Physics without Equations

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Education, Physics
An original training course offered to all the UniversitÃ© Grenoble Alpes doctoral students

This article was written by Larissa, a doctoral student in life sciences at the "Laboratory for microorganism adaptation and pathogenesis", (Laboratoire adaptation et pathogénie des microorganisms - LAPM), and was first published on the web site echosciences.fr.

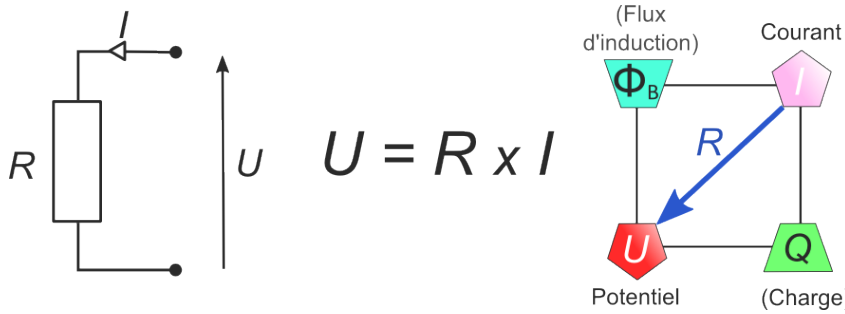
Former director of the "Grenoble Electrochemistry and Physical Chemistry of Materials and Interfaces Laboratory" (LEPMI), and today a highly experienced research supervisor, Eric Vieil is an electrochemist who enjoys himself. Using circles and arrows, he redesigns physics and chemistry, subjects traditionally studied by mathematics. This is what he teaches to the Université de Grenoble doctoral students in his module named "Physics without equations".

From conductive polymers to physics without equations
"I have always hesitated between physics and chemistry, and that's why I put off my choice to the last possible moment" Eric Vieil says with a laugh. Native of Paris, he studied at the "Higher Institute for Physics and Industrial Chemistry" (ESPCI) and finally chose to specialise in chemistry. However, he remained at the interface between these two fields by going into analytical chemistry. For his doctorate, he was invited by a professor from Grenoble who was interested in his computer skills acquired in the United States (this was in the 1970's, back when computers were still quite rare in laboratories).Then he joined the CEA where he worked on conductive polymers - materials with a complex behaviour, varying according to whether they are oxidised or reduced. The diversity of their physicochemical properties made their study difficult and prompted him to get out of his favourite field of study. This made him realise that each field has its own concepts and languages. He started using graphs, designed for his students, to convey what he observed in other fields. These graphs, made of circles and arrows, actually had the same structure regardless of the field, from physics to biology. Intrigued by this discovery, he continued developing his tool named the "formal graph". For the record, the conductive polymer has not yet revealed all its secrets.

Formal graphs, a transdisciplinary vision from physics to chemistry
Processes studied in physics or chemistry are described by variables (pressure, temperature, etc.) and relations between these variables, also called operators. Take for example Ohm's law, U = R x I. Here the variables are U

(voltage) and I (current), whereas R (resistance) is an operator. But the operator may be more complex, like a mathematical function. Eric Vieil proposes to transcribe this into a square-shaped formal graph (see illustration): each vertex represents a variable, which is linked to the other variables by operators - relations between variables represented by arrows.
"The traditional method is the algebraic equation. But with this form, it is sometimes difficult to know who is who (variable or operator). With formal graphs, there often is only one way to describe the system. This makes it possible to converge towards a unique description form of the model, regardless of the field." Thus, this tool facilitates comparisons between disciplines and gives meaning to the analogies which have been observed for a long time. Another point: each corner of the square corresponds to a type of variable (corresponding to an entity number or to the energy per entity), which also gives formal graphs a descriptive quality.

A tool targeting a varied audience
Simple and comprehensive, formal graphs can offer several advantages. They remind researchers and theoreticians of the meaning of variables and facilitate inter-disciplinarity. This allows for instance to extend laws from one field to another. In addition, formal graphs make up a network and can be modelled using "neural networks", a technique which is already used in other fields such as finance, to simulate its evolution.



Ohm's law and its formal graph representation

However, formal graphs can also be part of physics and chemistry teaching, allowing us to get round the abstraction of algebra. "We access the physical meaning of things directly thanks to a stripped down approach", Eric Vieil says. "It's a bit like learning "with your hands". Formal graphs can be a visual means to help understand certain concepts, and they make it easy to move from one discipline to another. "This allows an economy of concepts. Of course, the graph language needs to be learned, which is no easy matter" That is why Eric Vieil has only taught at university up to now.

Teaching above all
Eric Vieil is careful not to present his tool as revolutionary and prefers developing it inside the classroom and thanks to interaction with students. "To make this tool accessible to high school pupils is my dream!" he says with a smile. "But to do this, I would need to work together with a teacher willing to implement the whole programme. This could help pupils understand subjects such as mechanics for instance, which often is a big challenge." This is quite obviously a call… While waiting to have the opportunity to make his dream come true, he continues to teach "physics without equations" at university.

A new module will be available next year. It will be open to all the Université de Grenoble doctoral students. Check the training catalogue.

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