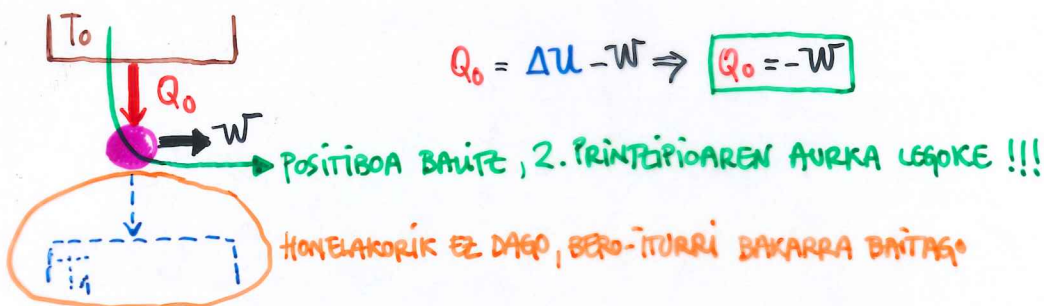
$$\boxed{n_1 Q_1 + m Q_1' \leq 0}$$

$$\left. \begin{aligned} -n |Q_2'| &= -m |Q_2| \Rightarrow n |Q_2'| = m |Q_2| \\ n |Q_1'| &\leq m |Q_1| \Rightarrow n |Q_1'| \leq m |Q_1| \end{aligned} \right\} \boxed{\frac{|Q_2|}{|Q_1|} \leq \frac{|Q_2'|}{|Q_1'|}}$$

(= CARNOT-EN KASUA)

$$\int \delta q_0 = T_0 \int \frac{\delta q}{T}$$

BERO-ITURRIAREN KIN SISTEMAK TRUKATU DUEN BERO-KANTITATEA, EFEKTIBOA



$$Q_0 = \Delta U - W \Rightarrow Q_0 = -W$$

$$T_0 \int \frac{\delta q}{T} \leq 0$$

$$\int \frac{\delta q}{T} \leq 0 \quad *$$

ITZULGARRIA DENEZ ; BUELTA EMAN DIBLAIOKEGU!!

$$\int \frac{\delta q}{T} = 0 \quad \text{ZIKLO ITZULGARRIA}$$

$$\int \frac{\delta q}{T} < 0 \quad \text{ZIKLO ITZULETZA}$$

CLAUSIUS-EN TEOREMA

↓ S ENTROPIA FUNTzioAREN EXISTENTZIA FROSA DAITEKE (ariketa)

* $\int \frac{\delta q}{T}$ EZ DA ENTROPIA KONTUZ!!!

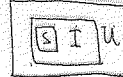
* Entropia berrakoa
iruntzia

$$* G_{p,v} = T \left(\frac{\partial S}{\partial T} \right)_{p,v}$$

* T/S diagraman
T=kTe, S=kTe, V=kTe, P=kTe

ENTROPIA-EMENDIOAREN PRINTZIPIOA

Prozesuaren zehazteko entropia-aldakuntza (Hasierako eta amaierako egoerak $\rightarrow$ orka-egoerak)



Ez-Adiabatiakoak

Hulgamiak		Hulgerinak					Adiabatiakoak
B-I bakarra	B-I-en sorta	Kanpoko (Hulgerintza) mekanikoa		barneko (Hulgerintza) mekanikoa	Kanpoko (Hulgerintza) termikoa	Kanpoko (Hulgerintza) kimikoa	Hulgerinak
		W isotermitikoki ΔU_{B-I} $\rightarrow W \left[\Delta U \right]$	W adiabatikoki ΔU_S 	$\Delta U \rightarrow$ energia mekanikoa $\rightarrow \Delta U$ "expansioa" askean 			
			(i) $p = kT$ (ii) $V = kT$ 				
		$\Delta S_{in} = \frac{W}{T}$	$\Delta S_{in} = 0$	$\Delta S_{in} = 0$	$\Delta S_{in} = \frac{Q}{T_2} - \frac{Q}{T_1}$	$\Delta S_{in} = 0$	
		$\Delta S_s = 0$	$\Delta S_s = \left\{ \begin{array}{l} C_p \ln \frac{T_f}{T_i} \\ C_v \ln \frac{T_f}{T_i} \end{array} \right.$	$\Delta S_s = R \ln 2$ *	$\Delta S_s = 0$	$\Delta S_s = 2 R \ln 2$ *	
		$\Delta S_o = \frac{W}{T} > 0$	$\Delta S_o = \left\{ \begin{array}{l} C_p \ln \frac{T_f}{T_i} \\ C_v \ln \frac{T_f}{T_i} \end{array} \right. > 0$	$\Delta S_o = R \ln 2 > 0$	$\Delta S_o = \frac{Q}{T_2} - \frac{Q}{T_1} > 0$	$\Delta S_o = 2 R \ln 2 > 0$	
K O N P R O B A T U							Frogatu

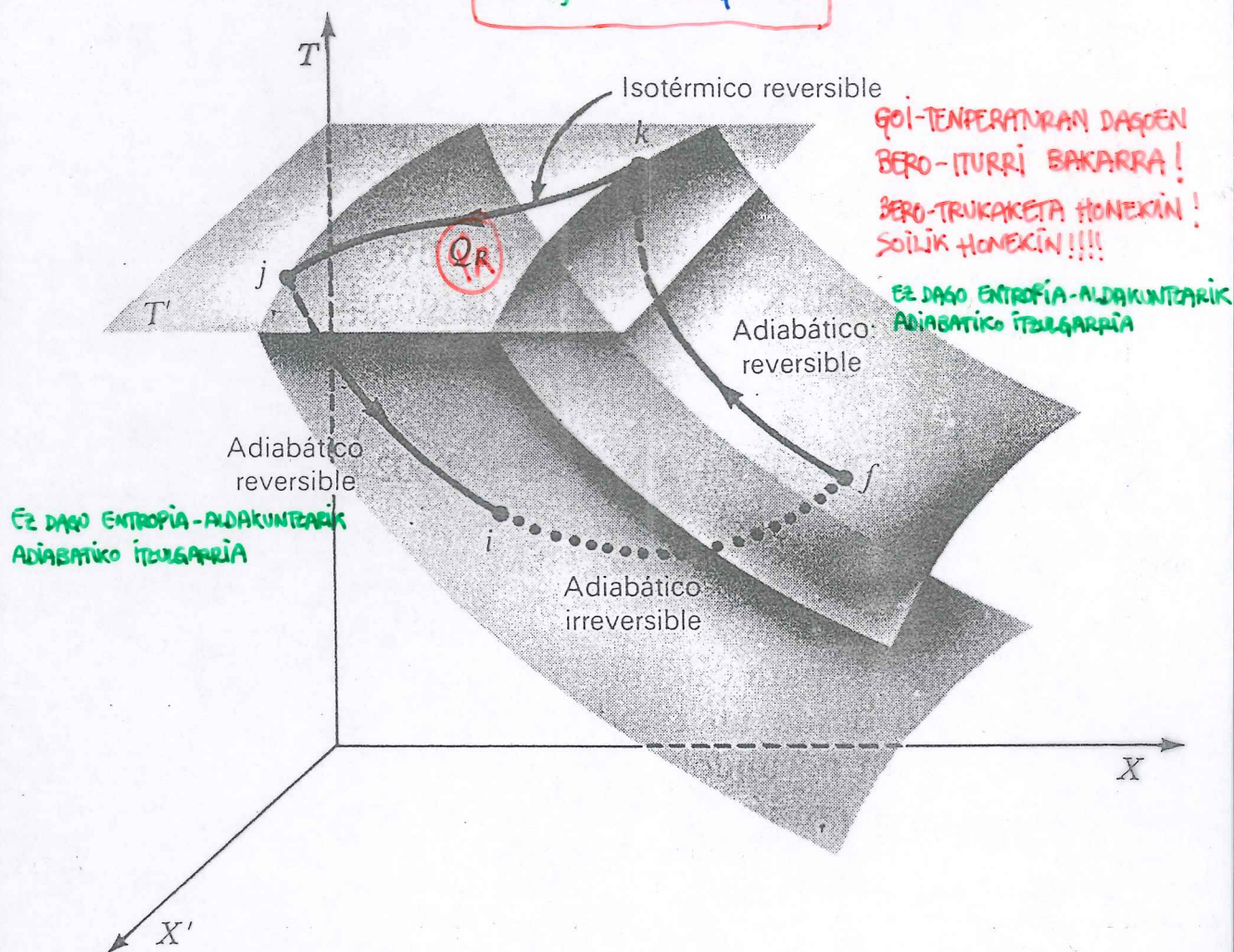
$$\Delta S_{tot} > 0$$

gutxirolatuak dagoen sistemari dagoetia

SISTEMA

$$\left[\Delta S_0 = \Delta S_{kj} + \underset{0}{\Delta S_{ji}} + \Delta S_{if} + \underset{0}{\Delta S_{fk}} = 0 \text{ (ZIKLOA)} \right]$$

$$\Delta S_{kj} + \Delta S_{if} = 0$$



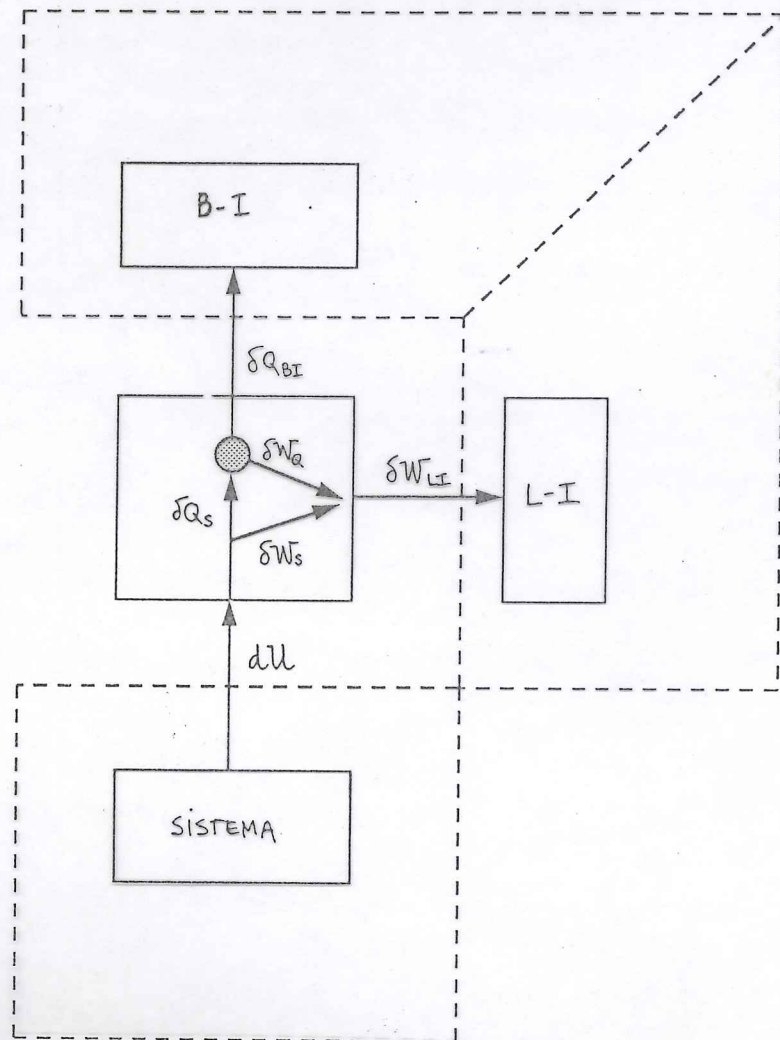
$$\left. \begin{array}{l} \Delta S_{kj} \equiv S_j - S_k \\ \Delta S_{if} \equiv S_f - S_i \end{array} \right\} \Delta S_{if} + \Delta S_{kj} = 0 \Rightarrow \Delta S_{if} = -\Delta S_{kj} \Rightarrow \Delta S_{if} = \Delta S_{jk} = S_k - S_j$$

$$Q_R = T' \Delta S_{kj}$$

$$Q_R \leq 0 \text{ (2.P)} \Rightarrow \Delta S_{kj} \leq 0 \Rightarrow \Delta S_{jk} \geq 0$$

$$\Delta S_{if} \geq 0$$

LAN MAXIMOA



KUALITATIBOKI

ΔU_s } SISTEMARI DAGOKION BI ALDAKUNTZA HAUEN
 ΔS_s } FINKOAK DIRA, OREKA-ESPERAK FINKOAK

$$(-\Delta U_s) = Q_{BI} + W_{LI} \quad \text{EKP}$$

MAXIMIZATU

MINIMIZATU

$$\Delta S_o = \Delta S_s + \Delta S_{BI} \rightarrow \text{MINIMIZATU}$$

FINKO

MINIMIZATU !!

HAR DEBAKEEN BAIORIK TXIKIENA
 BERDINTA DUGUNEAN DA, BEHAR
 PROZESU ITZULGARRIA BURUTUZ

$$Q = \Delta U' - W$$

$$\Delta U' = U_B - U_A$$

$$Q + W - \Delta U' = 0$$

$$\Delta U = -\Delta U'$$

$$Q + W + \Delta U = 0$$

$$Q_{\text{api}} + W_{\text{api}} + \Delta U_s = 0$$

$$Q_{\text{api}} + W_{\text{api}} + (U_A - U_B) = 0$$

W_{api} maksimisasi $\Rightarrow$ Q_{api} minimisasi $\Rightarrow \Delta S_{\text{api}}$ minimisasi $\Rightarrow \Delta S_{\text{sem}}$ minimisasi $\Rightarrow$
 ΔS_{sem} minimisasi $\Rightarrow$ "Minimumk bayuana"
 Minimum, absolutus

$$\Delta S_{\text{sem}} = 0 \quad \text{PROSES ITULGAKRJA}$$

$$dU + \delta Q_{\text{api}} + \delta W_{\text{api}} = 0$$

EKP

$$dS_{\text{sem}} = dS + \frac{\delta Q_{\text{api}}}{T_{\text{api}}} (\geq 0) \begin{cases} > 0 & \text{IE} \\ = 0 & \text{IG} \end{cases}$$

EEM

$$\delta W_{\text{api}} = -dU - \delta Q_{\text{api}}$$

$$dS + \frac{\delta Q_{\text{api}}}{T_{\text{api}}} \geq 0 \Rightarrow \frac{\delta Q_{\text{api}}}{T_{\text{api}}} \geq -dS \Rightarrow -\delta Q_{\text{api}} \leq T_{\text{api}} dS$$

$$\delta W_{\text{api}} \leq -dU + T_{\text{api}} dS$$

$$\delta Q = dU - \delta W \Rightarrow -dU = -\delta Q - \delta W$$

$$\delta W_{\text{api}} \leq -\delta Q - \delta W + T_{\text{api}} dS$$

$$[\delta W_{\text{api}}]_M = -\delta Q - \delta W + T_{\text{api}} dS$$

maksimum berdimensi beta deselan
 berdimensi beta $\Rightarrow$ prosesnya itulganin

$$\delta Q = T dS$$

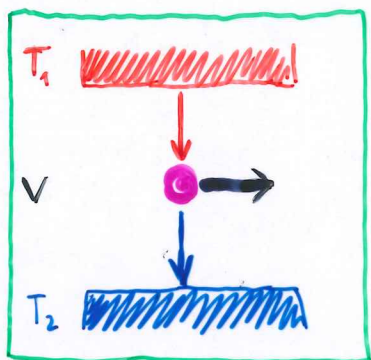
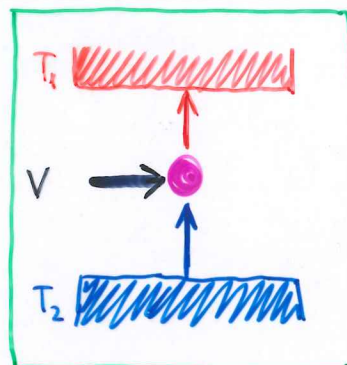
$$[\delta W_{\text{api}}]_M = -T dS - \delta W + T_{\text{api}} dS$$

$$= -T dS \left(1 - \frac{T_{\text{api}}}{T}\right) - \delta W$$

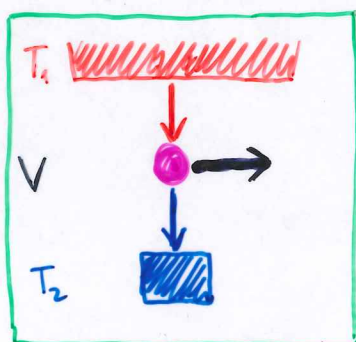
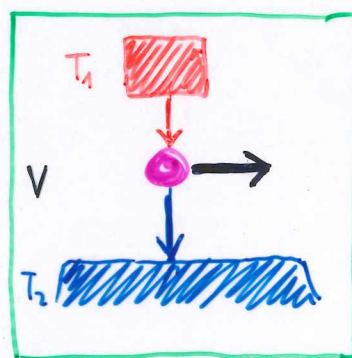
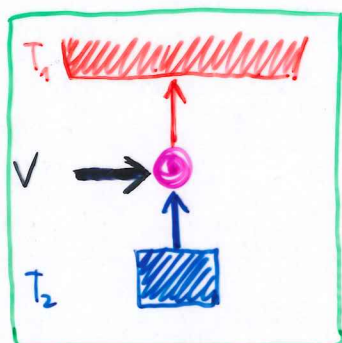
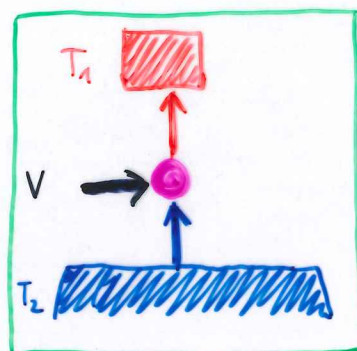
$$[\delta W_{\text{api}}]_M = \left(1 - \frac{T_{\text{api}}}{T}\right) (-\delta Q) + (-\delta W)$$

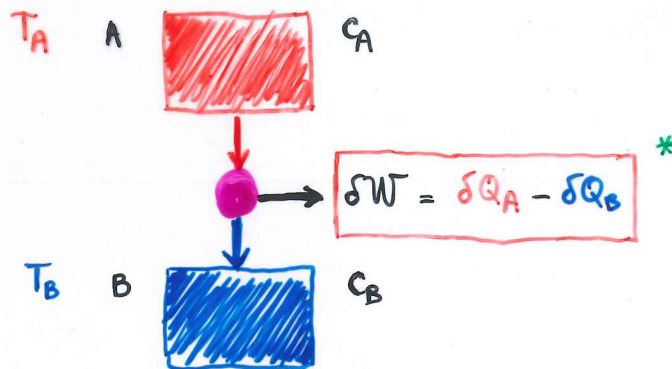
$(-\delta W)$ zureman atentakolana
 $(-\delta Q)$ zureman atentakolana beraturan
 fra klorin

LAN MAXIMOAREKIN LOTURIKO ZENBAIT ADIBIDE : "PROBLEMA-MOTAK"



SISTEMAREN (BERO-ITURRIA EZ DENAREN) BERO-AHALMENA JAKINA DA : C , C_v , C_p
SISTEMAREN TEMPERATURA ALDATUZ JOANGO DA !!!!





$$\delta W = \delta Q_1 - \delta Q_2$$

$$\int \delta W = \int \delta Q_1 - \int \delta Q_2 \Rightarrow \boxed{W = Q_1 - Q_2} \quad \text{HAUXE DA KALKULATU BEHARRERKOA}$$

$$\delta Q_i = T_i dS_i \Rightarrow dS_i = \frac{\delta Q_i}{T_i} \quad i=1,2 \quad \left. \begin{array}{l} \delta Q_i = c_i dT_i \end{array} \right\} \boxed{dS_i = \frac{c_i}{T_i} dT_i} \quad c_i = kT_i$$

$$\boxed{dS_0 = 0} \Rightarrow dS_0 = dS_1 + dS_2 \Rightarrow dS_1 + dS_2 = 0$$

BALDINTZA!!

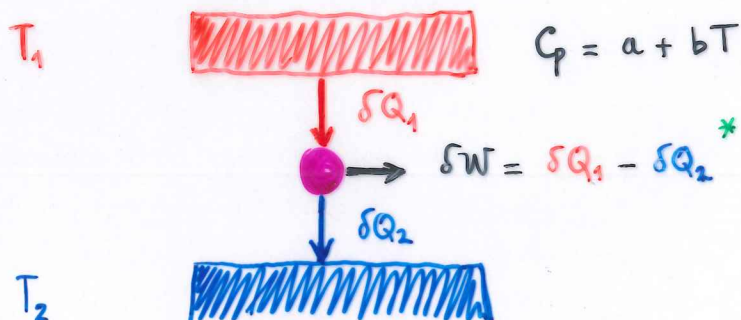
$$\frac{C_A}{T_A} dT_A + \frac{C_B}{T_B} dT_B = 0$$

$$C_A \ln \frac{T_f}{T_A} + C_B \ln \frac{T_f}{T_B} = 0 \Rightarrow \left[\frac{T_f}{T_B} \right]^{C_B} = \left[\frac{T_A}{T_f} \right]^{C_A} \Rightarrow \boxed{T_f = \left[T_B^{C_B} T_A^{C_A} \right]^{\frac{1}{C_A+C_B}}}$$

$$\left. \begin{array}{l} Q_A = -C_A (T_f - T_A) \\ Q_B = C_B (T_f - T_B) \end{array} \right\} \boxed{W = [C_A (T_f - T_A)] - [C_B (T_f - T_B)]}$$

T_f

* BALJO GUTXIAR POSITIBOAK DIRA, BADA KIGULAKO ZEIN NORANERKOK DIREN !!! (GHEIAK)



$$\delta W = \delta Q_1 - \delta Q_2$$

$$\int \delta W = \int \delta Q_1 - \int \delta Q_2 \Rightarrow \boxed{W = Q_1 - Q_2} \quad \text{HAUXE DA KALKULATU BEHARRERKOA}$$

$$\delta Q_2 = T_2 dS_2$$

$$\boxed{dS_0 = 0} \Rightarrow dS_0 = dS_1 + dS_2 \Rightarrow -dS_1 = dS_2 \quad \left. \begin{array}{l} \\ \end{array} \right\} \boxed{\delta Q_2 = -T_2 dS_1}$$

BALDINTZA!!

$$dS_1 = \frac{C_{p1}}{T_1} dT_1$$

$$\delta Q_2 = -T_2 \frac{C_{p1}}{T_1} dT_1 \Rightarrow \boxed{Q_2 = -T_2 \int \frac{C_{p1}}{T_1} dT_1}$$

ADAGAI TUTUA

$$\delta Q_1 = C_{p1} dT_1 \Rightarrow \boxed{Q_1 = \int C_{p1} dT_1}$$

ADAGAI TUTUA

$$\boxed{W = \left[\int C_{p1} dT_1 \right] - \left[-T_2 \int \frac{C_{p1}}{T_1} dT_1 \right]}$$

EMAN DITUEN DATUA (C_{p1}) ORDEZKATU !!!

$$\left[C_{p1} dT_1 - \left[-T_2 \int \frac{C_{p1}}{T_1} dT_1 \right] \right]$$

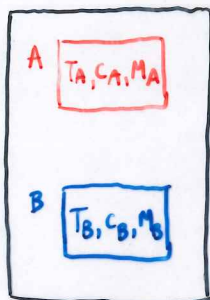
$$C_{p1} dT_1 = -\delta Q$$

$$\left(1 - \frac{T_2}{T_1} \right) (-\delta Q)$$

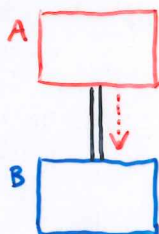
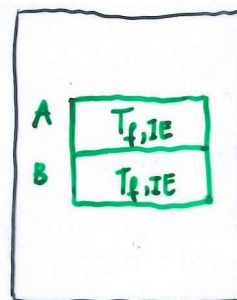
* BALIO GUZTIK POSITIBOAK DIRA, BADAIGULAKO ZEIN NORANZKOTARDAK DIREN !!! (GERTAK)

BI SISTEMEN ARTEKO TEMPERATURA-DIFERENTZIA : LANA EGITEKO APROBENA DAITEKE
 SISTEMEN OREKA-ESPERA : ESPERA TERMIKOA; TEMPERATURA

(i) KONTAKTU TERMIKO "ARRUNTA" : ESKUA SARTU GABE ITZULEZINA



(i)



(f)

$$Q_{osoa} = Q_A + Q_B ; Q_{osoa} = 0 \Rightarrow Q_A + Q_B = 0 \rightarrow T_f, IE$$

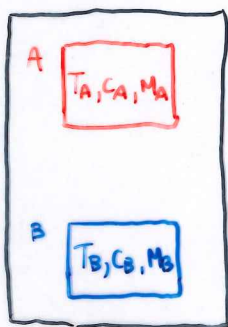
$$\Delta S_{osoa} = \Delta S_A + \Delta S_B ; \Delta S_{osoa} > 0 \Rightarrow \Delta S_A + \Delta S_B > 0$$

$$Q_i = \int_{T_i}^{T_{f, IE}} C_i dT_i$$

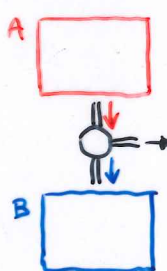
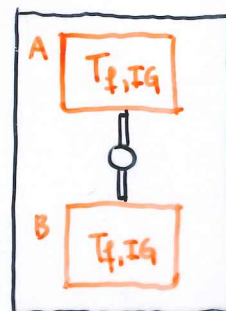
$$\Delta S_i = \int_{T_i}^{T_{f, IE}} \frac{C_i}{T_i} dT_i$$

$$\left. \begin{array}{l} \\ \end{array} \right\} i = A, B$$

(ii) KONTAKTU TERMIKO "BEREZIA" : ESKUA SARTUZ ITZULGARRIA



(i)



(f)

$$Q_{osoa} = Q_A + Q_B ; Q_{osoa} \neq 0 (\equiv W_{max}) \Rightarrow Q_A + Q_B < 0 \rightarrow T_f, IG$$

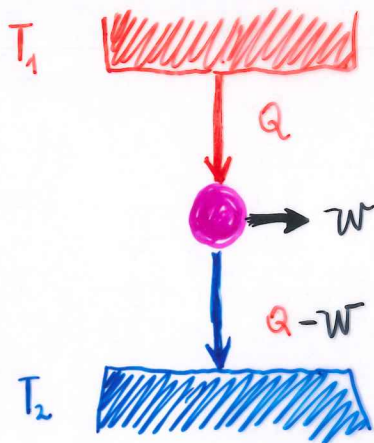
$$\Delta S_{osoa} = \Delta S_A + \Delta S_B ; \Delta S_{osoa} = 0 \Rightarrow \Delta S_A + \Delta S_B = 0$$

$$Q_i = \int_{T_i}^{T_{f, IG}} C_i dT_i$$

$$\Delta S_i = \int_{T_i}^{T_{f, IG}} \frac{C_i}{T_i} dT_i$$

$$\left. \begin{array}{l} \\ \end{array} \right\} i = A, B$$

- LAN MAXIMOA :

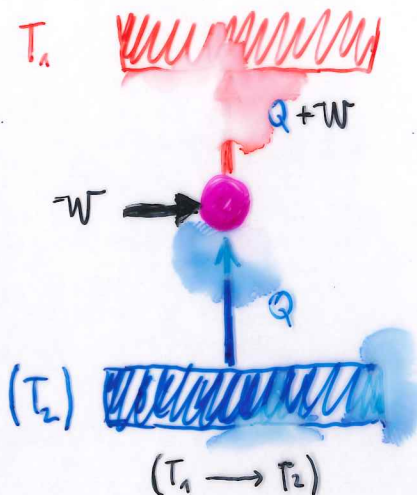


UNIBERTSOARI DABOKION ENTROPIA-ALDAKUNTZA :

$$\begin{aligned}\Delta S_u &= \Delta S_u + \Delta S_{ing} \geq 0 \\ &= 0 + (\Delta S_{T_1} + \Delta S_{T_2}) \geq 0 \quad \left(\Delta S = \frac{Q}{T}\right) \\ &= \left(-\frac{Q}{T_1} + \frac{Q-W}{T_2}\right) \geq 0\end{aligned}$$

$$W_{\max} = Q \left(1 - \frac{T_2}{T_1}\right)$$

- LAN MINIMOA : GORPUZ FINITOA T_1 -ENIK T_2 -RA HOZTEKO (?)



UNIBERTSOARI DABOKION ENTROPIA-ALDAKUNTZA :

$$\begin{aligned}\Delta S_u &= \Delta S_s + \Delta S_{ing} \geq 0 \\ &= 0 + (\Delta S_{T_1} + (S_2 - S_1)) \geq 0 \\ &= + \left(\frac{Q+W}{T_1} + (S_2 - S_1)\right) \geq 0 \\ W &\geq T_1(S_2 - S_1) - Q\end{aligned}$$

$$W_{\min} = T_1(S_2 - S_1) - Q$$

ENERGIA EZ ERABILGARRIA E

$$\{T, Q\}; T_0 \Rightarrow W_{\max} = Q \left(1 - \frac{T_0}{T}\right)$$

GOI-TEMPERATURAN DAGOEN BERO-ITURRITIK Q ENERGIA BERO MODUAN ATERATEAN,
ESKURA DUGUN TEMPERATURARIK BAXUENA T_0 IZANIK.

ATERA DAITEKEEN ENERGIA LAN MODUAN $W_{\max}$ LAN MAXIMOIA DA.

BERAHI DA LAN MODUAN ERABILTEKO ESKURA DUGUN (ESKURA DEZAKEGUN) $W_{\max}$,
HOTS; BERO ERAN SOILIK T_0 BERO-ITURRITIK ATERA DAITEKEEN ENERGIA
EZIN DA LANA ERATEKO ERABILI

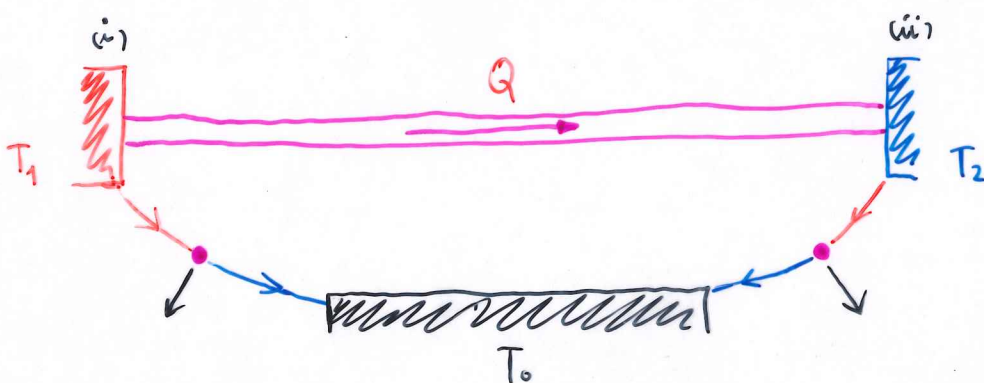
ONDORIOA:

ENERGIAK BAIKU IZATERA: LANERAKO ERABIL DAITEKE

LANERAKO EZIN ERABIL DAITEKE

ZENBAT KASUTAN LANA ATERA DAITEKE ETA BESTE ZENBAT KASUTAN EZ

TEMPERATURA-GRADIENTE FINITUAREN ONDORITZKO BERO-GARRAIO ITZULEZINA:



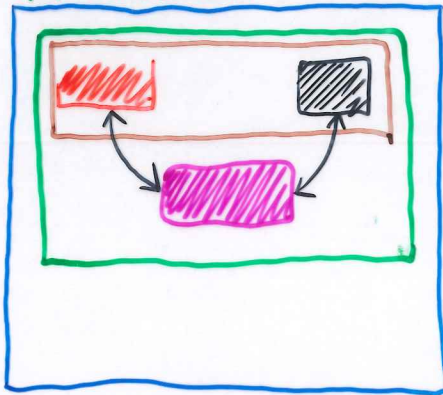
$$W_{\max}^{(i)} = Q \left(1 - \frac{T_0}{T_1}\right)$$

$$W_{\max}^{(ii)} = Q \left(1 - \frac{T_0}{T_2}\right)$$

$$E = T_0 \left(\frac{Q}{T_2} - \frac{Q}{T_1} \right)$$

$$E = T_0 \Delta S_{\text{ing}}$$

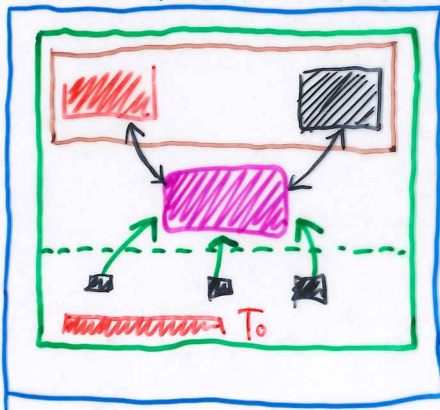
ERA ITZULEZINEAN : PROZESUA BEREZ GERTATU DA



$$Q = (U_f - U_i) - W$$

$$\Delta S_o = (S_f - S_i) + \Delta S_{\text{ing.H}} > 0 (S_f - S_i)$$

ERA ITZULGARRIAN : BEREZKO PROZESUAN GERTATU DEN BERBERA, BAINA IG:



$$\Delta S_o = \{(S_f - S_i) + \Delta S_{\text{ing.H}}\} + \Delta S_{\text{ing.L}}$$

$$= (S_f - S_i) + \Delta S_{\text{ing.L}} = 0$$

$$(S_f - S_i) > 0 \Rightarrow \Delta S_{\text{ing.L}} < 0 \Rightarrow T_o \text{ BERO-ITURRIAK } E \text{ ENERGIA } (\Rightarrow)$$

BAINA AURREKO BUKAERAKO EGORRA ERAMAN BEHAR DUGUNEZ SISTEMA $(S + H)$

E ENERGIA BERORI MAKINA BERRIETARA LAN MODUAN PASATU DA, BERAZ

ESKU ARTEAN DUGUN **SISTEMAN ING. HURBILEAN** ERA ITZULEZINEAN GERTATU DIREN AIDAKETAK, ERA ITZULGARRIAN LOTZEAN, HORRETAGAKO ERABILITAKO BERO-ITURRI LAGUNAKETIK ATERAKO DEN BEROA LAN MODUAN LAN-ITURRI LAGUNERA PASATUKO DA

LAN MODUAN ERABILGARRIA ZEN
EZ DA LAN MODUAN ERABILGARRIA

$$E = T_o (S_f - S_i)$$

"GALDUTAKO ENERGIA"

EDOZEIN PROZESU ITZULEZINAREN ONDORIOZ :

UNIBERTSOAREN GAINEKO ERAGINA ONDOKO HAU DA :

LAN EGITEKO ERABILGARRIA DEN ENERGIA-KANTITATEAREN ZATIREN BAT

LAN EGITEKO EZ ERABILGARRI BIHURTUKO DA

$$E = T_0 \Delta S_u$$

LUR DAITEKEEN TEMPERATURARIK BAXUENAKO BERO-ITURRIA

ENERGIA "DEGRADATUZ" DOA !!!

