

FORMALISMO ALDAKETA

1.10

- I POSTULATUA

1.9

- TERMODINAMIKAREN OINARRIZKO PROBLEMA (ADIBIDE KONKRETUA, ADIBIDE OROKORRA)

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- III POSTULATUA

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2.5

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- ERLAZIOAK

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- ENERGIAREN EKUAZIOAK

- GERO-AHALMENAREN EKUAZIOAK

- PROZESUAK

Aniketak

2.

I POSTULATUA : OREKA-EGOEREN DEFINIZIOA

II POSTULATUA : ENTROPIA FUNTzioAREN DEFINIZIOA

III POSTULATUA : ENTROPIA FUNTzioAREN EZAGARRIAK

IV POSTULATUA : ENTROPIA FUNTzioAREN PROPIETATEAK (TEMPERATURA BAXUAK)

1.

0 PRINtzipioA : TENPERATURA , OREKA TERMikOA

1 PRINtzipioA : ENERgiAREN KONTtERBAzioAREN PRINtzipioA

2 PRINtzipioA : ItADIKO ASIMtERIA

3 PRINtzipioA : EE DAGO TENPERATURA ABSOLUTUAREN tERORik

* I POSTULATUA : OREKA-EGOEREN DEFINIZIOA

SISTEMA BAKUNEI DAGOZKIEN EGOERA BEREZIAK EXISTITEN DIRA,
IKUSPEAI MAKROSKOPIKOA ERABILIZ ONDOKO MAGNITUDEZ EZAGARRITUKO DITUGU:

U BARNE-ENERGIA

V BOLUMENA

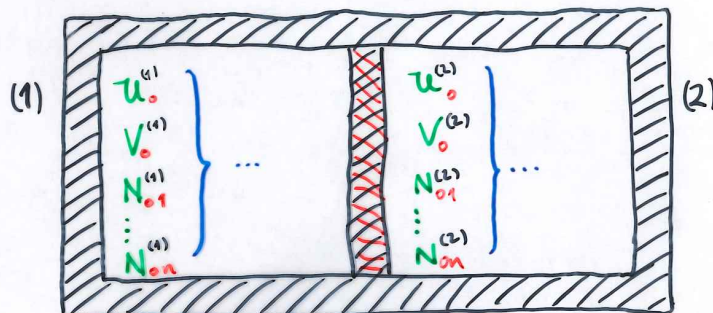
N_i OSAGAII KIMIKOEN MOL-KOPURUA

MAGNITUDE ESTENTSIBOAK, SOILIK!!

OREKA-EGOERA LOTUA : KANPOTIKO ERAGINEN BATEK FUNKTUTAKOAK

* 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 BATEAN ASKAPENA

BUKAERAKO OREKA-EGOERA LOTUA
EZ-LOTUA

[BEREZKO PROZESUA MARTXAN JARRI]

ITXIDURA-BALDINTZAK

* II POSTULATUA : ENTROPIA FUNTzioAREN ESISTENTZIA (PRINZIPIO EXTREMA)

S ikurrez EZAUGARRITUTAKO ENTROPIA FUNTzioA EXISTITZEN DA, NON :

- EDOZEIN SISTEMA KONPOSATURI DABERKIDEN PARAMETRO ESTENTSIBO GUTTIEN FUNTzioA DEN,
- SISTEMA KONPOSATUAREN OREKA-EGOKIA GUTTIETAN DEFINITURIK IZANGO DEN,
- UNDOKO PROPIETATEAK BETEKO DITZEN :

BARNE-LOTURARIK EE DABOEN KASUAN

PARAMETRO ESTENTSIBOEN BAIKOEK ENTROPIA MAXIMIZATUKO DUTE
MAXIMIZAZIOA OREKA-EGOKIA LOTURERIKO BUKATU BENA DA

0INARRIZKO EKUAZIOA

* III POSTULATUA : ENTROPIA FUNTzioAREN EZAUGARRIAK

SISTEMA KONPOSATUAREN ENTROPIA :

AZPISISTEMERIKO BATUKORRA DA

FUNTzio JARRAIA ETA DERIBAGARRIA

BARNE-ENERGIAREN FUNTzio MONOTONO GORAKORRA

- EZAUGARRIEN ONDORIOAK :

(1) - BATUKORRA

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

$$(b) - S^{(i)} = S^{(i)}(u^{(i)}, v^{(i)}, N_1^{(i)}, \dots)$$

$$(c) - \text{LEHEN ORDENAKO FUNTzio HOMOGENEOA : } S(\lambda u, \lambda v, \dots) = \lambda S(u, v, \dots)$$

ESKALAKETA

(2) - MONOTONO GORAKORRA

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

(3) - JARRAITASUNA, DERIBAGARRITASUNA

$$- S(u, v, N_1, \dots) \longrightarrow u(S, v, N_1, \dots) \quad \text{BABIKIDETASUNA}$$

— PROZESUEN ADIERAZPENA: OINARRIZKO EKWAZIOAREN DIFERENTIALAREN BIDEZ

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

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

PARAMETRO INTENSIBOAK / EGOERA-EKWAZIOAK

$$T \equiv \left(\frac{\partial U}{\partial S} \right)_{V, N_1, \dots} = T(S, V, N_1, \dots)$$

$$P \equiv - \left(\frac{\partial U}{\partial V} \right)_{S, N_1, \dots} = P(S, V, N_1, \dots)$$

$$\mu_K \equiv \left(\frac{\partial U}{\partial N_K} \right)_{S, V, \dots} = \mu_K(S, V, N_1, \dots)$$

$$Y_j \equiv \left(\frac{\partial U}{\partial X_j} \right)_{S, \dots}$$

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

ZERO ORDENAKO FUNTZIO HOMOGENEOAK: PROPIETATEA

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

"AURREKO FORMALISMO"AREN KIRKOA ALDERAKETA: LEHENENGO PRINTZIPIOA

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

BARNE-ENERGIA $\rightsquigarrow$ LANA ("TERMIKOA", EDOZEN MOTA MOTA)

u ETA S ADIERAZPENAK SÍMETRÍKOAK DIRA
(BALOKIDEAK !!)

$$u = u(S, X_1, \dots, X_n) \quad S \equiv X_0$$

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

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

$$du = T dS + \sum_{j=1}^N P_j dX_j$$

$$S = S(u, X_1, \dots, X_n) \quad u \equiv X_0$$

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

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

$$dS = \sum_{k=0}^N F_k dX_k$$

$$F_0 \equiv \frac{1}{T_0} \quad , \quad F_k \equiv -\frac{P_k}{T}$$

ADIERAZPENEN ARTEKO LOTURA !!

ADIBIDEAK : OINARRIZKO EKUAZIOAK ESPERA-EKUAZIOAREN ONDORIOZTAPENA

ADIERAZPEN : ENERGETIKOAN
ENTROPIKOAN

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

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

TERMODINAMIKAREN OINARRIZKO PROBLEMAREN EBAZPENA: **PRINTZÍPIO ESTREMAIA**

OREKA-EGOKERA LOTUAN DAGOEN SISTEMA ITXIAK (KONPOSATUA, BAKUNA)

BARNE-LOTURAREN BAT ASKATUTAKOAN

(TERMÍKOA, MEKANÍKOA, KÍMÍKOA, ...)

ZÉIN OREKA-EGOKERATAN BUKATUKO DU ?

* H funtzioa transformatzioa erabiliz era orokorrean
dena azaldu.

* Ondoren, murrerak orokortzeko arrazoiak, bi adibide

- Temperatura : $S = S(U, V, N)$

- Temperatura eta presioa : $U = U(S, V, N)$

Hazierako oreka-egoera

gutiz karakterizatu da dago:

oinarizko ekuazioa/egoera-ekuazioak eragunak dira

aldagai estensibo gutien balioak eragunak dira

berme-loturaen bat azkafuz

PROZESUA ERAGIN DUGU;

lots, sistema konposatuaren azkafuz-graduekin bat maitatu jarrit

Azkafuz-graduekin lotutako dogu bikotearen balioak $(Y, X) = (\text{intensibo}, \text{extensibo})$ aldatuko dira:

Sistema konposatuak oinarrizko X aldagaia trinkatuak dute, itxidura-baldintzak utzi ditzaten arazera,

Y aldagai intensiboaren balioak azpiztemetan berdindu arte, ENTROPIA maximizatzeke armoz

(BERDINDUKO 24 BADIKA: OREKA-EGOERA LOTUA **S_{tot} MAX**)

$\{X^{(j)}\}$ banaketa berrak $\Rightarrow \{Y^{(1)} = Y^{(2)} = \dots = Y^{(n)}\}$ oreka-egoera berrak ekariko du, zirkular ENTROPIA maximoa den

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

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

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

$$\sum_{j=1}^n U^{(j)} = Kte$$

$$\sum_{j=1}^n V^{(j)} = Kte$$

$$\sum_{j=1}^n N_k^{(j)} = Kte \quad k=1, \dots, t$$

itxidura-baldintzak

hauze da lotari behar dugu sistema

Bukaerako oreka-egoera

gutiz karakterizatu behar dugu:

oinarizko ekuazioa/egoera-ekuazioak eragunak dira

aldagai estensibo gutien balio berrak eragunak behar dira

$$S^{(j)} = S^{(j)}(U^{(j)}, V^{(j)}, N_1^{(j)}, \dots, N_t^{(j)}) \left\{ \begin{array}{l} \frac{1}{T^{(j)}} = \frac{1}{T^{(j)}}(U, V, N_1, \dots, N_t) \\ \frac{P^{(j)}}{T^{(j)}} = \frac{P^{(j)}}{T^{(j)}}(U, V, N_1, \dots, N_t) \\ \frac{\mu_k^{(j)}}{T^{(j)}} = \frac{\mu_k^{(j)}}{T^{(j)}}(U, V, N_1, \dots, N_t) \end{array} \right\} \quad j=1, \dots, n$$

$$\{U_1^{(j)}, V_1^{(j)}, N_1^{(j)}, \dots, N_t^{(j)}\} \quad j=1, \dots, n$$

oreka-egoera berrak

* EULER - REN EKVÁZÍÓÁ (VÁRRAZKO EKVÁZÍÓÁ, 1. ORDENAKO FUNTZIO HOMOGÉNÉÁ)

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

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

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

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

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

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

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

$$\lambda=1 \quad \left(\frac{\partial u}{\partial S} \right) \cdot S + \left(\frac{\partial u}{\partial V} \right) \cdot V + \dots + \left(\frac{\partial u}{\partial N} \right) \cdot N =$$

$$\downarrow \quad \quad \downarrow \quad \quad \downarrow$$

$$T \quad \quad -P \quad \quad \mu$$

$$T dS - P dV + \sum_{k=1}^{N-2} \mu_k dN_k = u(S, V, N_1, \dots)$$

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

ADIERAZPEN ENERGETIKOA

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

ADIERAZPEN ENTROPIKOA

* GIBBS/DUHEM-EN ERLAZIOA

(PARAMETRO INTENTSIBOAK EZ DIRA INDEPEND.)
(LEHEN ORDENA HOMOGENEITASUNAREN ON.)

(1) - ERA FORMALEAN :

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

$u = u(s, v)$

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

ii). $U = U(S, V, N_1, \dots, N_n)$

$u = u(S, x_1, x_2, \dots, x_n)$

$p_k \equiv \left(\frac{\partial U}{\partial X_k} \right)_{S, X_{\dots}} = p_k(S, x_1, \dots)$

$\frac{1}{x_k} [\{ S, x_1, \dots, x_n \}]$

$p_k = p_k \left(\frac{S}{x_k}, \frac{x_1}{x_k}, \dots, \frac{x_n}{x_k} \right)$ $x_1/x_1 = 1$

(ALDAGAI-KOPURUA) = EKVAZIO-KOPURUA - 1

(2) - EULER-REN EKVAZIOTIK ABIATUZ :

iii). $d \left\{ u = TS + \sum_{k=1}^N p_k x_k \right\}$

$$du = Tds + SdT + \sum_{k=1}^N p_k dx_k + \sum_{k=1}^N dp_k \cdot x_k$$

$$0 = SdT + \sum_{k=1}^N x_k dp_k$$

$$\sum_{k=1}^N x_k dp_k = 0$$

ALDAKUNTZEN ARTEKO LOTURAK

G/D erlazioaren
adibidea

LABURBILDUMA

EULER-REN EKVAZIOA

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

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

$$F_k = -\frac{P_k}{T} \quad k=1, \dots, n$$

GIBBS/DUHEM-EN ERLAZIOA

$$\sum_{k=0}^N X_k dP_k = 0$$

$$\sum_{k=0}^N X_k d\left(\frac{P_k}{T}\right) = 0$$

OINARRIZKO EKVAZIOAREN ERAIKUNTZA :

(1) - OINARRIZKO EKVAZIO MULAR DIFERENTZIALA INTEGRATUZ

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

FORMALISMO BERRIAREN LABURBILDUMA

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

OINARRIZKO EKVAZIOA
INFORMAZIO OSOA

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

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

$$\mu = \mu(S, V, N) = \mu(S, V)$$

EGOKER - EKVAZIOAK
INFORMAZIO PARTEIALA
DENEK $\Rightarrow$ INFORMAZIO OSOA

INFORMAZIO OSOA : SISTEMAREN DESKRIPZIO TERMODINAMIKO OSOA

INFORMAZIO PARTEIALA : OINARRIZKO EKVAZIOA ERAIKI, BAIÑA
INTEGRAZIO KONSTANTEAREN FUNTzioAN DAGO (JENIA)
ERAIKITZEKO BI METODO DAGO !

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

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

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

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

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

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

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

$$U = U\left(\left(\frac{\partial U}{\partial S}\right)_V, V, N\right)$$

(adierazpide grafikoa)

adibideak
- oin. eku. eraikun
- sistamen
adibideak

AUKERAKO FORMULAZIOAK : BALOKIDETASUNA

* AUKERAKO FORMULAZIOAK LORZEKO BIDEA : "TRANSLAZIOA"

$S = S(u, v, N_1, \dots, N_n)$	PRINTZIPIO ESTREMA	S_{max}
$u = u(S, v, N_1, \dots, N_n)$	?	?

 }

* KUAINTATIBOKI
FISIKOKI
MATEMATIKOKI



ENTROPIA ETA ENERGIAREN KASUAN

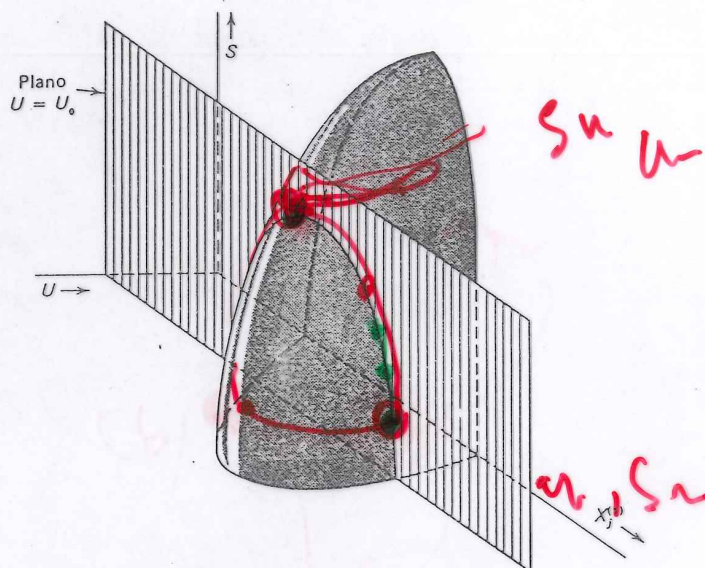
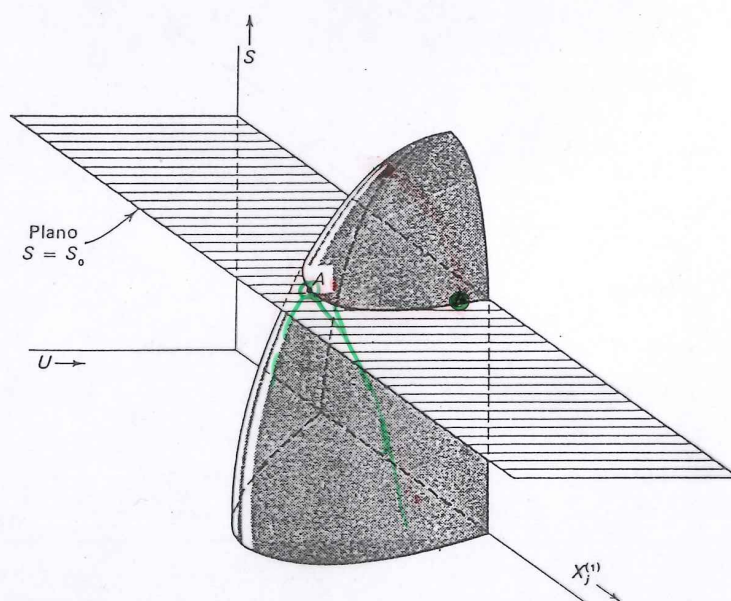
* BALDINTZA ESPERIMENTALEK FINKATUKO DUTE "FORMULAZIOA"

* ONARTU DUGUN BALDINTZA ANALITIKOARI ESKER :

$$\left(\frac{\partial S}{\partial u}\right)_{\dots} > 0$$

FORMULAZIOEN BALOKIDETZA HONETAN DATZA
PRINTZIPIO ESTREMALEI DAGOKIENEZ

(1) - KUALITATIBOKI : $S_{\max} \leftrightarrow U_{\min}$



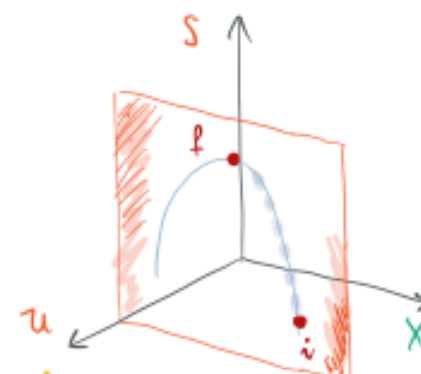
IE



$$U_{ni} \equiv S_{is}$$

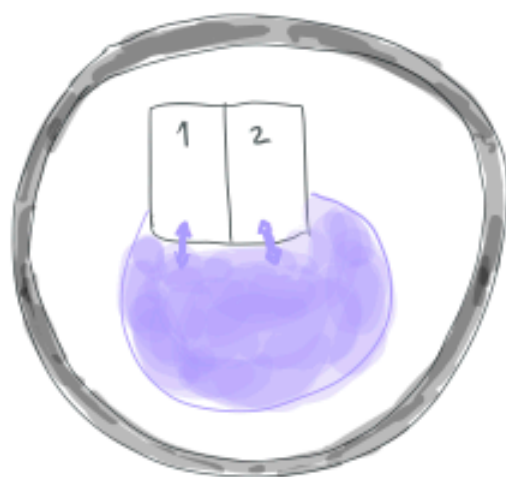
$$S_{max}^u = S^1 + S^2 \quad [2P]$$

$$U_{osm} = kte \quad [1P]$$



$\neq$

IG



$$U_{ni} \equiv S_{is} + i_{ng}$$

$$U_{osm} = U_{Sis} + U_{ing} \quad [1P]$$

$$S_{min}^u = kte \quad [2P]$$

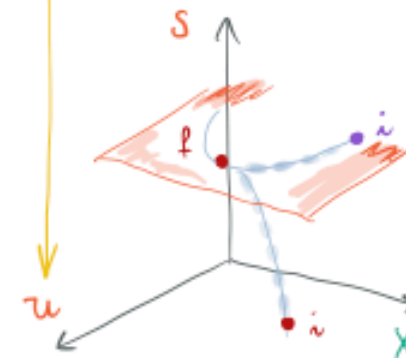
$$\parallel$$

$$S^{is} + S^{ing}$$

$$\equiv$$

$$(S^1 + S^2)$$

$\bullet f \updownarrow$



(2) - "FÍSİKOKI" : $S_{\max} \Leftrightarrow U_{\min}$

(i) - $S_{\max} \Rightarrow U_{\min}$; $EZ U_{\min} \Rightarrow EZ S_{\max}$

$S_{\max}$ BAINA $EZ U_{\min}$

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

(2) U HANDITU : AURREKO ESPERA BERRESKURATU , BEROA SARTUZE , LANIK BAIN GABE
 S HANDITU , BERAZ EZ ZEN MAXIMOA

(ii) - $U_{\min} \Rightarrow S_{\max}$; $EZ S_{\max} \Rightarrow EZ U_{\min}$

$U_{\min}$ BAINA $EZ S_{\max}$

(1) S HANDITU ; BEROA SARTUZE , U KONSTANTE IBANIK , ERA ITZULGARRIAN

(2) S GUTXITU : AURREKO ESPERA BERRESKURATU , LANA ATERAEZ , BEROA ~~TERATU~~ GABE
 U GUTXITU , BERAZ EZ ZEN MINIMOA

* LEHENENGO PRINTZÍPIOA ERABILIZ , PROZESUA BI PAUSOTAN

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

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

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

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

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

(3) - MATEMATIKOKI : $S_{\max} \leftrightarrow U_{\min}$

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

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

(i) - ① $\Rightarrow$ ②

$$\left(\frac{\partial U}{\partial X} \right)_s = - \frac{\left(\frac{\partial S}{\partial X} \right)_u}{\left(\frac{\partial S}{\partial U} \right)_x} = - \left(\frac{\partial U}{\partial S} \right)_x \left(\frac{\partial S}{\partial X} \right)_u = -T \left(\frac{\partial S}{\partial X} \right)_u = 0$$

$\uparrow$
 $\left(\frac{\partial S}{\partial X} \right)_u = 0$

$$\begin{aligned} \left(\frac{\partial^2 U}{\partial X^2} \right)_s &= \frac{\partial}{\partial X} \left[\left(\frac{\partial U}{\partial X} \right)_s \right] = \frac{\partial}{\partial X} \left[- \left(\frac{\partial U}{\partial S} \right)_x \left(\frac{\partial S}{\partial X} \right)_u \right] = - \left\{ \left(\frac{\partial^2 U}{\partial X \partial S} \right) \left(\frac{\partial S}{\partial X} \right)_u + \left(\frac{\partial U}{\partial S} \right)_x \left(\frac{\partial^2 S}{\partial X^2} \right)_u \right\} \\ &= - \left\{ \left(\frac{\partial^2 U}{\partial X \partial S} \right) \left(\frac{\partial S}{\partial X} \right)_u + T \left(\frac{\partial^2 S}{\partial X^2} \right)_u \right\} \quad \left(\frac{\partial S}{\partial X} \right)_u = 0 \end{aligned}$$

$$\left\{ \left(\frac{\partial^2 U}{\partial X^2} \right)_s = -T \left(\frac{\partial^2 S}{\partial X^2} \right)_u \Rightarrow \left(\frac{\partial^2 U}{\partial X^2} \right)_s > 0 \right.$$

(ii) - ② $\Rightarrow$ ①

$$\left(\frac{\partial S}{\partial X} \right)_u = - \frac{\left(\frac{\partial U}{\partial X} \right)_s}{\left(\frac{\partial U}{\partial S} \right)_x} = - \left(\frac{\partial U}{\partial X} \right)_s \left(\frac{\partial S}{\partial U} \right)_x = - \frac{1}{T} \left(\frac{\partial U}{\partial X} \right)_s = 0$$

$\uparrow$
 $\left(\frac{\partial U}{\partial X} \right)_s = 0$

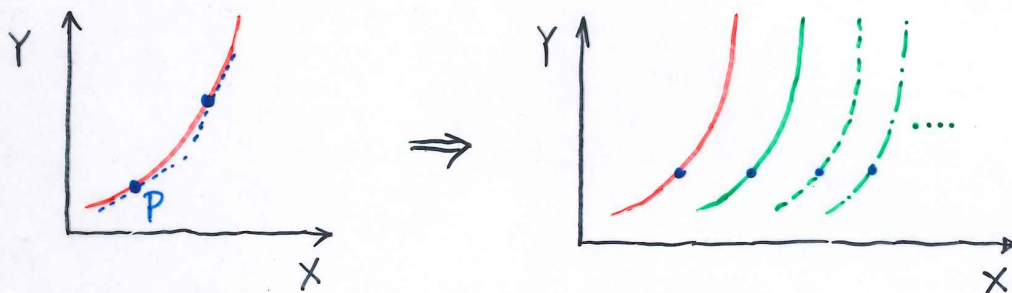
$$\begin{aligned} \left(\frac{\partial^2 S}{\partial X^2} \right)_u &= \frac{\partial}{\partial X} \left[\left(\frac{\partial S}{\partial X} \right)_u \right] = \frac{\partial}{\partial X} \left[- \left(\frac{\partial U}{\partial X} \right)_s \left(\frac{\partial S}{\partial U} \right)_x \right] = - \left\{ \left(\frac{\partial^2 S}{\partial X \partial U} \right) \left(\frac{\partial U}{\partial X} \right)_s + \left(\frac{\partial S}{\partial U} \right)_x \left(\frac{\partial^2 U}{\partial X^2} \right)_s \right\} \\ &= - \left\{ \left(\frac{\partial^2 S}{\partial X \partial U} \right) \left(\frac{\partial U}{\partial X} \right)_s + \frac{1}{T} \left(\frac{\partial^2 U}{\partial X^2} \right)_s \right\} \quad \left(\frac{\partial U}{\partial X} \right)_s = 0 \end{aligned}$$

$$\left\{ \left(\frac{\partial^2 S}{\partial X^2} \right)_u = - \frac{1}{T} \left(\frac{\partial^2 U}{\partial X^2} \right)_s \Rightarrow \left(\frac{\partial^2 S}{\partial X^2} \right)_u < 0 \right.$$

LEGENDRE-REN TRANSFORMAZIOAK MATEMATIKOKI

$$\left. \begin{array}{l} Y = Y(X) \\ P = \frac{dY}{dX} \end{array} \right\} \Rightarrow \boxed{Y = Y(P)} \text{ INFORMAZIO-RIK GALDU GABE}$$

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

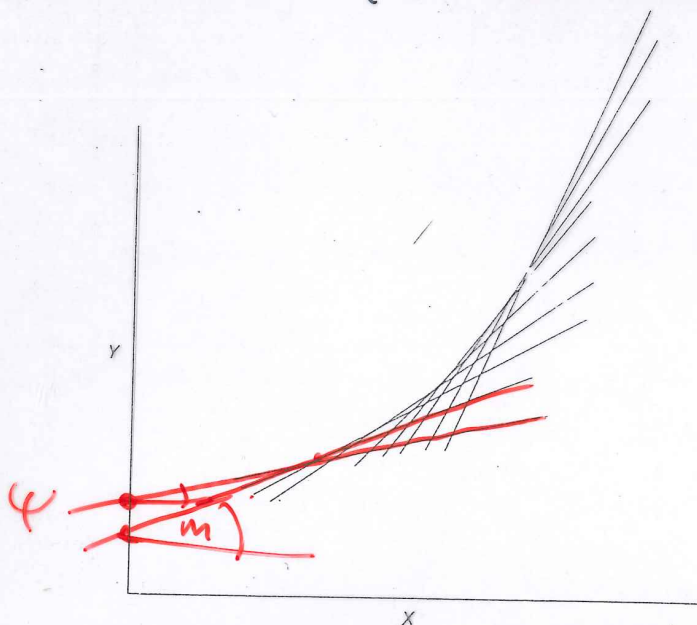


INFORMAZIO-GALERA DAGO !!

BERAZ, METODOA EZ DA "ORDEZKATZEA", EZ DA HAIN ERRAZA !!
IKUSPEGI-EZ ALDATU METODOAREN OINARRIA ULERTZEKO

BI IKUSPEGIAK ALDIBEREAN

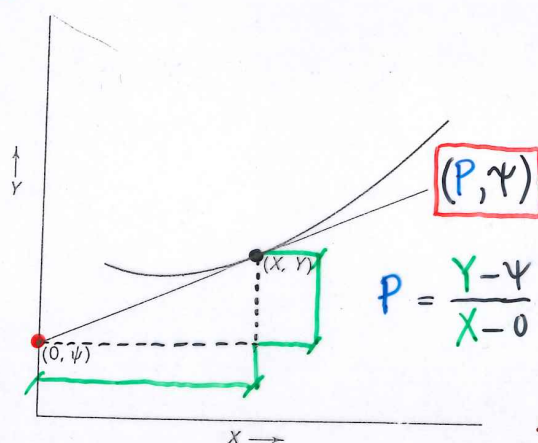
PUNTUEN SEGIDA, PUNTUEN KOKAPENA
LERRU TANGENTEEN SORTAREN INGUATZAILEA



METODOA BERA :

$$Y = Y(X)$$

$$P = \frac{dY}{dX}$$



$$P = \frac{Y - \Psi}{X - 0}$$

$$\Rightarrow \Psi = Y - PX$$

$$\Psi = \Psi(P)$$

$$\left. \begin{array}{l} Y = Y(X) \\ P = P(X) \Rightarrow X = X(P) \end{array} \right\} \begin{array}{l} Y = Y(X(P)) \Rightarrow Y = Y(P) \\ \Psi = Y(P) - P X(P) \end{array}$$

metodoaren 2
adibide

LEGENDRE-REN TRANSFORMAZIOAK (AUKERAKO FORMULAZIOAK)

* ARAZOA :

$$\left. \begin{array}{l} S = S(u, V, N_1, \dots, N_n) \\ u = u(S, V, N_1, \dots, N_n) \end{array} \right\} \begin{array}{l} \{u, V, N_1, \dots, N_n\} \\ \{S, V, N_1, \dots, N_n\} \end{array}$$

EXTENTSIBOAK

INTENTSIBOAK ?

LABORATEGIAN EZ

LABORATEGIAN BAI

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

$$du = \left(\frac{\partial u}{\partial S}\right)_V dS + \left(\frac{\partial u}{\partial V}\right)_S dV$$

$$du = T dS - p dV$$

$$T \equiv \left(\frac{\partial u}{\partial S}\right)_V$$

$$p \equiv -\left(\frac{\partial u}{\partial V}\right)_S$$

PROPIETATE INTENTSIBOAK $\Rightarrow$ PROPIETATE DERIBATUAK
INFORMAZIO-GALERA

- KONPONKETA LEGENDRE-REN TRANSFORMAZIOAK EKARRIKO DU

- OROKORREAN

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

$$P_k \equiv \left(\frac{\partial Y}{\partial X_k}\right)_-$$

$$Y = Y(X_0, X_1, \dots, P_k, \dots, X_n)$$

INFORMAZIOARIK GALDU GABE !!

BALDINTZA FISIKOEK FINKATUKO DUTE ZEIN TRANSFORMAZIO BURUTU
FISIKOKI KONSTANTE MANTENDURIKO PROPIETATEAK ALDAGAI BIHURTU
KONSTANTEAK DIRENEZ FORMALISMOTIK ATERA DITAKEGU: ERRAZTU !!

ENERGIA ETA ENTROPIAREN KASUAN AZERTU DUGUNA

--

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

$Y = Y(X_0, X_1, \dots, X_t)$ $P_k = \frac{\partial Y}{\partial X_k}$ <p>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 $j \neq k$).</p> $dY = \sum_0^t P_k dX_k$ $Y[P_0, \dots, P_n] = Y - \sum_0^n P_k X_k$ <p>Eliminando $Y, X_0, X_1, \dots, X_n$ entre (5.23), (5.26) y las $n+1$ primeras ecuaciones de (5.24) se obtiene la relación fundamental transformada.</p>	$Y[P_0, P_1, \dots, P_n] = \text{función de } P_0, P_1, \dots, P_n, X_{n+1}, \dots, X_t \quad (5.23)$ $-X_k = \frac{\partial Y[P_0, \dots, P_n]}{\partial P_k}, \quad k \leq n \quad (5.24)$ $P_k = \frac{\partial Y[P_0, \dots, P_n]}{\partial X_k}, \quad k > n$ <p>La derivación parcial denota la constancia de todas las variables naturales $Y[P_0, \dots, P_n]$ distintas de aquella con respecto a la cual se deriva.</p> $dY[P_0, \dots, P_n] = - \sum_0^n X_k dP_k + \sum_{n+1}^t P_k dX_k \quad (5.25)$ $Y = Y[P_0, \dots, P_n] + \sum_0^n X_k P_k \quad (5.26)$ <p>Eliminando $Y[P_0, \dots, P_n]$ y $P_0, P_1, \dots, P_n$ entre (5.23), (5.26) y las $n+1$ primeras ecuaciones de (5.24) se obtiene la relación fundamental original.</p>
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$$H \equiv U[P]$$

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

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

$$F \equiv U[T]$$

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

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

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

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

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

--

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

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

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

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

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

$S = S(U, V, N_1, N_2, \dots)$ $P/T = \partial S / \partial V$ $S[P/T] = S - (P/T) V$ <p>Eliminando S y V se obtiene $S[P/T]$ como función de $U, P/T, N_1, N_2, \dots$</p>	$S[P/T] = \text{función de } U, P/T, N_1, N_2, \dots \quad (5.57)$ $-V = \partial S[P/T] / \partial (P/T) \quad (5.58)$ $S = S[P/T] + (P/T) V \quad (5.59)$ <p>Eliminando $S[P/T]$ y P/T se obtiene $S = S(U, V, N_1, N_2, \dots)$</p>
--	--

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

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POTENTIAL TERMODINAMIKOETAKO PRINTZIPIO EXTREMALAK

ADIERAZPENA	PRINTZIPIO EXTREMALA
$S = S(u, v, \dots)$	$S_{\max}$
$u = u(s, v, \dots)$	$u_{\min}$
$F = F(T, V, \dots)$ $H = H(S, P, \dots)$ $G = G(T, P, \dots)$	?

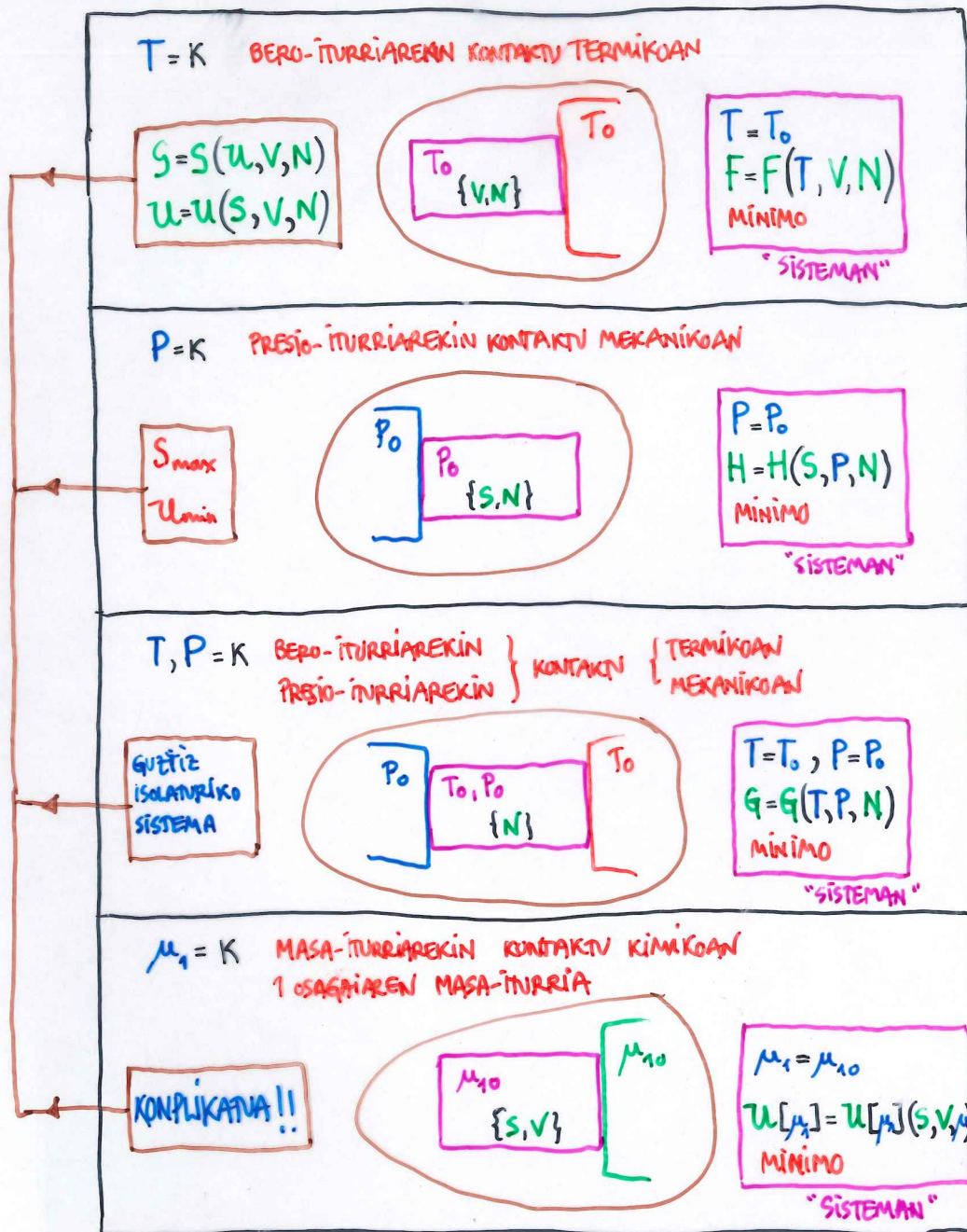
- INFORMAZIORIK GALDU GABE, PARAMETRO INTENTSIBOAK, ALDAGAI BIHURTU ESPERIMENTALKI NEURGARRIAK
- POTENTIAL TERMODINAMIKOAK ERAIKI DITUGU (MATEMATIKOKI LEGENDRE-REN TRA.)
- PRINTZIPIO EXTREMALA: TERMODINAMIKAREN OINARRIZKO PROBLEMA EBAZTEKO
 $S_{\max}$ $u_{\min}$
- GAINONTZEKO "POTENTIAL TERMODINAMIKOETARA",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

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

OROKURREAN: BALDINTZA ESPERIMENTALEK "ESANGO DUTE" ZEIN DEN
 POTENTIAL TERMODINAMIKORIK EGOKIENA

; Hots ...

ADIBIDEAK :



$$\Delta S_{\text{oson}} = \Delta S_{\text{sis}} + \Delta S_{\text{ing}} \quad \begin{cases} \text{IE} > 0 \\ \text{IG} = 0 \end{cases}$$

$$T, p = \text{Kte} \quad Q_{\text{oson}} = Q_{\text{sis}} + Q_{\text{ing}} = 0 \Rightarrow Q_{\text{ing}} = -Q_{\text{sis}}$$

$$T, p = \text{Kte}$$

$$Q_{\text{sis}} = \Delta H_{\text{sis}}$$

$$Q_{\text{ing}} = T \Delta S_{\text{ing}} \Rightarrow \Delta S_{\text{ing}} = \frac{Q_{\text{ing}}}{T}$$

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

$$\boxed{\Delta S_{\text{oson}} = \Delta S_{\text{sis}} - \frac{\Delta H_{\text{sis}}}{T}} \Rightarrow \Delta S_{\text{oson}} = \frac{1}{T} (T \Delta S_{\text{sis}} - \Delta H_{\text{sis}})$$

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

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

● definitsioon: $G = H - TS$

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

$$\boxed{\Delta G = -T \Delta S_{\text{oson}}}$$

- ① oskanna den pintoipio ehtemala ristumisen propiitateekin soilik ool danteke
- ② pintoipio ehtemala translatatu dugu pintoipio oskanna $\Delta S_{\text{oson}} > 0$ maximoos ristumisen, seelast baldintum, minime

③ ideia : ΔG da lam maximoos et mekaniika / lam et mekaniika maximoos

97 omi
Atkins

$$dG = dH - T dS$$

$$dH = dU + p dV$$

$$dG = dU + p dV - T dS$$

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

$$T = \text{Kte}$$

$$p, T = \text{Kte}$$

$$dG = \delta W + \delta Q + p dV - T dS$$

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

$$dG = -p_{\text{ex}} dV + \delta W' + \delta Q + p dV - T dS$$

IG

IG

$$\text{Kte } p_{\text{ex}} = p \Rightarrow -p_{\text{ex}} dV + p dV = 0 \\ \delta Q = -T dS$$

$$dG = \delta W'$$

④ ideia : interpretatsio mikroskoopikse (fotoaparaat dapsena)

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 $q_{\text{sur}} > 0$ and $\Delta S_{\text{sur}} > 0$. 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. ■

MAXWELL-EN ERLAZIOAK

$$\begin{aligned} &U \\ H &= U + PV \\ F &= U - TS \\ G &= U + PV - TS \end{aligned}$$

$$\begin{array}{cc} T & P \\ S & V \end{array}$$

BARNE-ENERGIA

ENTALPIA

HELMHOLTZ-EN FUNTZIOA

GIBBS-EN FUNTZIOA

$$\begin{array}{c} \mu \\ N \end{array}$$

+

$$\begin{array}{cc|cccc} T & P & & & & \\ \hline S & V & U & H & F & G \end{array}$$

INTENSIBOAK

EXTENSIBOAK

$$z = z(x, y)$$

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

DIFERENZIAL BEHATZA

$$dU = T dS - P dV + \dots \Rightarrow \left(\frac{\partial T}{\partial V}\right)_S = -\left(\frac{\partial P}{\partial S}\right)_V$$

$$dH = T dS + V dP + \dots \Rightarrow \left(\frac{\partial T}{\partial P}\right)_S = \left(\frac{\partial V}{\partial S}\right)_P$$

(...)

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

$$dG = -S dT + V dP + \dots \Rightarrow \left(\frac{\partial S}{\partial P}\right)_T = -\left(\frac{\partial V}{\partial T}\right)_P$$

U

$$dU = T dS - P dV + \mu dN$$

 S, V

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

 S, N

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

 V, N

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

 $U[T] \equiv F$

$$dF = -S dT - P dV + \mu dN$$

 T, V

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

 T, N

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

 V, N

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

 $U[P] \equiv H$

$$dH = T dS + V dP + \mu dN$$

 S, P

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

 S, N

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

 P, N

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

 $U[\mu]$

$$dU[\mu] = T dS - P dV - N d\mu$$

 S, V

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

 S, μ

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

 V, μ

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

 $U[T, P] \equiv G$

$$dG = -S dT + V dP + \mu dN$$

 T, P

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

 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

POTENTIAL TERMODINAMIKOA

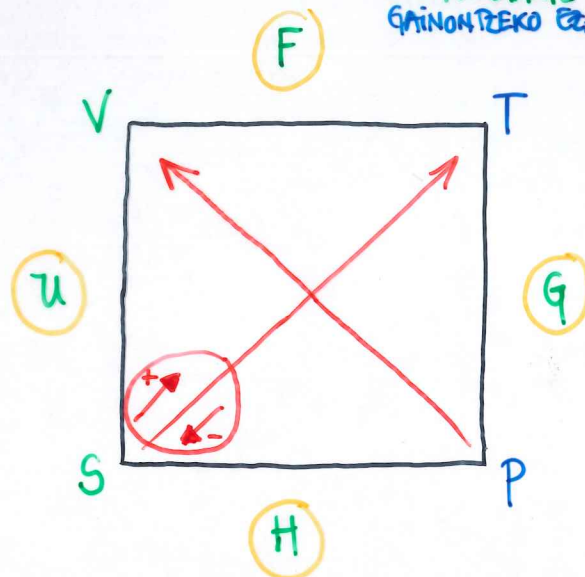
"SİKOTE NATURALA"

ERLAZIOAK

+ N

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

$N = \text{KONSTANTE}$
GAINONTZEKO ERAGARRIEKIN LOTURIKOAK = KONSTANTE



- (1) - POTENTIAL TERMODINAMIKOAK IDATZI ; F-TIK HASITA (BERAN EZ DA BEHARRERKOA)
- (2) - ALDAGAI TERMODINAMIKO "NATURALAK" ALBOETAN ; S-TIK HASITA
- (3) - ALDAGAI TERMODINAMIKO OSAGARRIAK LOTUKO DITUEN BI GEEI IRUDIKATU

EXTENTSIBO $\longrightarrow$ INTENTSIBO

ZEINU ALDAKETARIK EZ BADAQO, BEHINERAT!

- (4) - ONDOKO ESKEMARI SEGITU

$$\begin{array}{cc} \begin{array}{c} \text{V} \\ \text{S} \end{array} \begin{array}{|c|} \hline \text{P} \\ \hline \end{array} & \begin{array}{c} \text{T} \\ \text{S} \end{array} \begin{array}{|c|} \hline \text{P} \\ \hline \end{array} & \Rightarrow & \left(\frac{\partial \text{V}}{\partial \text{S}} \right)_\text{P} = \left(\frac{\partial \text{T}}{\partial \text{P}} \right)_\text{S} \\ \begin{array}{c} \text{T} \\ \text{S} \end{array} \begin{array}{|c|} \hline \text{P} \\ \hline \end{array} & \begin{array}{c} \text{V} \\ \text{S} \end{array} \begin{array}{|c|} \hline \text{P} \\ \hline \end{array} & \Rightarrow & \left(\frac{\partial \text{S}}{\partial \text{P}} \right)_\text{T} = - \left(\frac{\partial \text{V}}{\partial \text{T}} \right)_\text{P} \\ \vdots & \vdots & & \end{array}$$

KALKULU TERMODINAMIKOA

SISTEMA HIDROSTATIKOA (BAKUNA)

(1) - POTENTZIALAK "GORA" ETA DEFINIZIOA APLIKATU

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

(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 TEMPERATURA "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

$$C_p - C_v = TV \frac{\alpha^2}{\kappa_T}$$

MAYER-EN ERLAZIOA

SISTEMA HIDROSTATIKOAN SOLIK
OROKORTU DAITEKE

MAYER-EN ERLAZIO OROKORTUA