FORMALISMO ALDAKETA

1.10 - I POSTULATUA
1.9 - TERMODINAMIKAREN OINARRIZKO PROBLEMA (ADIBIDE KONKRETUA, ADIBIDE OROKORRA)
- II POSTULATUA
- III POSTULATUA

- PROZESUAK : OINARRIZKO EKUAZIOAREN DIFERENTZIALA
  - 2.1, 2.3 - PARAMETRO INTENTSIBOAK
  - 2.2, 2.4 - EGOERA-EKUAZIOAK
  - 2.5 - OREKA-EGOERAREN AZTERKETA, BARNE-LOTURAK ASKATUTAKOAN
    - OROKORRA
    - 2.7, 2.8, 2.9 - BI ADIBIDE

- OINARRIZKO EKUAZIOAREN ERAIKUNTZA
  - 3.1 - EULER-REN EKUAZIOA
  - 3.2 - GIBBS/DUHEM-EN ERLAZIOA
    - OSAGAI BAKARREKO SISTEMA
    - 3.3 (Laburpena) - OSAGAI ANITZEKO SISTEMA : OROKORREAN
      ERA DIFERENTZIALEAN
  - OINARRIZKO EKUAZIOA ERAIKITZEKO METODOA
    - ZENBAIT ADIBIDE

- AUKERAKO FORMULAZIOAK
  - 5.1 - PRINTZIPIOEN ARTEKO BALIOKIDETASUNA : ENERGIA/ENTROPIA
    - FISIKOKI
    - MATEMATIKOKI
  - 5.2 - LEGENDRE-REN TRANSFORMAZIOAK
    - KUALITATIBOKI
    - MATEMATIKOKI
    - 5.3, (5.4) - FISIKOKI : POTENTZIAL TERMODINAMIKOAK ; F, G, H
      - DEFINIZIOA
      - 6.1; 6.2, 6.3, 6.4 - PRINTZIPIOEN ARTEKO BALIOKIDETASUNA
      - POTENTZIALAREN ADIBIDEA

- 7.1 - MAXWELL-EN ERLAZIOAK
  - 7.2 - ERLAZIOAK
  - 7.3 - KALKULU TERMODINAMIKOA
  - 7.4 - ADIBIDEAK
    - 7.5 - ENTROPIAREN EKUAZIOAK
    - ENERGIAREN EKUAZIOAK
    - BERO-AHALMENAREN EKUAZIOAK
    - PROZESUAK

Ariketak

2.

I POSTULATUA : OREKA-EGOEREN DEFINIZIOA

II POSTULATUA : ENTROPIA FUNTZIOAREN DEFINIZIOA

III POSTULATUA : ENTROPIA FUNTZIOAREN EZAUGARRIAK

IV POSTULATUA : ENTROPIA FUNTZIOAREN PROPIETATEAK (TENPERATURA BAXUAK)

1.

0 PRINTZIPIOA : TENPERATURA, OREKA TERMIKOA

1 PRINTZIPIOA : ENERGIAREN KONTZERBAZIOAREN PRINTZIPIOA

2 PRINTZIPIOA : IZADIKO ASIMETRIA

3 PRINTZIPIOA : EZ DAGO TENPERATURA ABSOLUTUAREN ZERORIK

* I POSTULATUA : OREKA-EGOEREN DEFINIZIOA

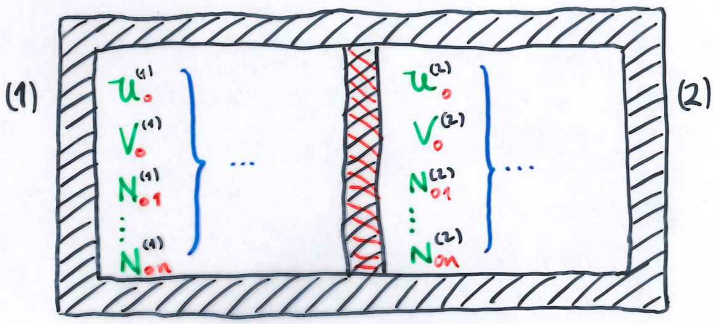
SISTEMA BAKUNEI DAGOZKIEN EGOERA BEREZIAK EXISTITZEN DIRA, IKUSPEGI MAKROSKOPIKOA ERABILIZ ONDOKO MAGNITUDEZ EZAUGARRITUKO DITUGU:

$$\left.\begin{array}{ll} U & \text{BARNE-ENERGIA} \\ V & \text{BOLUMENA} \\ N_i & \text{OSAGAI KIMIKOEN MOL-KOPURUA} \end{array}\right\} \text{MAGNITUDE ESTENTSIBOAK, SOILIK!!}$$

OREKA-EGOERA LOTUA : KANPOTIKO ERAGINEN BATEK FINKATUTAKOA

* TERMODINAMIKAREN OINARRIZKO PROBLEMA

(i) SISTEMA BAKUNEZ OSATURIKO SISTEMA KONPOSATUA



(ii) OROKORTUZ : ERA ABSTRAKTOAN, EDOZEIN KASUTARAKO BALIAGARRIA

OREKA-EGOERA LOTUAN DAGOEN SISTEMA ITXIAK
BARNE-LOTURAREN BAT ASKATUTAKOAN
ZEIN OREKA-EGOERATAN BUKATUKO DU ?

HASIERAKO OREKA-EGOERA LOTUA
BARNE-LOTURAREN BATEN ASKAPENA [BEREZKO PROZESUA MARTXAN JARRI]
BUKAERAKO OREKA-EGOERA $\left\{\begin{array}{l}\text{LOTUA}\\\text{EZ-LOTUA}\end{array}\right.$

ITXIDURA-BALDINTZAK

* II POSTULATUA : ENTROPIA FUNTZIOAREN ESISTENTZIA (PRINTZIPIO EXTREMALA)

S IKURREZ EZAUGARRITUTAKO ENTROPIA FUNTZIOA EXISTITZEN DA, NON:

- EDOZEIN SISTEMA KONPOSATURI DAGOKION PARAMETRO ESTENTSIBO GUZTIEN FUNTZIOA DEN,
- SISTEMA KONPOSATUAREN OREKA-EGOERA GUZTIETAN DEFINITURIK IZANGO DEN,
- UNDOKO PROPIETATEAK BETEKO DITUEN:

  BARNE-LOTURARIK EZ DAGOEN KASUAN
  PARAMETRO ESTENTSIBOEN BALIOEK ENTROPIA MAXIMIZATUKO DUTE
  MAXIMIZAZIOA OREKA-EGOERA LOTUEKIKO BURUTU BEHAR DA

OINARRIZKO EKUAZIOA

* III POSTULATUA : ENTROPIA FUNTZIOAREN EZAUGARRIAK

SISTEMA KONPOSATUAREN ENTROPIA:

AZPISISTEMEKIKO BATUKORRA DA
FUNTZIO JARRAIA ETA DERIBAGARRIA
BARNE-ENERGIAREN FUNTZIO MONOTONO GORAKORRA

- EZAUGARRIEN ONDORIOAK:

(1) - BATUKORRA

(a) - $S = \sum_{\alpha=1}^{N} S^{(\alpha)}$

(b) - $S^{(\alpha)} = S^{(\alpha)}(U^{(\alpha)}, V^{(\alpha)}, N_1^{(\alpha)}, \dots)$

(c) - LEHEN ORDENAKO FUNTZIO HOMOGENEOA : $S(\lambda U, \lambda V, \dots) = \lambda S(U, V, \dots)$

ESKALAKETA

(2) - MONOTONO GORAKORRA

- $\left(\frac{\partial S}{\partial U}\right)_{V, N_1, \dots} > 0$

(3) - JARRAITASUNA, DERIBAGARRITASUNA

- $S(U, V, N_1, \dots) \longrightarrow U(S, V, N_1, \dots)$ BALIOKIDETASUNA

– PROZESUEN ADIERAZPENA: OINARRIZKO EKUAZIOAREN DIFERENTZIALAREN BIDEZ

$$\boxed{U = U(S, V, N_1, \dots N_n)}$$

$$\boxed{dU = \left(\frac{\partial U}{\partial S}\right)_{V,N_1,\dots,N_n} dS + \left(\frac{\partial U}{\partial V}\right)_{S,N_1,\dots,N_n} dV + \left(\frac{\partial U}{\partial N_1}\right)_{S,V,\dots N_n} dN_1 + \dots + \left(\frac{\partial U}{\partial N_n}\right)_{S,V,N_1\dots} dN_n}$$

PARAMETRO INTENTSIBOAK / EGOERA-EKUAZIOAK

$$\left.\begin{aligned} T &\equiv \left(\frac{\partial U}{\partial S}\right)_{V,N_1,\dots} = T(S, V, N_1, \dots) \\ P &\equiv -\left(\frac{\partial U}{\partial V}\right)_{S,N_1,\dots} = P(S, V, N_1, \dots) \\ \mu_K &\equiv \left(\frac{\partial U}{\partial N_K}\right)_{S,V,\dots} = \mu_K(S, V, N_1, \dots) \end{aligned}\right\} \quad \boxed{Y_j \equiv \left(\frac{\partial U}{\partial X_j}\right)_{S,\dots}}$$

$$\boxed{dU = T\,dS - p\,dV + \sum_{K=1}^{N} \mu_K\, dN_K}$$

ZERO ORDENAKO FUNTZIO HOMOGENEOAK: PROPIETATEA

$$\boxed{Y(\lambda S, \lambda V, \lambda N_1, \dots, \lambda N_n) = Y(S, V, N_1, \dots, N_n)}$$

"AURREKO FORMALISMOAREKIKO" ALDERAKETA: LEHENENGO PRINTZIPIOA

$$\boxed{dU = T\,dS + \sum_{j=1}^{N} P_j\, dX_j}$$

BARNE-ENERGIA $\rightsquigarrow$ LANA ("TERMIKOA", EDOZEIN MOTATAKOA)

$\mathcal{U}$ ETA S ADIERAZPENAK SIMETRIKOAK DIRA
(BALIOKIDEAK !!)

$$\mathcal{U} = \mathcal{U}(S, X_1, \dots, X_n) \qquad S \equiv X_0$$

$$\mathcal{U} = \mathcal{U}(X_0, X_1, \dots, X_n)$$

$$P_j \equiv \left(\frac{\partial \mathcal{U}}{\partial X_j}\right)_{X_0, \dots, X_n} \qquad j = 0, \dots, n$$

$$\boxed{d\mathcal{U} = T\, dS + \sum_{j=1}^{N} P_j\, dX_j}$$

$$S = S(\mathcal{U}, X_1, \dots, X_n) \qquad \mathcal{U} \equiv X_0$$

$$S = S(X_0, X_1, \dots, X_n)$$

$$F_j \equiv \left(\frac{\partial S}{\partial X_j}\right)_{X_0, \dots X_n} \qquad j = 0, \dots, n$$

$$\boxed{dS = \sum_{K=0}^{N} F_K\, dX_K}$$

$$\boxed{F_0 \equiv \frac{1}{T_0} \quad , \quad F_K \equiv -\frac{P_K}{T}}$$

ADIERAZPENEN ARTEKO LOTURA !!

ADIBIDEAK : OINARRIZKO EKUAZIOTIK EGOERA-EKUAZIOAREN ONDORIOZTAPENA

ADIERAZPEN : ENERGETIKOAN

ENTROPIKOAN

(i) $$u = \left(\frac{v_0\theta}{R^2}\right)\frac{S^3}{NV}$$

(ii) $$u = \left(\frac{v_0^{1/2}\theta}{R^{3/2}}\right)\frac{s^{5/2}}{v^{1/2}}$$

adibideak

TERMODINAMIKAREN OINARRIZKO PROBLEMAREN EBAZPENA: PRINTZIPIO ESTREMALA

OREKA-EGOERA LOTUAN DAGOEN SISTEMA ITXIAK (KONPOSATUA, BAKUNA)
BARNE-LOTURAREN BAT ASKATUTAKOAN (TERMIKOA, MEKANIKOA, KIMIKOA, ...)
ZEIN OREKA-EGOERATAN BUKATUKO DU?

* Hurrengo trasparentzia erabiliz era orokorrean dena azaldu.
* Ondoren, prozedura osoa argitzeko asmotan, bi adibide
  - Temperatura : $S=S(U,V,N)$
  - Temperatura eta presioa : $U=U(S,V,N)$

adibideak C.2.6.3/C.2.6.4

Hasierako oreka-egoera

guztiz karakterizatuta dago :

oinarrizko ekuazioa / egoera-ekuazioak ezagunak dira

aldagai estentsibo guztien balioak ezagunak dira

$$S^{(j)} = S^{(j)}(U^{(j)}, V^{(j)}, N_1^{(j)}, \ldots, N_t^{(j)}) \qquad \left\{ \begin{array}{l} \dfrac{1}{T^{(j)}} = \dfrac{1}{T^{(j)}}(U, V, N_1, \ldots, N_t) \\ \dfrac{P^{(j)}}{T^{(j)}} = \dfrac{P^{(j)}}{T^{(j)}}(U, V, N_1, \ldots, N_t) \\ \dfrac{\mu_i^{(j)}}{T^{(j)}} = \dfrac{\mu_i^{(j)}}{T^{(j)}}(U, V, N_1, \ldots, N_t) \quad i = 1, \ldots, t \end{array} \right\} \quad j = 1, \ldots, n$$

$j = 1, \ldots, n$ azpisistema-kopurua

$i = 1, \ldots, t$ osagai-kopurua

$\{U_0^{(j)}, V_0^{(j)}, N_{01}^{(j)}, \ldots N_{0t}^{(j)}\}$ $j = 1, \ldots, n$ **HASIERAKO EGOERA EZAGUNA**

barne-loturaren bat askatuz.

PROZESUA ERAGIN DUGU ;

hots, sistema konposatuaren askatasun-graduren bat martxan jarriz

Askatasun-graduarekin loturik dagoen bikotearen balioak (Y, X) [=(intentsibo, estentsibo)] aldatuko dira :

sistema konposatuko azpisistemek X aldagaia trukatuko dute , itxidura-baldintzek utziko dieten eran,

Y aldagai intentsiboen balioak azpisistemetan berdindu arte , ENTROPIA maximizatzeko asmoz (**BERDINDUKO ez BADIRA : OREKA-EGOERA LOKALA** $\boxed{S \text{ ez MAX}}$

$\{X^{(j)'}\}$ banaketa berriak (itxidura-baldintzak) $\Rightarrow \{Y^{(1)} = Y^{(2)} = \ldots = Y^{(j)}\}$ oreka-egoera berria ekarriko du, zeinean ENTROPIA maximoa den

$$\boxed{S = \sum_{j=1}^{n} S^{(j)}(U^{(j)}, V^{(j)}, N_1^{(j)}, \ldots N_t^{(j)})} \; ; \qquad dS = \sum_{j=1}^{n} \left\{ \left(\frac{\partial S^{(j)}}{\partial U^{(j)}}\right)_{V^{j}, N_k^{j}} dU^{(j)} + \left(\frac{\partial S^{(j)}}{\partial V^{(j)}}\right)_{U^{j}, N_k^{j}} dV^{(j)} + \sum_{k=1}^{t} \left(\frac{\partial S^{j}}{\partial N_k^{(j)}}\right)_{U^{j}, V^{j}, N_\ell^{j}} dN_k^{(j)} \right\}$$

$dS = 0$ | $(d^2S < 0)$!

$$0 = \sum_{j=1}^{n} \left\{ \frac{1}{T^{(j)}} dU^{(j)} + \frac{P^{(j)}}{T^{(j)}} dV^{(j)} - \left(\sum_{k=1}^{t} \frac{\mu_k^{(j)}}{T^{(j)}} dN_k^{(j)} \right) \right\}$$

$\sum_{j=1}^{n} U^{(j)} = kte$ $\sum_{j=1}^{n} V^{(j)} = kte$ $\sum_{j=1}^{n} N_k^{(j)} = kte \quad k = 1, \ldots, t$	itxidura-baldintzak

hauxe da ebatzi beharreko sistema

Bukaerako oreka-egoera

guztiz karakterizatu behar dugu:

oinarrizko ekuazioa / egoera-ekuazioak ezagunak dira

aldagai estentsibo guztien balio berriak ezagutu behar dira

$$S^{(j)} = S^{(j)}(U^{(j)}, V^{(j)}, N_1^{(j)}, \ldots, N_t^{(j)}) \qquad \left\{ \begin{array}{l} \dfrac{1}{T^{(j)}} = \dfrac{1}{T^{(j)}}(U, V, N_1, \ldots N_t)\Big]_1 \\ \dfrac{P^{(j)}}{T^{(j)}} = \dfrac{P^{(j)}}{T^{(j)}}(U, V, N_1, \ldots, N_t)\Big]_1 \\ \dfrac{\mu_i^{(j)}}{T^{(j)}} = \dfrac{\mu_i^{(j)}}{T^{(j)}}(U, V, N_1, \ldots, N_t)\Big]_1 \quad i = 1, \ldots, t \end{array} \right\} \quad j = 1, \ldots, n$$

$\{U_1^{(j)}, V_1^{(j)}, N_{11}^{(j)} \ldots N_{1t}^{(j)}\}$ $j = 1, \ldots, n$ $\rightarrow$ oreka-egoera berria

* EULER-REN EKUAZIOA (OINARRIZKO EKUAZIOA, 1. ORDENAKO FUNTZIO HOMOGENEOA)

$$U(\lambda S, \lambda V, \lambda N_1, \dots) = \lambda U(S, V, N_1, \dots)$$

$$\frac{d}{d\lambda}\{ \quad \}$$

$$= U(S, V, N, \dots)\frac{d\lambda}{d\lambda}$$

$$= U(S, V, N, \dots)$$

$$\left(\frac{\partial U}{\partial(\lambda S)}\right)\left(\frac{\partial(\lambda S)}{\partial \lambda}\right)d\lambda + \dots + \left(\frac{\partial U}{\partial(\lambda N)}\right)\left(\frac{\partial(\lambda N)}{\partial \lambda}\right)d\lambda =$$

$$\frac{1}{d\lambda} \quad \left\{\left(\frac{\partial U}{\partial \lambda S}\right)\underset{S}{\left(\frac{\partial(\lambda S)}{\partial \lambda}\right)} + \dots + \left(\frac{\partial U}{\partial(\lambda N)}\right)\underset{N}{\left(\frac{\partial(\lambda N)}{\partial \lambda}\right)}\right\}d\lambda =$$

$$\left(\frac{\partial U}{\partial(\lambda S)}\right) \cdot S + \dots + \left(\frac{\partial U}{\partial(\lambda N)}\right) \cdot N =$$

$$\lambda = 1 \qquad \underset{T}{\left(\frac{\partial U}{\partial S}\right)} \cdot S + \underset{-p}{\left(\frac{\partial U}{\partial V}\right)} \cdot V + \dots + \underset{\mu}{\left(\frac{\partial U}{\partial N}\right)} \cdot N =$$

$$\boxed{T\cancel{d}S - p\cancel{d}V + \sum_{k=1}^{N-2} \mu_k \cancel{d}N_k = U(S, V, N_1, \dots)}$$

$$\boxed{\sum_{k=0}^{N} P_k X_k = U}$$

ADIERAZPEN ENERGETIKOA

$$\boxed{\sum_{k=0}^{N} F_k X_k = S}$$

ADIERAZPEN ENTROPIKOA

* GIBBS/DUHEM-EN ERLAZIOA

(PARAMETRO INTENTSIBOAK EZ DIRA INDEPEN.)
(LEHEN ORDENA HOMOGENEOTASUNAREN ON.)

(1) - ERA FORMALEAN :

(i) - $\mathcal{U} = \mathcal{U}(S, V, N)$

$u = u(s, v)$

$$\left.\begin{array}{l} T = T(s,v) \\ p = p(s,v) \\ \mu = \mu(s,v) \end{array}\right\} \begin{array}{l} \rightarrow s = s(T,v) \\ \rightarrow v = v(s,p) \end{array} \Bigg\} \Rightarrow \boxed{\mu = \mu(T,p)}$$

(ii) - $\mathcal{U} = \mathcal{U}(S, V, N_1, \ldots, N_n)$

$\mathcal{U} = \mathcal{U}(S, X_1, X_2, \ldots, X_n)$

$$P_K \equiv \left(\frac{\partial \mathcal{U}}{\partial X_K}\right)_{S, X \ldots} = P_K(S, X_1, \ldots)$$

$$\frac{1}{X_K}\left[\{S, X_1, \ldots, X_n\}\right]$$

$$P_K = P_K\left(S/X_K, X_1/X_K, \ldots, X_n/X_K\right) \rightarrow X_1/X_1 = 1$$

(ALDAGAI-KOPURUA) = EKUAZIO-KOPURUA − 1

(2) - EULER-REN EKUAZIOTIK ABIATUZ :

(iii) - $$d\left\{ \mathcal{U} = TS + \sum_{K=1}^{N} P_K X_K \right\}$$

$$d\mathcal{U} = TdS + SdT + \sum_{K=1}^{N} P_K dX_K + \sum_{K=1}^{N} dP_K \cdot X_K$$

$$\boxed{0 = SdT + \sum_{K=1}^{N} X_K dP_K}$$

$$\boxed{\sum_{K=1}^{N} X_K dP_K = 0}$$

ALDAKUNTZEN ARTEKO LOTURAK

G/D erlazioaren adibidea

LABURBILDUMA

EULER-REN EKUAZIOA

$$\sum_{K=0}^{N} P_K X_K = U \qquad \sum_{K=0}^{N} F_K X_K = S$$

$$F_K \equiv -\frac{P_K}{T} \qquad K = 1, \dots, n$$

GIBBS/DUHEM-EN ERLAZIOA

$$\sum_{K=0}^{N} X_K \, dP_K = 0 \qquad \sum_{K=0}^{N} X_K \, d\left(\frac{P_K}{T}\right) = 0$$

OINARRIZKO EKUAZIOAREN ERAIKUNTZA :

(1) - OINARRIZKO EKUAZIO MOLAR DIFERENTZIALA INTEGRATUZ

(2) - GIBBS/DUHEM-EN ERLAZIOA ERABILI FALTA DEN PARAMETRO INTENTSIBOA LORTZEKO EULER-REN EKUAZIOA ERBILI

FORMALISMO BERRIAREN LABURBILDUMA

$$\boxed{u = u(S,V,N)}$$

OINARRIZKO EKUAZIOA
INFORMAZIO OSOA

$$\boxed{\begin{aligned} T &= T(S,V,N) = T(s,v) \\ p &= p(S,V,N) = p(s,v) \\ \mu &= \mu(S,V,N) = \mu(s,v) \end{aligned}}$$

EGOERA-EKUAZIOAK
INFORMAZIO PARTZIALA
DENEK ⇒ INFORMAZIO OSOA

INFORMAZIO OSOA : SISTEMAREN DESKRIPZIO TERMODINAMIKO OSOA

INFORMAZIO PARTZIALA : OINARRIZKO EKUAZIOA ERAIKI, BAINA INTEGRAZIO KONSTANTEAREN FUNTZIOAN DAGO (DENA)

ERAIKITZEKO BI METODO DAGO!

$\{S, V, N\}$ ALDAGAI INDEPENDENTEEN SORTA : ALDAGAI ESTENTSIBOAK

$$u = u(S,V,N)$$

$$T = T(S,V,N) \Rightarrow S = S(T,V,N)$$

$$u = u(S(T,V,N),V,N)$$

$$u = u(T,V,N)$$

$$\boxed{u = u(T,V,N)}$$

KONTUZ!! BERAU EZ DA OINARRIZKO EKUAZIOA, INFORMAZIO FALTAN DAGO

$$\boxed{u = u\left(\left(\frac{\partial u}{\partial S}\right)_{VN}, V, N\right)}$$

(adierazpide grafikoa)

adibideak
- oin. eku. eraikun
- sistemen adibideak

AUKERAKO FORMULAZIOAK : BALIOKIDETASUNA

* AUKERAKO FORMULAZIOAK LORTZEKO BIDEA : "TRANSLAZIOA"

$$\left.\begin{array}{ll} \boxed{S = S(U, V, N_1, \dots, N_n) \quad \text{PRINTZIPIO ESTREMALA} \quad S_{max}} \\ U = U(S, V, N_1, \dots, N_n) \quad ? \quad ? \end{array}\right\} *$$

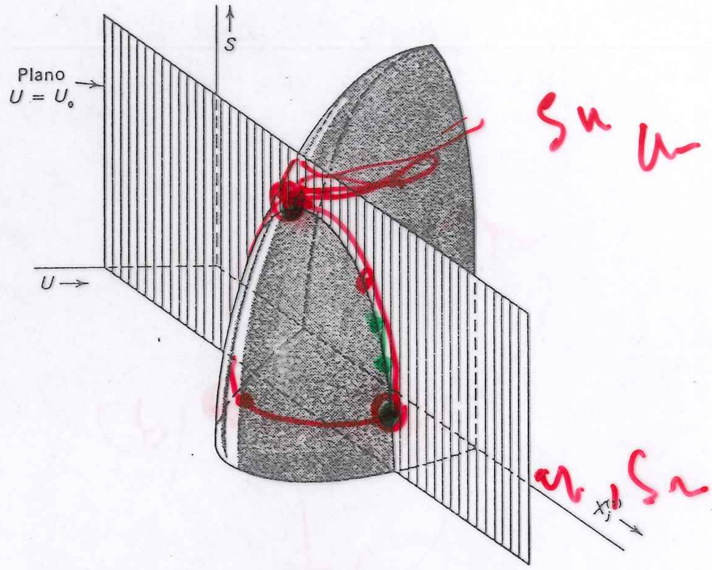
* $\boxed{\begin{array}{l}\text{KUALITATIBOKI} \\ \text{FISIKOKI} \\ \text{MATEMATIKOKI}\end{array}}$ $\Longrightarrow$ ENTROPIA ETA ENERGIAREN KASUAN

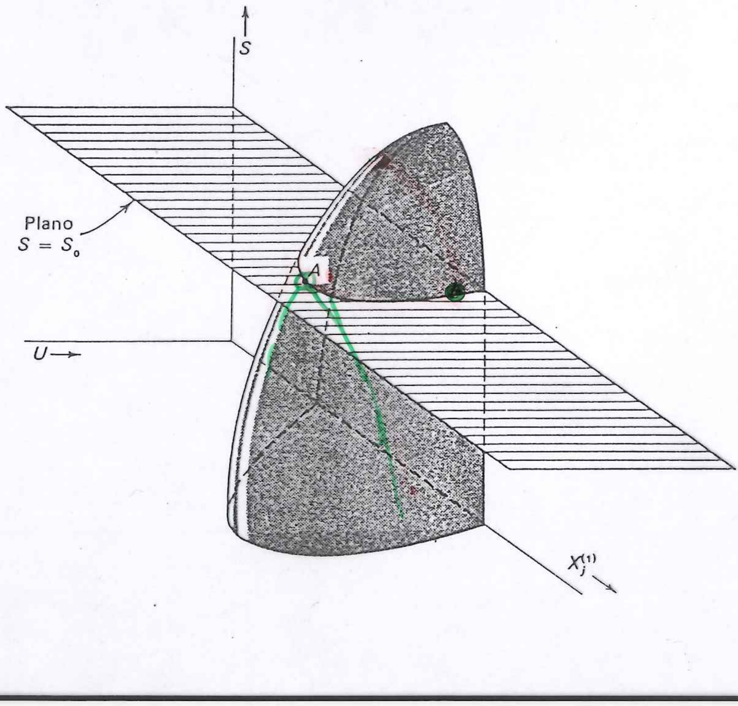
* BALDINTZA ESPERIMENTALEK FINKATUKO DUTE "FORMULAZIOA"

* ONARTU DUGUN BALDINTZA ANALITIKOARI ESKER :

$\left(\dfrac{\partial S}{\partial U}\right)_{\dots} > 0$ FORMULAZIOEN BALIOKIDETZA HONETAN DATZA PRINTZIPIO ESTREMALEI DAGOKIENEZ

(1) – KUALITATIBOKI : $\boxed{S_{max} \Leftrightarrow U_{min}}$





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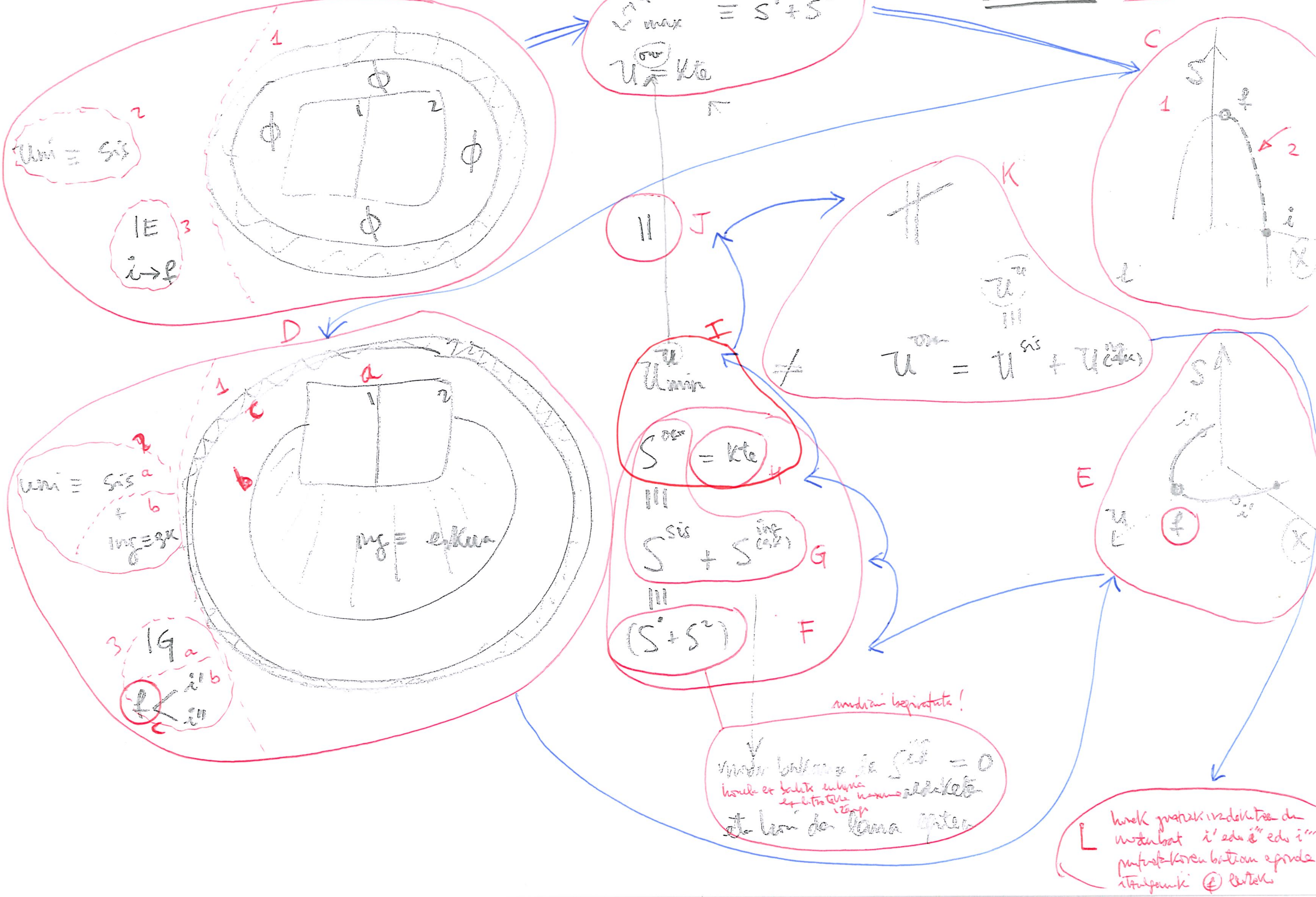
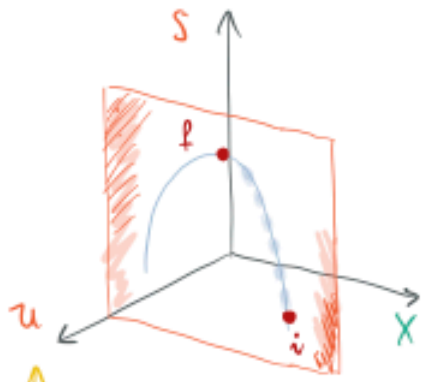

A
B
C
D
E
F
G
H
I
J
K
L
U = kte
Uni ≡ Sis
S = kte
S' + S²
ϕ
erdizi begiratuta!
hau da

IE

$U_{ni} \equiv Sis$

$$\boxed{\begin{aligned} S^{U}_{max} &= S^1 + S^2 \quad [2P] \\ U^{osoa} &= Kte \quad [1P] \end{aligned}}$$

$\neq$



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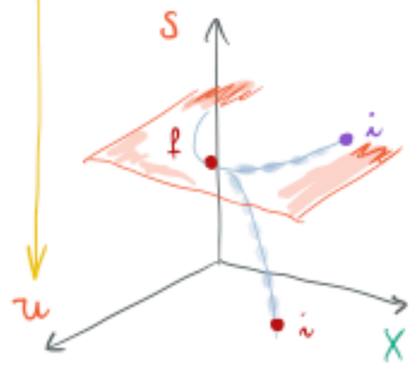
$$U^{osoa} = U^{sis} + U^{ing} \quad [1P]$$

$$\boxed{\begin{aligned} &U^{sis}_{min} \\ &S^{U} = Kte \quad [2P] \end{aligned}}$$

$$= S^{sis} + S^{ing} \equiv (S^1 + S^2)$$



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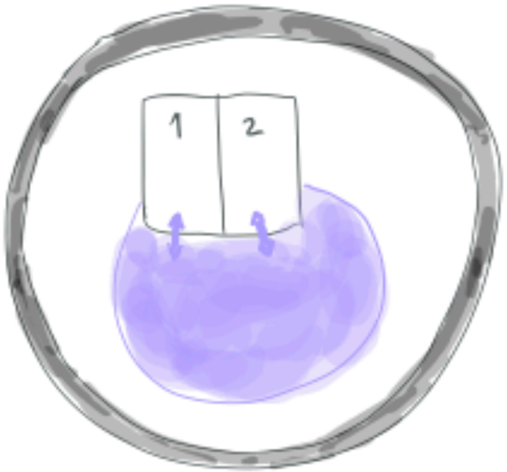


$U_{ni} \equiv Sis + ing$

(2) – "FISIKOKI" : $\boxed{S_{max} \Leftrightarrow U_{min}}$

(i) – $S_{max} \Rightarrow U_{min}$; $\boxed{\text{EZ } U_{min} \Rightarrow \text{EZ } S_{max}}$

S_{max} BAINA EZ U_{min}

(1) U GUTXITU : LANA ATEREAZ , S KONSTANTE IZANIK, ERA ITZULGARRIAN

(2) U HANDITU: AURREKO EGOERA BERRESKURATU, BEROA SARTUZ ,LANIK EGIN GABE

S HANDITU, BERAZ EZ ZEN MAXIMOA

(ii) – $U_{min} \Rightarrow S_{max}$; $\boxed{\text{EZ } S_{max} \Rightarrow \text{EZ } U_{min}}$

U_{min} BAINA EZ S_{max}

(1) S HANDITU ; BEROA SARTUZ, U KONSTANTE IZANIK, ERA ITZULGARRIAN

(2) S GUTXITU : AURREKO EGOERA BERRESKURATU , LANA ~~AT~~ERAZ, BEROA ~~TRUKATU GABE~~

U GUTXITU , BERAZ EZ ZEN MINIMOA

* LEHENENGO PRINTZIPIOA ERABILIZ, PROZESUA BI PAUSOTAN

$$\delta Q = dU - dW$$

(i) (1) $\delta Q = 0 \Rightarrow dU = \delta W \quad \delta W < 0 \Rightarrow dU < 0$

(2) $\delta W = 0 \Rightarrow \delta Q = dU \Rightarrow T dS = \delta Q \Rightarrow \boxed{dS = \frac{\delta Q}{T} > 0}$ EZ ZEN MAXIMOA

(ii) (1) $dU = 0 \Rightarrow \delta Q = -\delta W \quad \delta W < 0 \Rightarrow \delta Q > 0$

(2) $\delta W = 0 \Rightarrow \delta Q = dU \qquad \boxed{dU < 0}$ EZ ZEN MINIMOA

(3) – MATEMATIKOKI : $\boxed{S_{max} \Leftrightarrow U_{min}}$

$$S_{max} \Rightarrow \left\{ \left(\frac{\partial S}{\partial X}\right)_U = 0 \quad ; \quad \left(\frac{\partial^2 S}{\partial X^2}\right)_U < 0 \right\} \quad (1)$$

$$U_{min} \Rightarrow \left\{ \left(\frac{\partial U}{\partial X}\right)_S = 0 \quad ; \quad \left(\frac{\partial^2 U}{\partial X^2}\right)_S > 0 \right\} \quad (2)$$

(i) – (1) $\Rightarrow$ (2)

- $$\left(\frac{\partial U}{\partial X}\right)_S = -\frac{\left(\frac{\partial S}{\partial X}\right)_U}{\left(\frac{\partial S}{\partial U}\right)_X} = -\left(\frac{\partial U}{\partial S}\right)_X \left(\frac{\partial S}{\partial X}\right)_U = -T \underbrace{\left(\frac{\partial S}{\partial X}\right)_U}_{\left(\frac{\partial S}{\partial X}\right)_U = 0} = 0$$

- $$\left(\frac{\partial^2 U}{\partial X^2}\right)_S = \frac{\partial}{\partial X}\left[\left(\frac{\partial U}{\partial X}\right)_S\right] = \frac{\partial}{\partial X}\left[-\left(\frac{\partial U}{\partial S}\right)_X \left(\frac{\partial S}{\partial X}\right)_U\right] = -\left\{\left(\frac{\partial^2 U}{\partial X \partial S}\right)\left(\frac{\partial S}{\partial X}\right)_U + \left(\frac{\partial U}{\partial S}\right)_X \left(\frac{\partial^2 S}{\partial X^2}\right)_U\right\}$$

$$= -\left\{\left(\frac{\partial^2 U}{\partial X \partial S}\right) \cdot \underbrace{\left(\frac{\partial S}{\partial X}\right)_U}_{\left(\frac{\partial S}{\partial X}\right)_U = 0} + T\left(\frac{\partial^2 S}{\partial X^2}\right)_U\right\} \quad \Bigg\} \quad \left(\frac{\partial^2 U}{\partial X^2}\right)_S = -T\left(\frac{\partial^2 S}{\partial X^2}\right)_U \Rightarrow \left(\frac{\partial^2 U}{\partial X^2}\right)_S > 0$$

(ii) – (2) $\Rightarrow$ (1)

- $$\left(\frac{\partial S}{\partial X}\right)_U = -\frac{\left(\frac{\partial U}{\partial X}\right)_S}{\left(\frac{\partial U}{\partial S}\right)_X} = -\left(\frac{\partial U}{\partial X}\right)_S \left(\frac{\partial S}{\partial U}\right)_X = -\frac{1}{T}\underbrace{\left(\frac{\partial U}{\partial X}\right)_S}_{\left(\frac{\partial U}{\partial X}\right)_S = 0} = 0$$

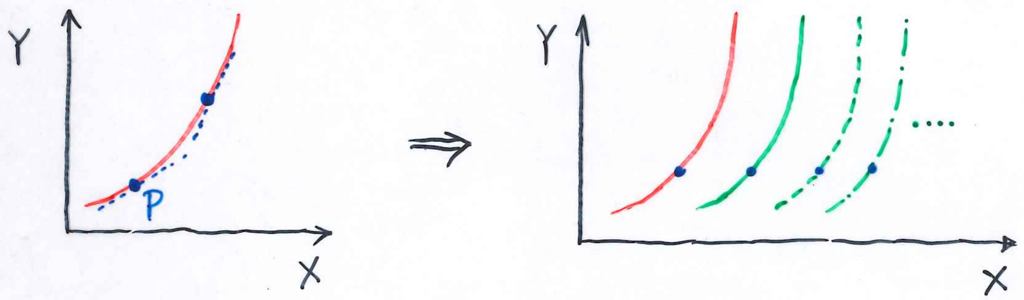
- $$\left(\frac{\partial^2 S}{\partial X^2}\right)_U = \frac{\partial}{\partial X}\left[\left(\frac{\partial S}{\partial X}\right)_U\right] = \frac{\partial}{\partial X}\left[-\left(\frac{\partial S}{\partial U}\right)_X \left(\frac{\partial U}{\partial X}\right)_S\right] = -\left\{\left(\frac{\partial^2 S}{\partial X \partial U}\right)\left(\frac{\partial U}{\partial X}\right)_S + \left(\frac{\partial S}{\partial U}\right)_X \left(\frac{\partial^2 U}{\partial X^2}\right)_S\right\}$$

$$= -\left\{\left(\frac{\partial^2 S}{\partial X \partial U}\right)\underbrace{\left(\frac{\partial U}{\partial X}\right)_S}_{\left(\frac{\partial U}{\partial X}\right)_S = 0} + \frac{1}{T}\left(\frac{\partial^2 U}{\partial X^2}\right)_S\right\} \quad \Bigg\} \quad \left(\frac{\partial^2 S}{\partial X^2}\right)_U = -\frac{1}{T}\left(\frac{\partial^2 U}{\partial X^2}\right)_S \Rightarrow \left(\frac{\partial^2 S}{\partial X^2}\right)_U < 0$$

LEGENDRE-REN TRANSFORMAZIOAK MATEMATIKOKI

$$\left.\begin{array}{l} Y=Y(X) \\ P=\dfrac{dY}{dX}\end{array}\right\} \Rightarrow \boxed{Y=Y(P)}$$ INFORMAZIORIK GALDU GABE

$$\left.\begin{array}{l} P=\dfrac{dY}{dX} \Rightarrow P=P(X) \Rightarrow X=X(P) \\ Y=Y(x) \end{array}\right\} \quad Y=Y(X(P)) \Rightarrow \boxed{Y=Y(P)}$$

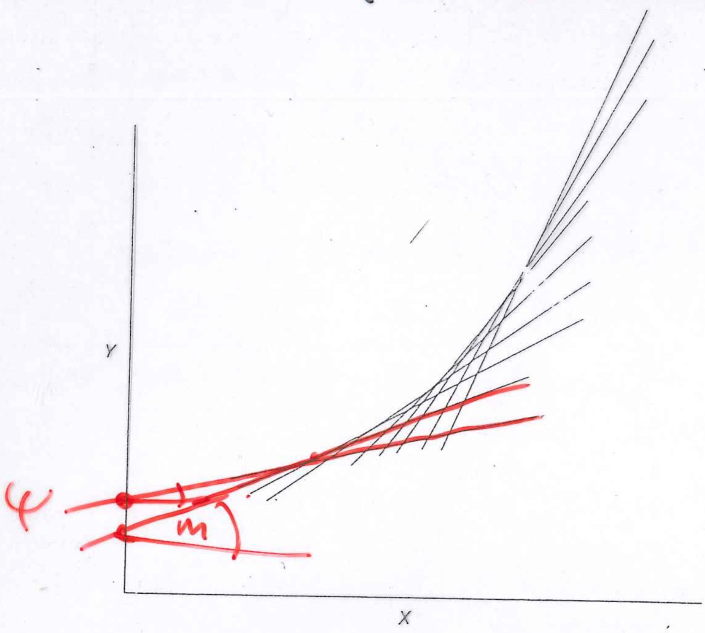


INFORMAZIO-GALERA DAGO !!

BERAZ, METODOA EZ DA "ORDEZKATZEA", EZ DA HAIN ERRAZA !!

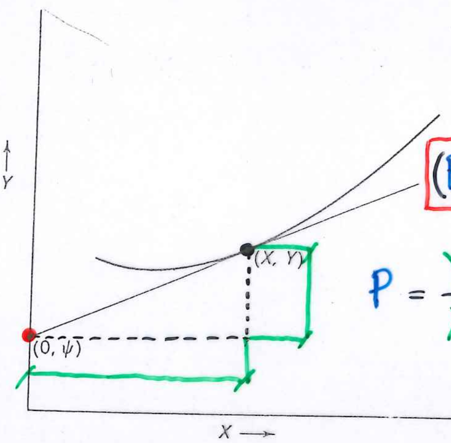
IKUSPEGIZ ALDATU METODOAREN OINARRIA ULERTZEKO

BI IKUSPEGIAK ALDIBEREAN $\begin{cases} \text{PUNTUEN SEGIDA, PUNTUEN KOKAPENA} \\ \text{LERRO TANGENTEEN SORTAREN INGURATZAILEA} \end{cases}$



METODOA BERA :

$$\boxed{\begin{array}{l} Y = Y(X) \\ P = \dfrac{dY}{dX} \end{array}}$$



$$\boxed{(P, \psi)}$$

$$P = \frac{Y - \psi}{X - 0} \Rightarrow \boxed{\psi = Y - PX} \quad \boxed{\psi = \psi(P)}$$

$$\boxed{\left.\begin{array}{l} Y = Y(X) \\ P = P(X) \Rightarrow X = X(P) \uparrow \; Y = Y(X(P)) \Rightarrow Y = Y(P) \end{array}\right\} \boxed{\psi = Y(P) - P\,X(P)}}$$

metodoaren 2 adibide

LEGENDRE-REN TRANSFORMAZIOAK (AUKERAKO FORMULAZIOAK)

* ARAZOA :

$$\left.\begin{array}{l} S = S(U, V, N_1, \ldots, N_n) \\ U = U(S, V, N_1, \ldots, N_n) \end{array}\right\} \qquad \begin{array}{l} \{U, V, N_1, \ldots, N_n\} \\ \underbrace{\{S, V, N_1, \ldots, N_n\}} \end{array}$$

EXTENTSIBOAK — LABORATEGIAN EZ

INTENTSIBOAK ? — LABORATEGIAN BAI

$$\left.\begin{array}{l} U = U(S, V) \\ dU = \left(\frac{\partial U}{\partial S}\right)_V dS + \left(\frac{\partial U}{\partial V}\right)_S dV \\ dU = T \; dS - p \; dV \end{array}\right\} \quad \boxed{\begin{array}{l} T \equiv \left(\frac{\partial U}{\partial S}\right)_V \\ p \equiv -\left(\frac{\partial U}{\partial V}\right)_S \end{array}}$$

PROPIETATE INTENTSIBOAK ⇒ PROPIETATE DERIBATUAK

INFORMAZIO-GALERA

- KONPONKETA LEGENDRE-REN TRANSFORMAZIOAK EKARRIKO DU

- OROKORREAN

$$\left.\begin{array}{l} Y = Y(X_0, X_1, \ldots, X_n) \\ P_k \equiv \left(\frac{\partial Y}{\partial X_k}\right) \end{array}\right\} \Rightarrow \boxed{Y = Y(X_0, X_1, \ldots, P_k, \ldots, X_n)}$$

INFORMAZIORIK GALDU GABE !!

BALDINTZA FISIKOEK FINKATUKO DUTE ZEIN TRANSFORMAZIO BURUTU

FISIKOKI KONSTANTE MANTENDURIKO PROPIETATEAK ALDAGAI BIHURTU KONSTANTEAK DIRENEZ FORMALISMOTIK ATERA DITZAKEGU: ERRAZTU !!

ENERGIA ETA ENTROPIAREN KASUAN AZTERTU DUGUNA

$Y = Y(X)$	$\psi = \psi(P)$
$P = \dfrac{dY}{dX}$	$-X = \dfrac{d\psi}{dP}$
$\psi = -PX + Y$	$Y = XP + \psi$
Eliminando X e Y se obtiene $\psi = \psi(P)$	Eliminando P y ψ se obtiene $Y = Y(X)$

$Y = Y(X_0, X_1, \ldots, X_t)$	$Y[P_0, P_1, \ldots, P_n]$ = función de $P_0, P_1, \ldots, P_n, X_{n+1}, \ldots, X_t$ (5.23)
$P_k = \dfrac{\partial Y}{\partial X_k}$	$-X_k = \dfrac{\partial Y[P_0, \ldots, P_n]}{\partial P_k}, \quad k \leqslant n$ (5.24) $P_k = \dfrac{\partial Y[P_0, \ldots, P_n]}{\partial X_k}, \quad k > n$
La derivación parcial denota la constancia de todas las variables naturales de Y distintas de X_k (es decir, de todas las X_j con $j \neq k$).	La derivación parcial denota la constancia de todas las variables naturales $Y[P_0, \ldots, P_n]$ distintas de aquélla con respecto a la cual se deriva.
$dY = \sum_0^t P_k\, dX_k$	$dY[P_0, \ldots, P_n] = -\sum_0^n X_k\, dP_k + \sum_{n+1}^t P_k\, dX_k$ (5.25)
$Y[P_0, \ldots, P_n] = Y - \sum_0^n P_k X_k$	$Y = Y[P_0, \ldots, P_n] + \sum_0^n X_k P_k$ (5.26)
Eliminando $Y, X_0, X_1, \ldots, X_n$ entre (5.23), (5.26) y las $n + 1$ primeras ecuaciones de (5.24) se obtiene la relación fundamental transformada.	Eliminando $Y[P_0, \ldots, P_n]$ y $P_0, P_1, \ldots, P_n$ entre (5.23), (5.26) y las $n + 1$ primeras ecuaciones de (5.24) se obtiene la relación fundamental original.

$$H \equiv U[P]$$

$U = U(S, V, N_1, N_2, \ldots)$	$H = H(S, P, N_1, N_2, \ldots)$ (5.37)
$-P = \partial U/\partial V$	$V = \partial H/\partial P$ (5.38)
$H = U + PV$	$U = H - PV$ (5.39)
Eliminando U y V se obtiene	Eliminando H y P se obtiene
$H = H(S, P, N_1, N_2, \ldots)$	$U = U(S, V, N_1, N_2, \ldots)$

$$dH = T\,dS + V\,dP + \mu_1\,dN_1 + \mu_2\,dN_2 + \cdots$$

$$F \equiv U[T]$$

$U = U(S, V, N_1, N_2, \ldots)$	$F = F(T, V, N_1, N_2, \ldots)$ (5.32)
$T = \partial U/\partial S$	$-S = \partial F/\partial T$ (5.33)
$F = U - TS$	$U = F + TS$ (5.34)
Eliminando U y S se obtiene	Eliminando F y T se obtiene
$F = F(T, V, N_1, N_2, \ldots)$	$U = U(S, V, N_1, N_2, \ldots)$

$$dF = -S\,dT - P\,dV + \mu_1\,dN_1 + \mu_2\,dN_2 + \cdots$$

$$G \equiv U[T, P]$$

$U = U(S, V, N_1, N_2, \ldots)$	$G = G(T, P, N_1, N_2, \ldots)$ (5.42)
$T = \partial U/\partial S$	$-S = \partial G/\partial T$ (5.43)
$-P = \partial U/\partial V$	$V = \partial G/\partial P$ (5.44)
$G = U - TS + PV$	$U = G + TS - PV$ (5.45)
Eliminando U, S y V se obtiene	Eliminando G, T y P se obtiene
$G = G(T, P, N_1, N_2, \ldots)$	$U = U(S, V, N_1, N_2, \ldots)$

$$dG = -S\,dT + V\,dP + \mu_1\,dN_1 + \mu_2\,dN_2 + \cdots$$

$U = U(S, V, N)$	$U[T, \mu] =$ función de T, V y μ (5.47)
$T = \partial U/\partial S$	$-S = \partial U[T, \mu]/\partial T$ (5.48)
$\mu = \partial U/\partial N$	$-N = \partial U[T, \mu]/\partial \mu$ (5.49)
$U[T, \mu] = U - TS - \mu N$	$U = U[T, \mu] + TS + \mu N$ (5.50)
Eliminando U, S y N se obtiene $U[T, \mu]$ como función de T, V, μ	Eliminando $U[T, \mu]$, T y μ se obtiene $U = U(S, V, N)$

$$dU[T, \mu] = -S\,dT - P\,dV - N\,d\mu$$

$$S[1/T] \equiv S - \frac{1}{T}U = -F/T$$

$$S[P/T] \equiv S - \frac{P}{T}V$$

$$S[1/T, P/T] = S - \frac{1}{T}U - \frac{P}{T}V = -G/T$$

$S = S(U, V, N_1, N_2, \ldots)$	$S[P/T] =$ función de U, P/T, N_1, $N_2, \ldots$ (5.57)
$P/T = \partial S/\partial V$	$-V = \partial S[P/T]/\partial(P/T)$ (5.58)
$S[P/T] = S - (P/T)V$	$S = S[P/T] + (P/T)V$ (5.59)
Eliminando S y V se obtiene $S[P/T]$ como función de U, P/T, N_1, $N_2, \ldots$	Eliminando $S[P/T]$ y P/T se obtiene $S = S(U, V, N_1, N_2, \ldots)$

$$dS[P/T] = (1/T)\,dU - V\,d(P/T) - (\mu_1/T)\,dN_1 - \frac{\mu_2}{T}\,dN_2, \ldots$$

POTENTZIAL TERMODINAMIKOETAKO PRINTZIPIO EXTREMALAK

ADIERAZPENA	PRINTZIPIO EXTREMALA
$S = S(U, V, \dots)$	S_{max}
$U = U(S, V, \dots)$	U_{min}
$F = F(T, V, \dots)$ $H = H(S, P, \dots)$ $G = G(T, P, \dots)$	?

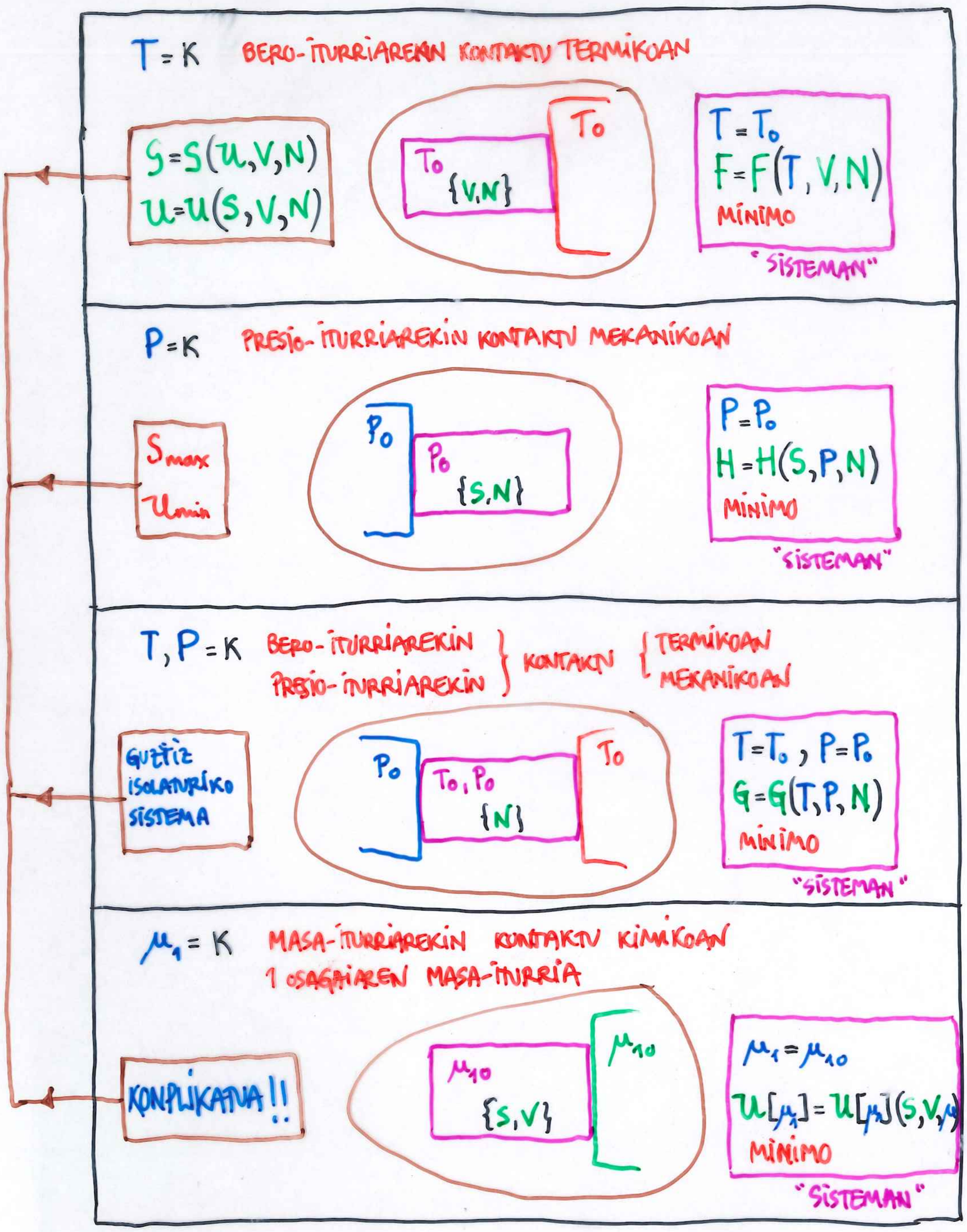
- INFORMAZIORIK GALDU GABE, PARAMETRO INTENTSIBOAK, ALDAGAI BIHURTU
  ESPERIMENTALKI NEURGARRIAK
- POTENTZIAL TERMODINAMIKOAK ERAIKI DITUGU (MATEMATIKOKI LEGENDRE-REN TRA.)
- PRINTZIPIO EXTREMALA: TERMODINAMIKAREN OINARRIZKO PROBLEMA EBAZTEKO
  S_{max} U_{min}
- GAINONTZEKO "POTENTZIAL TERMODINAMIKOETARA", PRINTZIPIOA TRANSLADATU

ADIBIDEA: BERO-ITURRIAREKIN KONTAKTUAN GERTATUKO DEN PROZESUA
SISTEMAREN TENPERATURA FINKOA (BERO-ITURRIARENA)
POTENTZIALETATIK (BALIOKIDEAK DIRENAK) ZEIN DA EGOKIENA?
ALDAGAI INDEPENDENTE MODUAN TENPERATURA DUENA
BALIO KONSTANTEA DUENEZ, FORMALISMOTIK ATERA DEZAKEGU!!
AHAZ GAITEZKE!!!

OROKORREAN: BALDINTZA ESPERIMENTALEK "ESANGO DUTE" ZEIN DEN POTENTZIAL TERMODINAMIKORIK EGOKIENA

¡HOTS ...

ADIBIDEAK:


T = K
BERO-ITURRIAREKIN KONTAKTU TERMIKOAN
S = S(U, V, N)
U = U(S, V, N)
T₀
T₀ {V, N}
T = T₀
F = F(T, V, N)
MINIMO
"SISTEMAN"
P = K
PRESIO-ITURRIAREKIN KONTAKTU MEKANIKOAN
S max
U min
P₀
P₀ {S, N}
P = P₀
H = H(S, P, N)
MINIMO
"SISTEMAN"
T, P = K
BERO-ITURRIAREKIN
PRESIO-ITURRIAREKIN
KONTAKTU
TERMIKOAN
MEKANIKOAN
GUZTIZ ISOLATURIKO SISTEMA
P₀
T₀, P₀ {N}
T₀
T = T₀ , P = P₀
G = G(T, P, N)
MINIMO
"SISTEMAN"
μ₁ = K
MASA-ITURRIAREKIN KONTAKTU KIMIKOAN
1 OSAGAIAREN MASA-ITURRIA
KONPLIKATUA!!
μ₁₀ {S, V}
μ₁₀
μ₁ = μ₁₀
U[μ₁] = U[μ₁](S, V, μ₁)
MINIMO
"SISTEMAN"

91 orri Atkins

$$\Delta S_{osoa} = \Delta S_{sis} + \Delta S_{ing} \left\langle \begin{array}{l} \text{IE} > 0 \\ \text{IG} = 0 \end{array} \right.$$

~~T, p ekte~~ $Q_{osoa} = Q_{sis} + Q_{ing} = 0 \Rightarrow Q_{ing} = -Q_{sis}$

$T, p = \text{kte}$ $\quad Q_{sis} = \Delta H_{sis}$

$Q_{ing} = T\Delta S_{ing} \Rightarrow \Delta S_{ing} = \dfrac{Q_{ing}}{T}$

$\Delta S_{ing} = -\dfrac{\Delta H_{sis}}{T}$

$$\boxed{\Delta S_{osoa} = \Delta S_{sis} - \frac{\Delta H_{sis}}{T}} \Rightarrow \Delta S_{osoa} = \frac{1}{T}\left(T\Delta S_{sis} - \Delta H_{sis}\right)$$

$T\Delta S_{osoa} = T\Delta S_{sis} - \Delta H_{sis}$

$-T\Delta S_{osoa} = -T\Delta S_{sis} + \Delta H_{sis}$

$= \Delta H_{sis} - T\Delta S_{sis}$

definizioa: $\quad G = H - TS$

$T, p = \text{kte}$ $\quad \Delta G = \Delta H - T\Delta S$

$$\boxed{\Delta G = -T\Delta S_{osoa}}$$

1. orokorra den printzipio extremala sistemaren propietateekin soilik adal dezake
2. printzipio extremala translada tu dugu printzipio orokorra $\Delta S_u > 0$ maximoa sistemara, zenbait baldintzan, minimoa

---

(3) ideia : ΔG da lan maximo ez mekanikoa / lan ez mekaniko maximoa — 97 orri Atkins

$T = \text{kte}$

$dG = dH - TdS$

$dH = dU + pdV$

$dG = dU + pdV - TdS$

$dU = \delta W + \delta Q$

$p, T = \text{kte}$

$dG = \delta W + \delta Q + pdV - TdS$

$\delta W = -p_{ex}dV + \delta W'$

$dG = -p_{ex}dV + \delta W' + \delta Q + pdV - TdS$

IG

$p_{ex} = p \Rightarrow -p_{ex}dV + pdV = 0$

$\delta Q = -TdS$

$dG = \delta W'$

---

(4) ideia : interpretazio mikroskopikoa (fotokopietan dagoena)

CASE STUDY 2.1 Life and the Second Law of thermodynamics

Every chemical reaction that is spontaneous under conditions of constant temperature and pressure, including those that drive the processes of growth, learning, and reproduction, is a reaction that changes in the direction of lower Gibbs energy, or—another way of expressing the same thing—results in the overall entropy of the system and its surroundings becoming greater. With these ideas in mind, it is easy to explain why life, which can be regarded as a collection of biological processes, proceeds in accord with the Second Law of thermodynamics.

It is not difficult to imagine conditions in the cell that may render spontaneous many of the reactions of catabolism described briefly in Section 1.3. After all, the breakdown of large molecules, such as sugars and lipids, into smaller molecules leads to the dispersal of matter in the cell. Energy is also dispersed, as it is released upon reorganization of bonds in foods. More difficult to rationalize is life's requirement of organization of a very large number of molecules into biological cells, which in turn assemble into organisms. To be sure, the entropy of the system—the organism—is very low because matter becomes less dispersed when molecules assemble to form cells, tissues, organs, and so on. However, the lowering of the system's entropy comes at the expense of an increase in the entropy of the surroundings. To understand this point, recall from Sections 1.3 and 2.1 that cells grow by converting energy from the Sun or oxidation of foods partially into work. The remaining energy is released as heat into the surroundings, so $q_{sur} > 0$ and $\Delta S_{sur} > 0$. As with any process, life is spontaneous and organisms thrive as long as the increase in the entropy of the organism's environment compensates for decreases in the entropy arising from the assembly of the organism. Alternatively, we may say that $\Delta G < 0$ for the overall sum of physical and chemical changes that we call life. ■

(i)

(ii)

MAXWELL-EN ERLAZIOAK

$$\mathcal{U}$$
$$H = \mathcal{U} + P$$
$$F = \mathcal{U} - TS$$
$$G = \mathcal{U} + PV - TS$$

T	P
S	V

BARNE-ENERGIA

ENTALPIA

HELMHOLTZ-EN FUNTZIOA

GIBBS-EN FUNTZIOA

μ	+	T	P			
N		S	V	$\mathcal{U}$ H	F	G

INTENTSIBOAK

EXTENTSIBOAK

$z = z(x,y)$

$$dz = M\,dx + N\,dy$$
$$\left(\frac{\partial M}{\partial y}\right)_x = \left(\frac{\partial N}{\partial x}\right)_y$$

DIFERENTZIAL ZEHATZA

$$d\mathcal{U} = T\,dS - p\,dV + \dots \Rightarrow \left(\frac{\partial T}{\partial V}\right)_S = -\left(\frac{\partial P}{\partial S}\right)_V$$

$$dH = T\,dS + V\,dp + \dots \Rightarrow \left(\frac{\partial T}{\partial p}\right)_S = \left(\frac{\partial V}{\partial S}\right)_p$$

$$dF = -S\,dT - p\,dV + \dots \Rightarrow \left(\frac{\partial S}{\partial V}\right)_T = \left(\frac{\partial P}{\partial T}\right)_V$$

$$dG = -S\,dT + V\,dp + \dots \Rightarrow \left(\frac{\partial S}{\partial p}\right)_T = -\left(\frac{\partial V}{\partial T}\right)_p$$

(...)

U	S, V	$\left(\frac{\partial T}{\partial V}\right)_{S,N} = -\left(\frac{\partial P}{\partial S}\right)_{V,N}$
$dU = T\,dS - P\,dV + \mu\,dN$	S, N	$\left(\frac{\partial T}{\partial N}\right)_{S,V} = \left(\frac{\partial \mu}{\partial S}\right)_{V,N}$
	V, N	$-\left(\frac{\partial P}{\partial N}\right)_{S,V} = \left(\frac{\partial \mu}{\partial V}\right)_{S,N}$
$U[T] \equiv F$	T, V	$\left(\frac{\partial S}{\partial V}\right)_{T,N} = \left(\frac{\partial P}{\partial T}\right)_{V,N}$
$dF = -S\,dT - P\,dV + \mu\,dN$	T, N	$-\left(\frac{\partial S}{\partial N}\right)_{T,V} = \left(\frac{\partial \mu}{\partial T}\right)_{V,N}$
	V, N	$-\left(\frac{\partial P}{\partial N}\right)_{T,V} = \left(\frac{\partial \mu}{\partial V}\right)_{T,N}$
$U[P] \equiv H$	S, P	$\left(\frac{\partial T}{\partial P}\right)_{S,N} = \left(\frac{\partial V}{\partial S}\right)_{P,N}$
$dH = T\,dS + V\,dP + \mu\,dN$	S, N	$\left(\frac{\partial T}{\partial N}\right)_{S,P} = \left(\frac{\partial \mu}{\partial S}\right)_{P,N}$
	P, N	$\left(\frac{\partial V}{\partial N}\right)_{S,P} = \left(\frac{\partial \mu}{\partial P}\right)_{S,N}$
$U[\mu]$	S, V	$\left(\frac{\partial T}{\partial V}\right)_{S,\mu} = -\left(\frac{\partial P}{\partial S}\right)_{V,\mu}$
$dU[\mu] = T\,dS - P\,dV - N\,d\mu$	S, μ	$\left(\frac{\partial T}{\partial \mu}\right)_{S,V} = -\left(\frac{\partial N}{\partial S}\right)_{V,\mu}$
	V, μ	$\left(\frac{\partial P}{\partial \mu}\right)_{S,V} = \left(\frac{\partial N}{\partial V}\right)_{S,\mu}$
$U[T, P] \equiv G$	T, P	$-\left(\frac{\partial S}{\partial P}\right)_{T,N} = \left(\frac{\partial V}{\partial T}\right)_{P,N}$
$dG = -S\,dT + V\,dP + \mu\,dN$	T, N	$-\left(\frac{\partial S}{\partial N}\right)_{T,P} = \left(\frac{\partial \mu}{\partial T}\right)_{P,N}$
	P, N	$\left(\frac{\partial V}{\partial N}\right)_{T,P} = \left(\frac{\partial \mu}{\partial P}\right)_{T,N}$
	V, μ	$\left(\frac{\partial P}{\partial \mu}\right)_{T,V} = \left(\frac{\partial N}{\partial V}\right)_{T,\mu}$

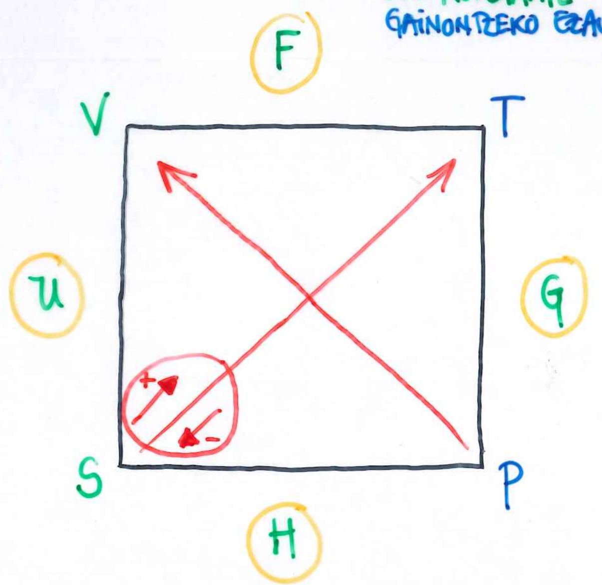
MAXWELL-EN ERLAZIOAK

POTENTZIAL TERMODINAMIKOA | "BIKOTE NATURALA" + N | ERLAZIOAK

MASA KONSTANTEKO SISTEMA BAKUNA $\Rightarrow \boxed{\{S(T), V(P) ; N\}}$

N = KONSTANTE

GAINONTZEKO EZAUGARRIEKIN LOTURIKOAK = KONSTANTE



(1) - POTENTZIAL TERMODINAMIKOAK IDATZI ; F-TIK HASITA (BERAU EZ DA BEHARREZKOA)

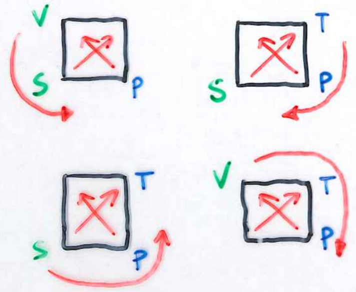
(2) - ALDAGAI TERMODINAMIKO "NATURALAK" ALBOETAN ; S-TIK HASITA

(3) - ALDAGAI TERMODINAMIKO OSAGARRIAK LOTUKO DITUEN BI GEZI IRUDIKATU

EXTENTSIBO $\longrightarrow$ INTENTSIBO

ZEINU ALDAKETARIK EZ BADAGO, BEHINTZAT!

(4) - ONDOKO ESKEMARI SEGITU



$$\Rightarrow \left(\frac{\partial V}{\partial S}\right)_P = \left(\frac{\partial T}{\partial P}\right)_S$$

$$\Rightarrow \left(\frac{\partial S}{\partial P}\right)_T = -\left(\frac{\partial V}{\partial T}\right)_P$$

⋮ ⋮

KALKULU TERMODINAMIKOA

SISTEMA HIDROSTATIKOA (BAKUNA)

(1) - POTENTZIALAK "GORA" ETA DEFINIZIOA APLIKATU

$$\left(\frac{\partial P}{\partial U}\right)_{G,N} =$$

(2) - POTENTZIAL KIMIKOA BADAGO, GIBBS/DUHEM-EN ERLAZIOA ERABILI

$$\left(\frac{\partial \mu}{\partial V}\right)_{S,N} =$$

(3) - ENTROPIA "GORA" ETA BERO-AHALMENEN DEFINIZIOAK APLIKATU

$$\left(\frac{\partial T}{\partial P}\right)_{S,N} =$$

ZENBAIT KASUTAN TENPERATURA "TARTEKATU"

$$\left(\frac{\partial S}{\partial V}\right)_{P,N} =$$

(4) - BOLUMENA "GORA", KOEFIZIENTE EXPERIMENTAK AGER DAITEZEN

$$\left(\frac{\partial T}{\partial P}\right)_{V,N} =$$

(5) - ONDOKO ERLAZIOA OSO ERABILGARRIA

$$\boxed{C_P - C_V = TV\frac{\alpha^2}{\kappa_T}}$$

MAYER-EN ERLAZIOA

SISTEMA HIDROSTATIKOAN SOILIK OROKORTU DAITEKE

MAYER-EN ERLAZIO OROKORTUA

ADIBIDEEN PROPOSAMENAK