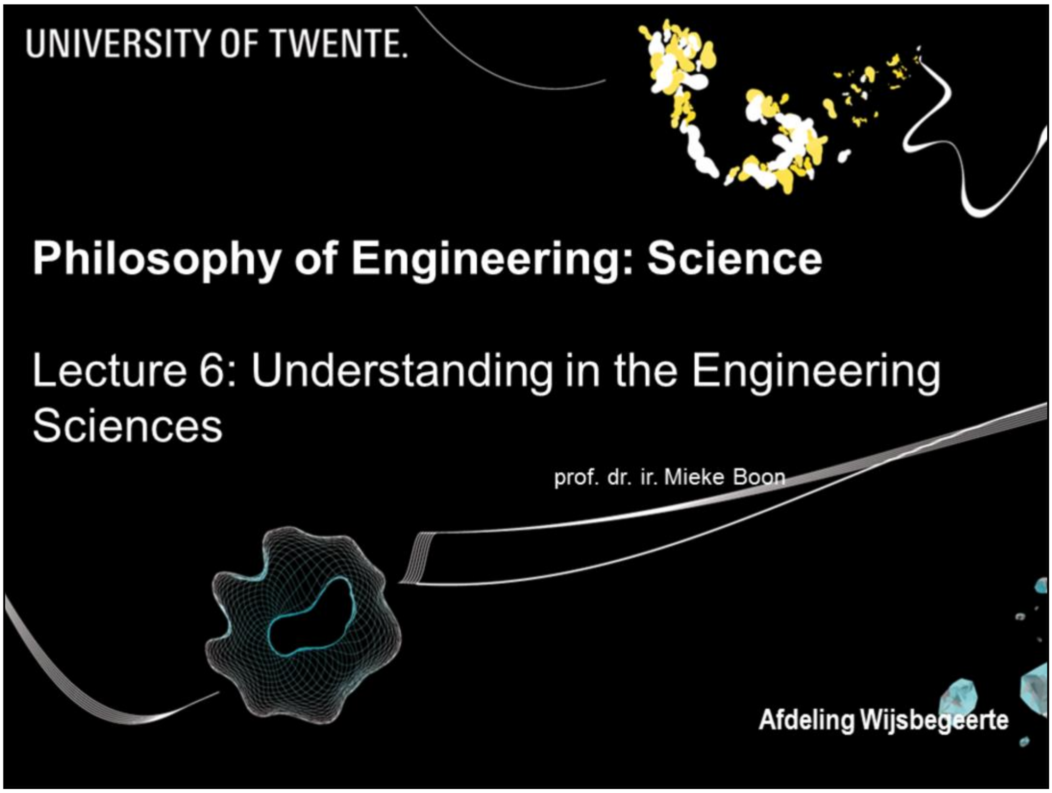


Overview

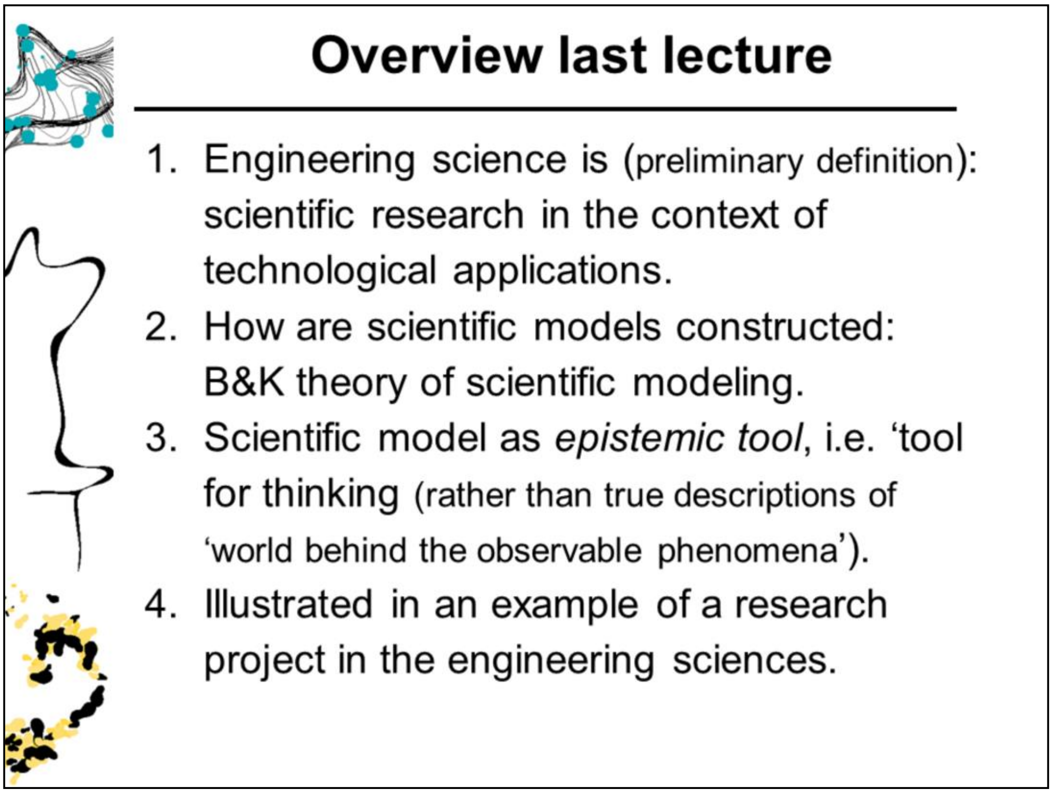
In the former classes, you have learned:

1. a vocabulary to talk about science (e.g., empiricism vs rationalism; inductive, deductive and hypothetical-deductive reasoning; some logic and logical schema's);

2. to use this vocabulary in analyzing several philosophical issues (e.g., logical issues of proving scientific knowledge, such as the problem of induction and 'affirming the consequent'; epistemic criteria such as truth and empirical adequacy; and the issue of what scientific knowledge such as laws of nature and scientific models actually describe of depict);

3. to understand competing *metaphysical* presuppositions on the nature of knowledge and how knowledge relates to the world (realism vs anti-realism);

4. alternative philosophical ideas about science (e.g., scientific knowledge as 'approximately true' descriptions of unobservable phenomena, thereby explaining the observed phenomena, versus scientific knowledge as epistemic tools for thinking about specific observable phenomena and target systems).



Examples of Engineering Sciences:

***Electrical Engineering* (e.g.)**

Electrical engineering is concerned with designing devices that convert or transform electrical, electro-magnetic or mechanical input into electrical, electro-magnetic or mechanical output, thereby meeting certain technological functions.
Scientific research in the field of electrical engineering proposes models of the *behaviour* of electrical devices. This task differs from the *design* (e.g. of electrical circuits) of such devices.
Scientific articles aim to contribute to optimizing the devices with regard to their functioning.

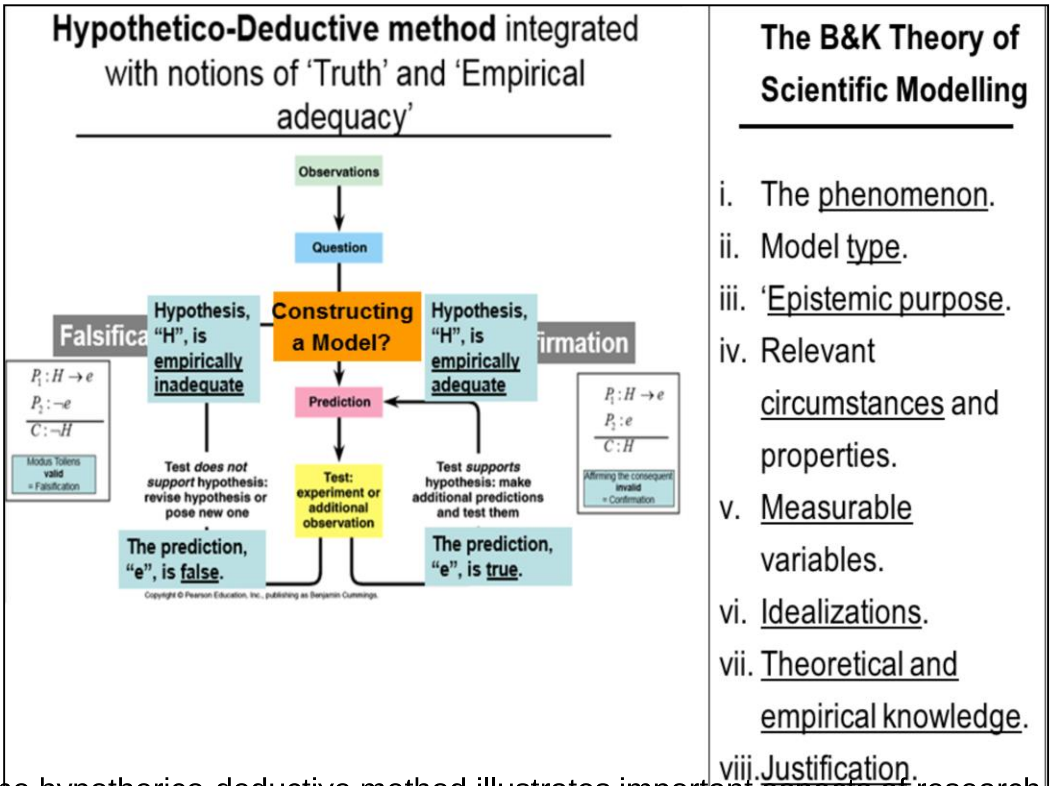
***Materials Science* (e.g.)**

Materials engineering: application of materials with properties (e.g. chemical, electrical or mechanical properties) that meet certain functions. For instance, metals which are resistant to corrosion, ceramics that are superconductive at

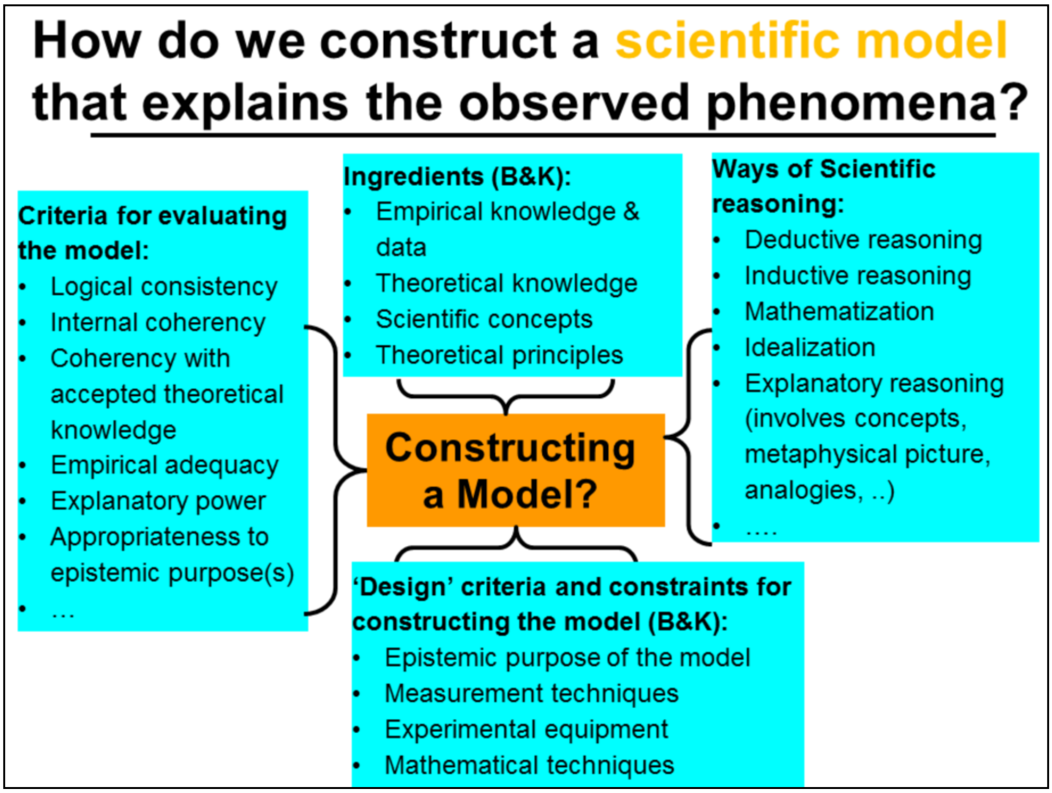
higher temperatures, and polymers of a particular strength.
Materials science: scientific understanding of materials – either of materials that already exist or of materials that scientists aim to create artificially – which may then indicate ways in how to create or intervene with specific material properties.
Scientific articles aim to contribute to optimizing or creating material properties with regard to their functioning.

Chemical Engineering (e.g.):

- Chemical engineering: designing processes for converting materials or chemicals into other materials and chemicals that meet certain functions or purposes. For these processes it uses devices, such as chemical reactors and equipment for separation of substances such as crystallization, precipitation, absorption, filtration and distillation.
- Scientific research in the field of chemical engineering proposes models of the behaviour of chemical devices. It typically proceeds through studying the behaviour of devices by interpreting them in terms of physical phenomena considered to be relevant to their proper or improper functioning, and then modelling these phenomena. Examples of such phenomena are desired and undesirable chemical reactions, the transport of liquids, gasses and solids within the device, the transport of chemical compounds by means of fluid flow or diffusion in the fluid, the transport of heat by convection or conduction, and other physical processes such as absorption, dissolution, ionization, precipitation, vaporization and crystallization.
- Scientific articles typically propose a certain type of design of the device – which consists of a configuration (e.g. a schema of its mechanical construction and dimensions) and its chemical and physical conditions — for meeting a certain function, for instance, for producing a compound at a high purity and with a minimum of waste production and energy use.



The hypotherico-deductive method illustrates important aspects of research, and their connections. It focuses on how to test the hypothesis, but does not explain how a hypothesis (a phenomenological law, a scientific model, etc.) comes about. Therefore, the general hypothetical-deductive model of aspects and dynamics in scientific methodology applies to scientific research in the engineering sciences as well. The B&K theory of modeling proposes that modeling involves a number of ingredients, which can usually be found in models, helping us in understanding how they are constructed.



We have discussed that constructing a model (1) makes use of empirical and theoretical knowledge; we never start from scratch. (2) We employ different kinds of reasoning such as to construct a model that (3) meets specific criteria, which in turn must be chosen such that (4) several other constraints in the 'design' of the model will be met, namely, the epistemic purpose of the model, but also the mathematical and experimental instruments that we have at our disposal. In the past when computers were less powerful, for instance, the mathematical structure of the model was made such that analytical solutions were possible, or just simple computer simulations. Similarly, available measurement-techniques and experimental equipment put constraints on how the model is constructed. In modelling, we aim to avoid variables that are not measurable, since measurements are the link between the scientific model and real-world target-system.

How is this schema related to the ingredients in the B&K theory? The B&K theory points out which ingredients are part of the model, but does not explain how the model is constructed. In this schema several aspects are added to account for the actual construction of the scientific model. Beside making use of the ingredients, the construction of the model involves:

(1) Different types of reasoning: not only logical ways of reasoning, but also mathematical reasoning, idealization, and explanatory reasoning, and,

(2) Criteria for evaluating the model: the model must be constructed such that

it is internally consistent and coherent (parts of the model must hang together); the model must also be coherent with (i.e. not contradicting) accepted theoretical knowledge; and it must be empirically adequate (that is, its predictions must agree to relevant empirical knowledge and relevant measurements in testing the model); and also, related to the *epistemic purpose* of the model, a pragmatic criterion is involved, which says that the model must be appropriate for the epistemic purpose.

Topics of lecture 6

1. What is knowledge in the engineering sciences typically about – How is this different from the natural sciences (physics, chemistry, ..)?
2. Different types of empirical and scientific knowledge
3. How are these different types of knowledge *constructed*?
4. The role of <u>measurements</u> in constructing scientific knowledge.
5. The role of <u>parameters</u> and scientific concepts.
6. Examples

Engineering sciences utilize and produce ***empirical and scientific knowledge* on:**

1. Natural phenomena
2. Technologically produced physical phenomena
3. Technologically produced material properties
4. Workings of technological instruments and devices.

Natural sciences *suggest* that they produce and utilize *empirical and scientific knowledge* on Natural phenomena only.

Empirical and scientific knowledge about what?

The idea of scientific knowledge (phenomenological laws, laws of nature, scientific models, scientific concepts, axiomatic theories) as *epistemic tool* (rather than a literal description or picture of 'the world *behind* the observable phenomena') is an important idea of *a philosophy of science for the engineering sciences*. When considering the natural sciences (e.g., fundamental topics in physics and chemistry) the generally accepted idea is that scientific knowledge is generated for its own sake: we just want to know; we just want to know what the world 'really', or 'fundamentally' is like. But in the engineering sciences, we usually produce empirical and scientific knowledge in view of specific (technological) applications. We may distinguish between different types of subjects of empirical and scientific knowledge produced in scientific research:

a. *empirical and scientific knowledge* of natural phenomena. For instance, the natural phenomenon of bacteria in nature that oxidize mineral sulfides. Empirical knowledge consists of knowledge about the physical and/or technological circumstances at which this phenomenon manifests. Scientific knowledge consist of phenomenological laws that mathematically 'describe' the observed phenomena, and secondly, of scientific models that 'explain' the observed phenomena.

b. *empirical and scientific knowledge* of <u>technologically produced physical phenomena</u> (e.g., the phenomenon of expanding and contracting steam in a heat engine; the phenomenon of super-conductivity),

c. *empirical and scientific knowledge* of all kinds of <u>technologically produced material properties</u> (e.g., chemical composition, chemical structure, crystal structure, material density, melting temperature, and the conductivity and electrical resistance of materials),

d. and we also produce *empirical and scientific knowledge* of the <u>workings of technological instruments and devices</u> (think of microscopes, thermometers, atomic force microscopes, chemical processes, electrical devices, etc.).

Different types of empirical and scientific knowledge

In all these cases, we construct (‘build’) knowledge, such as a phenomenological law ‘describing’ a phenomenon (see explanation in next section) and/or a scientific model of it, for specific ‘epistemic aims.’ In the engineering sciences we aim, for instance, at scientific models that can be used as epistemic tools in technological design, development and innovation. For instance, scientific models are used for different kinds of epistemic aims:

- (ad a) thinking about possibilities of technologically utilizing or producing the natural phenomenon for performing technological functions (e.g., a technology that is based on the design-concept of the phenomenon ‘artificial photosynthesis for converting sunlight in electricity’),
- (ad b) thinking about possibilities of interventions with the technology to improve or optimize it, or, making computer-models for computer-simulations in which all kinds of technological interventions can be tried (e.g., once they have a rudimentary technology for artificially producing electricity from sunlight, researchers will aim to make it more efficient, more technologically robust, etc.)
- (ad c) thinking about technological ways of producing new or improved

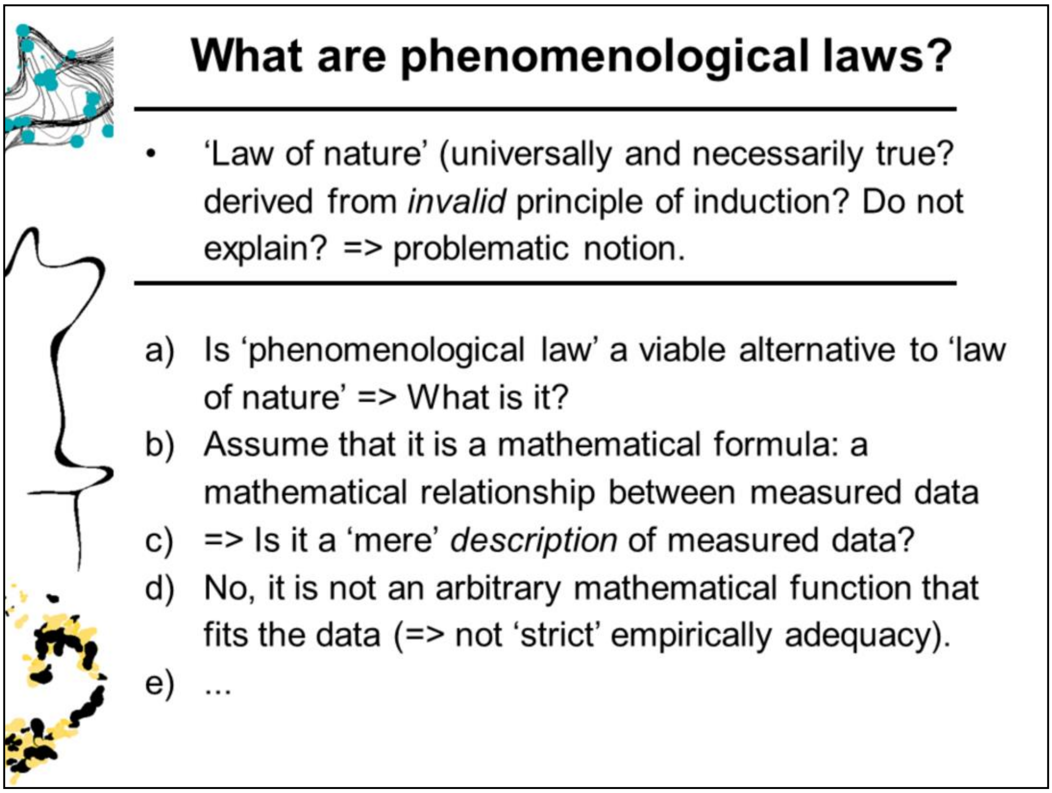
material properties for performing (improved) technological functions (e.g., materials used in chips, in solar-panels or in batteries).

- (ad d) thinking about possibilities of improving the technological instrument or device (e.g., this may involve new design-concepts for producing the same technological function – in the example above, artificial photosynthesis is a new design-concept that may solve the problem of low efficiency in traditional solar-panels).

Different types of *empirical and scientific knowledge*:

Empirical knowledge, e.g.:
i.practical knowledge about workings of devices; knowledge of conditions at which an experimental system is stable; …

Scientific knowledge, e.g.
ii. Phenomenological (or empirical) laws
iii.Scientific concepts
iv.Scientific models
v.Fundamental theories (e.g. axiomatic theories)
vi...



What are phenomenological laws?

In the former classes, we have reflected on the meaning and character of 'laws of nature', such as Boyle's law, Hooke's law and Ohm's law. By means of a philosophical analysis of the role of the (invalid) *principle of logical induction*, which we presumably use when justifying generalization, called *inductive inference* (i.e., inference from a set of reproducible observation or measurements to a universal law), it was concluded that 'law of nature' is a problematic notion. A pragmatic solution to this philosophical issue is to focus on the construction and epistemic uses of 'laws of nature,' in order to better understand how to safely use them in scientific practice.

But the outline of a PhoEngSc that has been presented so far, will allow for coming up with a more substantial alternative for our understanding of laws. Firstly, it was proposed that the *empirical adequacy* of, e.g., a law of nature is an important *epistemic criterion* for *accepting* it. But this involves to give up the idea that laws of nature are necessarily and/or universally *true*. Indeed, giving up this idea agrees to scientific practice: laws such as Boyle's, Hooke's and Ohm's, are only true at very strict conditions, or, are definitions. Let us look at this situation a bit closer.

In scientific practice, we know from experience that we should be cautious in using a law at entirely new conditions. Nevertheless, *we do believe that at exactly the same conditions the same effects will happen* (i.e., the phenomenon described by the law). Claiming that a law applies at other, yet untested conditions is a *hypothesis*, whereas it would be a true claim if the law is universally true (because then, the claim is a conclusion derived by means of a deductive argument in which the law is used as a universal and true statement). True conclusions derived from deductive arguments don't need to be tested, but hypotheses need to be tested in one or another way.

To express their caution about those things that were traditionally called 'laws of nature,' scientists also call them *empirical laws*, or *phenomenological laws*. We may now ask whether a phenomenological law merely is a summary of measured data (e.g., the data listed in a table), or whether there is more 'epistemic content' in a phenomenological law. What are they: are they pure descriptions of observed data, or is there something more to them?

In the explorative phase of research, researchers firstly aim to generate reproducible phenomena (e.g., by means of experiments and the use of measuring instruments and procedures). Then, they aim to 'describe' the observed (reproducible) phenomena in terms of *phenomenological laws*, which are mathematical equations that draw relationships between *measured variables*. It will now be explained why phenomenological laws are not mere descriptions of measured data, but actually have several other interesting features, which explains: why phenomenological laws are very useful in scientific research; how they are constructed; how they are applied at new circumstances; and, also how they are tested:

- Let us start from the idea that phenomenological laws are *empirically adequate* (rather than *true*). However, if we take empirical adequacy literal, this would reduce phenomenological laws to mere descriptions of what has been measured, and there does not seem to be much additional value in such a description. But, in scientific practice, constructing a phenomenological law usually does not consist in merely fitting the data with an arbitrary mathematical polynomial function that *exactly* describes the measured data. Firstly, we aim to keep it simple, for instance, by assuming a proportional (linear) or inversely proportional relationship between measured variable. This mathematical function for describing the relationships between measured variables (such as proportionality or linearity) may be a choice on mere mathematical grounds, but may also involve physical reasoning. A scientific researcher will aim to support the hypothesis (e.g., *that* the relationship between measured variables is proportional) by some kind of explanation of *why* this hypothesis is physically plausible. Importantly, this implies that actually, laws constructed in this manner are not empirically adequate in a strict sense: the law does not literally describe the measured data; the law is not *true* about the data (which should be the case if we take Van Fraassen's notion of empirical adequacy in a very strict sense). So, in actual scientific practice, a *phenomenological law is not a literal description of measured data*. Instead, constructing a phenomenological law involves: (1) the use of mathematical templates (such as the mathematical function for proportionality; the mathematical function for harmonic oscillation is another example), and (2) empirical and theoretical knowledge to support the physical plausibility of the mathematical template, and to support the hypothesis that the purported mathematical relationship between the measured variable (e.g. proportionality) is correct. [In philosophical language, this means that the phenomenological law is not an objective fact, a true description of what has been observed, but instead, is already theory-laden; we will come back to this topic later in the course].

- It has been argued that inductive reasoning is indispensable - however, it does not result into *certain*, *true* knowledge. Actually, in scientific practice, we apply inductive reasoning in a more sophisticated manner, by (implicitly) adopting a general principle, which can be called 'same conditions same effects.' [this principle is not a logical principle, nor is it a physical principle, nor is it an empirical finding in the strict sense, although it has proven to be a productive assumption in science. This kind principle, can be called a 'regulative principle' as it 'regulates' or 'guides' our reasoning when doing empirical and experimental research]. 'Same conditions – same effects' is the assumption that at the same physical conditions the same physical effects will happen. This principle supports the inductive conclusion that the observed phenomenon (the regularity) will appear at *the same* conditions (i.e., the phenomenon is reproducible), which we then stretch further by assuming that the observed phenomenon will appear at *similar* conditions, and therefore, we have a phenomenological law that applies at similar conditions as those at which it was constructed. However, *we do not know exactly which conditions matter* (e.g., that our equipment is blue probably does not matter, but the temperature may be an important condition). The challenging part of scientific research is then to investigate which physical conditions are significant, and which are not.
- In order to formulate hypotheses on possibly relevant and irrelevant conditions, we make use, again, of available *empirical and theoretical knowledge*. Testing hypotheses on relevant and irrelevant conditions will add to our empirical knowledge about where and how to use the phenomenological law. In this manner, the domain in which we know that the law is empirically adequate will expand. Furthermore, by means of the empirical and theoretical knowledge used in formulating the hypotheses (on relevant and irrelevant conditions), we also gain some insight in *why* it does apply. In sum, constructing and applying a phenomenological laws involves the use of a fundamental principle ('that at the same conditions the same effects

will occur') supporting inductive inferences; and the use of empirical and theoretical knowledge that may point at plausible mathematical relationships between measured variables, and that may help in formulating hypotheses about (ir)relevant conditions.

- Furthermore, the construction of a phenomenological law usually involves something more, because also new kinds of *parameters* such as *specific material constants* or *kinetic* constants are introduced. As a consequence, phenomenological laws can be considered in different kinds of ways, each of which is correct depending on how the law is used: (a) Phenomenological laws are *empirically adequate descriptions of observed regularities*. (b) Phenomenological laws are *operational definitions of the parameters introduced*. For instance, Hooke's law, can be considered as the operational definition of the elasticity coefficient, k (which is a parameter). The phenomenological law *defines* what k means – namely, the elasticity coefficient is defined as the (inverse of) the reversible extension of an elastic object per unit of force exerted on that object. (c) Therefore, the phenomenological law also tells *how to measure the parameter* such as the elasticity coefficient of a specific object or material – namely, the specific value of k is measured by measuring the extension, dx, as a function of the exerted force, F, according to $k = F/dx$.
- In a next step, this parameter may become object of further investigation, namely, to investigate its dependency on other measurable physical conditions. For instance, the value of the elasticity-coefficient may be dependent on temperature and/or on the density of the material. Next, correlations with other parameters may be found, and empirical and theoretical knowledge may be used to explain these (in)dependencies. In this manner, phenomenological laws of parameter are constructed and developed further.

All in all, it turns out that important aspects in constructing a scientific model (ways of reasoning, different types of knowledge, 'design' criteria and constraints, and criteria for acceptance) also apply to the construction of phenomenological laws [slide 9 and 10].

What are phenomenological laws?

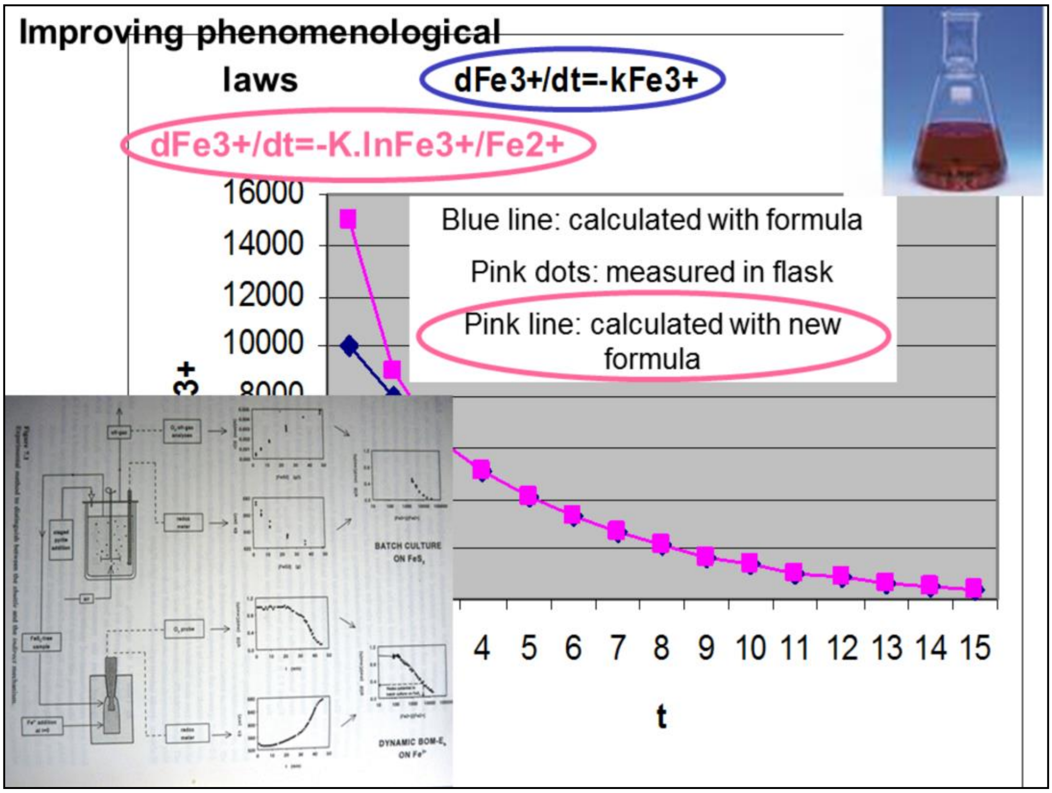
d) ..

e) Constructing the mathematical function involves scientific knowledge (or, understanding) about the phenomenon (the regularity observed in measured data).

f) *Applying* it at new circumstances involves adopting an important presupposition / principle": "same conditions – same effects."

g) Scientific research aims at furthering knowledge about (ir-)relevant conditions.

h) Construction of a phenomenological law also involves introducing new kinds of *parameters* such as specific material constants or kinetic constants.



[Repetition of text in lecture 5]

Some remarks on what we can learn from this example:

[the graph is schematic; it does not show real data, nor their units.]

The blue equation in this graph is the original phenomenological description of the rate at which the mineral is dissolved, adopted by many authors at that time. The phenomenological description explains that the observed/measured metal oxidation rate is proportional to the Fe3+ concentration in the fluid. This phenomenological law (also called 'empirical law') is empirically adequate about the tail of the measurements (t=3 onwards), but apparently not about the initial phase. The decision of researchers to discard of these 'outliers' at the start of the experiments makes sense, since in actual experiments, this phase only takes a few seconds, whereas the whole experiment takes days. Indeed, in the past, researchers considered these initial high values as outliers probably due to measurement errors, and accepted that the blue formula did not take these 'false data' into account.

The improved phenomenological description (the pink equation) also is empirically adequate. The new equation covers the initial 'outliers', and is an improvement as compared to the original blue equation, especially for describing the phenomenon (the oxidation rate) in those very first few seconds. The pink equation describes the mineral oxidation rate as proportional to the redox potentional [which is a measure of the Fe3+/Fe2+

ratio], instead of the original proportionality to $Fe3+$ only.

We learn from this example that phenomenological descriptions (the blue and the pink equation) build on what has been measured. These phenomenological equations aim at (a) describing patterns in the measured data, and (2) to make the equation as general as possible by introducing parameters, k, that are believed to be specific for a material or a system (e.g., the gas-constant, the elasticity constant, the electical resistance of a material, etc). Note that this 'epistemic strategy' in scientfic research is still very similar to what Boyle, Hooke, Ohm, Faraday and Balmer did in the past.

We also learn, therefore, that variables that are *not* measured do *not* occur in these phenomenological equations [it is not that the redox-potential as a measure for the ratio between Fe3+/Fe2+ was not taken into account because scientists believed that it was irrelevant, but because they had not thought of using this measurement-technique]. The moral is that much of the developments in science are due to development, application and combination of new measurement techniques.

Another important thing to notice in this example is that, based on the new measurement-techniques in this research project (especially, the measurement of the redox-potential in the leaching fluid as a measure for the ratio between the concentrations of Fe3+ en Fe2+), scientists could come up with this improved *phenomenological description* of the process, yet, without any 'deeper' understanding of how bacteria dissolve the mineral sulphide (such as pyrite). In other words, in scientific research, we can choose to do different things: (1) we just search for phenomenological laws (= mathematical equations) that relate apparently relevant measured data in an efficient and empirically adequate manner, (2) or we try to come up with a scientific model that is explanatory richer of what happens in the process (as in the causal-mechanistic and mathematical model just shown).

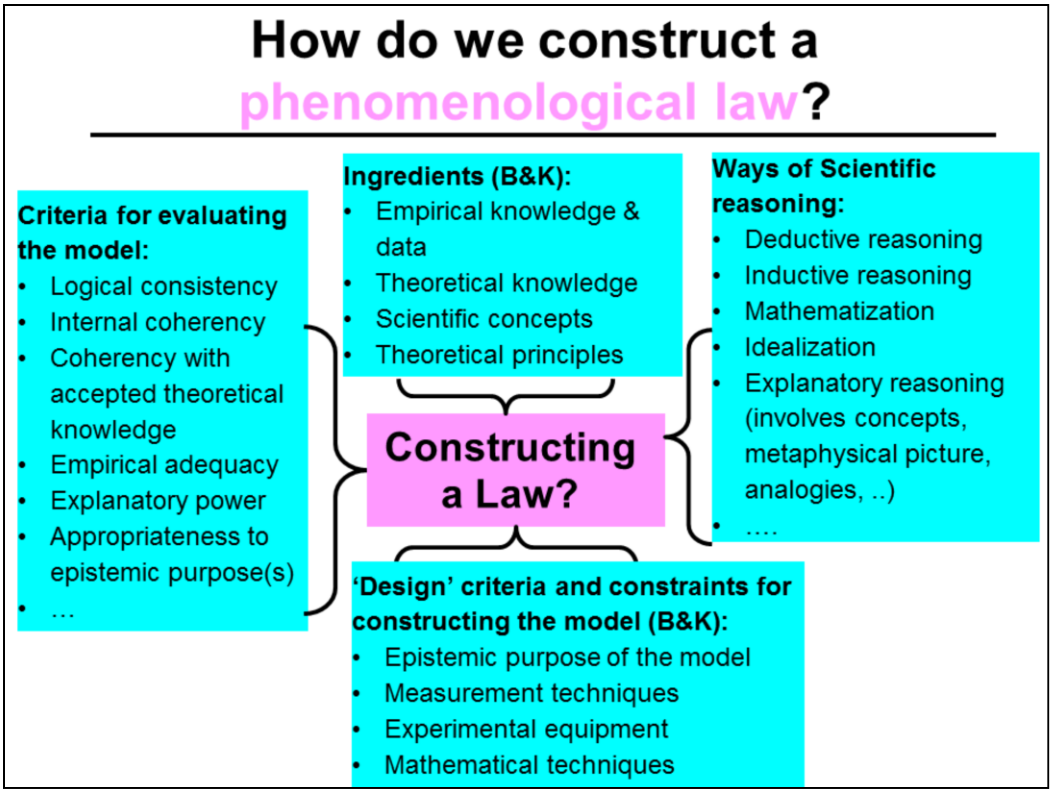
Summarizing and applying some of the philosophical terms we have learned: although the pink formula is an empirically adequate 'law of nature', its explanatory power is very limited. Therefore, the improved phenomenological equation is poor as an epistemic tool for the original epistemic aim (the original epistemic aim was generating knowledge that helps in the optimization of bioleaching processes). Conversely, the model (the causal-mechanistic model, interrelated with the mathematical model that relates measured data) is a much richer epistemic tool for reasoning about possible improvements (optimization), or even new types of technology in bioleaching (= new design-concepts).

Indeed, it turned out that this improved understanding of the mechanism, together with the mathematical model that quantifies it, allowed for drafting new design-concepts.

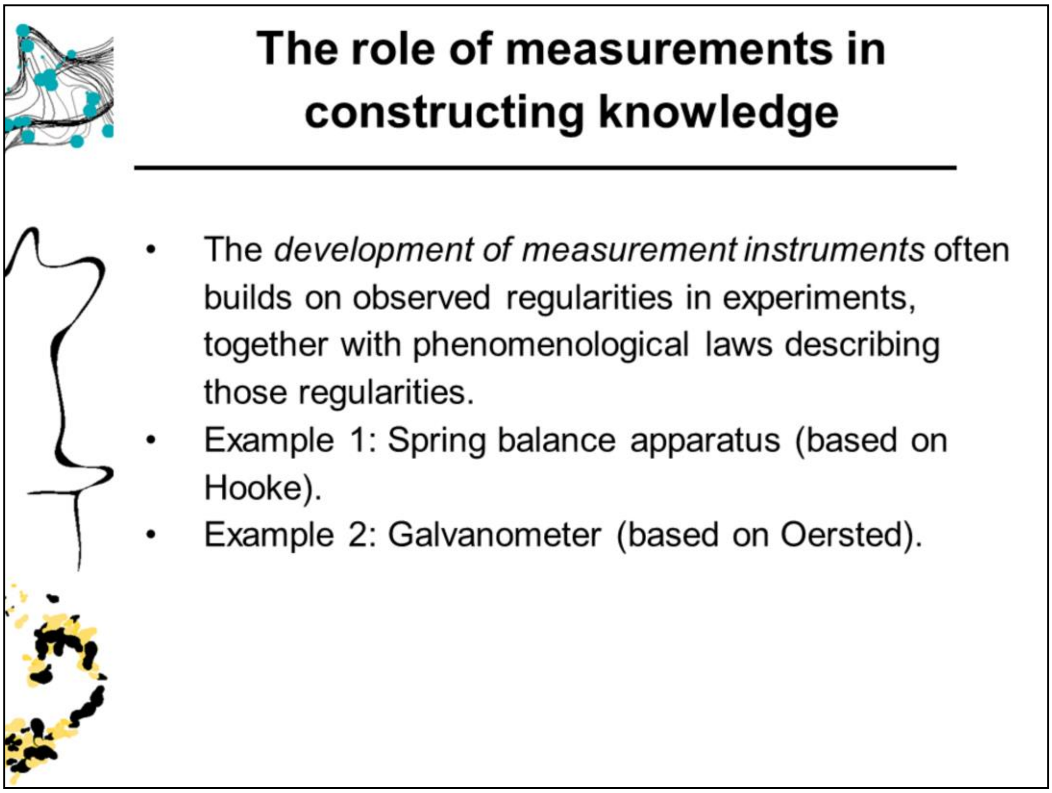
What are phenomenological laws?

Conclusions:

1. Phenomenological laws are not just *descriptions* of measured data (as in tables).
2. They are ‘empirically adequate’ mathematical formula ‘describing’ observed regularities in measured data. (However, what the law predicts about the data often is only approximately true => not strict empirical adequacy).
3. Constructing and using them involves *principles* (same conditions same effects), *scientific understanding*, and introduction of new scientific concepts (parameters).
4. Phenomenological laws can also be read as *operational definitions* of the parameters introduced.
5. Therefore, the phenomenological law also tells *how to measure the parameter*.



In other words: what applies to the construction of scientific models, also seems to apply to the construction of phenomenological laws.



The role of measuring instruments

Given this explanation of phenomenological laws, we can now understand that the development of measurement instruments often builds on observed regularities in experiments, together with phenomenological laws describing those regularities.

Example 1: Spring balance apparatus (based on Hooke).

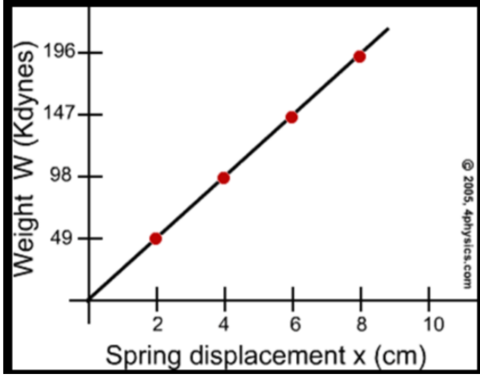
Example 2: Galvanometer (based on Oersted).

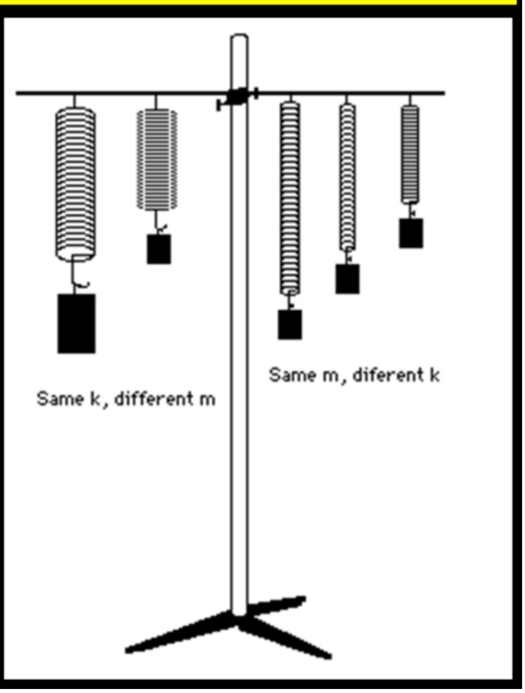
Constructing a phenomenological law

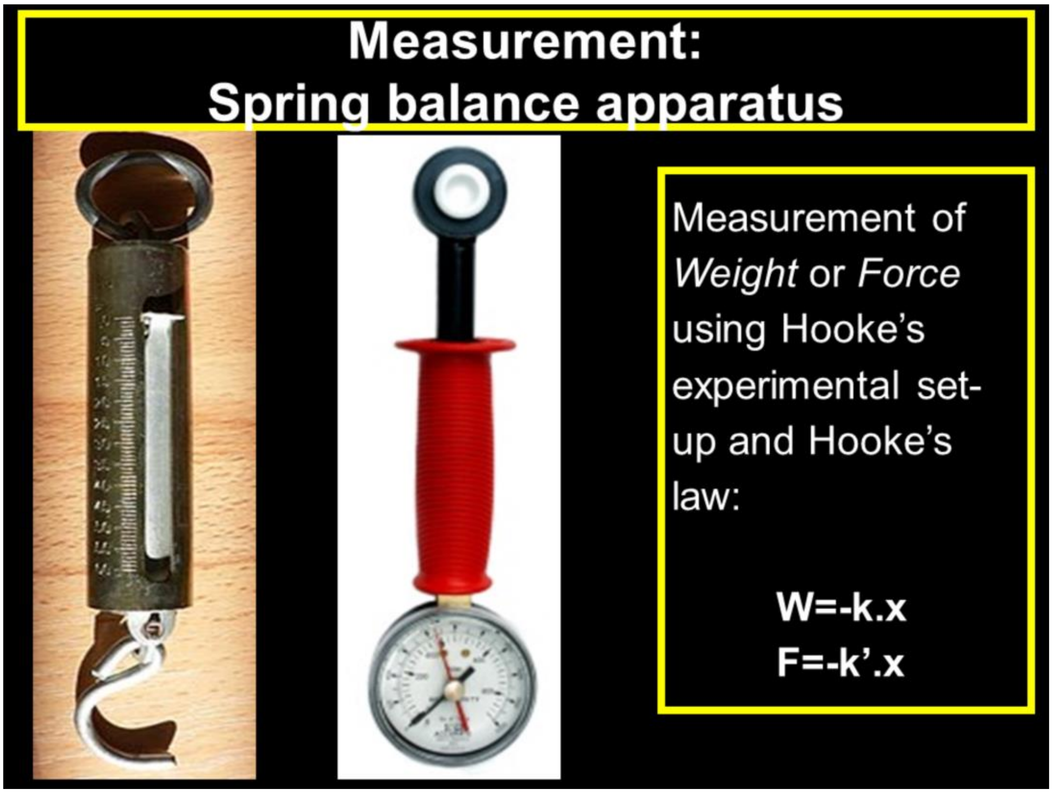
Robert Hooke's law (1635)

Induction: Inference from measured data to a law.
Scientific concept: elasticity coefficient, k. Also called **parameter**

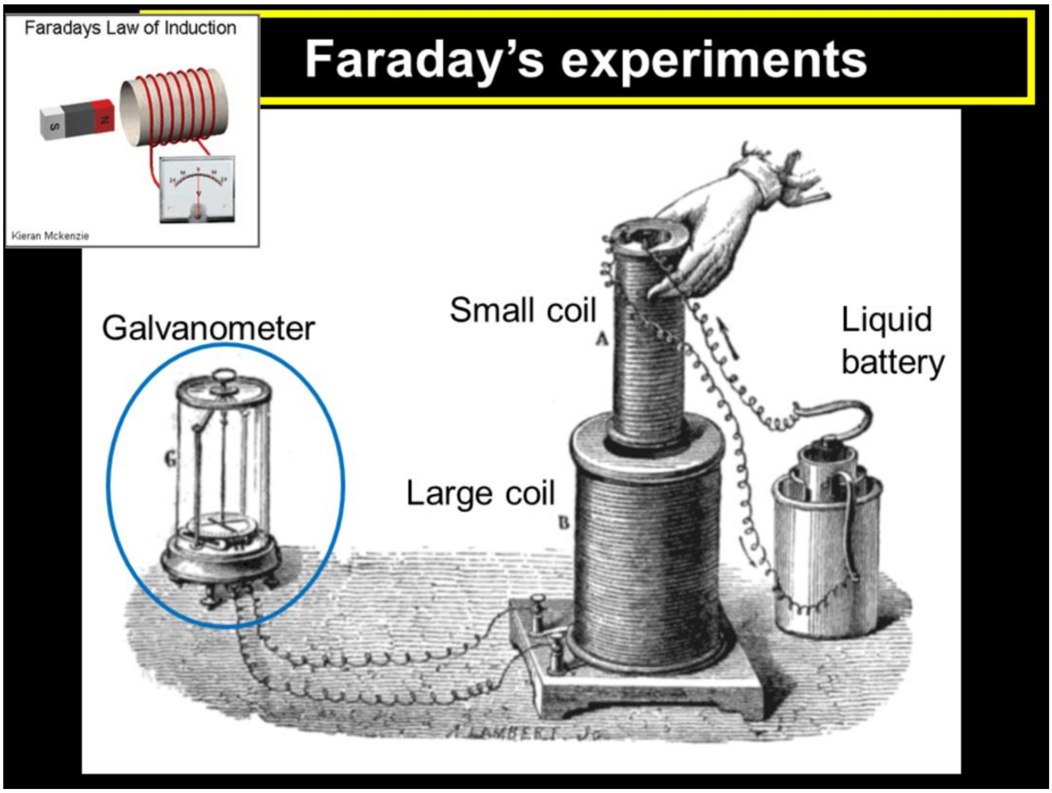
F=-k.x



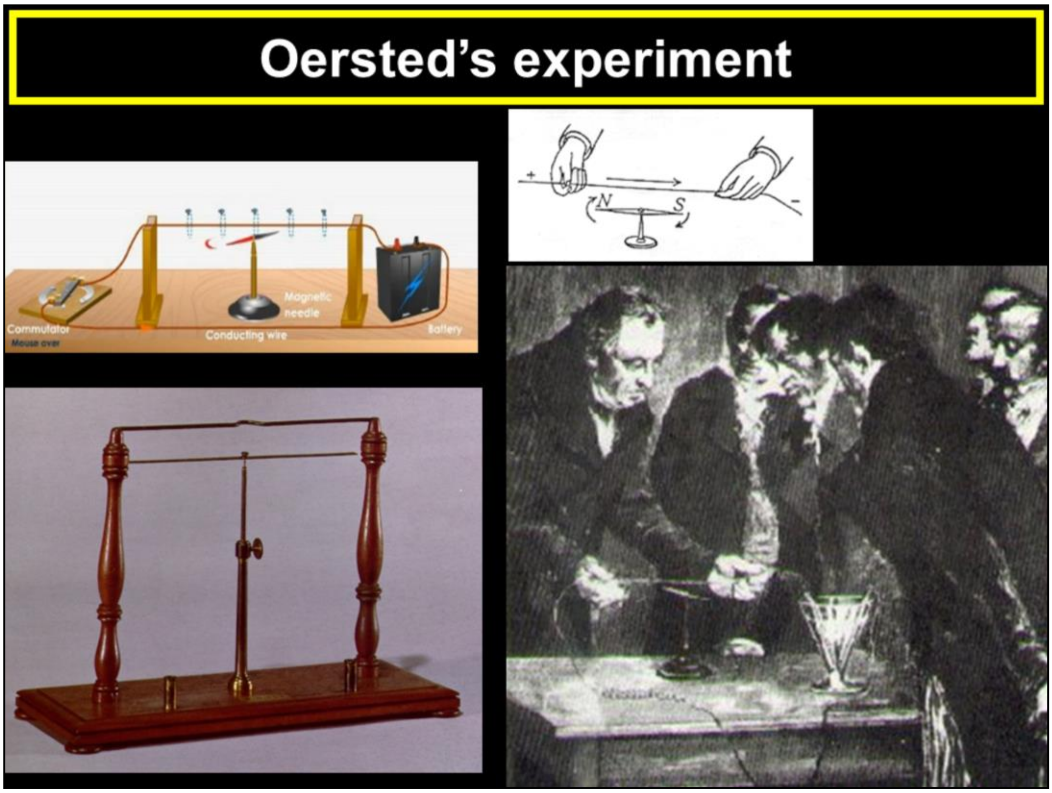




A **spring balance** apparatus is simply a spring fixed at one end with a hook to attach an object at the other. It works by Hooke's Law, which states that the force needed to extend a spring is proportional to the distance that spring is extended from its rest position. Therefore the scale markings on the spring balance are equally spaced. http://en.wikipedia.org/wiki/Spring_scale

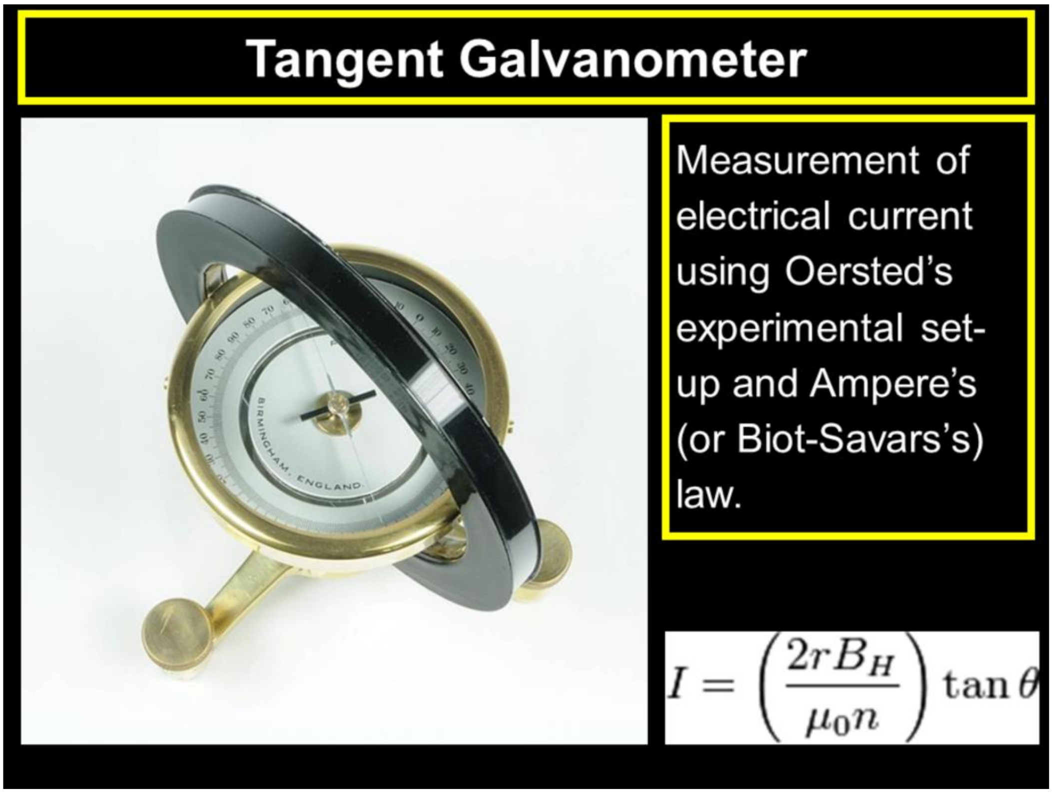


Drawing of Michael Faraday's 1831 experiment showing electromagnetic induction between coils of wire, using 19th century apparatus, from an 1892 textbook on electricity. On the right is a liquid battery that provides a current that flows through the small coil of wire *(A)* creating a magnetic field. When the small coil is stationary, no current is induced. However, when the small coil is moved in or out of the large coil *(B)*, the change in magnetic flux induces a current in the large coil. This is detected by the deflection of the needle in the galvanometer instrument *(G)* on the left.



However, no firm evidence existed that linked electricity and magnetism until Hans Christian Oersted performed a critical experiment during a lecture in 1820. He placed a wire above the compass needle and connected both ends across a battery and the needle spun until it was at right angles to the wire. In further experiments, using instruments similar to the one pictured below, he was able to determine that the magnetic influence surrounded the wire in a circle.

A magnetic needle balances on the central rod. The two end posts support a metal wire. Each end of the wire extends down through the wooden posts and is connected to a small metal post in the base. When one metal post was connected to the positive pole of a battery and the other metal post was connected to the negative pole of a battery, current would flow in the wire. The needle would then swing until it was at right angles to the wire.



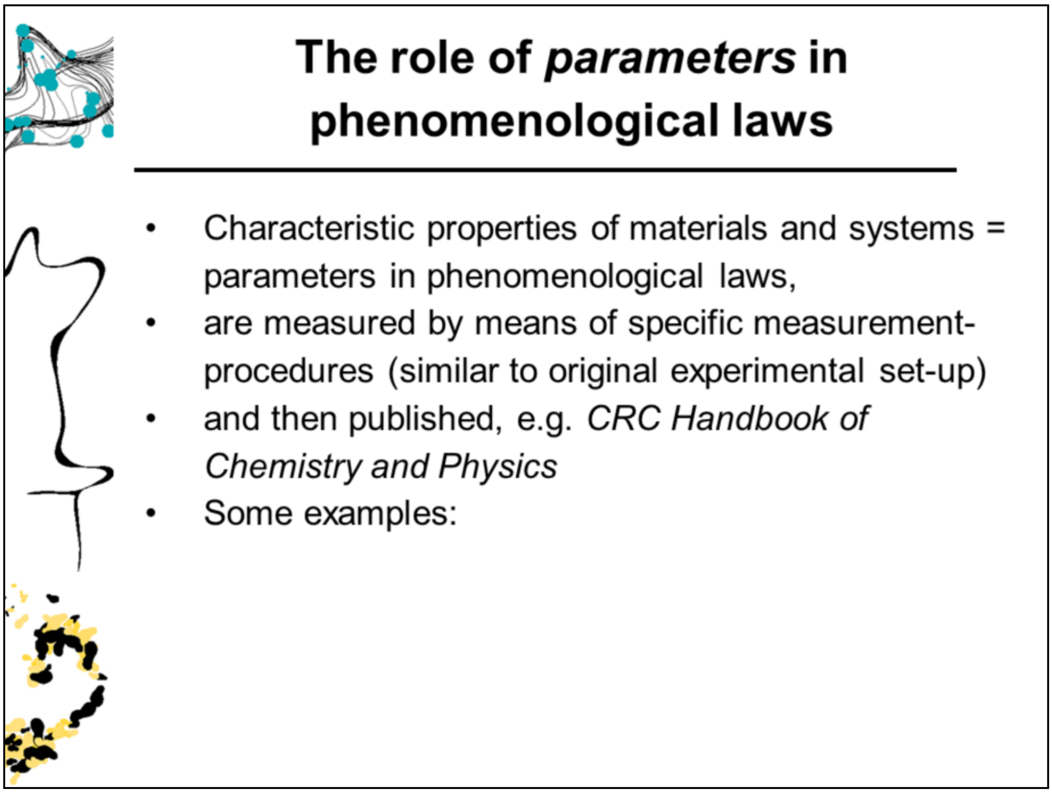
[Tangent galvanometer](#) made by [en:Philip Harris Ltd.](#), Birmingham, England, ca. 1950. From the *Sammlung historischer Messtechnik* (Collection of historical measurement apparatus), A. Kusdas. In the middle of the galvanometer is a compass that is aligned to be horizontal using the brass leveling screws. The black ring has a diameter of 17 cm; it houses a circular coil of wire. In use, the galvanometer is rotated on a table so that this ring is parallel to the direction of the earth's local magnetic field, and the compass needle will be parallel to the ring. As can be seen, the apparatus was not aligned when the photograph was taken. When a source of electrical current is hooked up to the coil, the resulting magnetic field causes the compass needle to rotate away from its initial alignment parallel to the coil. The angle of rotation is used to calculate the current through the coil.

The galvanometer is oriented so that the plane of the coil is vertical and aligned along parallel to the horizontal component of the Earth's magnetic field (i.e. parallel to the local "magnetic meridian"). When an electrical current flows through the galvanometer coil, a second magnetic field is created. At the center of the coil, where the compass needle is located, the coil's field is perpendicular to the plane of the coil. The magnitude of the coil's field is:

where I is the current in [amperes](#), n is the number of turns of the coil and psi is the radius of the coil. These two perpendicular magnetic fields add [vectorially](#), and the compass needle points along the direction of their resultant. Mu0 is the magnetic constant. The current in the coil causes the compass needle to rotate by an angle

A **galvanometer** is a type of sensitive ammeter: an instrument for detecting electric current. It is an analog electromechanical transducer that produces a rotary deflection of some type of pointer in response to electric current flowing through its coil in a magnetic field.

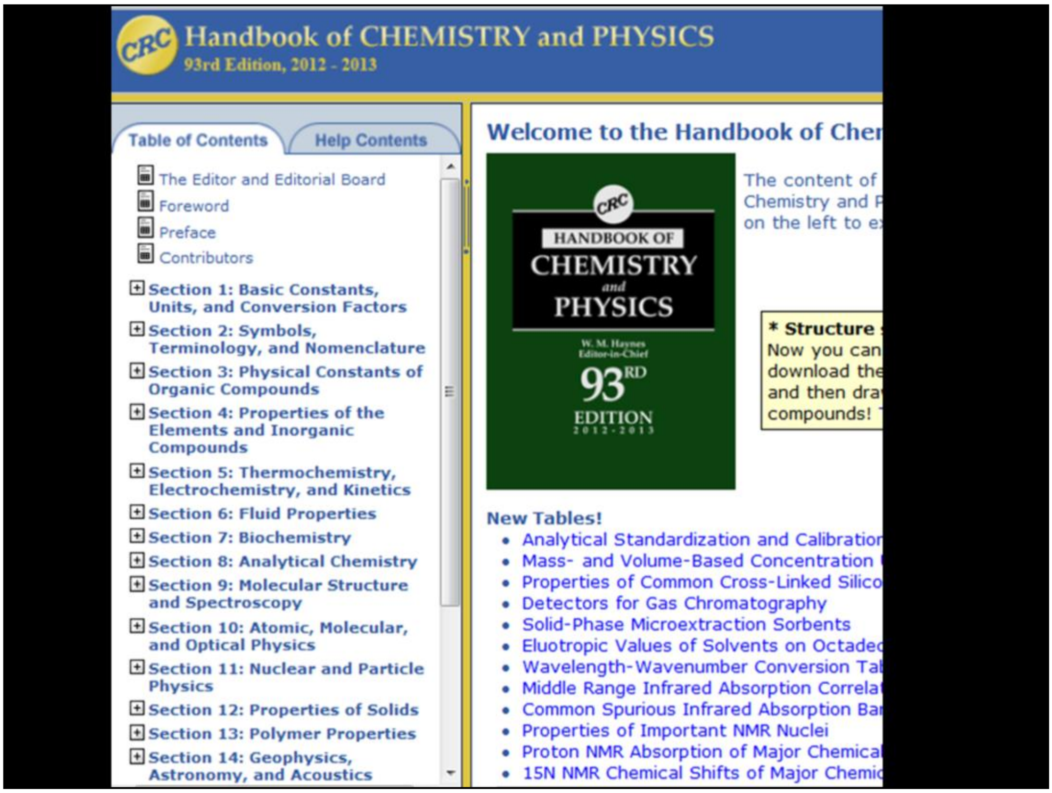
Galvanometers were the first instruments used to detect and measure electric currents. Sensitive galvanometers were used to detect signals from long submarine cables, and were used to discover the electrical activity of the heart and brain. Some galvanometers used a solid pointer on a scale to show measurements, other very sensitive types used a tiny mirror and a beam of light to provide mechanical amplification of tiny signals. **Initially a laboratory instrument relying on the Earth's own magnetic field to provide restoring force for the pointer**, galvanometers were developed into compact, rugged, sensitive portable instruments that were essential to the development of electrotechnology. A type of galvanometer that permanently recorded measurements was the chart recorder. The term has expanded to include uses of the same mechanism in recording, positioning, and servomechanism equipment.



The role of *parameters* in phenomenological laws

Characteristic properties of materials and systems = parameters in phenomenological laws, are measured by means of specific measurement-procedures (similar to original experimental set-up) and then published, e.g. CRC Handbook of Chemistry and Physics.

Some examples:



Interestingly, many of these material properties have ‘just’ a technological meaning. They are relevant, for instance, to the development of technological functionality.

Table 2: Lower Heating Value (HHV) Of Various Common Fuels							
Fuel	Phase	Molecular Weight	kJ/mol	MJ/kg	MJ/m^3	Btu/lb	Btu/ft^3
Hydrogen [4]	gas	2.016	241.83	119.96	10.79	51,596	274
Methane [4]	gas	16.043	802.32	50.01	35.80	21,511	909
Ethane [4]	gas	30.069	1,427.84	47.49	63.70	20,424	1,618
Propane [4]	gas	44.096	2,044.00	46.35	91.19	19,937	2,317
Butane [4]	gas	58.122	2,658.45	45.74	118.61	19,673	3,013
Ethanol [6]	liquid	46.0684	1,241.66	26.95		11,593	
Gasoline [6]	liquid	110	4,675.00	42.50		18,280	
Kerosene [11]	liquid	178	7,519.05	42.24		18,169	
Diesel oil [11]	liquid	225	9,395.99	41.76		17,961	
Coal [11]	solid			24.429		10,507	
Wood (dry) [11]	solid			20.09		8,639	
Peat (dry) [11]	solid			20.65		8,883	

-- The gas temperature and pressure for the values of MJ/m^3 are 0 °C and 101.325 kPa.

-- The gas temperature and pressure for the values of Btu/ft^3 are 60 °F and 14.696 psia.

-- LPG is marketed as propane or butanes or a mixture of propane and butanes.

-- Natural gas, after removal of impurities and natural gas liquids (NGL), is essentially pure methane.

Compound	CAS number	pKa value (in interval 8 - 9,6)	Solubility in water, g/kg
Arginine	74-79-3	9,00	182,6 [a)]
Aspargine	70-47-3	8,73	25,1
Glutamic acid	56-86-0	9,58	8,61 [a) b)]
Glutamine	56-85-9	9,00	42
Glycine	56-40-6	9,58	250,9
Histidine	71-00-1	9,09	43,5
Isoleucine	73-32-5	9,60	34,2
Leucine	61-90-5	9,58	22,0
Lysine	56-97-1	9,16	Very soluble [a) b)]
Methionine	63-68-3	9,08	56
Phenylalanine	63-91-2	9,09	27,9
Serine	56-45-1	9,05	50,2
Threonine	72-19-5	8,96	98,1
Valine	72-18-4	9,52	88,5
Cysteic acid	13100-82-8	8,70	Very soluble
N-Glycylglycine	556-50-3	8,10	No information
Ornithine	70-26-8	8,78	Very soluble

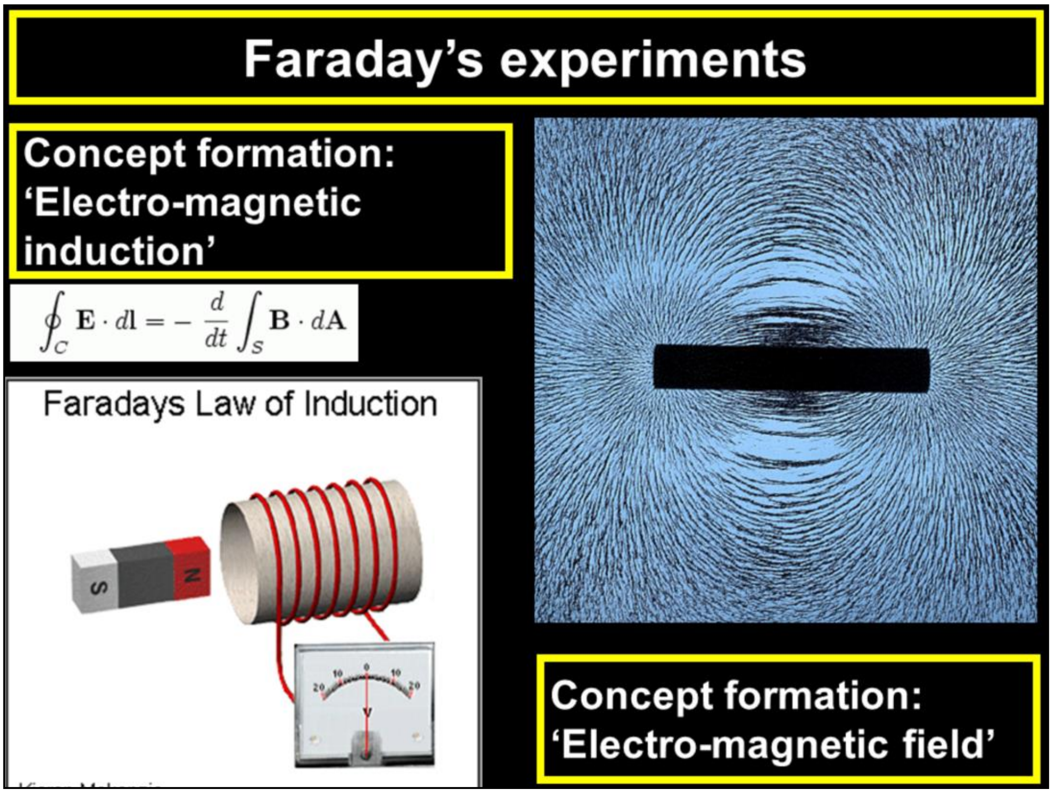
Solvent (Temperature , Kelvin)	Dielectricity constant, ε*
Water (293.2)	80.1
Propanetriol [Glycerol] (293.2)	46.53
Ethanediol [Ethylene Glycol] (293.2)	41.4
1,3-propanediol (293.2)	35.1
Methanol (293.2)	33.0
1,4-butanediol (293.2)	31.9
1,3-butanediol (293.2)	28.8
1,2-propanediol [propylene glycol] (303.2)	27.5
Ethanol (293.2)	25.3
Isopropanol (293.2)	20.18

What is a scientific concept?

Examples of scientific concepts (of objects, properties, processes):

Gravitational force, (aether), electro-magnetic field, light-waves, (caloric), energy, (perpetual mobile), entropy, atom, (phlogiston), molecule, electron, photon, gene, DNA, evolution, mind, intelligence, personality, cognitive dissonance, ...

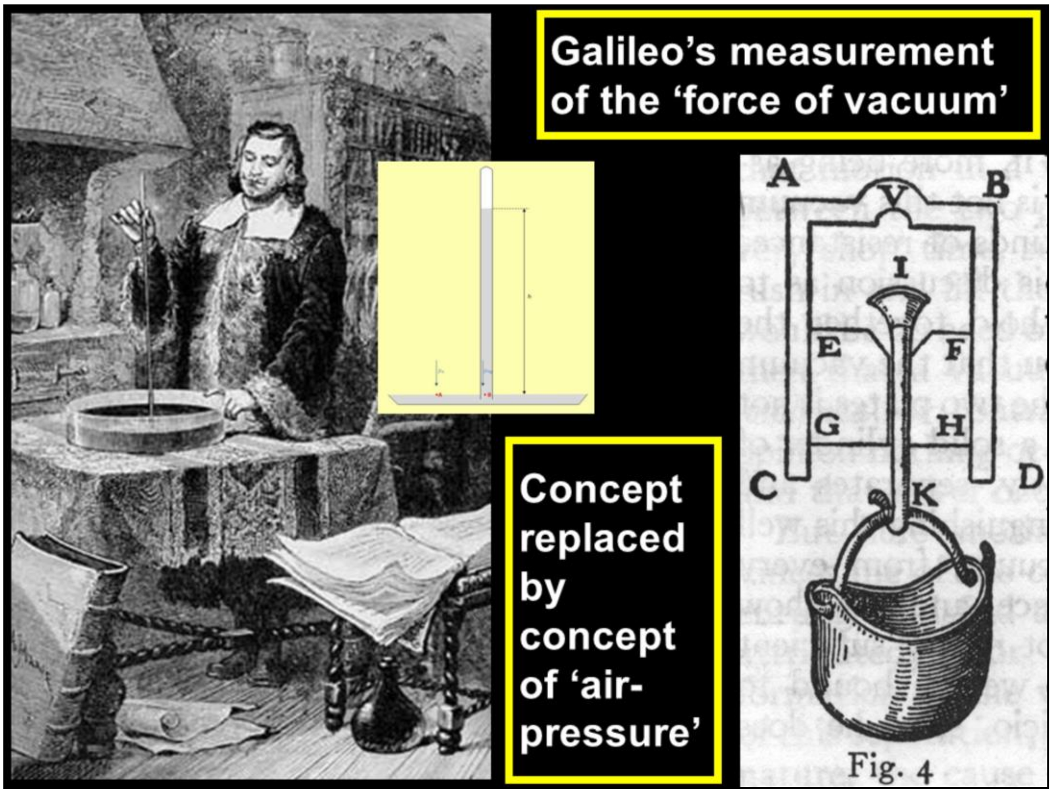
Typical for engineering sciences:
Diffusion, elasticity, hysteresis, magnetic permeability; electrical resistance; heat resistance, super conduction, piezoelectricity, ….



The induced electromotive force in a closed circuit is equal to the negative of the time rate of change of the magnetic flux through the circuit.

Fluxmeter = any instrument for measuring magnetic flux, usually by measuring the charge that flows through a coil when the flux changes.

Φ_B is the magnetic flux through the open surface. **v** is the velocity of the boundary $\partial\Sigma$,**E** is the electric field, **B** is the magnetic field.



http://galileoandeinstein.physics.virginia.edu/tns_draft/index.html Dialogues Concerning Two New Sciences.

Since the times of the famous Greek philosophers, Demokritos (460-370 B.C.) and his teacher Leukippos (5th century B.C.), one is discussing the concept of vacuum and is speculating whether there might exist an absolutely empty space, in contrast to the matter of countless numbers of indivisible atoms forming the universe. It was Aristotle (384-322 B.C.), who claimed that nature is afraid of total emptiness and that there is an insurmountable "*horror vacui". Therefore, he doubted and even rejected* an absolute vacuum. He assumed, for example, that the idea of empty space would invite the concept of motion without resistance, i.e. a motion at infinite velocity. This opinion became a paradigma for almost 2000 years. It was believed by famous writers, like Roger Bacon (1214-1299) and René Descartes (1596-1650) and was strongly supported also by the church.

Only in the 17th century were vacuum physics and technology born. Galileo (1564-1642) was among the first to conduct experiments attempting to measure forces required to produce vacuum with a piston in a cylinder.

First I shall speak of the vacuum, demonstrating by definite experiment the quality and quantity of its force [virtù]. If you take two highly polished and smooth plates of marble, metal, or glass and place them face to face, one will slide over the other with the greatest ease, showing conclusively that there is nothing of a viscous nature between them. But when you attempt to separate them and keep them at a constant distance apart, you find the plates exhibit such a repugnance to separation that the upper one will carry the lower one with it and keep it lifted indefinitely, even when the latter is big and heavy.

This experiment shows the aversion of nature for empty space, even during the brief moment required for the outside air to rush in and fill up the region between the two plates. It is also observed that if two plates are not thoroughly polished, their contact is imperfect so that when you attempt to separate them slowly the only resistance offered is that of weight; if, however, the pull be sudden, then the lower plate rises, but quickly falls back, having followed the upper plate only for that very short interval of time required for the expansion of the small amount of air remaining between the plates, in consequence of their not fitting, and for the entrance of the surrounding air. This resistance which is exhibited between the two plates is doubtless likewise present between the parts of a solid, and enters, at least in part, as a concomitant cause of their coherence.

SAGR. Allow me to interrupt you for a moment, please; for I want to speak of something which just occurs to me, namely, when I see how the lower plate follows the upper one and how rapidly it is lifted, I feel sure that, contrary to the opinion of many philosophers, including perhaps even Aristotle himself, motion in a vacuum is not instantaneous. If this were so the two plates mentioned above would separate without any resistance whatever, seeing that the same instant of time would suffice for their separation and for the surrounding medium to rush in and fill the vacuum between them. The fact that the lower plate follows the upper one allows us to infer, not only that motion in a vacuum is not instantaneous, but also that, between the two plates, a vacuum really exists, at least for a very short time, sufficient to allow the surrounding medium to rush in and fill the vacuum; for if there were no vacuum there would be no need of any motion in the medium. One must admit then that a vacuum is sometimes produced by violent motion [violenza] or contrary to the laws of nature, (although in my opinion nothing occurs contrary to nature except the impossible, and that never occurs).

..

SALV. I do not wish just now to enter this discussion as to whether the vacuum alone is sufficient to hold together the separate parts of a solid body; but I assure you that the vacuum which acts as a sufficient cause in the case of the two plates is not alone sufficient to bind together the parts of a solid cylinder of marble or metal which, when pulled violently, separates and divides. And now if I find a method of distinguishing this well known resistance, depending upon the vacuum, from every other kind which might increase the coherence, and if I show you that the aforesaid resistance alone is not nearly sufficient for such an effect, will you not grant that we are bound to introduce another cause? Help him, Simplicio, since he does not know what reply to make.

I will tell you how to separate the force of the vacuum from the others, and afterwards how to measure it. For this purpose let us consider a continuous substance whose parts lack all resistance to separation except that derived from a vacuum, such as is the case with water, a fact fully demonstrated by our Academician in one of his treatises. Whenever a cylinder of water is subjected to a pull and offers a resistance to the separation of its parts this can be attributed to no other cause than the resistance of the vacuum. In order to try such an experiment I have invented a device which I can better explain by means of a sketch than by mere words. Let CABD represent the cross section of a cylinder either of metal or, preferably, of glass, hollow inside and accurately turned. Into this is introduced a perfectly fitting cylinder of wood, represented in cross section by EGHF, and capable of up-and-down motion. Through the middle of this cylinder is bored a hole to receive an iron wire, carrying a hook at the end K, while the upper end of the wire, I, is provided with a conical head. The wooden cylinder is countersunk at the top so as to receive, with a perfect fit, the conical head I of the wire, IK, when pulled down by the end K.

Now insert the wooden cylinder EH in the hollow cylinder AD, so as not to touch the upper end of the latter but to leave free a space of two or three finger-breadths; this space is to be filled with water by holding the vessel with the mouth CD upwards, pushing down on the stopper EH, and at the same time keeping the conical head of the wire, I, away from the hollow portion of the wooden cylinder. The air is thus allowed to escape alongside the iron wire (which does not make a close fit) as soon as one presses down on the wooden stopper. The air having been allowed to escape and the iron wire having been drawn back so that it fits snugly against the conical depression in the wood, invert the vessel, bringing it mouth downwards, and hang on the hook K a vessel which can be filled with sand or any heavy material in quantity sufficient to finally separate the upper surface of the stopper, EF, from the lower surface of the water to which it was attached only by the resistance of the vacuum. **Next weigh the stopper and wire together with the attached vessel and its contents; we shall then have the force of the vacuum** [**forza del vacuo**]. If one attaches to a cylinder of marble or glass a weight which, together with the weight of the marble or glass itself, is just equal to the sum of the weights before mentioned, and if breaking occurs we shall then be justified in saying that the vacuum alone holds the parts of the marble and glass together; but if this weight does not suffice and if breaking occurs only after adding, say, four times this weight, we shall then be compelled to say that the vacuum furnishes only one fifth of the total resistance [resistenza].

The concept of 'force of vacuum' measured by Galileï, was replaced by Toricelli's concept of 'air-pressure'.

What is a scientific concept?

- Is it the name or definition of a phenomenon (an object / property / process)?
- However, phenomena (objects, properties, processes) in science, such as 'electro-magnetic field', 'DNA' or 'artificial photo-synthesis' usually are not observable in an unproblematic manner.

- => The formation of scientific concepts cannot be understood as merely describing an observable phenomenon.
- Are scientific concepts constructed similar to phenomenological laws and parameters in these laws? => Again a crucial role of experimental set-up and measurements in the formation of scientific concepts?

Take home - Overview

- In the engineering sciences, empirical and scientific knowledge is about naturally and technologically produced phenomena, and technological devices.
- Different types of empirical and scientific knowledge: phenomenological laws, parameters, scientific concepts, scientific models, fundamental theories.
- How is this knowledge constructed?
  - Bricolage: we use empirical and scientific knowledge – similar to design.
  - Constrained by our cognitive capacities and available mathematics and technologies.
  - Crucial role of measurements in constructing scientific knowledge.