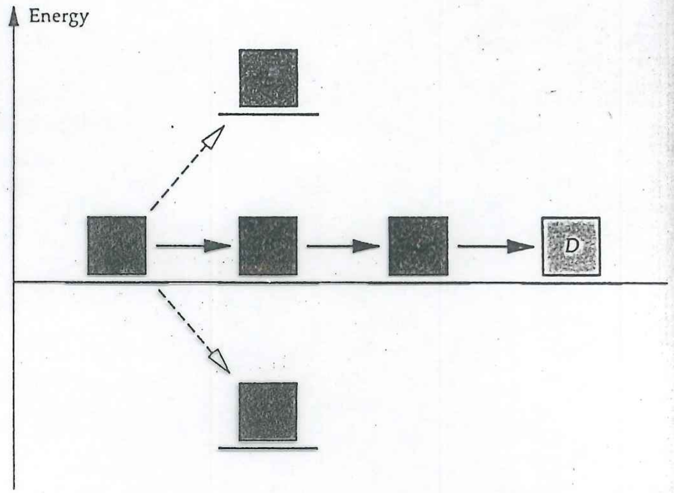
Toward Corruption

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.

de biología social; pero la tendencia actual a considerar los australopitecos y parántropos como «chimpancés bípedos», es decir, vegetarianos, sin tecnología lítica, ni aumento cerebral importante, ni lenguaje, y con un desarrollo rápido, sitúa este gran cambio dentro del género *Homo*.

"LA ESPECIE ELEGIDA"
ISBN 84-7880-909-0 (1998)

Tamaño del cerebro y tamaño del grupo social

En otro capítulo de este libro nos hemos preguntado para qué sirve ser bípedo, es decir, qué tipo de adaptación es ésta y con qué nicho ecológico está relacionada. Ya vimos que la respuesta no es fácil. Sin embargo, nadie se pregunta para qué sirve ser inteligente. Estamos tan convencidos de que la inteligencia es un don que nos hace superiores a cualquier otra forma viviente que no nos preocupamos por su valor adaptativo. Sin embargo, la expansión cerebral es una especialización como la de cualquier otro órgano, y la selección natural la ha favorecido porque presentaba ventajas en el contexto del nicho ecológico de los homínidos en los que se produjo (que no fueron todos, como se ha visto). ¿Cuáles fueron esas ventajas?

Hay dos momentos de la evolución humana en los que se produce una marcada expansión del tamaño cerebral, que podría ponerse en relación con cambios significativos en las pautas sociales. La primera de estas expansiones se produce con el *Homo ergaster*, donde el volumen cerebral pasa de representar aproximadamente un tercio del valor promedio de nuestra especie, como en los australopitecos y parántropos, a llegar hasta los dos tercios (el *Homo habilis* ocuparía una posición intermedia). La segunda gran expansión tiene lugar en el último medio millón de años, y produce los enormes cerebros de nuestra especie y de los neandertales.

El aumento del volumen cerebral comporta, como hemos visto, un cambio en la alimentación, porque afecta a un tejido energéticamente costoso. En consecuencia, se incorporan a la dieta en cantidades sustanciales las proteínas y grasas animales. A diferencia de algunos vegetales muy abundantes (aunque poco energéticos), estos recursos no se distribuyen de manera continua en el medio, ni son fáciles de obtener, por lo que aumenta el tamaño del territorio a

recorrer y el tiempo de búsqueda. Al mismo tiempo, desde el *Homo ergaster* los ritmos de crecimiento se sitúan ya próximos a los nuestros, lo que supone un periodo de dependencia infantil más prolongado que en antropomorfos y homínidos anteriores. Todo esto implica que difícilmente una madre podría hacerse cargo, ella sola, de varias crías al mismo tiempo. Por este motivo es posible que el gran cambio social se produjera en el *Homo ergaster*, aunque algunos autores sostienen que tuvo lugar en la segunda gran expansión cerebral, la nuestra y la de los neandertales.

Pero no sólo existe una relación indirecta entre el aumento de tamaño del cerebro y las relaciones entre los dos sexos, sino que es posible que la expansión cerebral esté directamente asociada a un aumento de la complejidad social. En primer lugar, se ha observado que los mamíferos que viven en sociedades complejas (como simios y delfines) tienen cerebros mayores que los mamíferos solitarios de tamaño similar. Aiello y Dunbar han descubierto también que entre las diferentes especies de primates el tamaño relativo del neocórtex respecto del resto del encéfalo está en función directa del tamaño de los grupos sociales que forman esas mismas especies.

Sin embargo, no se ha encontrado una relación similar entre el tamaño relativo del neocórtex y el tipo de vida, por lo que la «teoría ecológica» del origen de nuestra muy desarrollada inteligencia pierde fuerza respecto de la «teoría social»; no obstante, no hay que perder de vista que a partir de los primeros *Homo* los homínidos entraron en un nicho ecológico totalmente nuevo para los primates, el de carroñeros y cazadores, que también pudo favorecer el desarrollo intelectual.

En resumen, es una teoría muy respetable la de que la expansión del cerebro y de la inteligencia (o al menos una parte sustancial de la misma) representa una adaptación a la vida social, un medio en el que uno tiene que cooperar y competir a la vez con los mismos individuos. Una inteligencia desarrollada con estos propósitos (una «inteligencia social») podría muy bien aplicarse a otro tipo de situaciones complejas. Para prosperar en ese difícil medio social hace falta utilizar diversas tácticas, que van desde la formación de alianzas con otros individuos, basadas en el parentesco o en el interés, hasta el engaño. Anne Pusey, Jennifer Williams y Jane Goodall han observa-

La Ley de la Entropía y el proceso económico (1971)

Nicholas Georgescu-Roegen

(1906 - 1994)

ISBN: 84-7774-973-6 (1996)

FUNDACIÓN ARGENTARIA

VISOR (distribuciones/sa)

TERMODINAMIKAREN BIGARREN PRINTZIPIOA

* IZADIKO ASIMETRIA

- LANA/BEROA ; BEROA/LANA TRANSFORMAZIO-MOTAK
6.1, 6.6 - ZIKLOAK ETA MOTORE TERMIKOAK : MOTOREAK, HOZKAILUAK, PUNPAK, ETEKINAK, EFIZIENTZIAK
6.5 - BIGARREN PRINTZIPIOAREN ENUNTZIATUAK
6.7 CLAUSIUS-EN ENUNTZIATUA, KELVIN/PLANCK-EN ENUNTZIATUA } BALIOKIDETASUNA
• Atkins - BIGARREN PRINTZIPIOAREKIN LOTURIK DAGOEN ALDAGAI TERMODINAMIKOA

7.1 * ITZULGARRITASUNA / ITZULEZINTASUNA

* BIGARREN PRINTZIPIOAREN ONDORIOAK

7.2, 7.3, 7.4, 7.5 } 1 - IZADIKO BEREZKO PROZESUAK ITZULEZINAK DIRA (ADIBIDEAK)
7.6 - ITZULGARRITASUNERAKO BALDINTZAK
- ONDORIOEKIN SEGITZEKO BI METODO:

AXIOMATIKOA : CARATHEODORY-REN ENUNTZIATUA

7.7 2 - GAINAZAL ADIABATIKO ITZUGARRIEN EXISTENTZIA
7.8 3 - δQ-REN FAKTORE INTEGRATZAILEA : ESANGURA FISIKOA
7.9 4 - KELVIN TENPERATURA-ESKALA
7.10, 7.11 KELVIN TENPERATURA-ESKALA = GAS IDEALARENA
8.1, 8.2, 8.3 } 5 (2') - ENTROPIA FUNTZIOAREN EXISTENTZIA adibideak Kalkulua
8.4

TEKNIKOA : KELVIN, PLANCK-EN METODOA

- CARNOT-EN ZIKLOA
8.5, 8.6 - CARNOT MOTOREAREN ETEKINAK : SISTEMAREKIKO MENPEKOTASUNIK EZ, BALIORIK ALTUENA
4 - KELVIN TENPERATURA-ESKALA
5 (2') - CLAUSIUS-EN TEOREMA : ENTROPIA FUNTZIOAREN EXISTENTZIA

8.8 * ENTROPIA-EMENDIOAREN PRINTZIPIOA

- BIGARREN PRINTZIPIOAREN FORMULAZIO 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 (ESPERIENTZIAREN ARABERA)

(i)- LANA → BEROA TRANSFORMAZIO-MOTAK (EDOZEIN LAN-MOTA)

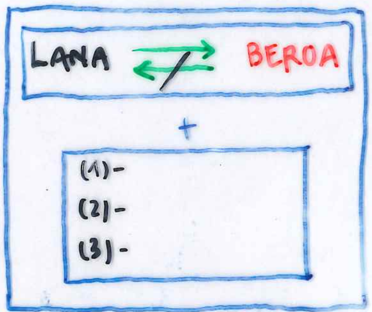
ADIBIDEA

EZAUGARRIAK : (1) - % 100
(2) - SISTEMAREN EGOERA ALDATU GABE
(3) - BEHIN ETA BERRIRO ("AD INFINITUM") } ALDIBEREAN

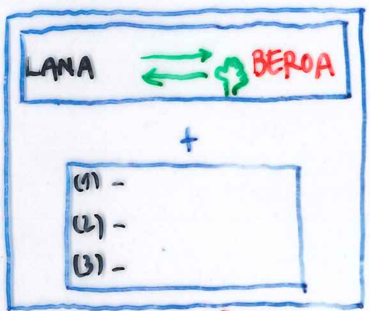
(ii)- BEROA → LANA TRANSFORMAZIO-MOTAK (EDOZEIN LAN-MOTA)

ADIBIDEA

EZAUGARRIAK : (1) - % 100
(2) - SISTEMAREN EGOERA ALDATU GABE
(3) - BEHIN ETA BERRIRO ("AD INFINITUM") } EZINEZKOA ALDIBEREAN



ASIMETRIA!!

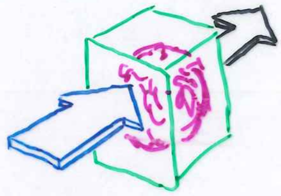


SIMETRIA!!

≡ INGURUNEAREKIN LOTU
(ALDIBEREAN HIRURAK LORTZEKO MOTOREAK BEHAR DIRA)

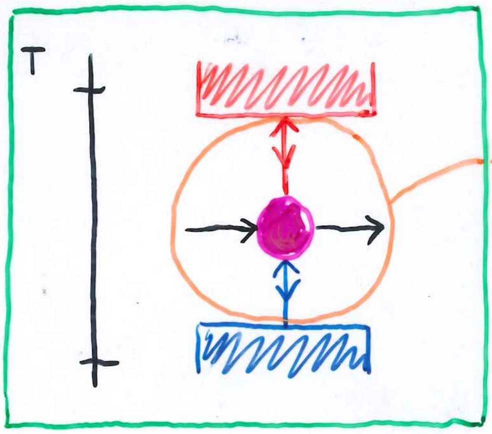
ZIKLOAK ETA MAKINA TERMIKOAK

SISTEMAK EGINGO DUENA



TRAMANKULUA (?)

$\Downarrow$

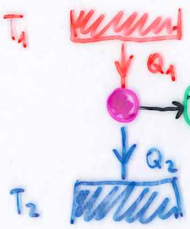


LEHENENGO PRINTZIPIOA

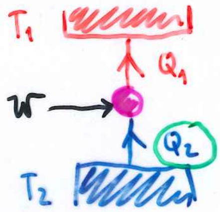
$\boxed{Q = \Delta U - W}$ $\quad \Delta U = 0$

$\boxed{Q = -W}$

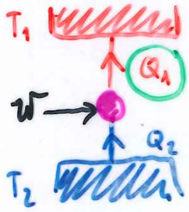
MOTORE TERMIKOA



HOZKAILUA



BERO-PUNPA



$$\boxed{|Q_1| - |Q_2| = |W|}$$

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

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

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

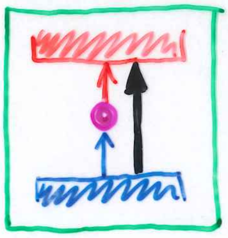
Adierazpena zuzendu

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

TERMODINAMIKAREN BIGARREN PRINTZIPIOAREN ENUNTZIATUAK

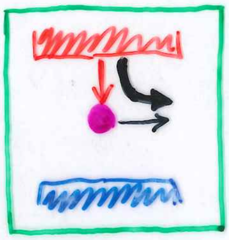
(1)- CLAUSIUS-EN ENUNTZIATUA (DENOK EZAGUTU DUGUNA)

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



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

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



ASIMETRIA BERAREN BI (BADAGO GEHIAGORIK) AURPEGIAK

BADAGO BESTE ENUNTZIATURIK

*"... BESTE INOLAKO ERAGINIK GABE."

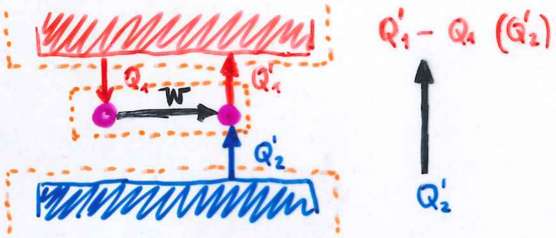
"... BESTE SISTEMAREN BATEAN ERAGINIK IZAN GABE."

"... ESKUARTU GABE."

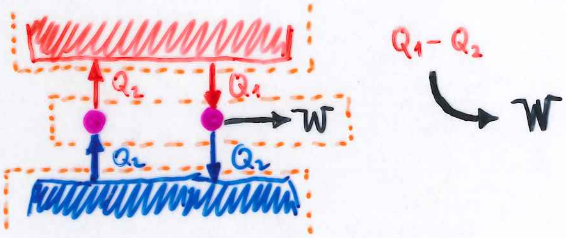
BIGARREN PRINTZIPIOAREKIN LOTURIK DAGOEN ALDAGAI TERMODINAMIKOA: ENTROPIA S

ENUNTZIATUEN ARTEKO BALIOKIDETASUNA : $\boxed{C \Leftrightarrow K/P}$

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

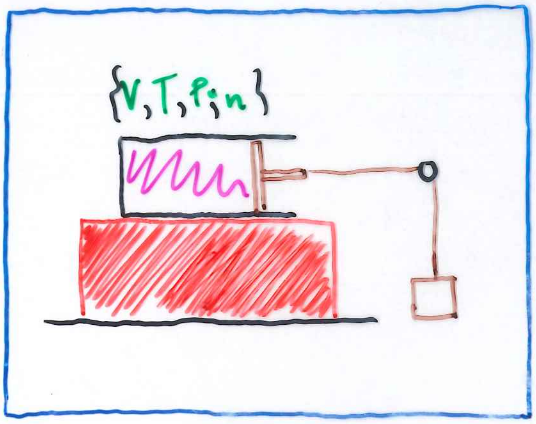


(ii) $(K/P \Rightarrow C) \Rightarrow \boxed{\text{Ez } C \Rightarrow \text{Ez } K/P}$



ITZULGARRITASUNA / ITZULEZINTASUNA

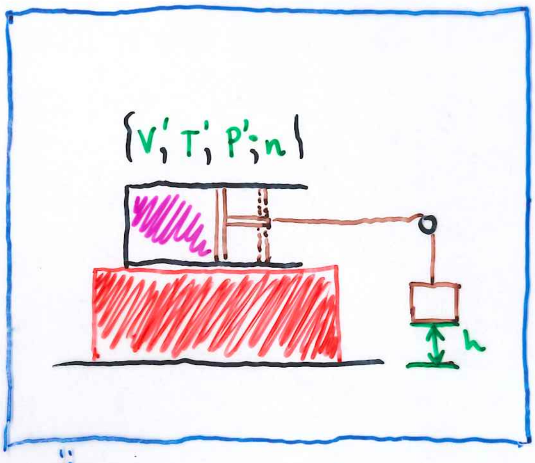
(i)



HASIERAKO OREKA-EGOERA

$\Downarrow$ ΔU, Q, W

(f)

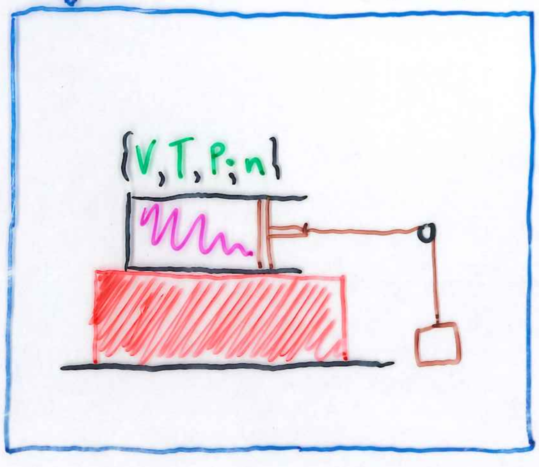


BUKAERAKO OREKA-EGOERA

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

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

(i)



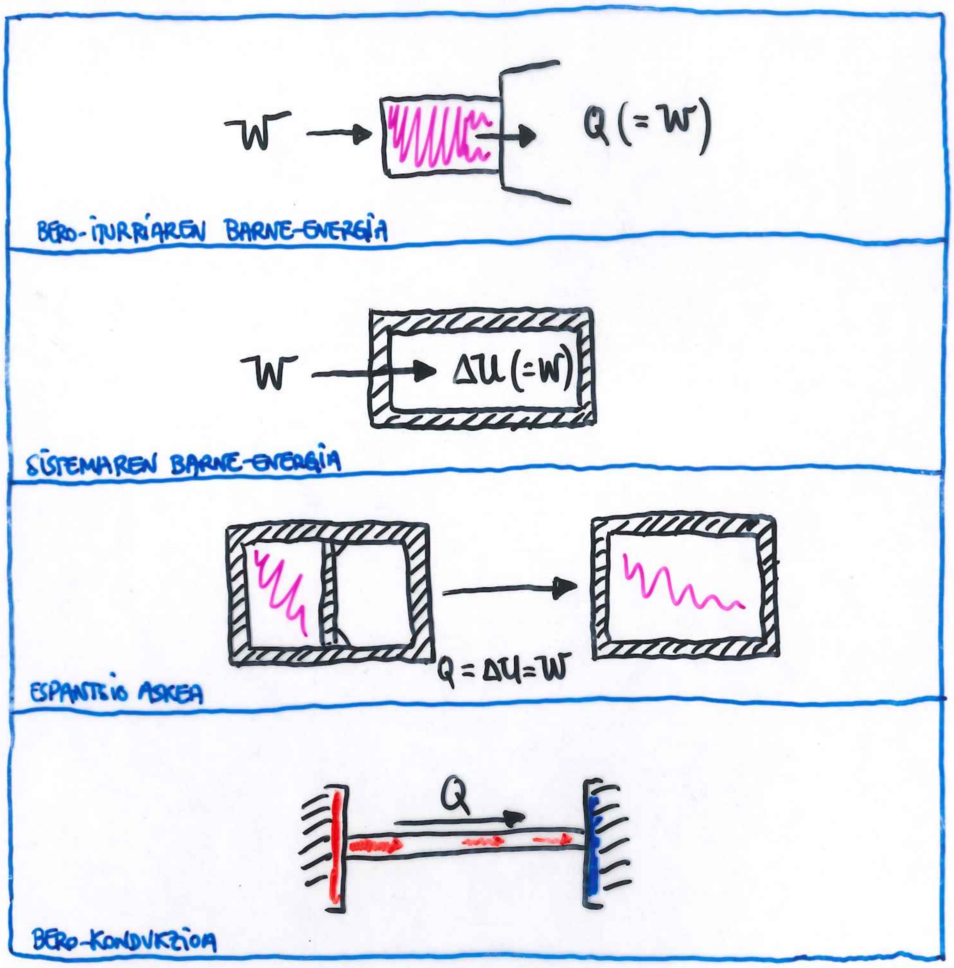
BESTE INOLAKO ERAGINIK IZAN GABE !!

KONEXIORIK GABE !!

 GABE !!

BIGARREN PRINTZIPIOAREN ONDORIOAK :

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



⋮

ITZULGARRITASUNERAKO* BALDINTZAK:

(a) EZ DAGO OREKA TERMODINAMIKORIK

(b) ENERGIA - BARREIAPENA (DISIPAZIOA)

$$\boxed{\text{PROZESU ITZULGARRIA}} \Leftrightarrow \begin{cases} \text{KUASIESTATIKOA} \\ \text{BARREIAPENIK GABEKOA} \end{cases}$$

METODO AXIOMATIKOA

CARATHEODORY-REN ENUNTZIATUA

EDOZEIN SISTEMAREN, EDOZEIN OREKA-EGOERAREN INGURUAN, PROZESU ADIABATIKO ITZULGARRIEN BIDEZ LOTU EZIN DIREN OREKA-EGOERAK DAUDE

EZ (ADIBATIKO ITZULGARRI)

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

(i) - OSAGAI BAKARREKO SISTEMA :

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

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

$$\delta W = Y dX$$

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

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

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

$$\delta Q = 0$$

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

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

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

$$\boxed{\sigma = \sigma(t,X) = Kte}$$

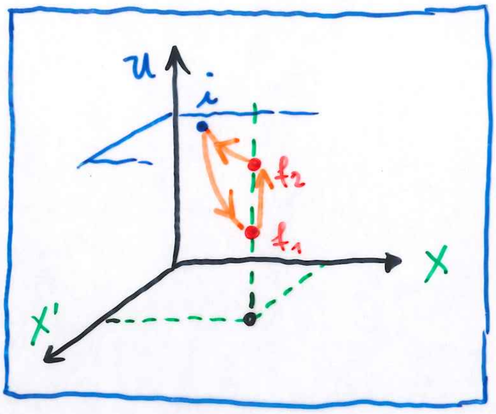
iruzkina :
lehenengo printzipioaren adierazpena prozesu itzulgarriaren kasuan.
eta aurrekoetan ?

(ii) ALDAGAI ANITZEKO SISTEMA :

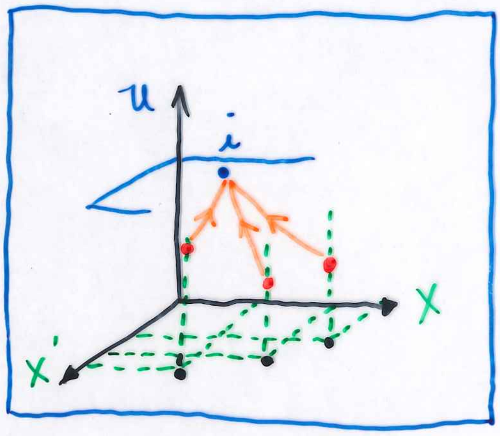
$$\{t, Y, X, Y', X'\} \Rightarrow \begin{array}{l} f(t,Y,X)=0 \Rightarrow Y=Y(t,X) \\ f'(t,Y',X')=0 \Rightarrow Y'=Y'(t,X') \end{array}$$

$$\boxed{t=t(U,X,X',Y,Y')}$$

$$\boxed{\delta Q = dU - Y\,dX - Y'\,dX'}$$



EZINEZKOA !!!



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

$$\boxed{\sigma = \sigma(t,X,X')}$$

GAINAZAL ADIABATIKO ITZULGARRIA

(3) δQ - REN FAKTORE INTEGRATZAILEA (2. ONDORIOAREN ONDORIOA)

$$\delta Q = dU - Y dX - Y' dX' \quad \left\{ \begin{array}{l} U = U(t, X, X') \\ Y = Y(t, X, X') \\ Y' = Y'(t, X, X') \end{array} \right\}$$

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

$$\boxed{\delta Q = \left(\frac{\partial U}{\partial \sigma}\right)_{X,X'} d\sigma + \left[\left(\frac{\partial U}{\partial X}\right)_{\sigma,X'} - Y\right] dX + \left[\left(\frac{\partial U}{\partial X'}\right)_{\sigma,X} - Y'\right] dX'}$$

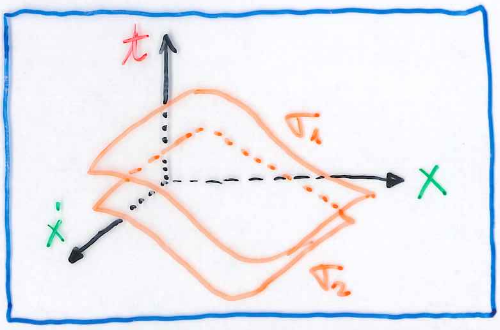
(i) $d\sigma = dX = 0$, $dX' \neq 0$

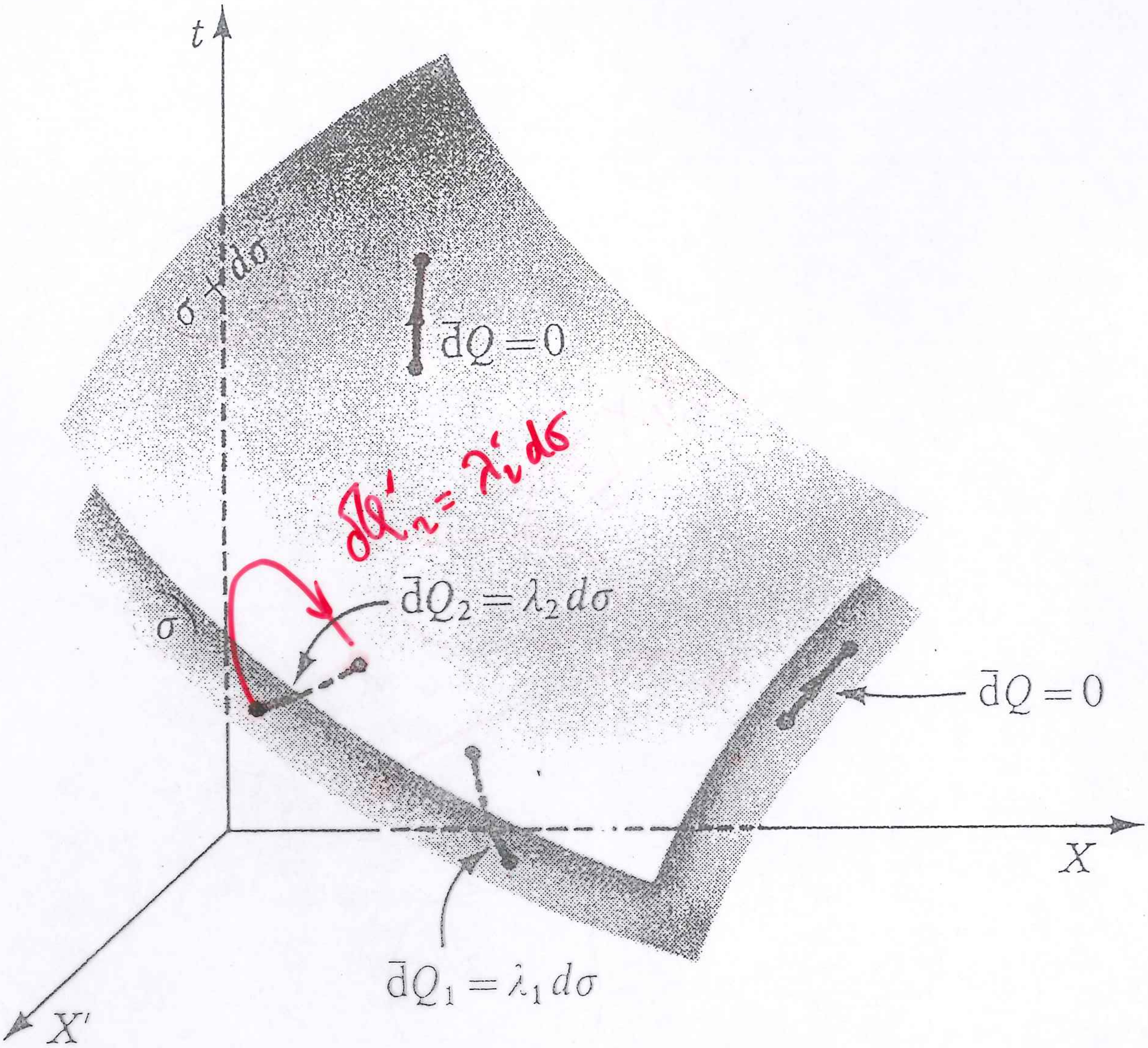
(ii) $d\sigma = dX' = 0$, $dX \neq 0$

$$\boxed{\delta Q = \left(\frac{\partial U}{\partial \sigma}\right)_{X,X'} d\sigma}$$

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

$$\boxed{\delta Q = \lambda \, d\sigma} \qquad \boxed{\lambda = \lambda(\sigma, X, X')}$$





t
$\sigma + d\sigma$
$\bar{d}Q = 0$
$\bar{d}Q'_2 = \lambda'_2 d\sigma$
$\bar{d}Q_2 = \lambda_2 d\sigma$
σ
$\bar{d}Q = 0$
X
$\bar{d}Q_1 = \lambda_1 d\sigma$
X'

FAKTORE INTEGRATZAILEAREN ESANGURA FISIKOA

BERO-ITURRIA

	SISTEMA NAGUSIA	ERREFERENTZIA-SISTEMA
ALDAGAI INDEPENDENTEAK	t, X, X'	$t, \hat{X}, \hat{X}'$
GAINAZAL ADIABATIKO ITG.	$\sigma = \sigma(t, X, X')$	$\hat{\sigma} = \hat{\sigma}(t, \hat{X}, \hat{X}')$
FAKTORE INTEGRATZAILEA	$\lambda = \lambda(t, \sigma, X)$	$\hat{\lambda} = \hat{\lambda}(t, \hat{\sigma}, \hat{X})$

SISTEMA KONPOSATUA

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

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

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

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

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

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

* $$\bar{\sigma} \longrightarrow \bar{\sigma} + d\bar{\sigma}$$

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

$\Rightarrow$

$$\delta Q = \lambda\, d\sigma \Rightarrow \boxed{\delta Q = \phi(t) f(\sigma)\, d\sigma}$$

- FAKTORE INTEGRATZAILEA (SISTEMA)
- TENPERATURAREN FUNTZIOA SOILIK
- FUNTZIO UNIBERTSALA

(1) $\boxed{\delta\bar{Q} = \delta Q + \delta\hat{Q}}$

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

adierazpen orokorra

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

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

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

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

$\bar{\sigma}$ hauek alderatu

$\Downarrow$

ondorioa

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

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

hauek dira alderatuko ditugunak mendekotasunak ezagututa

$$\left.\begin{aligned} \bar{\lambda} &= \bar{\lambda}(t,\sigma,\hat{\sigma},X,\hat{X}) \\ \lambda &= \lambda(t,\sigma,X) \\ \hat{\lambda} &= \hat{\lambda}(t,\hat{\sigma},\hat{X}) \end{aligned}\right\}$$

$$\frac{\lambda}{\bar{\lambda}} = \frac{\lambda(t,\sigma,X)}{\underbrace{\bar{\lambda}(t,\sigma,\hat{\sigma},X,\hat{X})}} = g_1(\sigma,\hat{\sigma}) \qquad \frac{\hat{\lambda}}{\bar{\lambda}} = \frac{\hat{\lambda}(t,\hat{\sigma},\hat{X})}{\underbrace{\bar{\lambda}(t,\sigma,\hat{\sigma},X,\hat{X})}} = g_2(\sigma,\hat{\sigma})$$

$\bar{\lambda}(t,\sigma,\hat{\sigma},X,\hat{X}) \longrightarrow \bar{\lambda}(t,\sigma,\hat{\sigma},X)$ 1 $\longrightarrow \bar{\lambda}(t,\sigma,\hat{\sigma},X) \longrightarrow \bar{\lambda}(t,\sigma,\hat{\sigma})$ 2

$\hat{\lambda}(t,\hat{\sigma},\hat{X}) \longrightarrow \hat{\lambda}(t,\hat{\sigma})$ 3

$\lambda(t,\sigma,X) \longrightarrow \lambda(t,\sigma)$ 4

$\Rightarrow$ alderaketaren ondorioz

$$\boxed{\begin{aligned} \lambda &= \lambda(t,\sigma) \\ \hat{\lambda} &= \hat{\lambda}(t,\hat{\sigma}) \\ \bar{\lambda} &= \bar{\lambda}(t,\sigma,\hat{\sigma}) \end{aligned}}$$

$\Downarrow$ jarraitu...

$\Downarrow$

$$\frac{\lambda}{\bar{\lambda}} = \frac{\lambda(t,\sigma)}{\bar{\lambda}(t,\sigma,\hat{\sigma})} = g_1(\sigma,\hat{\sigma}) \qquad \frac{\hat{\lambda}}{\bar{\lambda}} = \frac{\hat{\lambda}(t,\hat{\sigma})}{\bar{\lambda}(t,\sigma,\hat{\sigma})} = g_2(\sigma,\hat{\sigma})$$

$$\lambda(t,\sigma) = \phi(t) f_1(\sigma) \qquad \hat{\lambda}(t,\hat{\sigma}) = \phi(t) f_2(\hat{\sigma})$$

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

(1) $\boxed{\delta\bar{Q} = \delta Q + \delta\hat{Q}}$

$\delta Q = \lambda\, d\sigma$ adierazpen orokorra

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

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

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

bi hauek alderatu

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

ondorioz $\Downarrow$

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

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

hauek dira alderatu beharreko deribatuak mendekotasunak ezagututa

---

$$\left.\begin{aligned} \bar{\lambda} &= \bar{\lambda}(t,\sigma,\hat{\sigma},X,\hat{X}) \\ \lambda &= \lambda(t,\sigma,X) \\ \hat{\lambda} &= \hat{\lambda}(t,\hat{\sigma},\hat{X}) \end{aligned}\right\}$$

$$\frac{\lambda}{\bar{\lambda}} = \underbrace{\frac{\lambda(t,\sigma,X)}{\bar{\lambda}(t,\sigma,\hat{\sigma},X,\hat{X})}} = g_1(\sigma,\hat{\sigma}) \qquad \frac{\hat{\lambda}}{\bar{\lambda}} = \underbrace{\frac{\hat{\lambda}(t,\hat{\sigma},\hat{X})}{\bar{\lambda}(t,\sigma,\hat{\sigma},X,\hat{X})}} = g_2(\sigma,\hat{\sigma})$$

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

(1) $\boxed{\bar{\lambda}(t,\sigma,\hat{\sigma},X) \longrightarrow \bar{\lambda}(t,\sigma,\hat{\sigma})}$

(2) $\hat{\lambda}(t,\hat{\sigma},\hat{X}) \longrightarrow \hat{\lambda}(t,\hat{\sigma})$

$\lambda(t,\sigma,X) \longrightarrow \lambda(t,\sigma)$

noranzko honetan goaz

$\Rightarrow$ alderaketaren ondorioz

$$\boxed{\begin{aligned} \lambda &= \lambda(t,\sigma) \\ \hat{\lambda} &= \hat{\lambda}(t,\hat{\sigma}) \\ \bar{\lambda} &= \bar{\lambda}(t,\sigma,\hat{\sigma}) \end{aligned}}$$

$\Downarrow$ jarraitu...

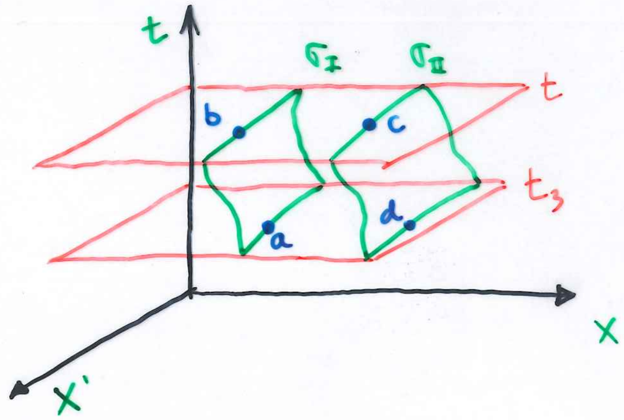
$$\frac{\lambda}{\bar{\lambda}} = \frac{\lambda(t,\sigma)}{\bar{\lambda}(t,\sigma,\hat{\sigma})} = g_1(\sigma,\hat{\sigma}) \qquad \frac{\hat{\lambda}}{\bar{\lambda}} = \frac{\hat{\lambda}(t,\hat{\sigma})}{\bar{\lambda}(t,\sigma,\hat{\sigma})} = g_2(\sigma,\hat{\sigma})$$

$$\lambda(t,\sigma) = \phi(t) f_1(\sigma) \qquad \hat{\lambda}(t,\hat{\sigma}) = \phi(t) f_2(\hat{\sigma})$$

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

(4) - KELVIN TENPERATURA-ESKALA

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



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

$$\frac{Q}{Q_3} = \frac{\phi(t)}{\phi(t_3)} = \frac{\text{Q TRANSFERITU DEN } t \text{ TENPERATURAREN FUNTZIOA}}{Q_3 \text{ TRANSFERITU DEN } t_3 \text{ TENPERATURAREN FUNTZIO BERBERA}}$$

EZ DAGO SISTEMA (SISTEMAREN EZAUGARRIRIK) $\Rightarrow$ $\boxed{\phi(t) \propto T}$ $\Longrightarrow$ TENPERATURA ABSOLUTUA

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

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

ZERO ABSOLUTUA... ?

KELVIN TENPERATURA-ESKALA $\Longleftrightarrow$ GAS IDEALAREN TENPERATURA-ESKALA

$\Downarrow$ KELVIN TENPERATURA

GAS-TERMOMETROA ERABILIZ NEURTU

(5) ENTROPIA FUNTZIOAREN EXISTENTZIA

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

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

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

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

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

$$\boxed{dS = \frac{\delta Q_{IG}}{T}}$$

FISIKOKI ZER DEN
ZER EGIN BEHAR DEN

$$S_f - S_i = \int_{i,\,IG}^{f} \frac{\delta Q_{IG}}{T}$$

$$\boxed{\oint_{IG} \frac{\delta Q}{T} = 0}$$

CLAUSIUS-EN TEOREMA

LABURBILDUMA

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

LEHENENGO PRINTZIPIOA PROZESU ITZULGARRIAN

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

ALDAGAI TERMODINAMIKOEN FUNTZIOAN

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

ZATIKETA

$$\int \left[dS = \frac{(\delta Q)_{IG}}{T} \right]$$

INTEGRAZIOA

FORMULAZIOZ ALDATZEAN, METODOA BESTE BAT IZANGO DA.

ADIBIDEA : GAS IDEALARI DAGOKION ENTROPIA

$$\boxed{dS = \frac{\delta Q_{IG}}{\cancel{d}T}}$$

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

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

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

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

(b) $dS = \frac{1}{T} C_p\, dT - \frac{1}{p} nR\, dp \rightsquigarrow$

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

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

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

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

$$\boxed{S = C_v \ln T + nR\ln V + S_0}$$

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

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

$$dS = \frac{\delta Q_{IG}}{T}$$

$$\left.\begin{array}{l} dS = \dfrac{\delta Q_{IG}}{T} \\[2ex] \delta Q_{IG} = dU - \delta W \end{array}\right\} \quad dS = \frac{dU - \delta W}{T}$$

aukera $\longrightarrow$

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

- prozesua
  hasierako } egoera
  amaierako }
  $\longrightarrow$ aldagai independenteen sorta aukeratu

- sistemari buruzko informazioa:
  - egoera-ekuazioak :
    - termikoa
    - mekanikoa (beste)
  - koefiziente esperimentalak : $(C_p, C_V, \alpha, \kappa_T)$
    - denak ez dira independenteak : $C_p - C_V = \dfrac{TV\alpha^2}{\kappa_T}$

- (T,V) $\quad \delta Q = C_V\, dT + \dfrac{C_p - C_V}{V\alpha} dV \Rightarrow \boxed{dS = \dfrac{\delta Q}{T} = \dfrac{C_V}{T} dT + \dfrac{C_p - C_V}{TV\alpha} dV} \Rightarrow S = S(T,V) \Rightarrow \begin{cases} \left(\dfrac{\partial S}{\partial T}\right)_V = \dfrac{C_V}{T} \\ \left(\dfrac{\partial S}{\partial V}\right)_T = \dfrac{C_p - C_V}{TV\alpha} \end{cases}$

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

- (p,T) $\quad \delta Q = C_p\, dT + \dfrac{\kappa_T}{\alpha}(C_V - C_p)\, dp \Rightarrow \boxed{dS = \dfrac{\delta Q}{T} = \dfrac{C_p}{T} dT + \dfrac{\kappa_T}{T\alpha}(C_V - C_p)\, dp} \Rightarrow S = S(T,V) \Rightarrow \begin{cases} \left(\dfrac{\partial S}{\partial T}\right)_p = \dfrac{C_p}{T} \\ \left(\dfrac{\partial S}{\partial p}\right)_T = \dfrac{\kappa_T}{\alpha T}(C_V - C_p) \end{cases}$

98/99 ikasturtean emandakoa

* Gaurko eskolan eman beharrekoa

* azken koadroa

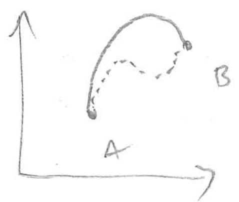
$\delta Q = dU - \delta W$ lehenengo printzipioaren adierazpena lortu prozesu itzulgarriaren kasuan

$(\delta Q)_{IG} = (\qquad)_{IG}$ → aldagai termodinamikoen menpe

$\frac{\delta Q_{IG}}{T}$ → tenperatura erabiliz zatitu

$\int \frac{\delta Q_{IG}}{T}$ → integrazioa burutu

* edozein prozesutan dS baina lortzeko modua: prozesu itzulgarrian zehar



ΔS_{AB} funtzioa

ΔS_{AB} lortzeko = prozesu itzulgarria erabiliz ordezkatu honetan lortu

* $dS = \frac{\delta Q_{IG}}{T}$

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

itzulgarria $dS = \frac{\delta Q_{IG}}{T}$
adiabatikoa $\delta Q_{IG} = 0$ $\Rightarrow dS = 0$ $S = kte$

$C_V = T\left(\frac{\partial S}{\partial T}\right)_V$

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

→ lehenengo printzipiotik abiatu $\delta Q = dU - \delta W$

$TdS = dU - \delta W$

$dS = \frac{1}{T}\left[dU - \delta W\right] \Rightarrow \boxed{dS = \frac{1}{T}\left[dU - YdX\right]}$

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

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

Lehenbiziko modura eta eragiketa-metodoa adierazteko: gas idealaren espantsio askea

METODO TEKNIKOA

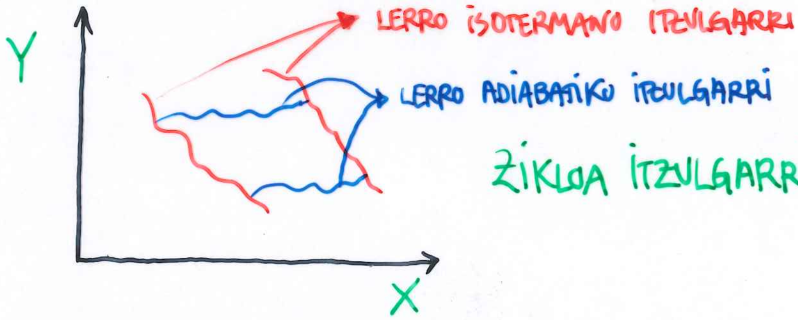
* CARNOT-EN ZIKLOA:

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

*

$\boxed{S = S(Y, X)}$

SISTEMA

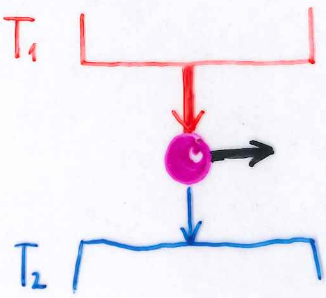


ZIKLOA ITZULGARRIA!!

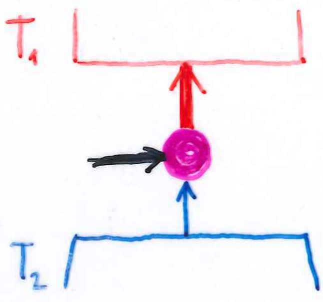
DEFINIZIOAREN ONDORIOZ:

ZURGATUTAKO BEROA, GOI-TENPERATURAN DAGOEN BERO-ITURRITIK
KANPORATUTAKO BEROA, BEHE-TENPERATURAN DAGOEN BERO-ITURRIRA
BI BERO-ITURRI BAINO EZ DAGO

* CARNOT-EN MOTOREA ETA HOZKAILUA



MOTORE TERMIKOA



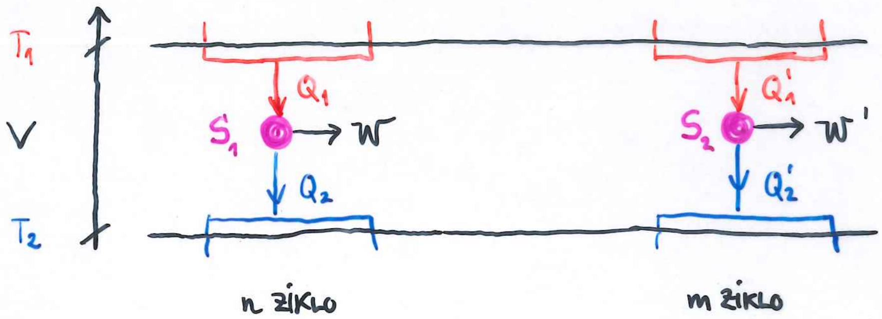
HOZKAILUA

* CARNOT-EN ZIKLOAREN ADIERAZPIDE GRAFIKOA T/S DIAGRAMAN

+ ETEKINAREN ADIERAZPENA

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

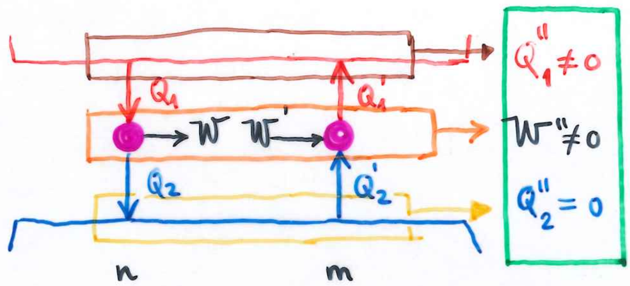
[$\left(-\frac{Q_2}{Q_1}\right)$ ADIERAZPENAK BALIO KONSTANTEA DAUKA (T_1, T_2) BIKOTEA FINKATUZ GERO]



(n, m) OSOAK

$n|Q_2| = m|Q_2'|$ $\{ nQ_2 + mQ_2' = 0 \}$ HAUXE DA EGIN DUGUN AUKERA

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



ZIKLO BAKAR OSOARI LEHENENGU PRINTZIPIOA APLIKATUKO DIOGU :

$$nQ_1 + mQ_1' = \Delta U - W''$$ $\Delta U = 0$ ZIKLOA BAITA

$$nQ_1 + mQ_1' = -W''$$

$$nQ_1 + mQ_1' > 0$$ EZINEZKOA !! 2. PRINTZIPIOAREN AURKA

$$\boxed{nQ_1 + mQ_1' \leq 0}$$

ZIKLOA ALDERANZTUZ GERO : ITZULGARRIA BAITA ...

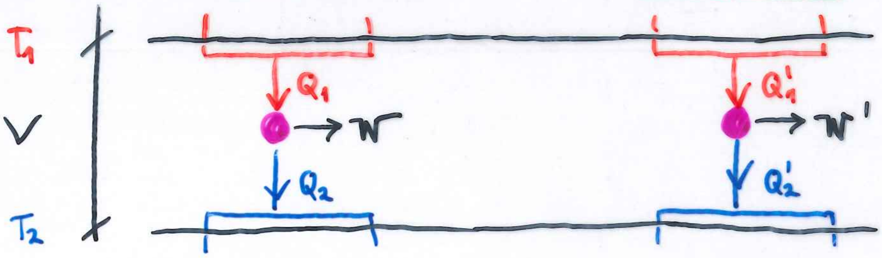
$$nQ_1 + mQ_1' \geq 0$$

$$\boxed{nQ_1 + mQ_1' = 0}$$ $nQ_2 + mQ_2' = 0$ HIPOTESIZ

$$\boxed{\frac{Q_2}{Q_1} = \frac{Q_2'}{Q_1'}}$$

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

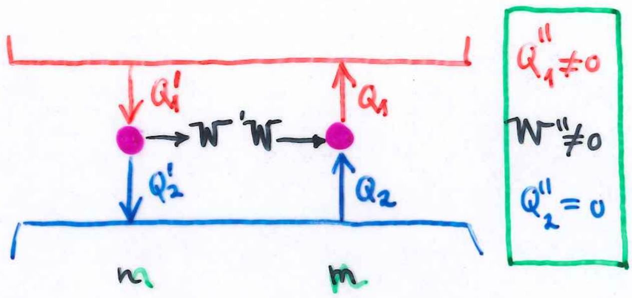
$$\eta = \frac{|W|}{|Q_1|} = \frac{|Q_1|-|Q_2|}{|Q_1|} \Rightarrow \boxed{\eta_C = 1 - \frac{|Q_2|}{|Q_1|}} \quad > \quad \boxed{\eta^* = 1 - \frac{|Q_2'|}{|Q_1'|}} \Rightarrow \boxed{\frac{|Q_2|}{|Q_1|} \leq \frac{|Q_2'|}{|Q_1'|}}$$



n ZIKLO   m ZIKLO   (n, m) OSOAK

$n|Q_2| = m|Q_2'|$ $\quad \{ n Q_2 + m Q_2' = 0 \}$ HAUXE DA EGIN DUGUN AUKERA

- MIHIZTATUKO DITUGU, (n, m) ZIKLO BAKARRA, CARNOT-EN MOTOREARI BUELTA



ZIKLO BAKAR OSOARI LEHENENGO PRINTZIPIOA APLIKATUKO DIOGU:

$$n Q_1 + m Q_1' = \Delta U - W'' \qquad \Delta U = 0 \text{ ZIKLOA BAITA}$$

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

$$n_1 Q_1 + m Q_1' > 0 \qquad \text{EZINEZKOA !! 2. PRINTZIPIOAREN KO.}$$

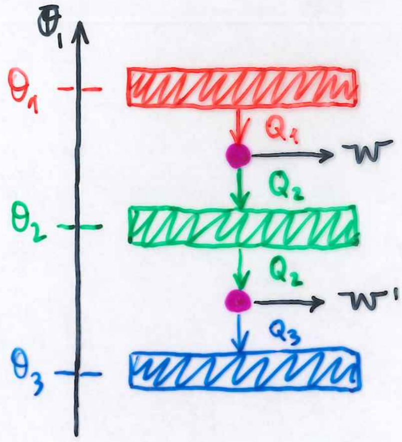
$$\boxed{n_1 Q_1 + m Q_1' \leq 0}$$

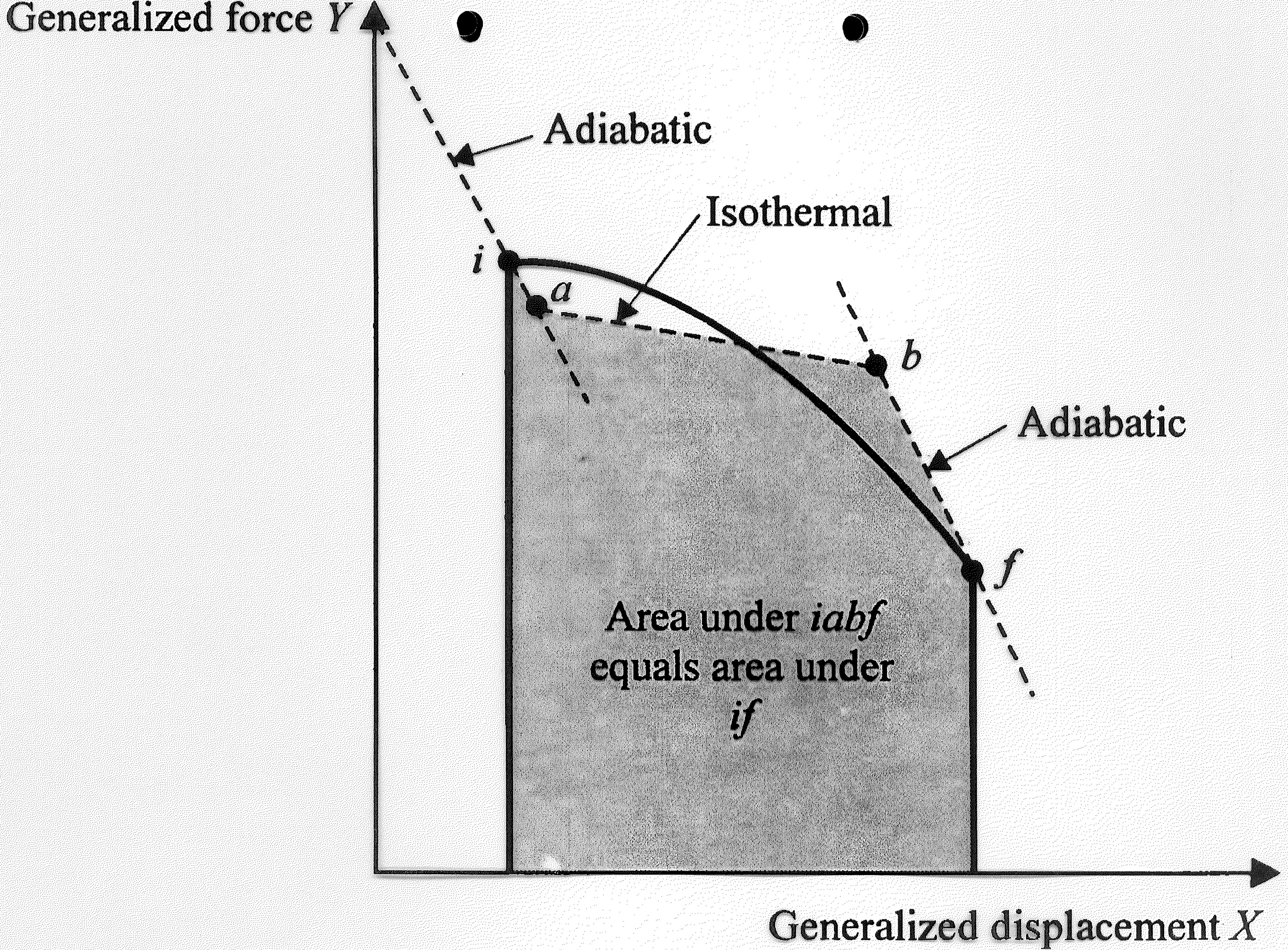
$$\left.\begin{array}{l} -n|Q_2'| = -m|Q_2| \Rightarrow n|Q_2'| = m|Q_2| \\ n|Q_1'| \leq m|Q_1| \Rightarrow n|Q_1'| \leq m|Q_1| \end{array}\right\} \boxed{\frac{|Q_2|}{|Q_1|} \leq \frac{|Q_2'|}{|Q_1'|}}$$

(= CARNOT-EN KASUAN)

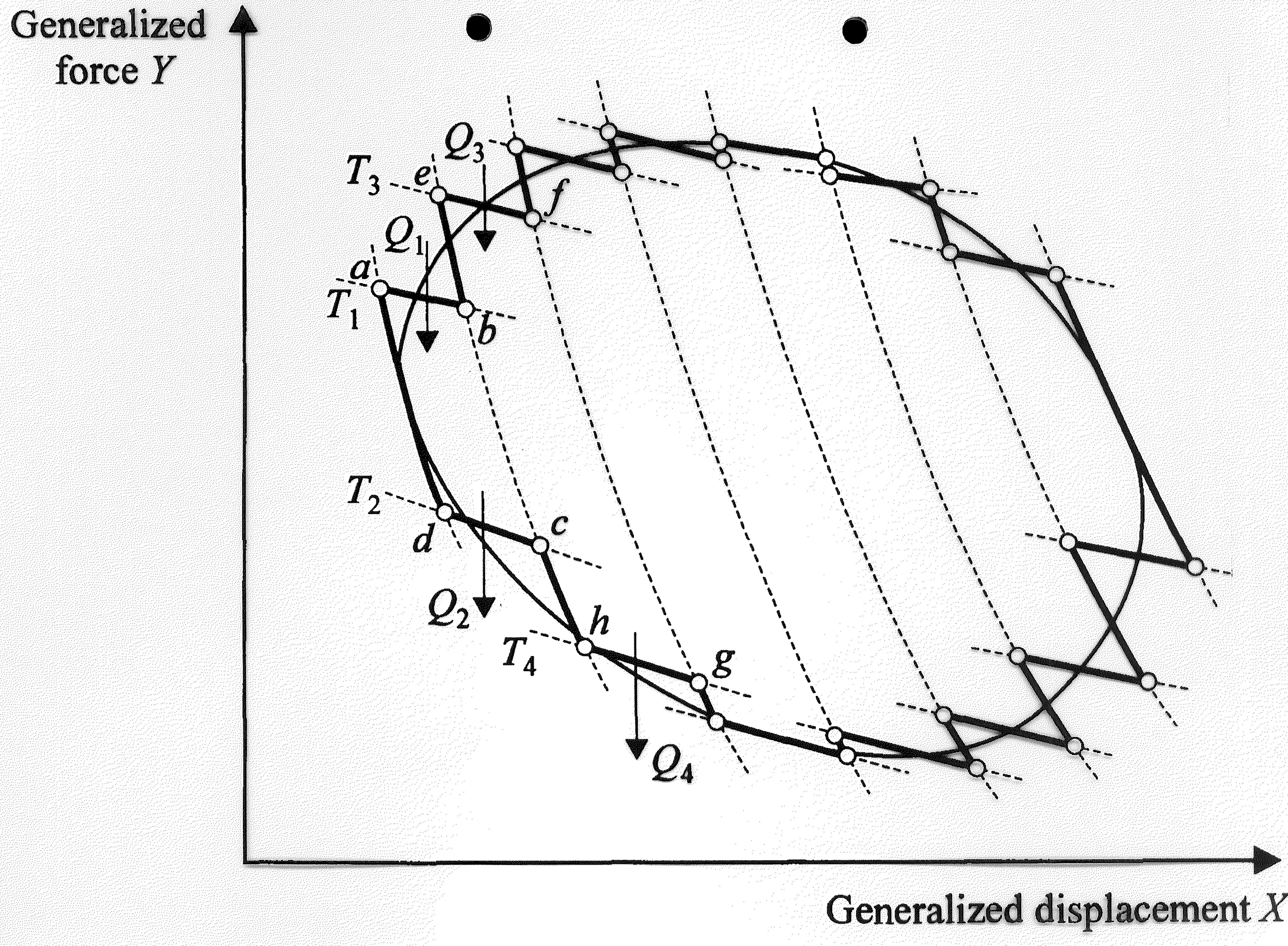
KELVIN TENPERATURA-ESKALA

$$\left[\ \frac{Q_2}{Q_1} = f(\theta_2, \theta_1) = \phi(\theta_2)\phi(\theta_1) = \frac{\psi(\theta_2)}{\psi(\theta_1)}\ \left\{ \begin{array}{l} \text{BANATUTA} \\ \text{UNIBERTSALA} \end{array} \right\}\ \right]$$





Generalized force Y
Adiabatic
Isothermal
i
a
b
Adiabatic
f
Area under *iabf* equals area under *if*
Generalized displacement X



Generalized force Y
Q_3
T_3
e
f
Q_1
a
T_1
b
T_2
c
d
Q_2
h
T_4
g
Q_4
Generalized displacement X

CLAUSIUS-EN TEOREMA

* PROZESU [illegible] HONETAN SISTEMA ETA INGURUNEAREN ARTEKO BERO-TRUKAKETAK POSITIBOAK ZEIN NEGATIBOAK IZAN DAITEZKEENAK

SISTEMA T_i TENPERATURAN DAGOENEAN Q_i BEROA TRUKATUKO DU (ZURGATU/KANPORATU)

* BERO-TRUKAKETAK CARNOT-EN MOTOREEN BIDEZ ADIERAZIKO DITUGU ONDOKO EREDUARI SEGITUZ

T_0 ARBITRARIOKI FINKATURIKO BERO-ITURRIAREN TENPERATURA

Q_j TRUKATUKO DEN BERO-KANTITATEA

BESTE BERO-ITURRIAREN TENPERATURA T_j DA ; Q_j BEROA TRUKATU AHAL IZATEKO

$$\left.\left[\{Q_j\}_{\substack{\downarrow \\ T_j}} \; j=1,\ldots,n \; ; \; T_0\right]\right\} \quad \boxed{[T_j \, , T_0] \quad j=1,\ldots,n}$$

CARNOT-EN MOTOREA/HOZKAILUA

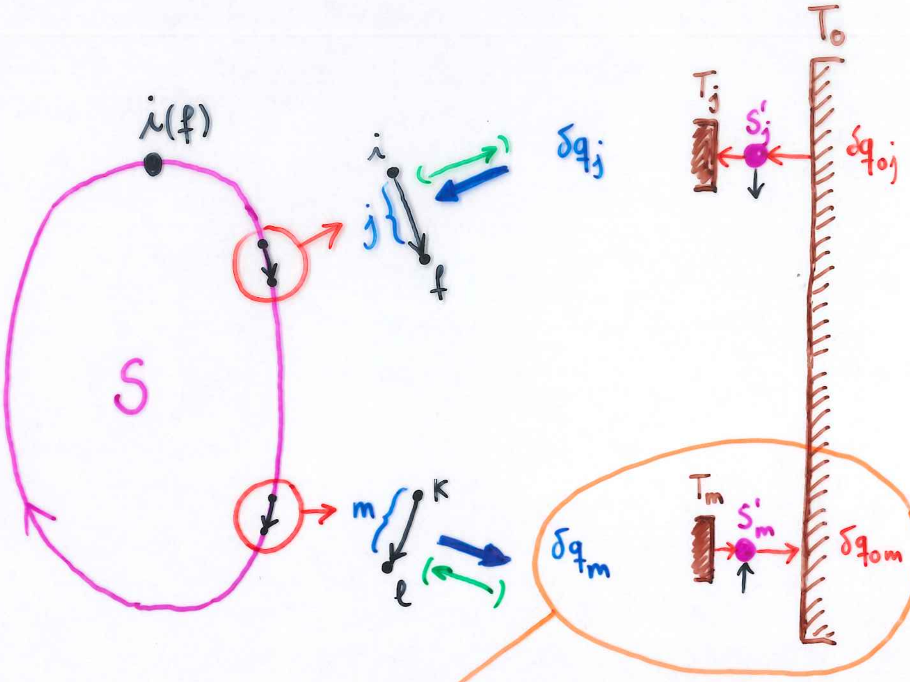
* T_j EZ DA ZIKLOKI ARITUKO DEN SISTEMA TARTEKARIAREN TENPERATURA (PRINTZIPIOZ, NAHIZ ETA ZIKLO ITZULGARRIAREN KASUAN BAI) BAIZIK ETA TRUKATUKO DEN Q_j TRUKATZEKO BEHAR DENA

T_0 ALDATUZ GERO T_j-REN BALIOA DIFERENTEA DA (NAHIZ ETA Q_j ALDATU EZ)

$$\boxed{Q_j = Q_0 \frac{T_j}{T_0}} \; ; \quad T_0 \longrightarrow T_0' \;\Rightarrow\; \boxed{Q_j = Q_0' \frac{T_j'}{T_0'}}$$

T_j SISTEMA BITARTEKARIAREN TENPERATURA ZIKLO OSOA ITZULGARRIA BADA

ZIKLIKOKI ARITUKO DEN SISTEMARENA <u>ERE</u>, OREKA BEHAR BAITUGU (BESTELA ITZULEZINTASUNAK AGERTUKO DIRA)

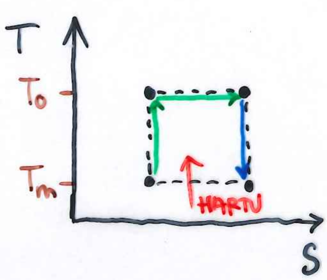


$$\frac{\delta q_{0j}}{\delta q_j} = \frac{T_0}{T_j} \Rightarrow \boxed{\delta q_{0j} = \delta q_j \frac{T_0}{T_j}}$$

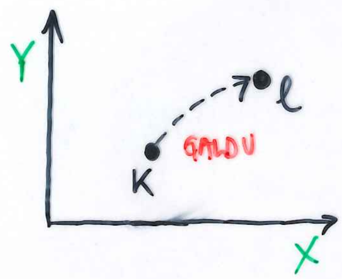
$$\vdots$$

$$\frac{\delta q_{0m}}{\delta q_m} = \frac{T_0}{T_m} \Rightarrow \boxed{\delta q_{0m} = \delta q_m \frac{T_0}{T_m}}$$

$$\boxed{\oint \delta q_0 = T_0 \oint \frac{\delta q}{T}}$$



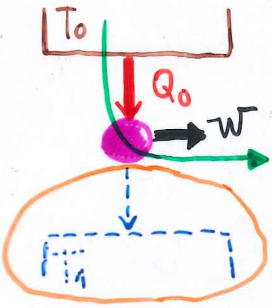
S'_m



S

$$\boxed{\oint \delta q_0 = T_0 \oint \frac{\delta q}{T}}$$

BERO-ITURRIAREKIN SISTEMAK TRUKATU DUEN BERO-KANTITATEA, EFEKTIBOA



$Q_0 = \Delta U - W \Rightarrow \boxed{Q_0 = -W}$

POSITIBOA BALITZ, 2. PRINTZIPIOAREN AURKA LEGOKE !!!

HONELAKORIK EZ DAGO, BERO-ITURRI BAKARRA BAITAGO

$$\boxed{T_0 \oint \frac{\delta q}{T} \leq 0} \qquad \boxed{\oint \frac{\delta q}{T} \leq 0} \ *$$

ITZULGARRIA DENEZ; BUELTA EMAN DIEZAIOKEGU!!

$\oint \frac{\delta q}{T} = 0$	ZIKLO ITZULGARRIA
$\oint \frac{\delta q}{T} < 0$	ZIKLO ITZULEZINA

CLAUSIUS-EN TEOREMA

$\Downarrow$

S ENTROPIA FUNTZIOAREN EXISTENTZIA FROGA DAITEKE (ariketa)

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

* Entropiari buruzko iruzkina

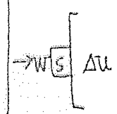
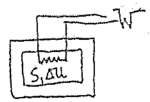
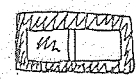
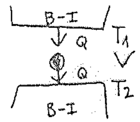
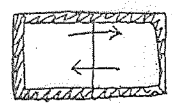
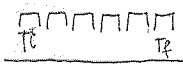
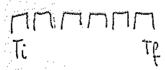
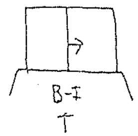
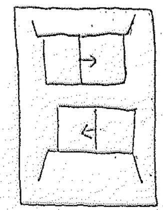
* $C_{p,v} = T\left(\frac{\partial S}{\partial T}\right)_{p,v}$

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

ENTROPIA-EMENDIOAREN PRINTZIPIOA

Prozesuetan gehaneko entropia-aldakuntza (Hasierako eta amaierako egoerak → oreka-egoerak)

$\boxed{S}$ I U

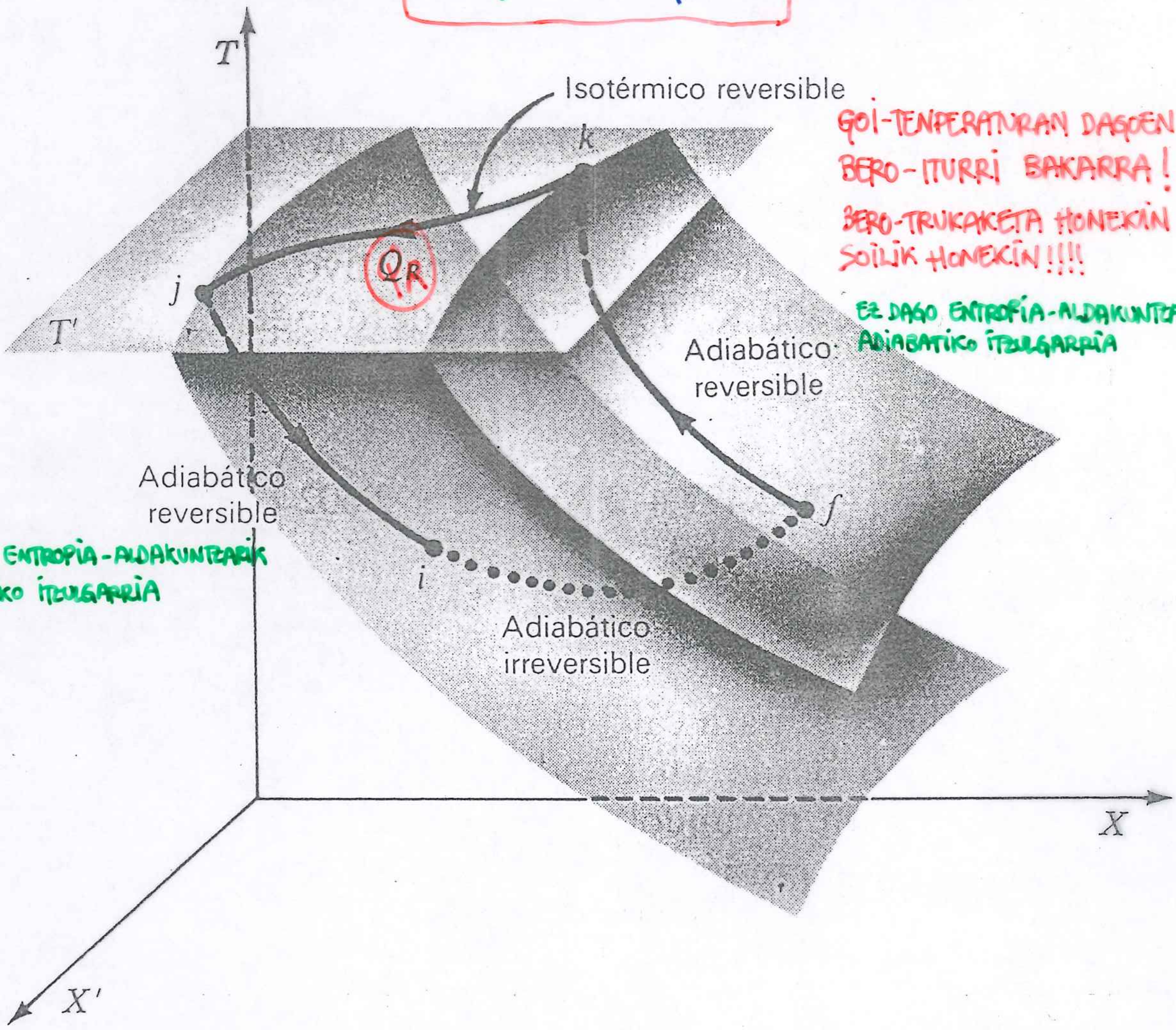
Ez-Adiabatikoak							Adiabatikoak
Itzulgarriak		Itzulezinak					Itzulezinak
B-I bakarra	B-I-en sorta	Kanpoko itzulezintasun mekanikoa		barneko itzulezintasun mekanikoa	Kanpoko itzulezintasun termikoa	Kanpoko itzulezintasun kimikoa	
		W isotermikoki ΔU_{BI} 	W adiabatikoki ΔU_s 	ΔU → energia Mekanikoa → ΔU expantsio askea 			
			(i) p=Kte  (ii) V=Kte 				
		$\Delta S_{in} = \frac{W}{T}$	$\Delta S_{in} = 0$	$\Delta S_{in} = 0$	$\Delta S_{in\,(1,2)} = \frac{Q}{T_2} - \frac{Q}{T_1}$	$\Delta S_{in} = 0$	
		$\Delta S_s = 0$	$\Delta S_s = \begin{cases} C_p \ln \frac{T_f}{T_i} \\ C_v \ln \frac{T_f}{T_i} \end{cases}$	$\Delta S_s = R\ln 2$ *	$\Delta S_s = 0$	$\Delta S_{s\,(1,2)} = 2R\ln 2$ *	
		$\Delta S_o = \frac{W}{T} > 0$	$\Delta S_o = \begin{cases} C_p \ln \frac{T_f}{T_i} \\ C_v \ln \frac{T_f}{T_i} \end{cases} > 0$	$\Delta S_o = R\ln 2 > 0$	$\Delta S_o = \frac{Q}{T_2} - \frac{Q}{T_1} > 0$	$\Delta S_o = 2R\ln 2 > 0$	
		KONPROBATU					Frogatu

$\boxed{(\Delta S)_{tu} > 0}$ guztiz isolaturik dagoen sistemari dagokio

SISTEMA

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

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



GOI-TENPERATURAN DAGOEN BERO-ITURRI BAKARRA!

BERO-TRUKAKETA HONEKIN! SOILIK HONEKIN!!!!

EZ DAGO ENTROPIA-ALDAKUNTZARIK ADIABATIKO ITZULGARRIA

EZ DAGO ENTROPIA-ALDAKUNTZARIK ADIABATIKO ITZULGARRIA

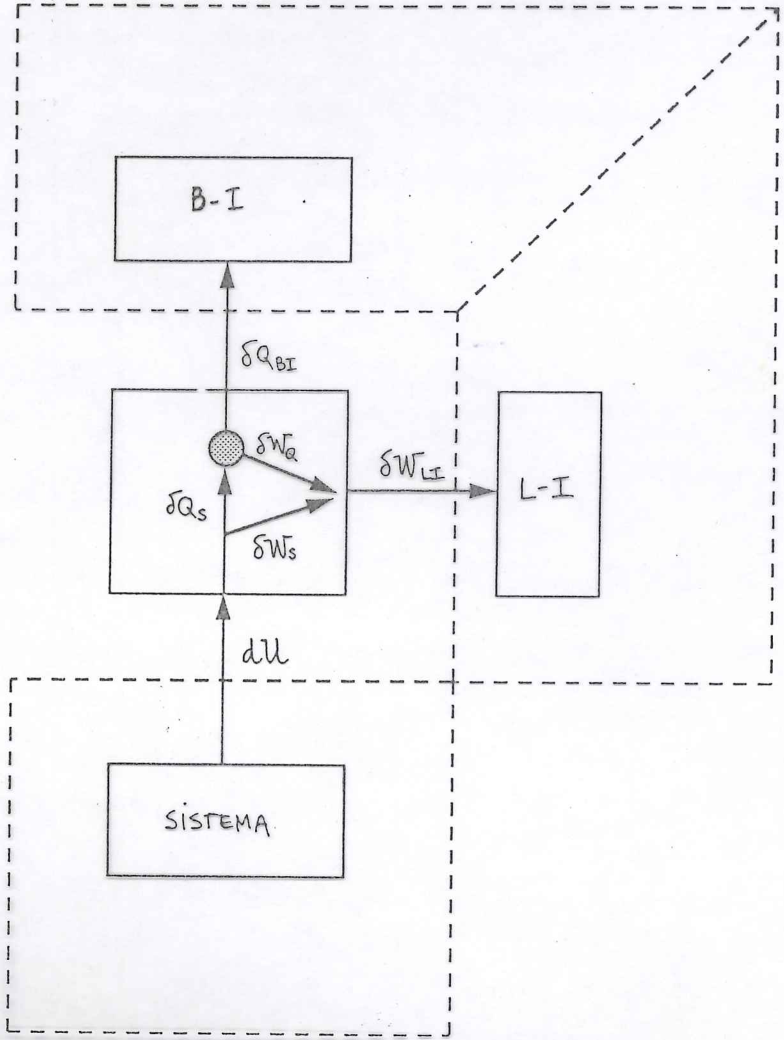
$$\left.\begin{aligned} \Delta S_{kj} &\equiv S_j - S_k \\ \Delta S_{if} &\equiv S_f - S_i \end{aligned}\right\} \Delta S_{if} + \Delta S_{kj} = 0 \Rightarrow \Delta S_{if} = -\Delta S_{kj} \Rightarrow \boxed{\Delta S_{if} = \Delta S_{jk} = S_k - S_j}$$

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

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

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

LAN MAXIMOA



KUALITATIBOKI

$\left.\begin{array}{l}\Delta U_s \\ \Delta S_s\end{array}\right\}$ SISTEMARI DAGOZKION BI ALDAKUNTZA HAUEK FINKOAK DIRA, OREKA-EGOERAK FINKOAK

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

MAXIMIZATU

MINIMIZATU

$$\Delta S_0 = \Delta S_s + \Delta S_{BI} \rightarrow \text{MINIMIZATU}$$

FINKO

$\Downarrow$

MINIMIZATU !!

HAR DEZAKEEN BALIORIK TXIKIENA BERDINTZA DUGUNEAN DA, BERAZ **PROZESU ITZULGARRIA** BURUTUZ.

$$Q = \Delta U' - W \qquad \Delta U' \equiv U_B - U_A$$

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

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

$$\boxed{Q_{bfi} + W_{efi} + \Delta U_s = 0} \qquad Q_{bfi} + W_{efi} + (U_A - U_B) = 0$$

W_{efi} maximatu $\Rightarrow$ Q_{bfi} minimizatu $\Rightarrow$ ΔS_{bfi} minimizatu $\Rightarrow$ ΔS_{osoa} minimizatu $\Rightarrow$

ΔS_{osoa} minimizatu $\Rightarrow$ "Minimorik txikiena" "Minimoa absolutua"

$$\boxed{\Delta S_{osoa} = 0 \quad \text{PROZESU ITZULGARRIA}}$$

$$\boxed{\begin{array}{l} dU + \delta Q_{bfi} + \delta W_{efi} = 0 \\ dS_{osoa} = dS + \dfrac{\delta Q_{bfi}}{T_{bfi}} \; (\geq 0) \begin{cases} > 0 & IE \\ = 0 & IG \end{cases} \end{array}} \qquad \begin{array}{l} EKP \\ EEM \end{array}$$

$$\left.\begin{array}{l} \delta W_{efi} = -dU - \delta Q_{bfi} \\ dS + \dfrac{\delta Q_{bfi}}{T_{bfi}} \geq 0 \Rightarrow \dfrac{\delta Q_{bfi}}{T_{bfi}} \geq -dS \Rightarrow -\delta Q_{bfi} \leq T_{bfi}\, dS \end{array}\right\} \Rightarrow \boxed{\delta W_{efi} \leq -dU + T_{bfi}\, dS}$$

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

$$\delta W_{efi} \leq -\delta Q - \delta W + T_{bfi}\, dS$$

$$\boxed{\left[\delta W_{efi}\right]_M = -\delta Q - \delta W + T_{bfi}\, dS}$$

maximoa berdintza bete denean
berdintza bada $\Rightarrow$ prozesua itzulgarria

$$\delta Q = T\, dS$$

$$\left[\delta W_{efi}\right]_M = -T\, dS - \delta W + T_{bfi}\, dS$$

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

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

$(-\delta W)$ zuzenean ateratako lana

$(-\delta Q)$ zuzenean ateratako beroaren frakzioa

$$Q = \Delta U - W$$

$$(Q = \Delta U - W)^{sis} \Rightarrow (-\Delta U)^{sis} = -(Q + W)^{sis}$$

$$= -Q^{sis} - W^{sis}$$

$$\quad\quad\quad \shortparallel$$

$$Q^{bi} + W^{li}$$

$$\boxed{(-\Delta U)^{sis} = Q^{bi} + W^{li}} \quad 1P \quad (EKP)$$

$$\boxed{}$$

finkatzen

maximatu

$\Downarrow$

minimizatu

$$0 \leq \boxed{\Delta S^{un}} = \boxed{\Delta S^{sis}} + \Delta S^{ing} \quad 2P \quad (EEP)$$

$$\quad\quad\quad\quad\quad\quad \shortparallel$$

$$\quad\quad\quad\quad\quad\quad \Delta S^{bi}$$

finkoa

minimizatua

minimizatua

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

$$(\delta Q = dU - \delta W)^{sis}$$

$$(-dU)^{sis} = -(\delta Q + \delta W)$$

$$-dU^{sis} = \delta Q^{bi} + \delta W^{li}$$

$$0 = dU + \delta Q^{bi} + \delta W^{li}$$

$$\delta W^{li} = -dU - \delta Q^{bi}$$

$$dS + \frac{\delta Q^{bi}}{T^{bi}} \geq 0$$

$$\frac{\delta Q^{bi}}{T^{bi}} \geq -dS$$

$$-\frac{\delta Q^{bi}}{T^{bi}} \leq dS$$

$$-\delta Q^{bi} \leq T^{bi} dS$$

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

$$dU = \delta Q + \delta W$$

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

$$\quad\quad\quad \shortparallel$$

$$\quad\quad TdS \quad\quad lan$$

$$\delta W^{li} \leq -dU + T^{bi} dS$$

$$\delta W^{li} \leq -\delta Q - \delta W + T^{bi} dS$$

$$\delta W^{li} = -TdS - \delta W + T^{bi} dS$$

$$\boxed{\delta W^{li} = -\delta W - T ds \left(1 - \frac{T^{ri}}{T}\right)}$$

$$Q = \Delta \mathcal{U}' - W \qquad \Delta \mathcal{U}' \equiv \mathcal{U}_B - \mathcal{U}_A$$

$$Q + W - \Delta \mathcal{U}' = 0 \qquad \Delta \mathcal{U} \equiv -\Delta \mathcal{U}'$$

$$Q + W + \Delta \mathcal{U} = 0$$

$$\boxed{Q_{bfi} + W_{efi} + \Delta \mathcal{U}_s = 0} \qquad \boxed{Q_{bfi} + W_{efi} + (\mathcal{U}_A - \mathcal{U}_B) = 0}$$

W_{efi} maximizatu $\Rightarrow$ Q_{bfi} minimizatu $\Rightarrow$ ΔS_{bfi} minimizatu $\Rightarrow$ ΔS_{osoa} minimizatu $\Rightarrow$

ΔS_{osoa} minimizatu $\Rightarrow$ "Minimorik baxuena"
"Minimoa, absolutua"

$$\boxed{\Delta S_{osoa} = 0 \quad \text{PROZESU ITZULGARRIA}}$$

$$\boxed{\begin{aligned} &d\mathcal{U} + \delta Q_{bfi} + \delta W_{efi} = 0 \\ &dS_{osoa} = dS + \frac{\delta Q_{bfi}}{T_{bfi}} \; (\geq 0) \begin{cases} > 0 & IE \\ = 0 & IG \end{cases} \end{aligned}} \qquad \begin{aligned} &\text{EKP} \\ &\text{EEM} \end{aligned}$$

$$\left.\begin{aligned} &\delta W_{efi} = -d\mathcal{U} - \delta Q_{bfi} \\ &dS + \frac{\delta Q_{bfi}}{T_{bfi}} \geq 0 \Rightarrow \frac{\delta Q_{bfi}}{T_{bfi}} \geq -dS \Rightarrow -\delta Q_{bfi} \leq T_{bfi}\, dS \end{aligned}\right\} \Rightarrow \boxed{\delta W_{efi} \leq -d\mathcal{U} + T_{bfi}\, dS}$$

$$\delta Q = d\mathcal{U} - \delta W \Rightarrow -d\mathcal{U} = -\delta Q - \delta W$$

$$\delta W_{efi} \leq -\delta Q - \delta W + T_{bfi}\, dS$$

$$\boxed{[\delta W_{efi}]_M = -\delta Q - \delta W + T_{bfi}\, dS}$$

maximoa berdintza bete denean
berdintza bada $\Rightarrow$ prozesua itzulgarria

$$\delta Q = T dS$$

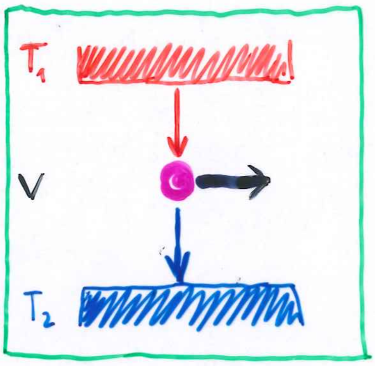
$$[\delta W_{efi}]_M = -T dS - \delta W + T_{bfi}\, dS$$

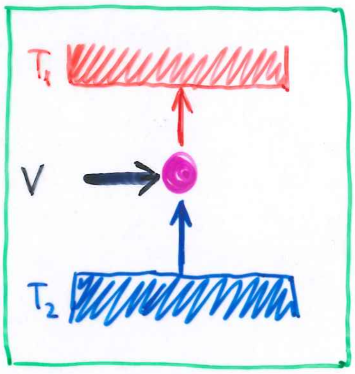
$$= -T dS \left(1 - \frac{T_{bfi}}{T}\right) - \delta W$$

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

$\begin{cases} (-\delta W) & \text{zuzenean ateratako lana} \\ (-\delta Q) & \text{zuzenean ateratako beroaren frakzioa} \end{cases}$

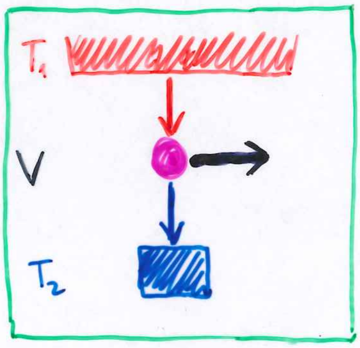
LAN MAXIMOAREKIN LOTURIKO ZENBAIT ADIBIDE : "PROBLEMA-MOTAK"

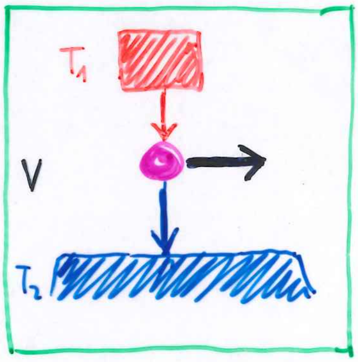


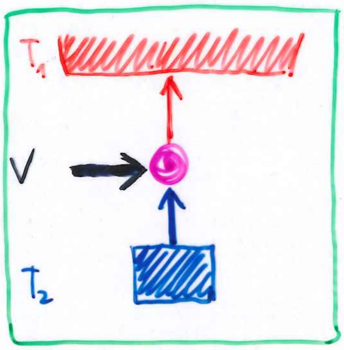


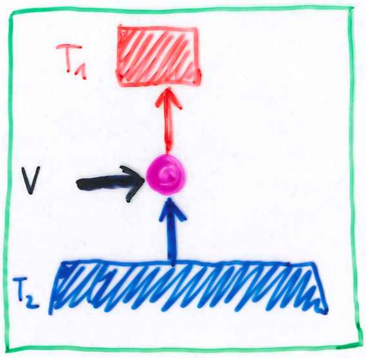
SISTEMAREN (BERO-ITURRIA EZ DENAREN) BERO-AHALMENA JAKINA DA : C, C_V, C_P

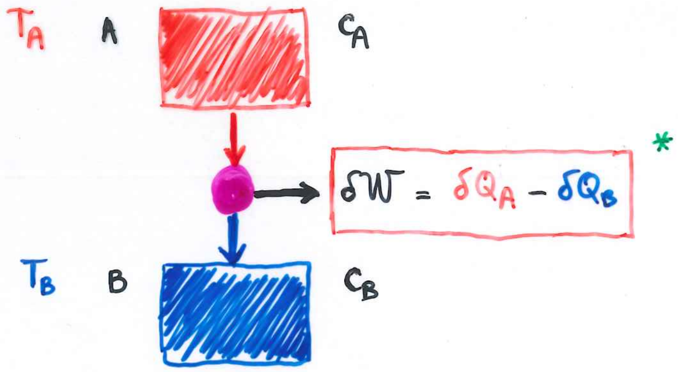
SISTEMAREN TENPERATURA ALDATUZ JOANGO DA !!!!











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

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

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

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

BALDINTZA!!

$$\frac{c_A}{T_A} dT_A + \frac{c_B}{T_B} dT_B = 0$$

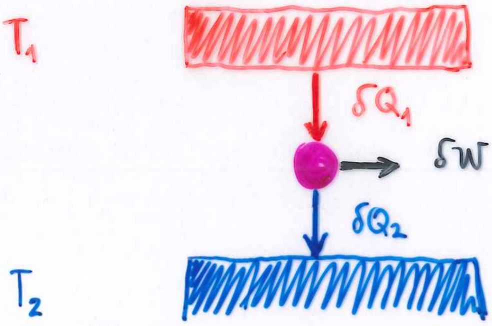
$$c_A \ln \frac{T_f}{T_A} + c_B \ln \frac{T_f}{T_B} = 0 \Rightarrow \left[\frac{T_f}{T_B}\right]^{c_B} = \left[\frac{T_A}{T_f}\right]^{c_A} \Rightarrow \boxed{T_f = \left[T_B^{c_B}\, T_A^{c_A}\right]^{\frac{1}{c_A + c_B}}}$$

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

T_f

* BALIO GUZTIAK POSITIBOAK DIRA, BADAKIGULAKO ZEIN NORANZKOAK DIREN !!! (GEZIAK)

$C_p = a + bT$



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

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

$$\int \delta W = \int \delta Q_1 - \int \delta Q_2 \Rightarrow \boxed{W = Q_1 - Q_2}$$

HAUXE DA KALKULATU BEHARREKOA

$$\delta Q_2 = T_2\, dS_2$$

$$\boxed{dS_0 = 0} \Rightarrow dS_0 = dS_1 + dS_2 \Rightarrow -dS_1 = dS_2 \quad \Big\} \quad \boxed{\delta Q_2 = -T_2\, dS_1}$$

BALDINTZA!!

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

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

ALDAGAI NAHASIA?

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

ALDAGAI MUTUA

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

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

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

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

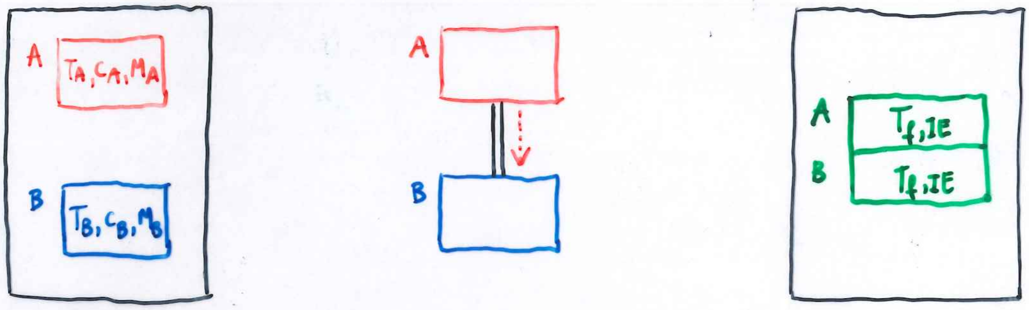
$$\left(1 - \frac{T_2}{T_1}\right)(-\delta Q)$$

* BALIO GUZTIAK POSITIBOAK DIRA, BADAKIGULAKO ZEIN NORANZKOTASUNA DIREN!!! (GEZIAK)

BI SISTEMEN ARTEKO TEMPERATURA-DIFERENTZIA : LANA EGITEKO APROBETXA DAITEKE

SISTEMEN OREKA-EGOERA : EGOERA TERMIKOA ; TENPERATURA

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



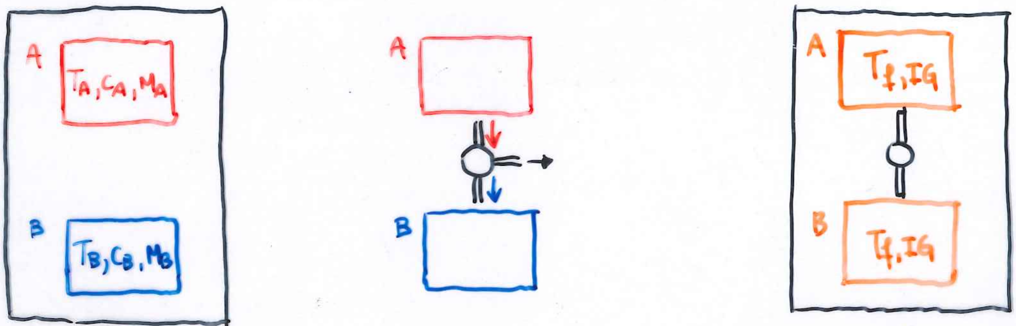
(i) (f)

$$Q_{osoa} = Q_A + Q_B \;;\; Q_{osoa} = 0 \Rightarrow \boxed{\begin{matrix} Q_A + Q_B = 0 \\ \Delta S_A + \Delta S_B > 0 \end{matrix}} \longrightarrow T_{f,IE}$$

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

$$\left.\begin{matrix} Q_i = \int_{T_i}^{T_{f,IE}} c_i \, dT_i \\ \Delta S_i = \int_{T_i}^{T_{f,IE}} \frac{c_i}{T_i} dT_i \end{matrix}\right\} \quad i = A, B$$

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



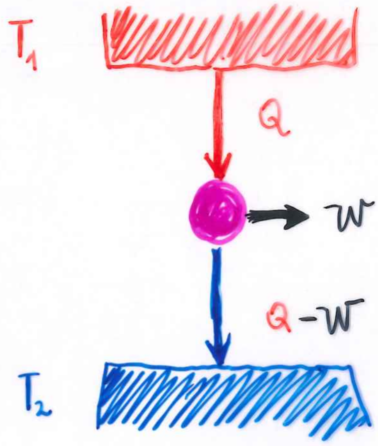
(i) (f)

$$Q_{osoa} = Q_A + Q_B \;;\; Q_{osoa} \neq 0 \; (\equiv W_{max}) \Rightarrow \boxed{\begin{matrix} Q_A + Q_B < 0 \\ \Delta S_A + \Delta S_B = 0 \end{matrix}} \rightarrow T_{f,IG} \downarrow$$

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

$$\left.\begin{matrix} Q_i = \int_{T_i}^{T_{f,IG}} c_i \, dT_i \\ \Delta S_i = \int_{T_i}^{T_{f,IG}} \frac{c_i}{T_i} dT_i \end{matrix}\right\} \quad i = A, B$$

- LAN MAXIMOA:



UNIBERTSOARI DAGOKION ENTROPIA-ALDAKUNTZA:

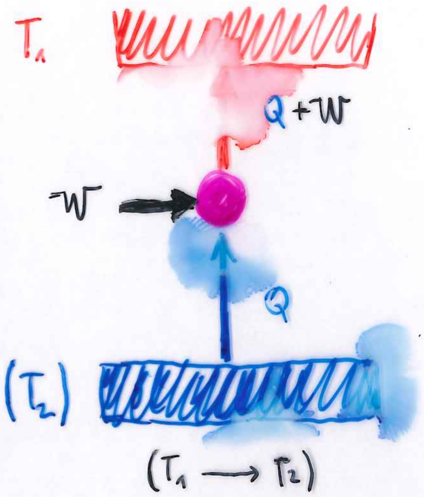
$$\Delta S_u = \Delta S_u + \Delta S_{ing} \geq 0$$

$$= 0 + \left(\Delta S_{T_1} + \Delta S_{T_2}\right) \geq 0 \qquad \left(\Delta S = \frac{Q}{T}\right)$$

$$= \left(-\frac{Q}{T_1} + \frac{Q-W}{T_2}\right) \geq 0$$

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

- LAN MINIMOA: GORPUTZ FINITOA T_1-ETIK T_2-RA HOZTEKO (?)



UNIBERTSOARI DAGOKION ENTROPIA-ALDAKUNTZA:

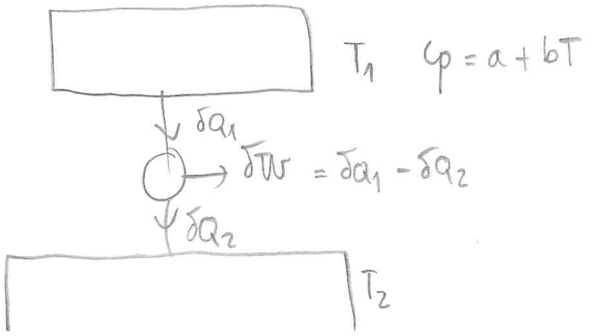
$$\Delta S_u = \Delta S_s + \Delta S_{ing} \geq 0$$

$$= 0 + \left(\Delta S_{T_1} + (S_2 - S_1)\right) \geq 0$$

$$= + \left(\frac{Q+W}{T_1} + (S_2 - S_1)\right) \geq 0$$

$$W \geq T_1 (S_2 - S_1) - Q$$

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



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

$$\int \delta W = \int \delta Q_1 - \int \delta Q_2 \Rightarrow \boxed{W = Q_1 - Q_2}$$ balio absolutuak

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

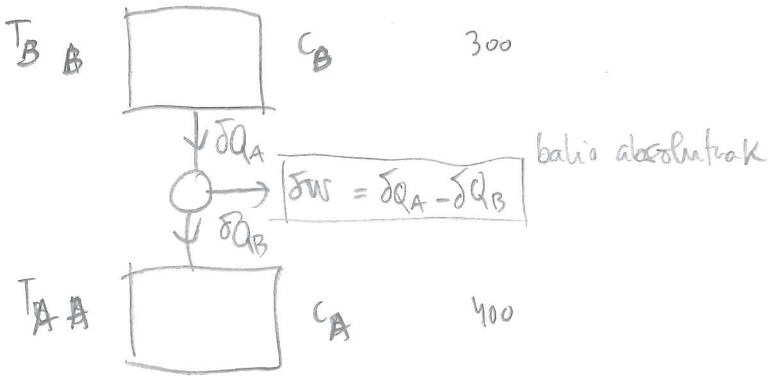
$$dS_1 = \frac{c_p}{T_1} dT_1$$

integratu gabe.

$$\delta Q_2 = -T_2 \frac{c_p}{T} dT_1 \Rightarrow Q_2 = -T_2 \int \frac{c_p}{T} dT \Rightarrow \cancel{\boxed{Q_2 = -T_2\, c_p \ln\left(\frac{T_2}{T_1}\right)}}$$

$$\delta Q_1 = c_p\, dT_1 \Rightarrow Q_1 = \int c_p\, dT \Rightarrow Q_1 = c_p \Delta T \Rightarrow \cancel{\boxed{Q_1 = c_p (T_2 - T_1)}}$$

$$W = c_p \left[(T_1 - T_2) + T_2 \ln\left(\frac{T_1}{T_2}\right) \right]$$



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

$$dS = 0 \Rightarrow dS_1 + dS_2 = 0 \qquad \frac{c_B}{T_B} dT_B + \frac{c_A}{T_A} dT_A = 0$$

$$\Delta S = 0 \Rightarrow c_B \ln \frac{T_f}{T_B} + c_A \ln \frac{T_f}{T_A} = 0 \Rightarrow \ln \left[\frac{T_f^{c_B}}{T_B^{c_B}} \cdot \frac{T_f^{c_A}}{T_A^{c_A}} \right] = 1$$

eta eraitzuletinean

aipatu zein den baldintza eta zer lortzeko den

$$T_f^{c_A + c_B} = T_B^{c_B} T_A^{c_A}$$

$$\boxed{T_f = \left[T_B^{c_B} T_A^{c_A} \right]^{\frac{1}{c_A + c_B}}}$$

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

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

$$- c_B (T_f - T_B) - c_A (T_f - T_A)$$

eta gero zeinua aldatu.

ENERGIA EZ ERABILGARRIA E

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

GOI-TENPERATURAN DAGOEN BERO-ITURRITIK Q ENERGIA BERO MODUAN ATERATZEAN, ESKURA DUGUN TENPERATURARIK BAXUENA T_0 IZANIK

ATERA DAITEKEEN ENERGIA LAN MODUAN W_{max} LAN MAXIMOA DA.

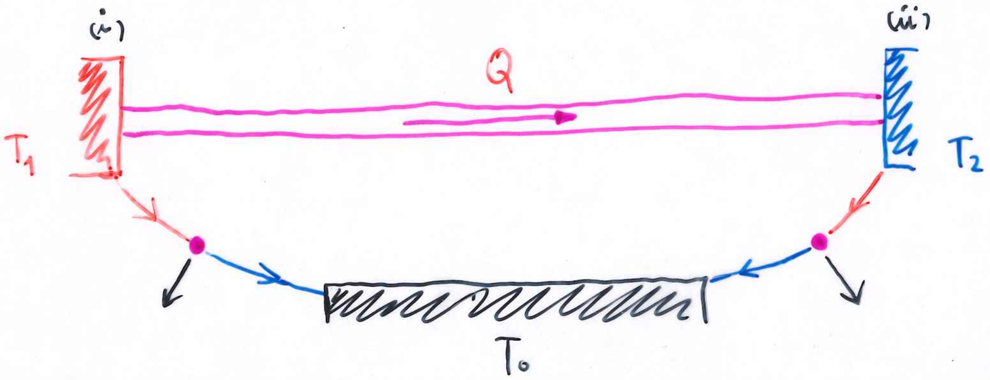
BERAU DA LAN MODUAN ERABILTZEKO ESKURA DUGUN (ESKURA DEZAKEGUN) W_{max}, HOTS; BERO ERAN SOILIK T_0 BERO-ITURRITIK ATERA DAITEKEEN ENERGIA EZIN DA LANA EGITEKO ERABILI

ONDORIOA:

ENERGIAK BADU IZAERA: LANERAKO ERABIL DAITEKE
LANERAKO EZIN ERABIL DAITEKE

ZENBAIT KASUTAN LANA ATERA DAITEKE ETA BESTE ZENBAIT KASUTAN EZ

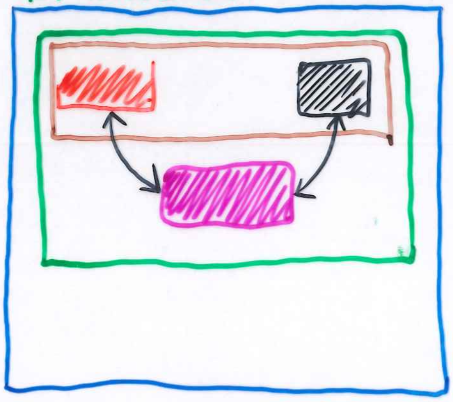
TENPERATURA-GRADIENTE FINITUAREN ONDORIOZKO BERO-GARRAIO ITZULEZINA:



$$W_{max}^{(i)} = Q\left(1 - \frac{T_0}{T_1}\right) \qquad W_{max}^{(ii)} = Q\left(1 - \frac{T_0}{T_2}\right)$$

$$\boxed{E = T_0\left(\frac{Q}{T_2} - \frac{Q}{T_1}\right)} \qquad \boxed{E = T_0\,\Delta S_{irr}}$$

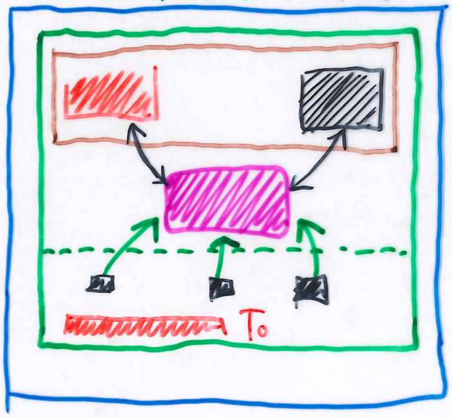
ERA ITZULEZINEAN : PROZESUA BEREZ GERTATU DA



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

$$\Delta S_0 = (S_f - S_i) + \Delta S_{ing.H} > 0 \; (S_f - S_i)$$

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



$$\Delta S_0 = \{(S_f - S_i) + \Delta S_{ing.H}\} + \Delta S_{ing.L}$$

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

$(S_f - S_i) > 0 \Rightarrow \Delta S_{ing.L} < 0 \Rightarrow T_0$ BERO-ITURRIAK E ENERGIA $(\longrightarrow)$

BAINA AURREKO BUKAERAKO EGORARA ERAMAN BEHAR DUGUNEZ SISTEMA (S + I.H)

E ENERGIA BERORI MAKINA BERRIETARA LAN MODUAN PASATU DA , BERAZ.

ESKU ARTEAN DUGUN $\boxed{\text{SISTEMAN / ING. HURBILEAN}}$ ERA ITZULEZINEAN GERTATU DIREN ALDAKETAK, ERA ITZULGARRIAN LORTZEAN , HORRETARAKO ERABILITAKO BERO-ITURRI LAGUNAKETIK ATERAKO DEN BEROA LAN MODUAN LAN-ITURRI LAGUNERA PASATUKO DA

LAN MODUAN ERABILGARRIA ZEN

EZ DA LAN MODUAN ERABILGARRIA

$$\boxed{E = T_0 (S_f - S_i)}$$

" 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

$$\boxed{E = T_0 \, \Delta S_u}$$

LOR DAITEKEEN TENPERATURARIK BAXUENEKO BERO-ITURRIA

ENERGIA "DEGRADATUZ" DOA !!!

KALITATE HANDIKO ENERGIA ; ENTROPIA BAXUKO ENERGIA

DEGRADAZIOA ↓ BEREZKO PROZESUA ↓

KALITATE TXIKIKO ENERGIA ; ENTROPIA ALTUKO ENERGIA