

# **DIFFERENCES AND CHANGE AND THE KARLSRUHE PHYSICS COURSE**

## **Structures of figurative thought in physics**

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# *Part 1*

## **INTRODUCTION: POLARITIES AND DYNAMICS**

Egyptian and Babylonian cosmology is based on polarities. The notion of polarities is a central element of mythic thought. Polarities are the source of dynamics in the world...

## CREATING AND MAINTAINING DIFFERENCES



<http://www.civilization.ca/civil/egypt/images/reli28b.jpg>

*In Egyptian mythology, the world is created by differentiation from the undifferentiated chaos. Shu (air) separates Nut (heavens) from Geb (earth). The sky must be supported, or it collapses onto the earth.*

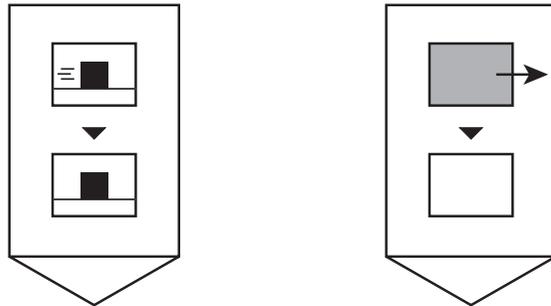
This sounds modern: The Sun has to supply useful energy to maintain potential differences on our planet. These differences are the causes of processes of life.

## *Part 2*

### **ENERGY AND CHANGE: AN EXAMPLE OF A BRITISH CURRICULUM PROJECT**

Richard Boohan and Jon Ogborn have created a curriculum that emphasizes processes of change. They stress that differences drive change, that differences decay, and that differences can create differences. They start with level differences, pressure differences, and temperature differences. And all of a sudden, they change their story...

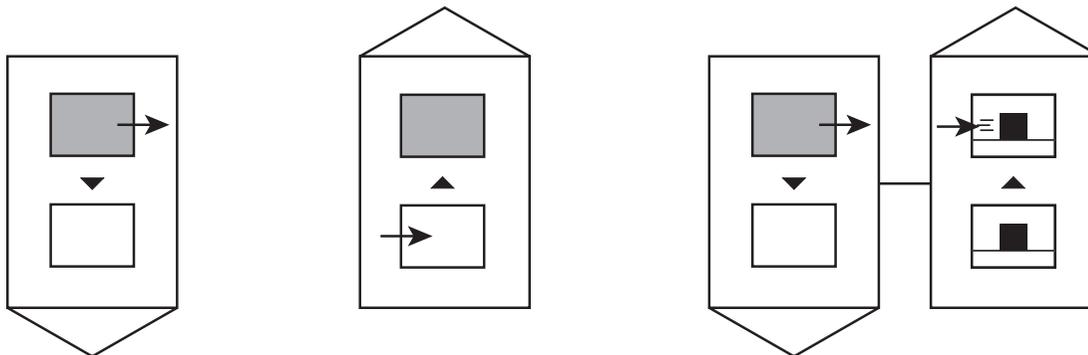
## DIFFERENCES AND CHANGE



*Left: A body is slowing down because of a speed difference between the body and the ground.*

*Right: A body cools to the temperature of the surroundings.*

## SPONTANEOUS AND NON-SPONTANEOUS CHANGE

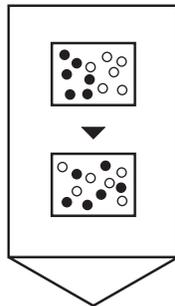
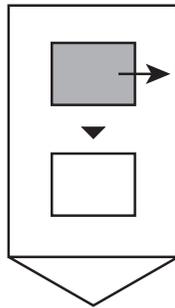


*Left: A body cools spontaneously.*

*Middle: A body gets warmer than the surroundings. This cannot happen spontaneously.*

*Right: A non-spontaneous change is coupled to a spontaneous one.*

## MATTER AND ENERGY SPREAD...



Boohan and Ogden change the story to concentration differences of matter and energy:

- Matter spreads because of concentration differences;
- Energy spreads because of energy-concentration differences.

Inconsistencies with the approach

- Pure energy is the counterpart of matter.
- Energy has two aspects whose difference is never explained: It spreads, and it is the measure of how much happens.
- Statistical mechanics as the background of the BO approach; first, however, they use examples from macroscopic physics.

# *Part 3*

## **THE GESTALT OF PHYSICAL PROCESSES**

Human perception leads to the abstraction of a structured gestalt of experiences as diverse as love, pain, heat, or motion. The aspects of the gestalt are quantity, intensity, and force...

A figure-ground reversal of this conceptualization may result in the concept of “motion of little particles” that explain how nature works.

## THE GESTALT OF ABSTRACT CONCEPTS

Concepts such as **evil** or **love** or **thought** are abstracted from experience in the form of a preconceptual structured gestalt having the aspects of

**substance (quantity) / intensity (quality) / force or power**

*Linguistic expressions for evil:*

- She had no idea how strong evil could be.
- Evil burned intensely.
- Evil grew amongst us.
- Evil gained control of this group of people.
- Slowly, evil left his soul.
- Evil made him do things he would not have done otherwise.

*Entailments of the conceptualization*

Two bad people means double the evil. More evil means higher intensity. More evil means it is more powerful. Higher intensity of evil increases its power.

# EVIDENCE FOR THE GESTALT OF PHYSICAL PROCESSES 1

Persons are asked if they agree or disagree with certain expressions

- The temperature is high
- Today, the heat is high
- There is lots of heat in this room
- There is lots of temperature in this room
- Heat drives the engine
- Temperature drives the engine

**Table 1: Agreement with classes of expressions<sup>a</sup>**

	<b>as substance</b>	<b>as level</b>	<b>as cause</b>
<b>Heat</b>	<b>0.67 (1)</b>	<b>0.14 (0)</b>	<b>0.77 (1)</b>
<b>Temperature</b>	<b>0.09 (0)</b>	<b>0.83 (1)</b>	<b>0.09 (0)</b>

a. Agreement (1) or disagreement (0) with expressions using heat and temperature. Expected results in parentheses. Results of a questionnaire given to journalism students in Summer of 2004.

## EVIDENCE FOR THE GESTALT OF PHYSICAL PROCESSES 2

*The concept of heat in the Accademia del Cimento*

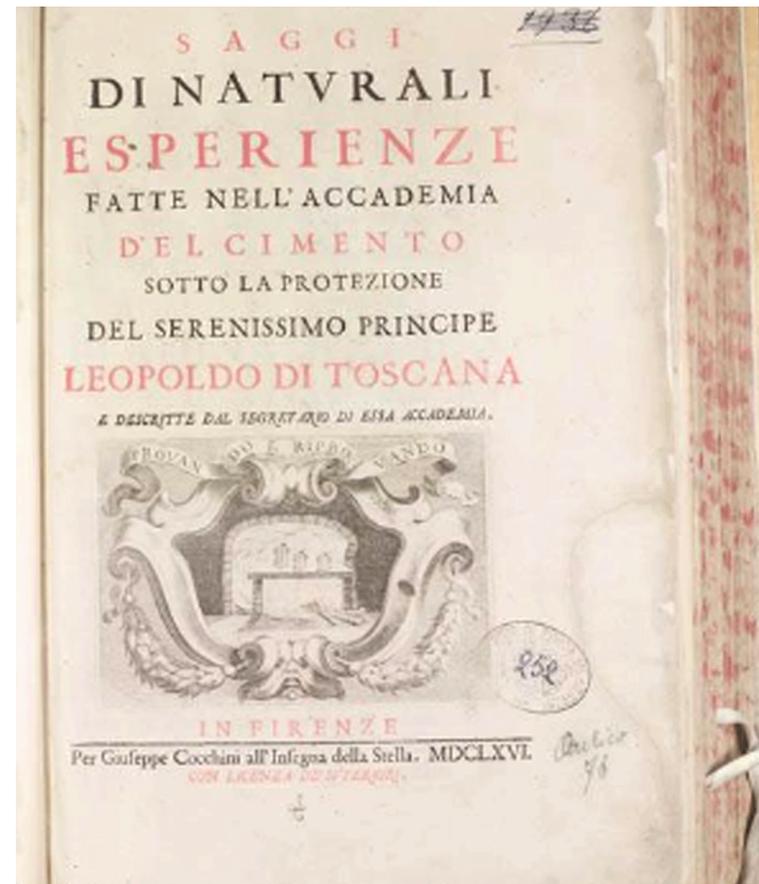
**The concept of heat of the members of the Accademia del Cimento: Saggi di naturali esperienze... (1667)**

M. Wisser and S. Carey (1983): When Heat and Temperature were one.

“The Experimenters’ concept of heat had three aspects: **substance** (particles), **quality** (hotness), and **force**.”

*A weakly differentiated gestalt*

It seems that the Experimenters did not really distinguish between these aspects of the gestalt of heat.

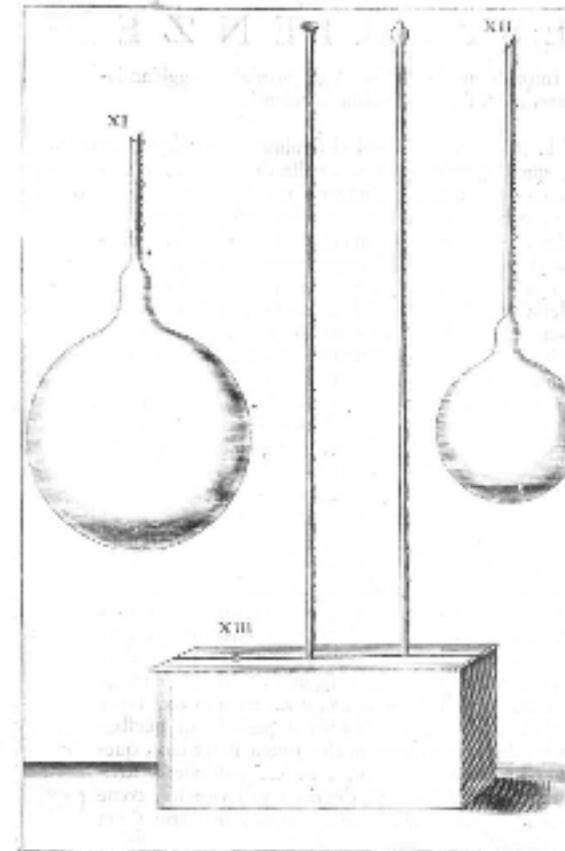


*The concept of heat in the Accademia del Cimento*

**The concept of heat of the members of the Accademia del Cimento: Saggi di naturali esperienze... (1667)**

The description of thermal phenomena by the Experimenters demonstrates clearly the image corresponding to direct causation: Hot or cold bodies are the sources of heat or cold. Heat or cold are emitted by the sources, and they influence other bodies. The Experimenters were interested in the “force” or “power” of heat (or of cold).

See M. Wisser and S. Carey (1983)



## THE GESTALT OF PHYSICAL PROCESSES

*Human perception of phenomena such as fluids, electricity, heat, motion*

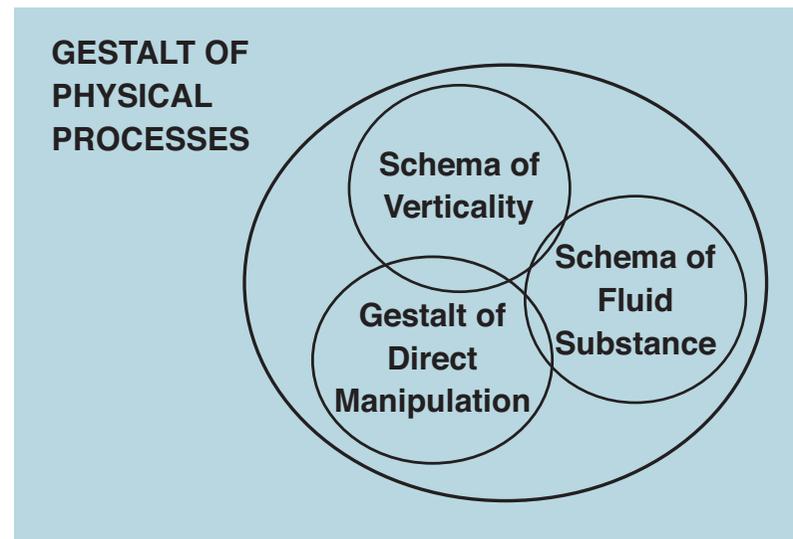
The concept of “heat,” for example, is abstracted by perception from the sum total of thermal experiences in the form of a **gestalt**: An entity that encompasses more than the sum of its parts. While we do not differentiate a gestalt of a collective of phenomena (such as electricity or heat) consciously, we do notice aspects. The most fundamental **aspects** humans use to talk about such a **gestalt** are

**Table 2: The gestalt of collectives of physical phenomena**

ASPECT OF GESTALT	METAPHORIC STRUCTURE
<b>Intensity (quality)</b>	Polarity such as light-dark, warm-cold, high-low, fast-slow, strong-weak. The concepts are structured metaphorically by the <b>image schema</b> of verticality (intensity as a level).
<b>Quantity (substance)</b>	Substance-like concepts are metaphorically structured in terms of the <b>image schema</b> of fluid substances.
<b>Force or power</b>	Prototypical causation as the <b>gestalt</b> of direct manipulation.

## GESTALTS AS STRUCTURED PRECONCEPTUAL WHOLES

- The gestalt is structured, it has aspects or elements.
- The gestalt is preconceptual. Concepts are generated by the application and the metaphoric projection of image schemata to the aspects of the gestalt. This is how form and structure are given to our experience and understanding (M. Johnson, 1987, p.75).
- You cannot take aspects away without destroying the gestalt.



## IMAGE SCHEMATA ARE GESTALTS

(M. Johnson, 1987; W. Croft and D. A. Cruse, 2004; V. Evans and M. Green, 2006)

<b>POLARITY</b>	light-dark, warm-cold, female-male, good-bad, just-unjust, slow-fast, high-low ...
<b>SPACE</b>	Polarities: up-down, front-back, left-right, near-far, center-periphery. Other: contact, path
<b>PROCESS</b>	process, state, cycle
<b>CONTAINER</b>	containment, in-out, surface, full-empty, content
<b>FORCE / CAUSATION</b>	balance, counterforce, compulsion, restraint, enablement, blockage, diversion, attraction
<b>UNITY / MULTIPLICITY</b>	merging, collecting, splitting, iteration, part-whole, mass-count, link
<b>IDENTITY</b>	matching, superimposition
<b>EXISTENCE</b>	removal, bounded space, object, substance, fluid substance

# PROTOTYPICAL CAUSATION: THE GESTALT OF DIRECT MANIPULATION

## The **gestalt of direct manipulation**

Lakoff (1987, p. 54), Lakoff and Johnson (1980, p. 70)

## Aspects of the gestalt

1. There is an **agent** that does something.
2. There is a **patient** that undergoes a change to a new state.
3. Properties 1 and 2 constitute a single event; they overlap in time and space; the agent comes in contact with the patient.
4. Part of what the agent does (either the motion or the exercise of will) precedes the change in the patient.
5. The agent is the **energy source**; the patient is the **energy goal**; there is a **transfer of energy from the agent to patient**.
6. ...

## THE GESTALT OF PHYSICAL PROCESSES IS ONLY WEAKLY DIFFERENTIATED

- We should not be deceived by this simple picture into thinking that physics is simple. The aspects of the gestalt stressed here are not commonly differentiated at a conscious level. Preconceptually, they are intertwined so strongly that a conscious differentiation takes some effort.
- Quantity and intensity (level) are metaphorically linked (MORE IS UP)
- The force (power) of the gestalt is intimately related to the intensity. We do not easily differentiate between intensity, strength, force...

Nevertheless, there is some hope...

- If we know about the existence of this structure in human thought, we may be inclined to use it in education from the earliest time on. The capacity of mythic thought which runs strong in young children can be put to good use (K. Egan, 1988, 1997).

## FIGURE-GROUND REVERSAL MAY BE THE ORIGIN OF THE STATISTICAL MECHANICS METAPHOR OF PHYSICAL PROCESSES



### Figure-ground reversal in dual metaphors

Many concepts have at least a spatial and a substance-based metaphoric structure that are related by a figure-ground reversal.

# DUAL METAPHORIC STRUCTURES 1

## Metaphorical conceptualization of mind

(G. Lakoff and M. Johnson: *Philosophy in the Flesh*, Chapter 12)

Metaphor	Linguistic metaphoric expression
<p><b>THINKING IS OBJECT MANIPULATION</b></p> <p>THE MIND IS A BODY</p> <p>THINKING IS OBJECT MANIPULATION</p> <p>IDEAS ARE MANIPULABLE OBJECTS</p> <p>COMMUNICATING IS SENDING</p> <p>UNDERSTANDING IS GRASPING</p>	<p>Combine these ideas...</p> <p>Students are cramming their heads full of ideas</p> <p>This is going right over my head</p> <p>He carefully crafted this idea</p> <p>Teachers put ideas into students heads</p> <p>Did you grasp this?</p> <p>MIND/PERSON = GROUND, IDEAS = FIGURE</p>
<p><b>THINKING IS MOVING</b></p> <p>THE MIND IS A BODY</p> <p>THINKING IS MOVING</p> <p>IDEAS ARE LOCATIONS</p> <p>REASON IS A FORCE</p>	<p>My mind wandered for a moment</p> <p>How did you reach that conclusion?</p> <p>We have arrived at a crucial point in our argument</p> <p>Where are you in the discussion?</p> <p>His argument forced me to conclude that...</p> <p>IDEAS = GROUND, MIND/PERSON = FIGURE</p>

## DUAL METAPHORIC STRUCTURES 2

### Spatial and substance-based metaphors in heat and motion

	Spatial metaphor	Substance-based metaphor
<b>Heat</b>	<p><b>THE STONE IS WARM</b></p> <p>The <b>temperature</b> is higher today</p> <p>The body quickly reached this <b>temperature</b></p> <p>The thermal state is metaphorically structured as a location of the body on a vertical scale</p> <p>HEAT = GROUND, BODY = FIGURE</p>	<p><b>THE STONE CONTAINS HEAT</b></p> <p><b>Heat</b> has flowed out of the room</p> <p>The room contains a lot of <b>heat</b></p> <p>The thermal state is metaphorically structured as the possession of heat that flows into or out of the object</p> <p>HEAT = FIGURE, BODY = GROUND</p>
<b>Motion</b>	<p><b>THE STONE IS MOVING</b></p> <p>The stone is fast</p> <p>The <b>speed</b> is a lot higher</p> <p>Motion is metaphorically structured as a location of the body on a vertical scale</p> <p>MOTION = GROUND, BODY = FIGURE</p>	<p><b>THE STONE POSSESSES MOMENTUM</b></p> <p>The stone has a lot more <b>momentum</b></p> <p>It has lost <b>momentum</b></p> <p>Motion is metaphorically structured as the possession of momentum that flows into or out of the object</p> <p>MOTION = FIGURE, BODY = GROUND</p>

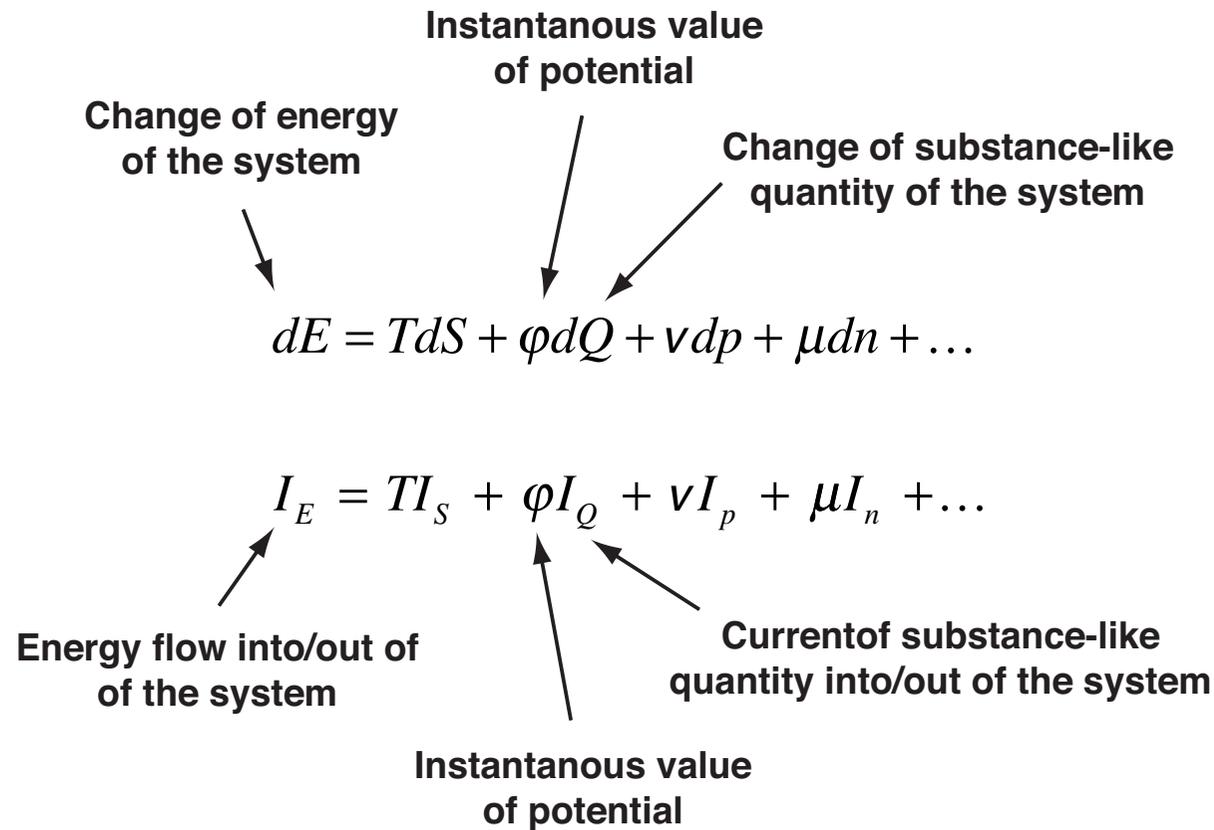
# *Part 4*

## **SUBSTANCE-LIKE QUANTITIES AND ENERGY IN THE KARLSRUHE PHYSICS COURSE**

One of the important aspects of the KPC—if not its most important—is the relation between substance-like quantities and energy. It is represented graphically by the concept of energy carriers. The relation is the same in every field (fluids, electricity, heat, motion,...). This is a beautiful example of the use of strong analogy in physics.

# THE GIBBS FUNDAMENTAL FORM

F. Herrmann: KPK, Lehrerband, 1995

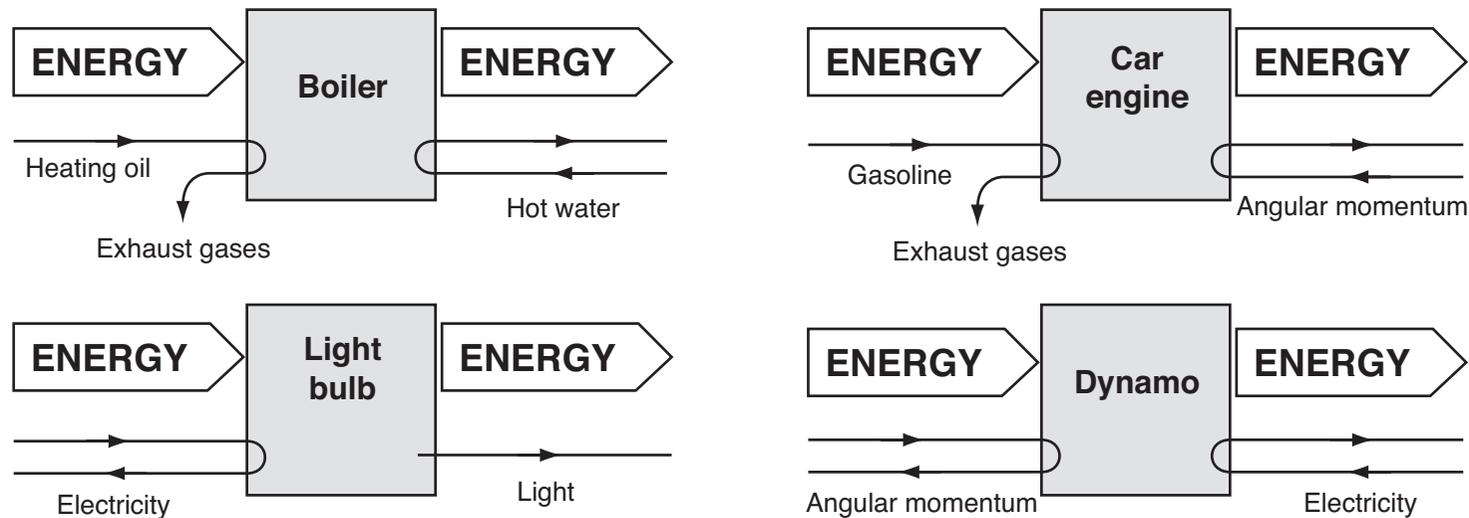


*Every phenomenon is characterized by a potential and a substance-like quantity. This allows us to treat all the fields analogously...*

# ENERGY CARRIERS, ENERGY, AND ENERGY FLOW DIAGRAMS 1

F. Herrmann: KPK, Vol. 1, 1995

## Energy carriers and energy flows



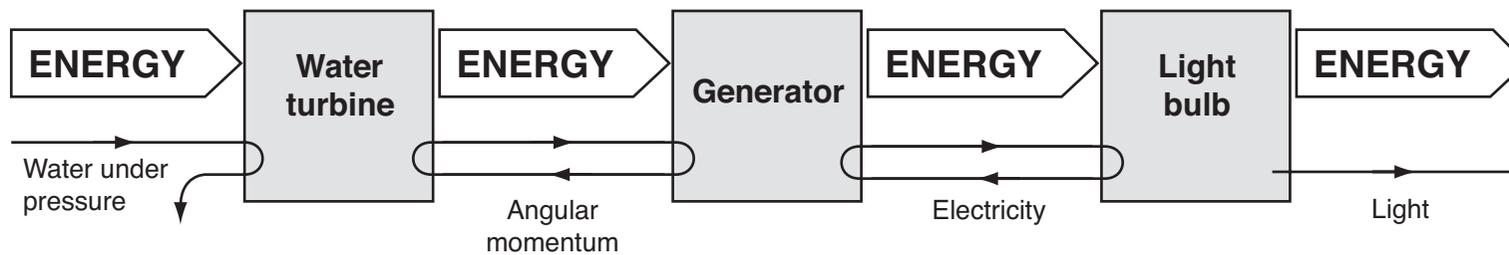
*Energy transfer into and out of a system together with energy carriers.*

*Energy is NOT like matter. It has a completely different role in physical processes.*

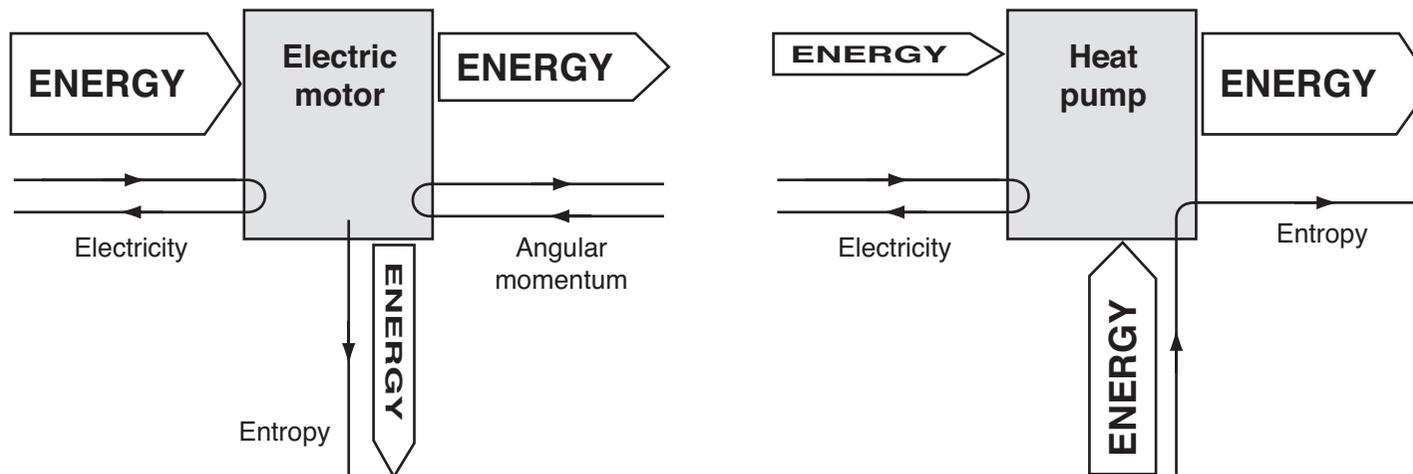
# ENERGY CARRIERS, ENERGY, AND ENERGY FLOW DIAGRAMS 2

F. Herrmann: KPK, Vol. 1

## A chain of systems and processes...



## Engines...

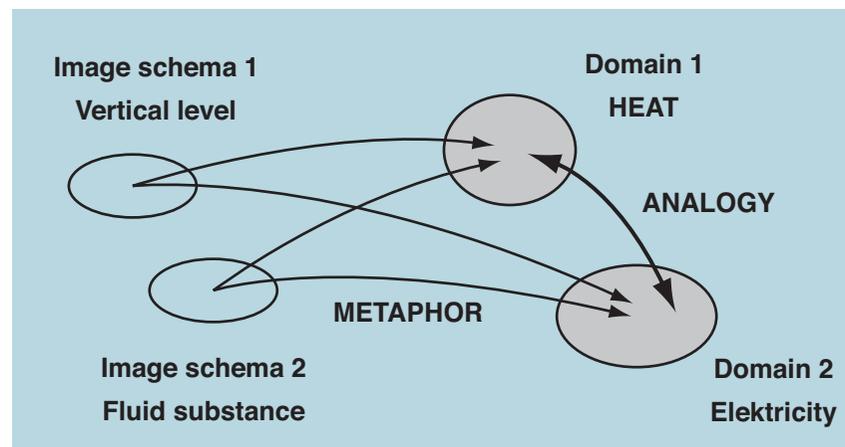


## Metaphors and analogical reasoning

### *Origin and meaning of analogies*

When different domains of experience are structured metaphorically by the same source domains (such as by the same image schemata), these domains become comparable (they start to look similar).

This comparison can be applied in the construction of analogies. An analogy is a double-sided mapping (more or less symmetrical).



# *Part 5*

## **DIFFERENCES OF POTENTIALS, ENERGY, AND PROCESSES**

If we start with, and stress the importance of differences as driving forces for change, an important figurative element is added to the approach of the Karlsruhe Physics Course. We obtain a faithful representation of the gestalt of physical processes that fits perfectly with the KPC...

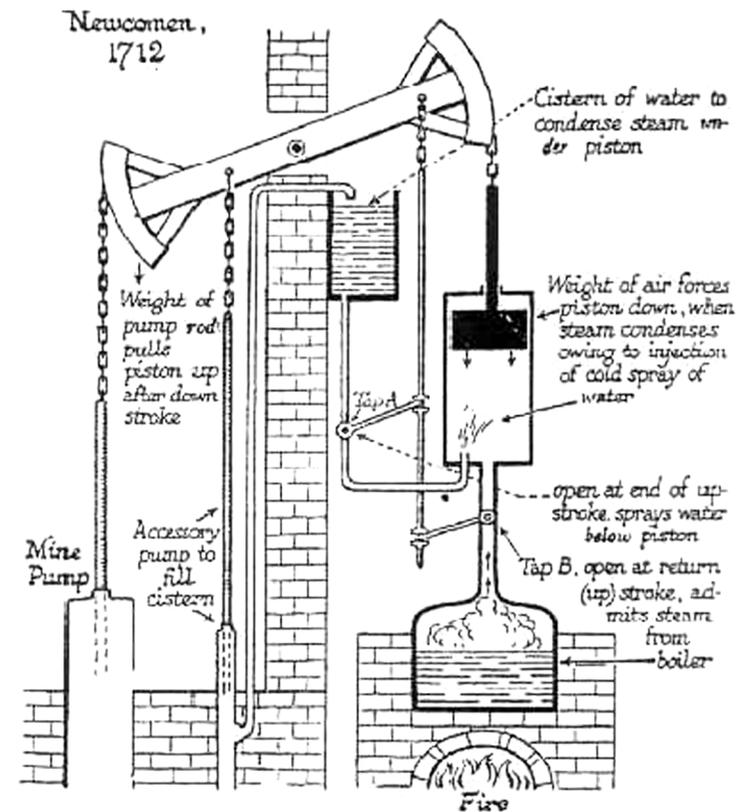
## SADI CARNOT'S IMAGE OF THE POWER OF HEAT



Sadi Carnot (1796-1832)

Réflexions sur la puissance motrice du feu

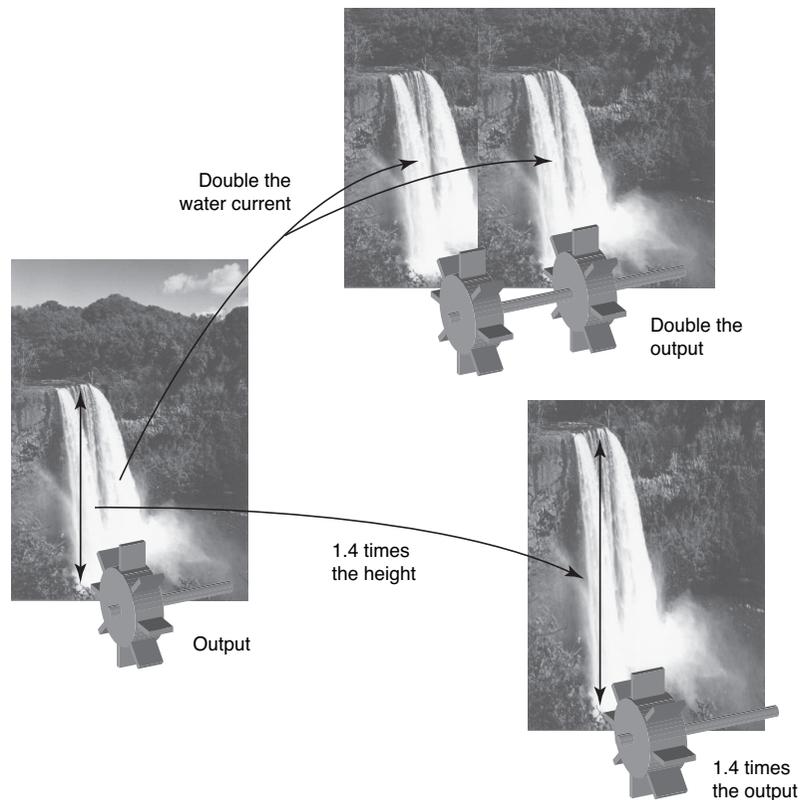
D'après les notions établies jusqu'à présent, on peut comparer avec assez de justesse la *puissance motrice de la chaleur* à celle d'une chute d'eau [...]. La puissance motrice d'une chute d'eau dépend de sa hauteur et de la quantité du liquide; la puissance motrice de la chaleur dépend aussi de la quantité de calorique employé, et de ce qu'on pourrait nommer, de ce que nous appellerons en effet *la hauteur de sa chute*, c'est-à-dire de *la différence de température* des corps entre lesquels se fait l'échange du calorique.



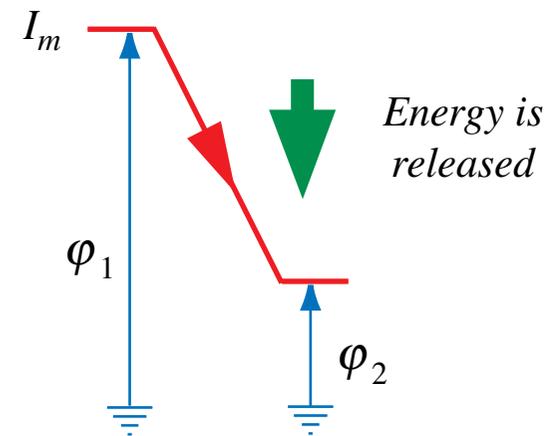
DIAGRAMMATIC VIEW OF NEWCOMEN'S ATMOSPHERIC OR FIRE ENGINE (1712)

# ENTAILMENTS OF THE METAPHORIC STRUCTURE OF PHYSICAL CONCEPTS

*An example of entailments that can be brought into quantitative form*

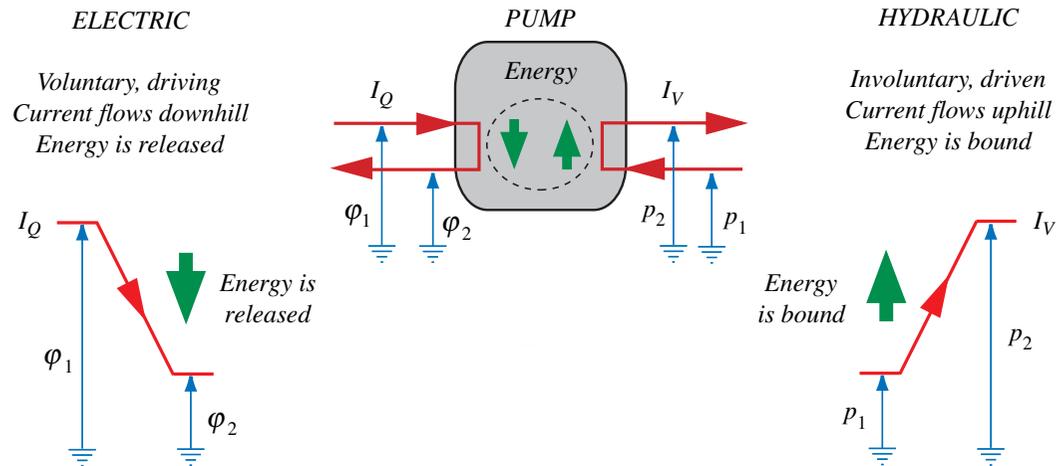


*Power =*  
*Level difference · Current of substance*

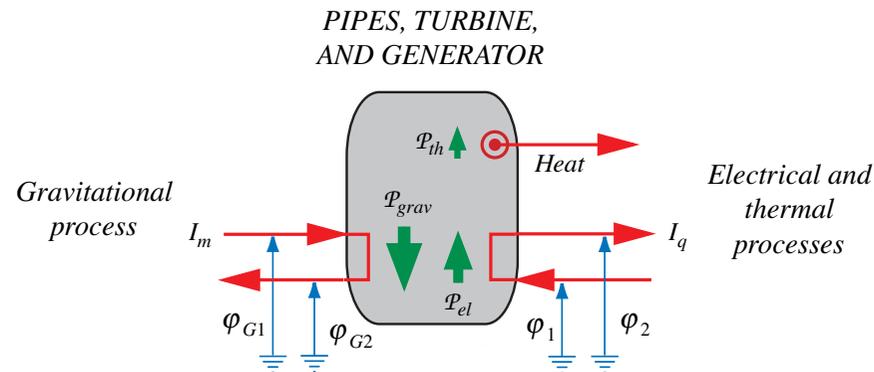


# THE WATERFALL IMAGE IN PROCESS DIAGRAMS

- Ideal coupling

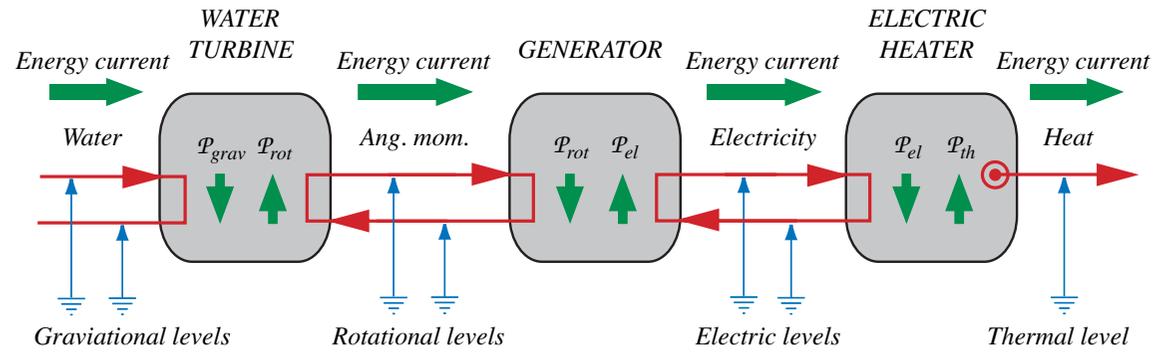


- Real coupling

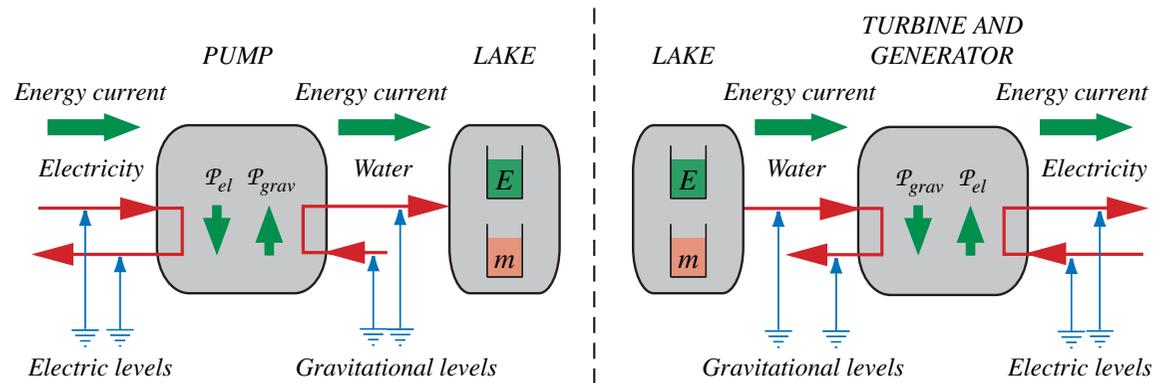


# ENERGY FLOW AND STORAGE IN PROCESS DIAGRAMS

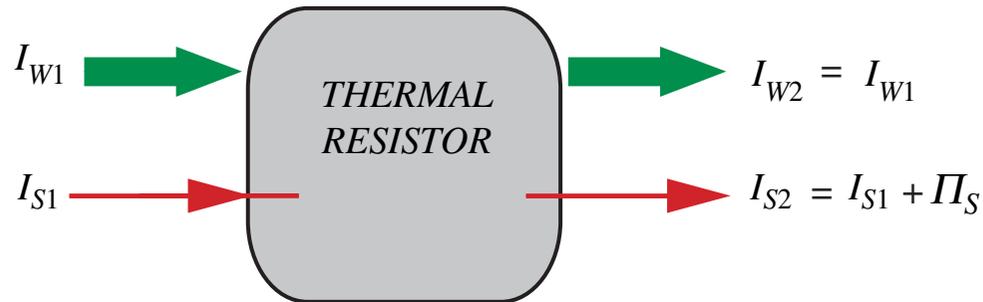
- Transport of energy



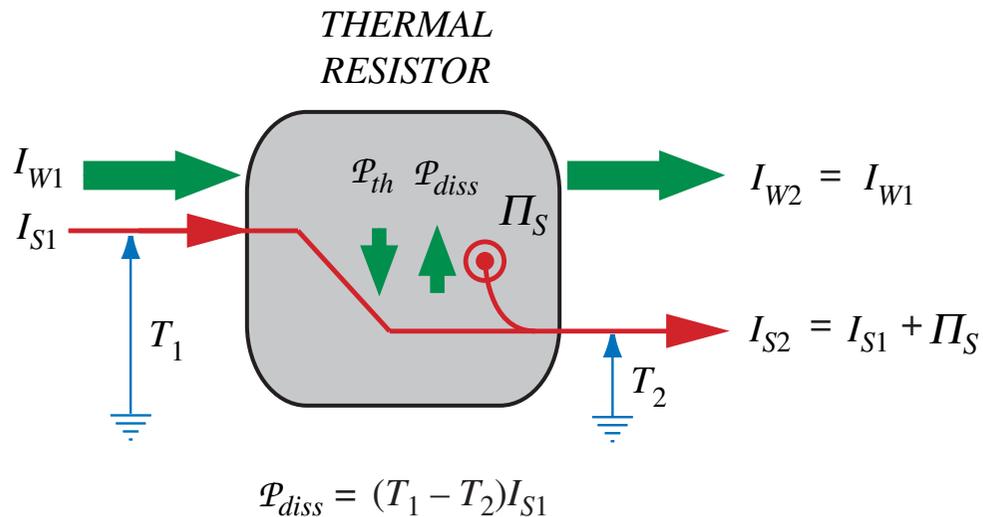
- Energy storage



# THE NECESSITY OF THE CONCEPT OF POWER



*There is no difference in energy currents that would serve as a measure of the rate of dissipation of energy.*

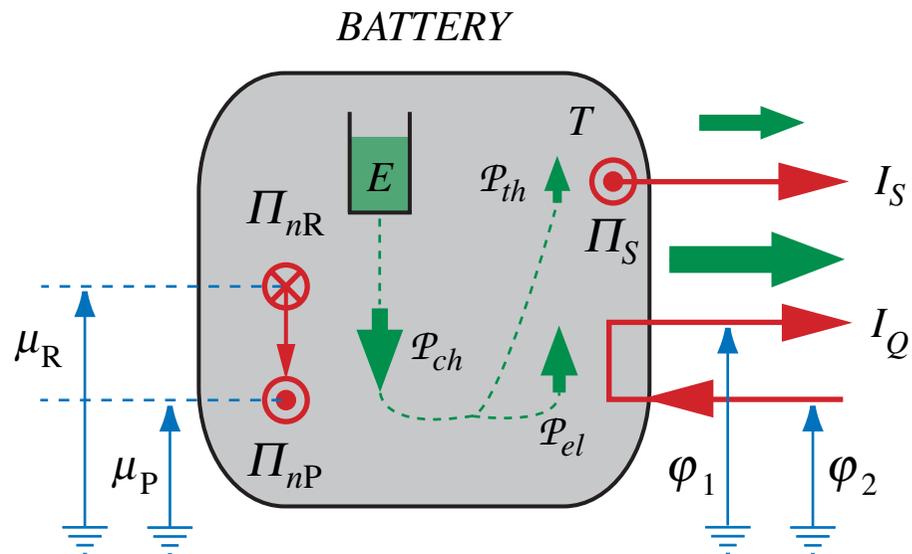


*The waterfall image easily explains the meaning of energy dissipated (and entropy produced) in the conduction of heat.*

$$\frac{dj_E}{dx} = 0 \quad , \quad j_E = Tj_S$$

$$\frac{d(Tj_S)}{dx} = T \frac{dj_S}{dx} + j_S \frac{dT}{dx} = 0$$

## A SYSTEM INVOLVING CHEMICAL REACTIONS



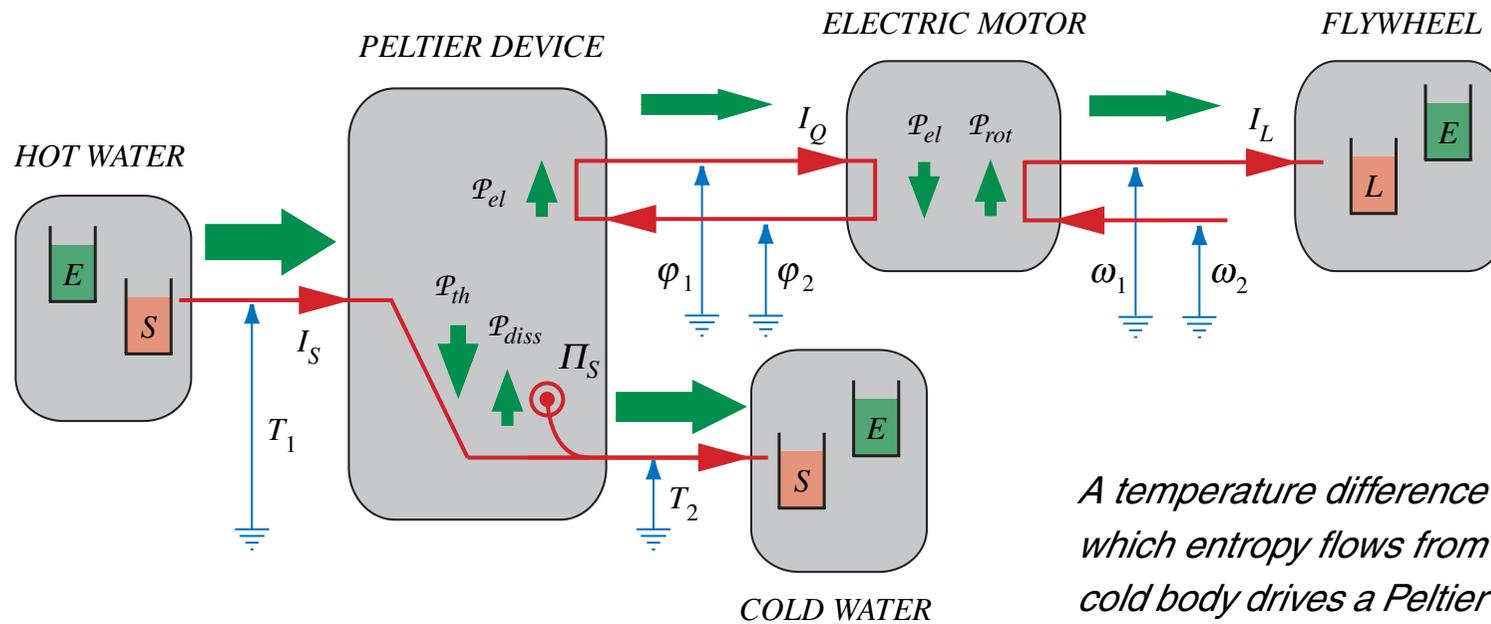
*Process diagram of a battery, including production of entropy.*

*There is no energy transfer relative to the system with chemical substances.*

*Energy released in the reactions comes from energy storage.*

*The power of the chemical process is split between the electrical and thermal processes.*

## A THERMAL DIFFERENCE DRIVES A FLYWHEEL



*A temperature difference through which entropy flows from a hot to a cold body drives a Peltier device, i.e., it sets up an electric difference.*

*The electric difference drives an electric motor, which sets up a difference of angular speeds...*

## SUMMARY

- The human mind “sees” a structured gestalt in physical processes. The structure is best described by three aspects: **quantity, intensity, and force**.
- With care and patience, the gestalt can be differentiated more and more as learners become more mature and sophisticated.
- In macroscopic physics, there are concepts that can be related to these aspects:

QUANTITY	Substance-like quantity
INTENSITY	Potential difference
FORCE	Power of a process

- It is possible to express the structure of the gestalt of processes with the help of process diagrams. This allows us to create a qualitative form of an interesting modern physics course.
- The KPC and continuum physics can teach us how to construct a formal theory of physics that is close to the preconceptual image described here.

# LITERATURE

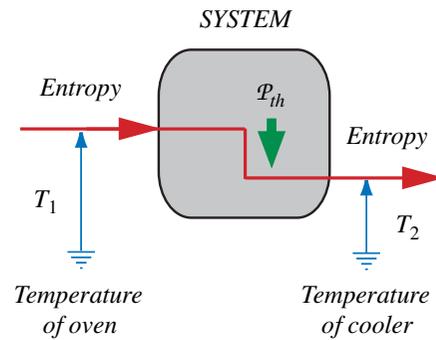
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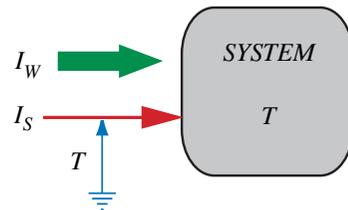
## Substance-like quantities, potentials, and energy currents

	Substance-like quantity	Current of quantity Production rate	Associated energy current
<b>HYDRAULICS</b>	Volume of liquid	Volume current	$I_W = pI_V$
<b>ELECTRICITY</b>	Electric charge	Current of charge	$I_W = \varphi_{el}I_Q$
<b>THERMODYNAMICS</b>	Entropy	Entropy current Entropy production rate	$I_W = TI_S$
<b>ROTATION</b>	Angular momentum	Angular momentum current	$I_W = \omega I_V$
<b>TRANSLATION</b>	Momentum	Momentum current	$I_W = v I_V$
<b>CHEMISTRY</b>	Amount of substance	Current of amount of substance Production rate of $n$	$I_W = \mu I_n$
<b>GRAVITATION</b>	(gravitational) mass	Current of mass	$I_W = \varphi_g I_m$

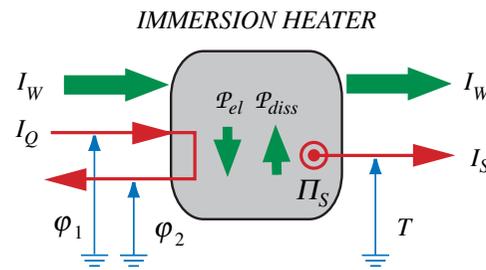
# ENERGY IN THERMAL PROCESSES



*Thermal power = Temperature difference · Entropy current*



*Energy current in heating and cooling = Temperature · Entropy current*



*Dissipation rate = Temperature · Entropy production rate*

## FORMAL BACKGROUND: VISCOUS HEAT-CONDUCTING FLUID

**Laws of balance**

$$\frac{\partial \rho}{\partial t} + \frac{\partial}{\partial x}(\rho v) = 0$$

$$\frac{\partial}{\partial t}(\rho s) + \frac{\partial}{\partial x}(s \rho v + j_s^{(c)}) = \pi_s$$

$$\frac{\partial}{\partial t}(\rho v) + \frac{\partial}{\partial x}(\rho v v + j_p^{(c)}) = 0$$

$$\frac{\partial}{\partial t} \left[ \rho \left( u + \frac{1}{2} v^2 \right) \right] + \frac{\partial}{\partial x} \left[ \rho v \left( u + \frac{1}{2} v^2 \right) + v j_p^{(c)} + j_{E,th} \right] = 0$$

**Constitutive relations**

$$j_p^{(c)} = P(\rho, T) - \mu'(\rho, T) \frac{\partial v}{\partial x}$$

$$j_s^{(c)} = -k_s(\rho, T) \frac{\partial T}{\partial x}$$

$$j_{E,th} = -\beta(\rho, T) \frac{\partial T}{\partial x}$$

**GFF**

$$\dot{u} = T \dot{s} + \frac{P}{\rho^2} \dot{\rho}$$