The meaning of the Second Law:

Nonlocal effects in continuum physics

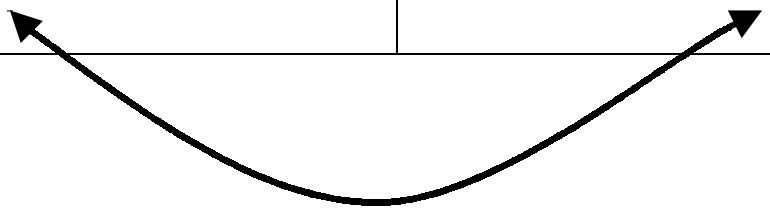
Peter Ván
BUTE, Department of Chemical Physics

- Irreversibility concepts in thermodynamics
- Stability and the Second Law
- How to construct constitutive functions?
- Example:
  - Ginzburg-Landau equation

– Concepts and theories

– What kind of thermodynamics?

Homogeneous $T(t)$	Continuum $T(t,\mathbf{x})$
Phenomenological (T is primitive)	Statistical (T is explained)
Equilibrium	Irreversible



Irreversibility

- time dependence (?)
- time reversal (?)
- variational principles (?)
- S exists
- S is increasing

} Second Law

- local equilibrium

Can be interpreted in a thermodynamic theory

Thermodynamic theory

Dynamic law: $\dot{a} = f(a)$

$a = (v, c, \varepsilon, \ldots)$

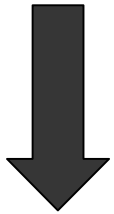
1 Statics (equilibrium properties)

$\exists S$ $\left(\frac{\partial S}{\partial e} = \frac{1}{T}, \quad \cdots \quad , \frac{\partial S}{\partial a} = \Gamma_a \right)$

2 Dynamics

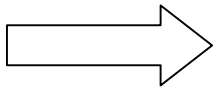
$$\dot{S}(a) = DS(a) \cdot \dot{a} = DS(a) \cdot f(a) \geq 0$$

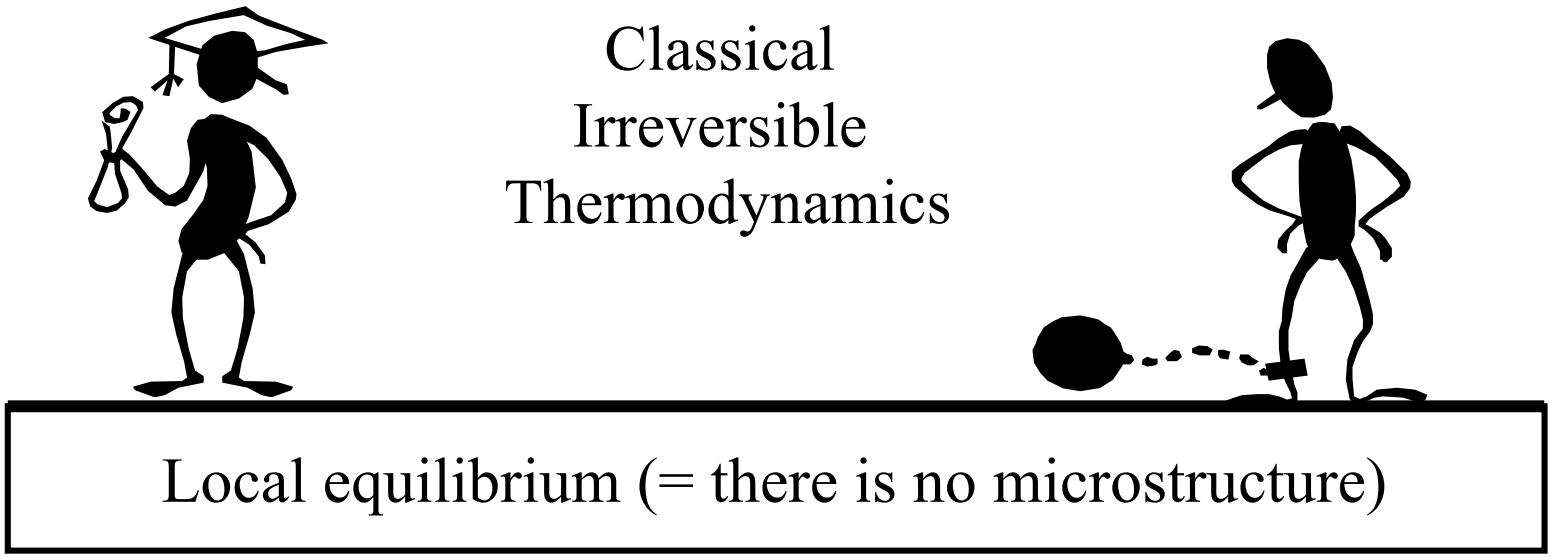
1 + 2 + closed system



S is a Ljapunov function

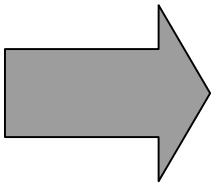
of the equilibrium of the dynamic law

Irreversibility  trend to equilibrium



Violations (nonlocality):

- in time (memory effects) → dynamic variables
- in space (structure effects) → ?

Stability structure  Dynamic structure

Example 1

$$\dot{a} = f(a)$$

$\dot{s}(a) \geq 0$ for all solutions of the dynamic law

$$\boxed{f(a) = ?}$$

$$0 \leq \dot{S}(a) = DS(a) \cdot f(a) \quad \Rightarrow \quad f(a) = l(a)DS(a)$$

relaxational dynamics

Example 2 (Ginzburg-Landau)

$$\partial_t \xi = g$$

$$\partial_t s + \nabla \cdot j_s \geq 0$$

$(\xi, \nabla\xi, \nabla^2\xi)$ state space

(g, s, j_s) constitutive functions

Liu procedure (Farkas's lemma)

$$s(\xi, \nabla\xi) \qquad j_s(.) = j_0(\xi, \nabla\xi) - \partial_\xi s \, g(.)$$

$$\sigma_s = -(\partial_\xi s - \nabla \cdot \partial_{\nabla\xi} s) g \geq 0$$

$$\partial_t \xi = g = -l(.)(\partial_\xi s - \nabla \cdot \partial_{\nabla\xi} s)$$

Conclusions

- Irreversibility - stability
- 1st Second Law - 2nd dynamic laws
- Predictive

  - Economics (?)