When Science Needs Conceptual Change

A Contribution to the Symposium

On the Nature of Continuity or Discontinuity Between
Lay and Scientific Conceptualizations in Physics

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Introductory Remarks and Overview

Thermodynamics and Conceptual Change

- **Traditional thermodynamics** *(*TTD*)* (1) does not deliver a theory for a changing world and (2) requires ***radical conceptual change*** (possibly in the form of ontological shift).
- **Modern thermodynamics** *(*MTD*)* is profoundly different. (1) It delivers an ***extended theory of irreversible processes***. (2) It allows us to rethink the very idea of conceptual change. It suggests that there is much more ***continuity*** between everyday thought and formal science than we commonly accept.

Overview of the Presentation...

1. Why is TTD a poor copy of a theory?
2. What is the form of MTD?
3. Why is MTD close to everyday abstract thought?
   - *A. Metaphoric projection of schemas*
   - *B. Gestalt of forces of nature*
   - *C. Narrativity and macroscopic physical science*

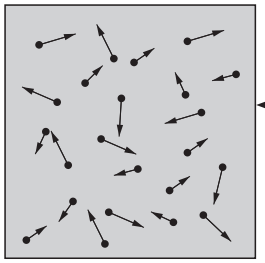
1. Why is TTD a Poor Copy of a Theory?

TTD is not a theory of the dynamics of heat. It does not produce ***initial value problems*** (no dynamics, ***timeless***). It is a theory of the statics of heat:

- In TTD, ***machines crawl***, they do not run.
- TTD uses ***a form of mathematics unknown to the rest of physics*** (funny d's).
- It (unnecessarily and misguidedly) celebrates ***equilibrium*** as a necessity and a deep insight.
- It makes us believe that a proper macroscopic approach is not possible and that TD ***can be reduced to mechanics***.

$$\frac{dp}{dt} = F_G + F_R \quad , \quad v(0) = v_0$$
$$p = mv$$
$$F_G = mg \quad , \quad F_R = -bv^2$$
$$\Rightarrow \frac{dv}{dt} = g - \frac{b}{m}v^2 \quad , \quad v(0) = v_0$$

$$dU = đQ - đW$$
$$\Delta S \geq \int \frac{đQ}{T}$$
$$\Delta Q = cm\Delta T$$



Note: Calusius' pre-conception (*heat as the energy of the motion of little particles*) is a ***misconception in his own theory***.

1. Why is TTD a Poor Copy of a Theory?

Why did TTD turn out to be a tragicomedy? (Truesdell)

- The physicists of the 19th century did not understand mathematics any longer. (C. Truesdell (1980): *The Tragicomical History of Thermodynamics*. (1984): *Rational Thermodynamics*.)
- A fundamental figure of the human mind (the ***gestalt of forces of nature***) was twisted into something unrecognizable: the concept of an extensive quantity of heat was lost. Psychological motivation for this change: ***heat as the (energy of the) motion of little particles***. (Fuchs (1986): *A surrealistic tale of electricity*.)

A simple cure...

- Use fluids and electricity as models for a dynamical theory of heat.
- Start with Sadi Carnot and make ***caloric*** and ***temperature*** the two fundamental quantities of a dynamical theory of heat. Use his image of the ***power of heat*** (analogy of a waterfall). (Fuchs (2010): *The Dynamics of Heat*.)

2. What is the Form of MTD?

Look at this as you would at a canvas of abstract art:

There are shapes that combine into figures...

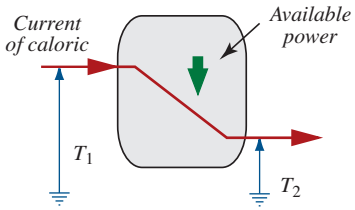
Some basic gestalts (shapes) and figures in continuum physics

	Law of balance for fluidlike quantity	*Capacitive relation*	*Resistive (diffusive) relation*	*Available power*
M	$\frac{\partial \rho_p}{\partial t} + \frac{\partial}{\partial x}\left(j_{p,cond} + j_{p,conv}\right) = \sigma_p$	$\frac{\partial \rho_p}{\partial t} = \rho \frac{\partial v}{\partial t}$	$j_{p,cond} = -k_p \frac{\partial v}{\partial x}$	$p = j_p \frac{\partial v}{\partial x}$
E	$\frac{\partial \rho_q}{\partial t} + \frac{\partial}{\partial x}\left(j_{q,cond} + j_{p,conv}\right) = 0$	$\frac{\partial \rho_q}{\partial t} = c \frac{\partial \varphi}{\partial t}$	$j_{q,cond} = -k_q \frac{\partial \varphi}{\partial x}$	$p = j_q \frac{\partial \varphi}{\partial x}$
S	$\frac{\partial \rho_n}{\partial t} + \frac{\partial}{\partial x}\left(j_{n,cond} + j_{n,conv}\right) = \pi_n$	$\frac{\partial \rho_n}{\partial t} = c_n \frac{\partial \mu}{\partial t}$	$j_{n,cond} = -k_n \frac{\partial \mu}{\partial x}$	$p = j_n \frac{\partial \mu}{\partial x}$
H	$\frac{\partial \rho_S}{\partial t} + \frac{\partial}{\partial x}\left(j_{S,cond} + j_{S,conv}\right) = \sigma_S + \pi_S$	$\frac{\partial \rho_S}{\partial t} = \kappa \frac{\partial T}{\partial t}$	$j_{S,cond} = -k_S \frac{\partial T}{\partial x}$	$p = j_S \frac{\partial T}{\partial x}$

2. What is the Form of MTD?

Some benefits of using a direct caloric (entropic) approach

- ***Available power***: Carnot's formula for the efficiency of a heat engine becomes a one-liner…



- ***Optimal thermal design*** means minimizing the production of caloric (***minimizing irreversibility***) in dynamical processes…

- Transport of caloric as the fundamental thermal process: the ***quantum of thermal conductivity*** (conductivity of caloric) is a universal constant (rather than being dependent upon temperature)…

- The ***figure of merit*** of a thermoelectric device is a non-dimensional quantity dependent only upon material parameters (and not upon temperature!)…

- Learning about ***thermoelectricity*** becomes a breeze…

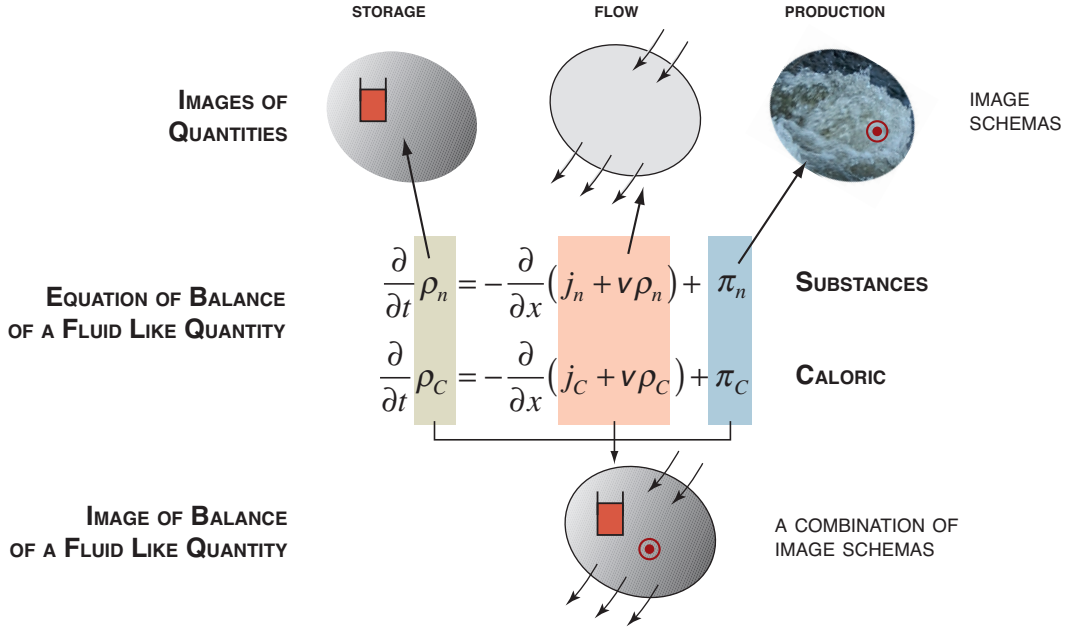
	MTD	TTD
→	$G_C = \frac{\pi k_B^2}{3h}$	$G_{th} = \frac{\pi k_B^2}{3h} T$
→	$z = \frac{\alpha^2 \sigma}{k_S}$	$z = \frac{\alpha^2 \sigma}{k_E} T$

3. Why is MTD Close to Everyday Abstract Thought?

A. Metaphoric projection of schemas

Thermodynamics is fundamentally metaphoric...

Metaphors are of the type also found in every-day life...



Metaphors found in this analysis are not unrelated: they are part of a ***network*** forming a ***larger-scale structure*** called → **Forces of Nature**.

3. Why is MTD Close to Everyday Abstract Thought?

Macroscopic physics is a collection of theories of Forces of Nature

B. The perceptual gestalt of forces of nature

Direct perception of forces of nature

Wind, water, light, fire, ice, thunderstorm, food, soil, motion…

[Formal versions: *fluids, electricity and magnetism, heat, substances, linear motion, rotation, gravity.*]

Examples of social and psychic forces

Justice, the market, love, pain, anger, music, evil, imagination…

Figurative structure of forces (basic aspects)

- **Intensity** (quality, derived from polarities; **tension** as differences of intensity)
- **Substance** (quantity)
- **Power** (as a measure of causation)

GESTALTS AT DIFFERENT SCALES?

The notion of gestalt seems to preclude the idea of different scales (all gestalts are equally simple).
However, the phenomena leading to the creation of gestalts can be simpler or richer. Stumbling and regaining ones equilibrium is smaller in extent (temporal and spatial) than a forrest fire.

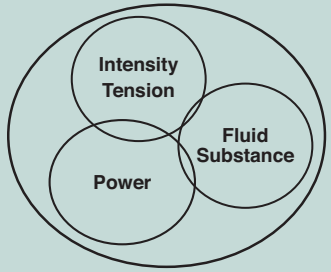
→ When analyzed, gestalts demonstrate different complexity.

GESTALT OF FORCES

Additional schemas:

Balance, Resistance
Letting, Enabling
Container
Path, Process

Figure-Ground Reversal



These aspects flesh out the figure of ***agency***.

Agents or ***characters*** (forces) are structured figuratively by borrowing from small-scale and large-scale gestalts. → **Story**

3. Why is MTD Close to Everyday Abstract Thought?

Macroscopic physics is a rendering of Stories Forces of Nature live through…

C. Narratives of the force of heat…

Examples of Stories of Nature

Birth of a child, a forest fire, hurricane Sandy, the creation of the world…

Forces and Narratives

When interacting with objects in the world and with other ***agents***, a force (of nature) creates an ***event*** that ***unfolds over time*** and ***changes*** things in the world → **Story**.

Narrative Framing

In stories, we can ***frame natural scenes*** where forces of nature live through adventures…

In other words, ***content*** and ***structure*** of scientific knowledge are ***integral components of stories***.

Theory, Model, Simulation, and Stories of Forces of Nature

- A ***theory*** is an ordered collection of the basic ***properties of forces of nature*** plus logical consequences.
- A ***model*** is a rendering of a particular ***story-world*** (framing of a scene) and…
- …its ***simulation*** is a ***story*** (Mary Morgan, Norton Wise).

On the Continuity Between Every-Day and Formal Thought…

Narrative Framing

We can tell *properly scientific stories* of forces of nature to small children.

In these stories, the ***differentiation of the gestalt of forces*** is a potentiality…

As children grow up, they can learn how to differentiate between the aspects of the gestalt (tension, quantity, power), how to relate these aspects to each other, and how to make use of the logic of additional schemas (balance, container, resistance, enabling, path, process…).

→ ***Learning as progressive differentiation and formalization of primary abstractions resulting from working with figures of the embodied mind (by becoming aware of their aspects, creating models, and using them in stories…).***

A Winter Story

On the Continuity Between Every-Day and Formal Thought…

Learning as progressive differentiation and formalization of primary abstractions resulting from working with figures of the embodied mind (by becoming aware of their aspects, creating models, and using them in stories…).

Differentiation of Perceptual Gestalts…

Analysis of the aspects (elements) of gestalts (e.g., by becoming aware of and analyzing the language used to speak about experience).

Formalization…

Two senses of formalization (discussed in the context of modeling by M. Morgan (2012): *The World in the Model*):

1. *Giving form to…* (assembling, synthesizing, e.g., by creating a story world, a model)
2. *Making subject to rules…*
   - rules of logic embedded in the language used
   - rules of logic embedded in scientific content (concepts)

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