CHEMICAL POTENTIAL – A QUANTITY IN SEARCH OF RECOGNITION

Learn One Field and Understand Four: Chemistry, Electricity, Heat, and Mechanics

F. Herrmann
University of Karlsruhe, Karlsruhe, Germany
e-mail: friedrich.herrmann@physik.uni-karlsruhe.de
Keywords: Chemical Potential, Education, Analogy

The various subfields of science have come into being rather independently from each other. They were developed at different times by different people. As a consequence, structural similarities do not manifest in representations of these fields.

We show that a far-reaching analogy exists between chemistry (the science of substances and their transformations), electricity (the science of electric charge and its currents), thermodynamics (the science of heat and heat flows), and mechanics (the science of momentum and momentum transmission).

If these fields are presented conveniently, each of them appears as a special case of a general scheme. Learning science in this way is not only more economic but also easier. The main advantage for chemistry is that the chemical potential gets a direct interpretation. A difference of chemical potentials appears as a driving "force" for all those processes in which the transformation or the transport of substances is involved, in the same sense as an electric potential difference can be seen as a driving force for an electric transport, a temperature difference appears as the cause of an entropy flow, or a velocity difference causes a momentum transfer.

The analogy is based on the correspondence of physical quantities, shown in Table I. In each of the mentioned fields one extensive or "substance-like" quantity plays a central role: amount of substance in chemistry, electric charge in electricity, entropy in thermodynamics and momentum in mechanics. To each of the extensive quantities corresponds an "energy-conjugated" intensive quantity: the chemical potential, the electric potential, temperature (the "thermal potential") and velocity, respectively. In addition, a current or flow can be attributed to each extensive quantity, see last column of Table I. Moreover, a resistance, a capacitance and other quantities can be defined in each field.

subfield of science	**extensive quantity**	**intensive quantity**	**current**
chemistry	amount of substance n	chemical potential μ	substance current I_n
electricity	electric charge Q	electric potential φ	electric current I
thermodynamics	entropy S	absolute temperature T	entropy current I_S
mechanics	momentum $\boldsymbol{p}$	velocity $\boldsymbol{v}$	force $\boldsymbol{F}$

Table I

In Table II, various processes and equations are confronted.

It is obvious that in order to take advantage of the analogy, the chemical potential has to be introduced as a basic quantity, just as we are accustomed to do with the electric potential, the temperature, or the velocity.

subfield of science	*chemistry*	*electricity*	*thermodynamics*	*mechanics*
energy flow equation	$P = \mu \cdot I_n$	$P = U \cdot I$	$P = T \cdot I_S$	$P = \boldsymbol{v} \cdot \boldsymbol{F}$
resistance, dissipation	reaction resistance	electric resistance	thermal resistance	friction
spontaneous flow	A chemical reaction runs spontaneously from substances of higher to substances of lower chemical potential.	Electric charge flows spontaneously from a body of higher to a body of lower electric potential.	Entropy flows spontaneously from a body of higher to a body of lower temperature.	Momentum flows spontaneously from a body of higher to a body of lower velocity.
driving force	A chemical potential difference is a driving force for a chemical reaction.	An electric potential difference is a driving force for an electric current.	A temperature difference is a driving force for an entropy current.	A velocity difference is a driving force for a momentum current.
equilibrium	If the chemical potential difference is zero, there is no chemical reaction: chemical equilibrium.	If the electric potential difference between two bodies is zero, there is no electric current: electric equilibrium.	If the temperature difference between two bodies is zero, there is no entropy current: thermal equilibrium.	If the velocity difference between two bodies is zero, there is no momentum current: mechanical equilibrium.
pump	To drive a chemical reaction from low to high chemical potential, a "reaction pump" is needed: an electrolytic cell.	To transfer electric charge from low to high electric potential, an "electricity pump" is needed: a battery, a generator…	To transfer entropy from a body of low to a body of high temperature, an "entropy pump" is needed: a heat pump.	To transfer momentum from a body of low to a body of high velocity, a "momentum pump" is needed: a motor.

Table II