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Is There Anything New with Statistical Physics Explanations?

1

Plan of my presentation

- I/ Statistical physics since the 1970s: A new kind of physical theory?
- II/ How to explain universality in critical phenomena
- III/ Why talk about “emergent explanation”?
Comparison with two other “ideal-types” of asymptotic explanations



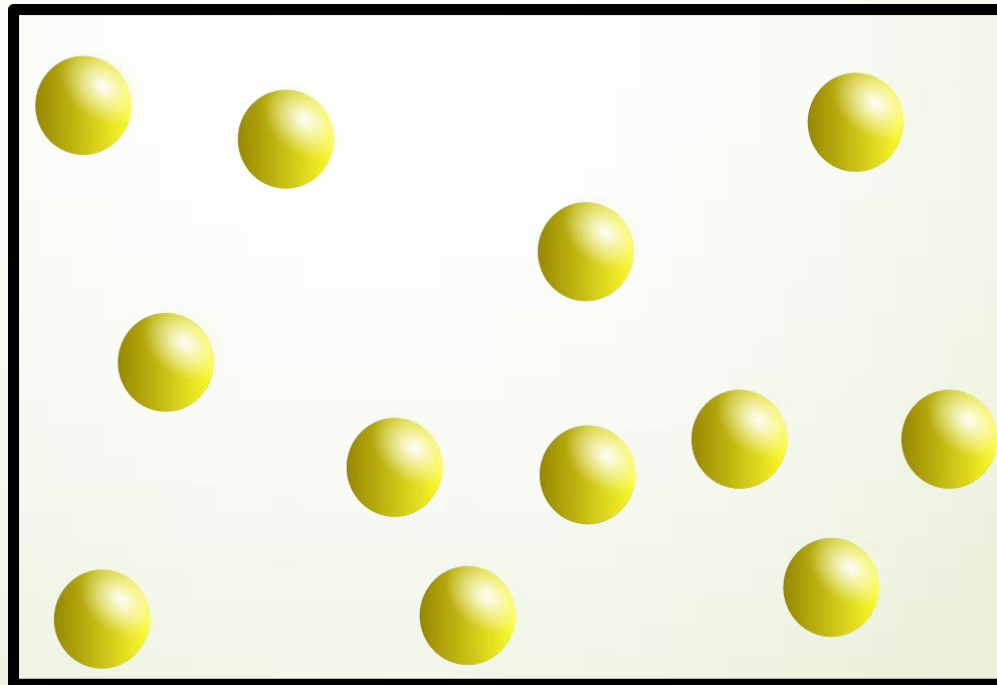
I/ Statistical physics since the 1970s

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A new kind of physical theory?

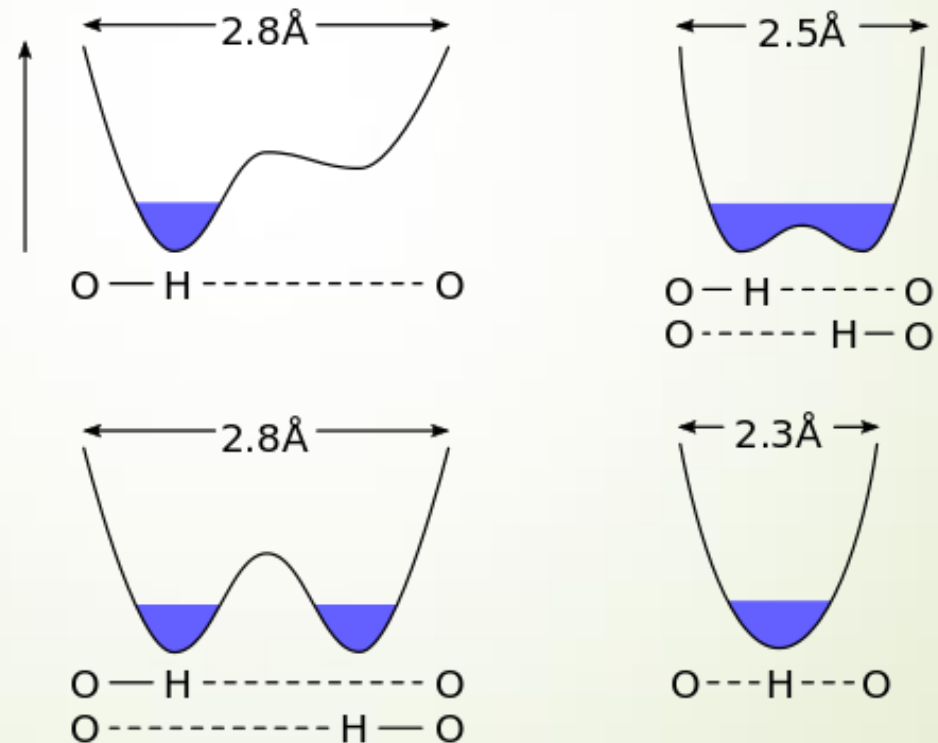
Mechanical models to reduce thermodynamics...

- Maxwell, Boltzmann...
- “Micro-reductive unification”: from the bottom up



... vs. unification by mathematical abstraction.

► “Duhemian unification”: from above



A “crisis in physical theory”?

- ▶ “The ability to reduce everything to simple fundamental laws does not imply the ability to start from those laws and reconstruct the universe. In fact, the more the elementary-particle physicists tell us about the nature of the fundamental laws, the less relevance they seem to have to the very real problems of the rest of science, much less to those of society.” (Anderson 1972)
- ▶ “... a new way of looking at physics emerged” (Goldenfeld 1992)

So what is statistical physics about?

Historical stand:

- Statistical physics underwent a drastic shift of focus during the 1970s,
- from a theory aiming to explain macroscopic matter properties on the basis of a mechanical theory of its constituents...
- ... to a “theory-framework” free of ontological content, concerned with “collective properties”.

A new kind of explanation for critical phenomena

Epistemological stand:

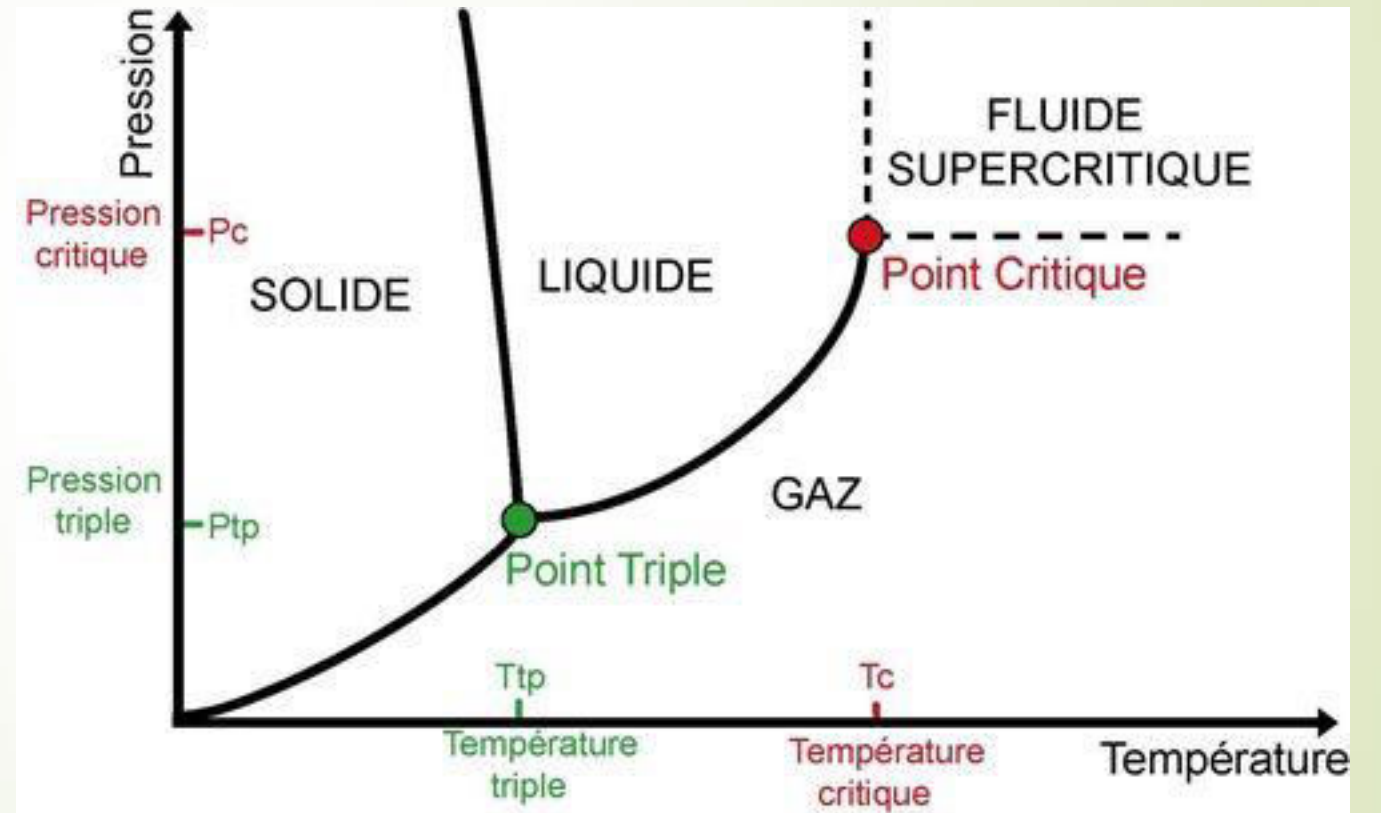
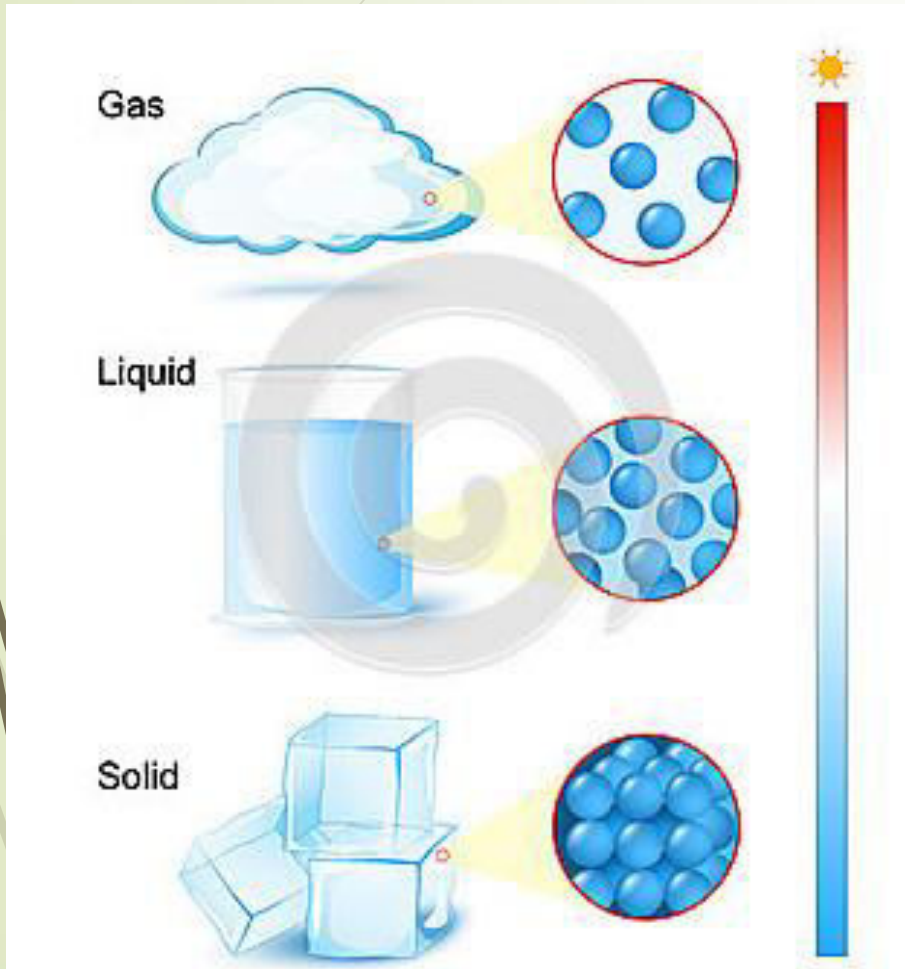
- A historical shift of focus that has been carried and justified by the rise of a new kind of explanation for *universality in critical phenomena*.
- Borrowing and distinct from both previous kinds of explanatory unification in physics.
- That ensures an *explicative autonomy*, allowing to talk about “emergent phenomena”.

Explanation with asymptotic reasonings

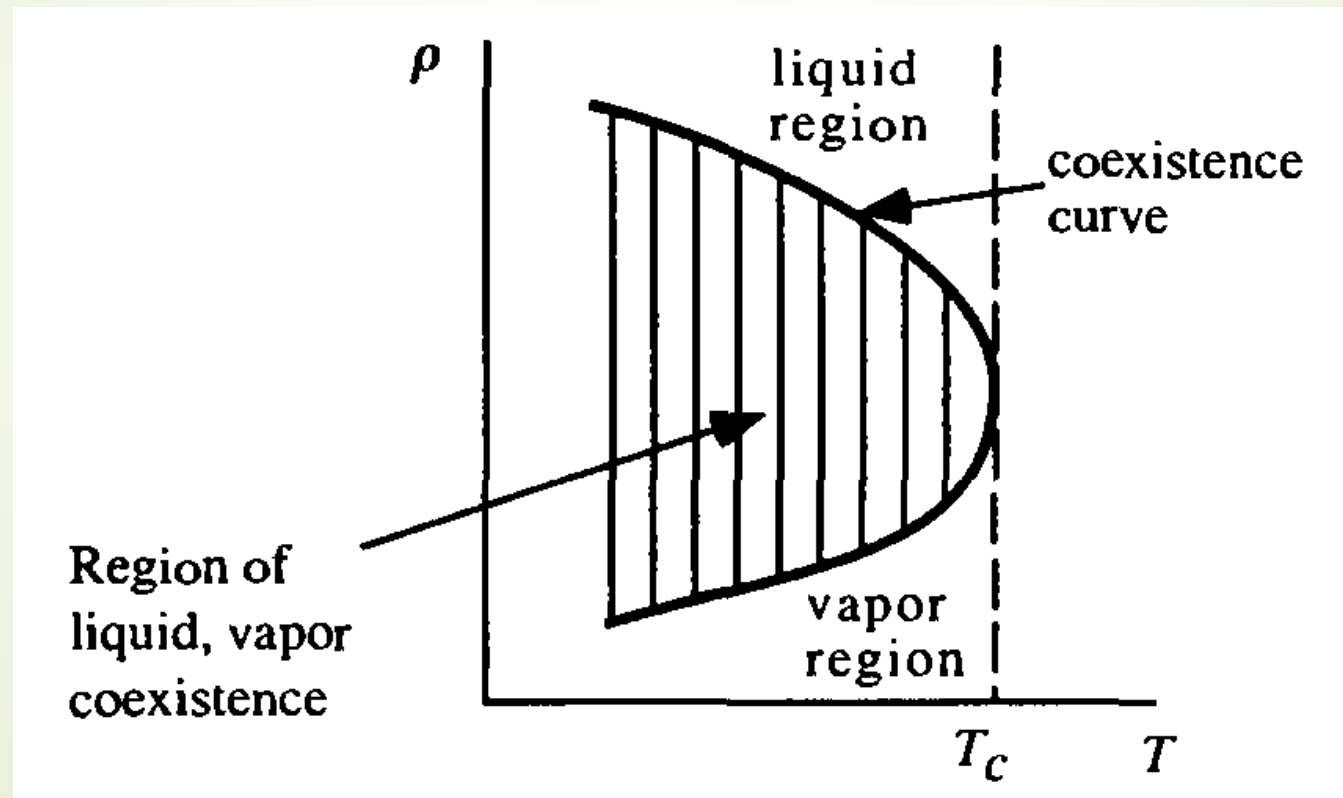
- ▶ In order to understand this new kind of explanation, philosophers need to make room for *asymptotic reasonings* (Batterman 2002)
 - ▶ when physicists deliberately eliminate details of the system under study by taking the limit of some quantities to infinity, in order to identify “universal” properties, independent of these details
- ▶ A type of reasoning everywhere in physics, but playing a very specific role in our context.

II/ How to explain universality in critical phenomena

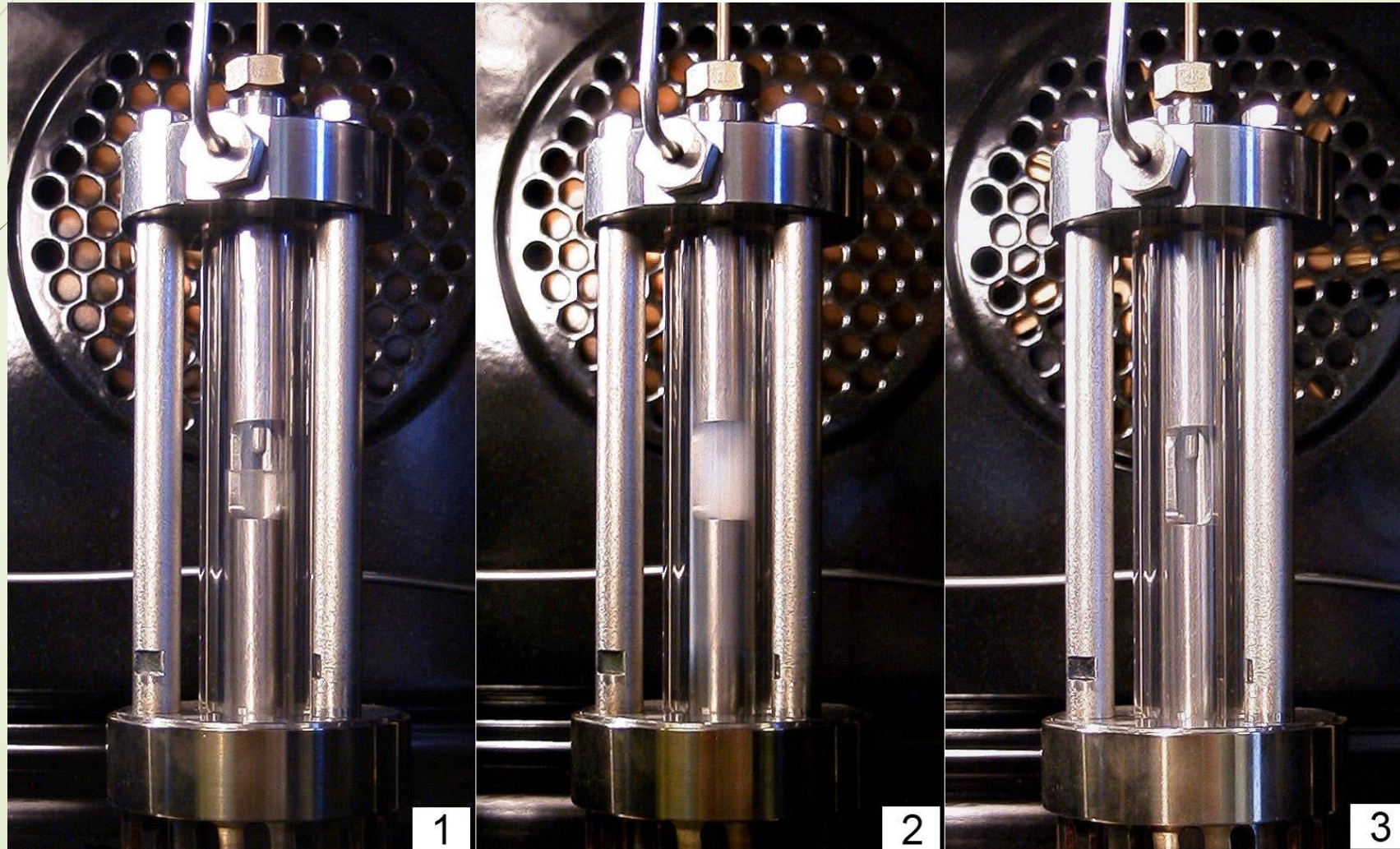
A special case of phase transitions



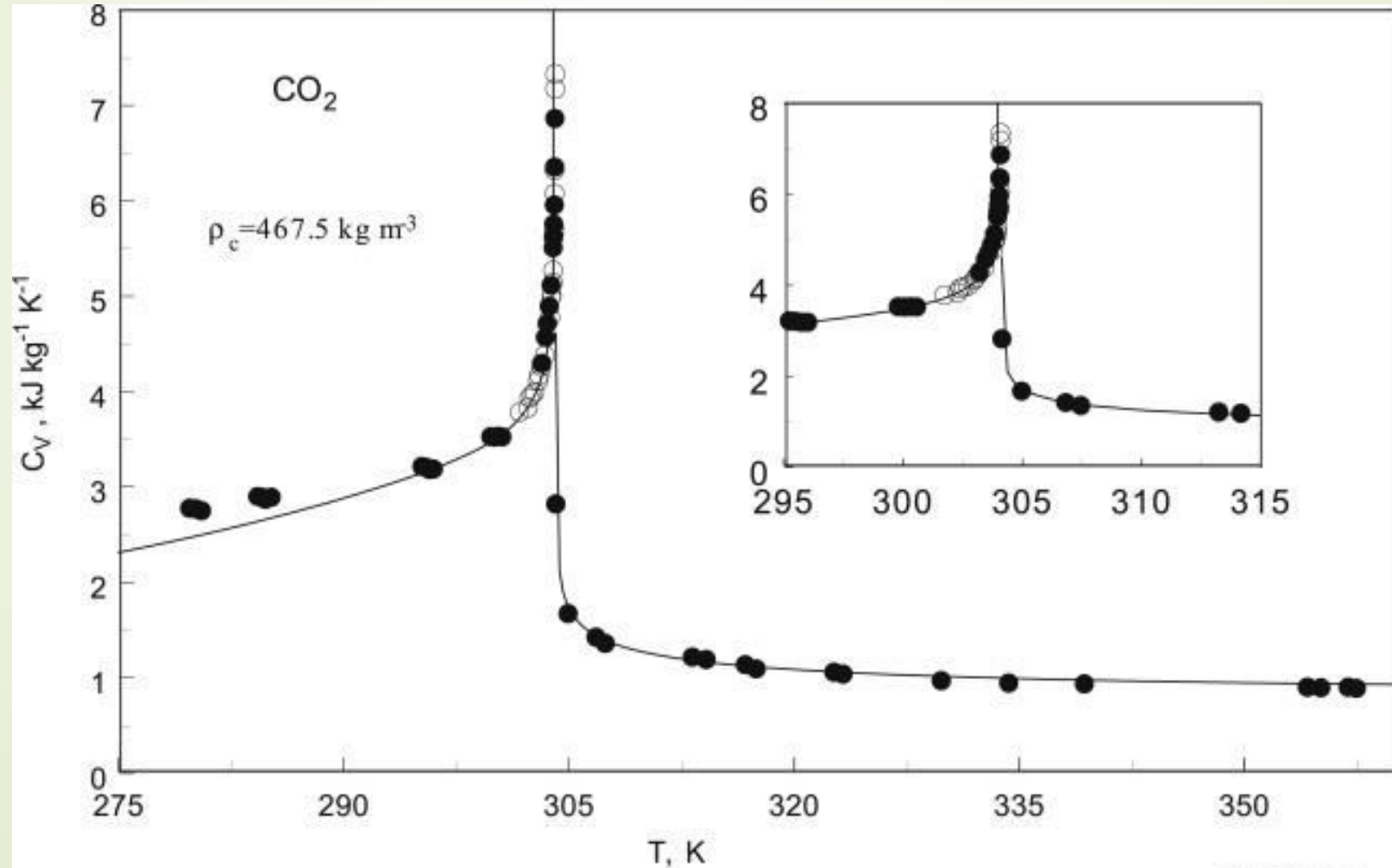
An instability producing a close mixture between the two phases



The instability made visible: critical opalescence



A divergence of certain physical quantities



Critical exponents

- ▶ Whatever the fluid, the curves around the critical point have the same shape in power law

$$\rho - \rho_c \sim \left| \frac{T - T_c}{T_c} \right|^\beta$$

- ▶ with the same exponent $\beta \approx 0.32\dots$

Universality classes

- Identical result in radically different systems (ferromagnetic materials, binary alloys).
- A *universality class* is defined by a set of critical exponents.

Universality in critical phenomena: an example of emergent explanation?

- What explanation? Scale invariance and renormalization methods.
- Universality classes are independent of local interactions, and defined only by the dimension d of space, and the dimension n of the order parameter (here: $d=3, n=1$).
- An example of asymptotic reasoning that blocks reductive explanation.

III/ Why talk about “emergent explanation”?

Comparison with two other “ideal-types” of asymptotic explanations

An archetype of micro-reduction: the ideal gas model

- Ideal gas law: $pV = nRT$ (thermodynamics).
- Valid for all gases, within the limit of large dilutions → “universality”.
- Explained by statistical physics by means of the construction of a model (idealization) starting from the atomic hypothesis (physical analogy about constituents).
- Reductive asymptotic reasonings → the contribution of atomic constituents (micro.) can be isolated in the final result (macro.).

1 "universal" relation
 $pV = nRT$

asymptotic
reasonings

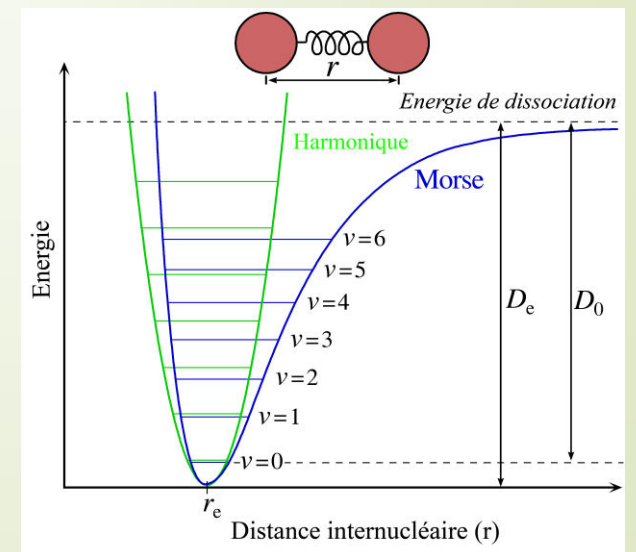
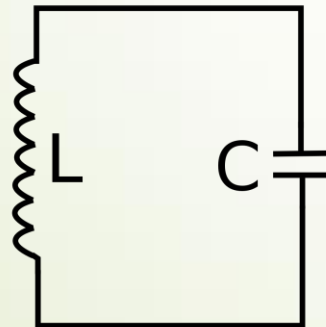
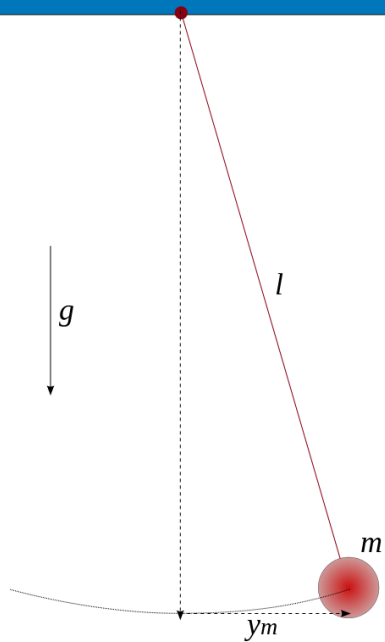
constitutive idealization (with parameters)

physical analogy

gas 1 ... gas 2 ... gas 3

A “universality” neutral towards reduction: the harmonic oscillator

- Within the limit of small variations around a state of equilibrium, all conservative physical systems can be described by the same equation.
- Idealization carried here by a formal analogy, not by the hypothesis of a shared constitution (“Duhemian unification”)



1 "universal" relation

$$\frac{d^2x}{dt^2} + \omega_0^2 x = 0$$

formal analogy

diff. eq.



diff. eq.



diff. eq.



diff. eq.

asymptot. r.
abstraction

LC electric circuit

asymptot. r.
abstraction

pendulum

asymptot. r.
abstraction

spring-mass

asymptot. r.
abstraction

molecular vibrations

Critical phenomena and renormalization: an explanatorily autonomous “universality”

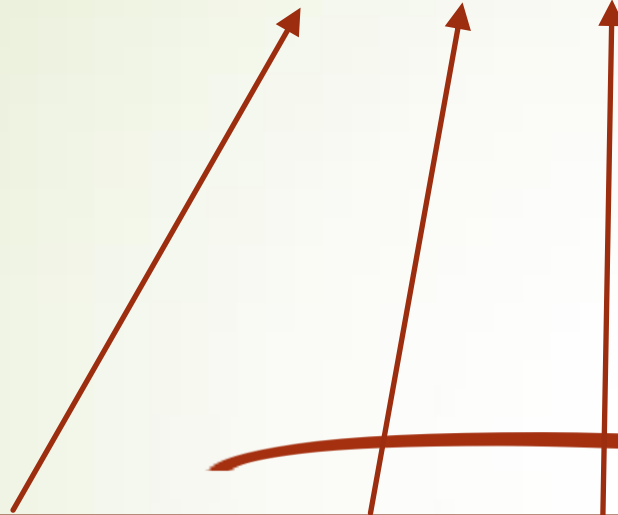
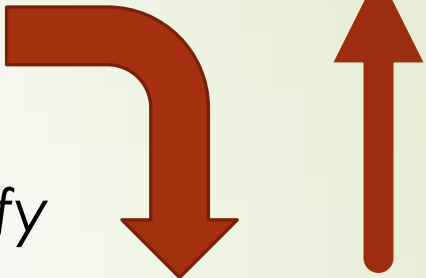
- An explanation based on a constitutive idealization (physical analogy about constituents)...
- ... but justifying a posteriori a formal analogy between systems of radically different constitutions.
- Borrows from both the micro-reductive ideal-type of the ideal gas model, and the autonomous ideal-type of the harmonic oscillator.

1 power law
1 set of critical exponents

asymptotic r.
(renormalization)

justify

formal analogy (1 universality class)

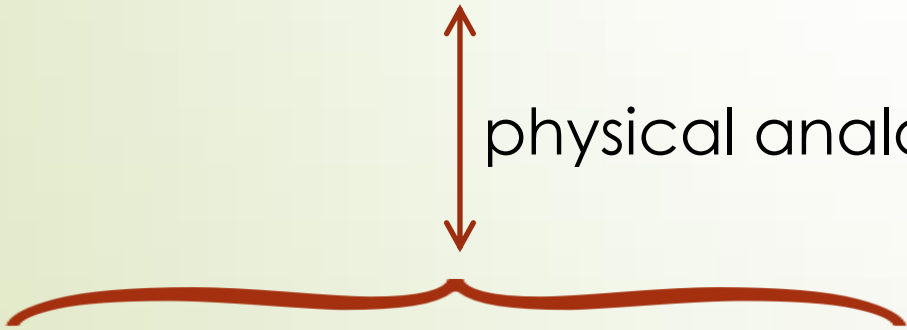


constitutive idealization (with param.)

fluid 1 ... fluid 2 | alloy 1 ... alloy 2

physical analogy

ferromagnetic m. 1 ... ferromagnetic m. 2



Thank you for your attention!

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