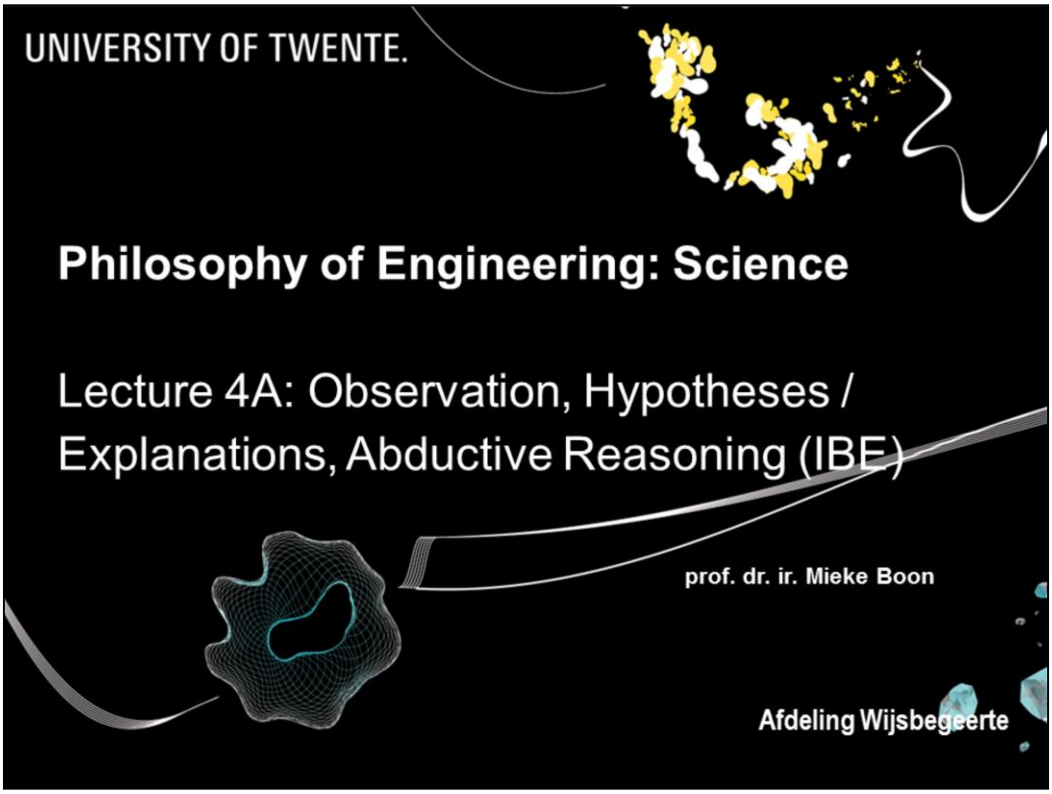

Classes 4 & 5 prepare for the final assignment.

INTRODUCTION

In the former lectures, you have learned a vocabulary – that is, some technical terms, and some philosophical understanding of science, which we will now start to apply.

Recall that one of the problem academics have to face is the status of science and scientific research. In the past decades, the authority of science and scientific claims has significantly diminished. If, for instance, scientist claim that there will be a climate problem due to increased, anthropogenic emissions of carbon dioxide, (part of) the general audience may argue that there is no scientific proof. They have learned that science cannot prove such causal relationships – in other words, they have learned that science does not give us certainty as scientific claims may always prove wrong (as has happened many times in the past). At this point, deciding whether there will be a problem, or even a serious threat, seems to be a political, rather than a scientific issue. See for instance, the responses to this recent article in Scientific American:
http://www.scientificamerican.com/article.cfm?id=dangerous-climate-change-imminent&goback=%2Egde_2731464_member_5815497061310689283#%21

“I'm all for developing technology to make things cheaper and more sustainable. I am not for wrecking the economy on the say so of experts. The experts have been 100% wrong on all the disasters they have predicted to date….”

One of the broader aims of this course in the philosophy of science is a better understanding of science, such that you will feel more capable to analyze and respond to such controversies. So far, you have learned in this course, that, indeed, science cannot give certainty. This is what scientists and philosophers in the past hoped for. Recall the *Rationalists* and *Empiricists* in the 17th century, who tried to find the solid ground of knowledge, for exactly this very reason. As was shown in the philosophy of science, especially in the 20th century, this project failed. At the same time, you believe (hopefully) that science is the best we have. One of the relevant aims of this course is to understand this situation into a bit more depth.

AN ALTERNATIVE PICTURE OF SCIENCE

Additionally, a topic for the remainder of this course, is to explore whether an alternative view of science is possible that is doing justice to the strength of science, but also acknowledges its weaknesses. The traditional (philosophical) picture of science will be called ‘scientific realism’ (also see the second part of Ladyman). The alternative is called constructivism (but beware: not ‘social constructivism’, in case you start searching this term on the internet). I will call it ‘epistemological constructivism’, which means to say that scientific theories are epistemic entities constructed for epistemic uses (rather than pictures or description that ‘supposedly’ correspond to reality).

An important first step in developing this alternative picture of science is turning our focus away from scientific theories, towards how scientists construct scientific theories.

This links up with another broader aim of this course: ‘learning to think as a scientists’, ‘learn from how scientists think’, ‘learn styles of scientific reasoning’, ‘learning about the creativity in scientific thinking’.

Related to this aim is to recognize that ‘scientific approaches’ and ‘styles of scientific reasoning’ and ‘ways in which scientists think’ are very similar in many scientific disciplines. The central idea for the remainder of this philosophy of science course is that the ways in which **scientists construct scientific theories** are similar throughout science.

This idea is more radically different than it may seem on face value. Our common idea about scientific theories is that scientific theories firstly are determined by how the world is. On this common view, there is, so to speak, a correspondence (or representational) relationship between theory and world, which is independent of the intellectual make-up of humans. In philosophy of science, this position is called ‘scientific realism’. It assumes that the scientific theory or model correctly or ‘truly’ (or approximately truly) describes the world.

SUMMARIZING

The remainder of this course aims at:

- Introducing an alternative philosophical picture of science (a ‘viable’ alternative to so-called scientific realism).
- This alternative picture involves the assumption that scientific theories are constructed in accordance with, say, the intellectual abilities of humans. Roughly: the theory is determined, not only by how the world is, but also by the intellectual abilities of humans.
- In effect, the ways in which theories in different disciplines are constructed are often similar (as their construction involves similar ways of reasoning, and often, re-using mathematical templates, and more abstract concepts).
- This situation is advantageous because it makes possible to understand other disciplines more easily.
- As a more practical consequence, this situation can be used for learning interdisciplinarity: The final assignment aims at learning a tool by means of which research in other disciplines can be understood more easily – clearly, it will not bring you at the expert level, but, at the level from which you can communicate and ask sensible questions in order to understand other disciplines. This ability is crucial for interdisciplinary work.


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HEALTH

Dangerous Global Warming Closer than You Think, Climate Scientists Say

Two new reports lay out the case for fast action and increased awareness

By David Biello on December 4, 2013 109

"I'm all for developing technology to make things cheaper and more sustainable. I am not for wrecking the economy on the say so of experts. The experts have been 100% wrong on all the disasters they have predicted to date…."

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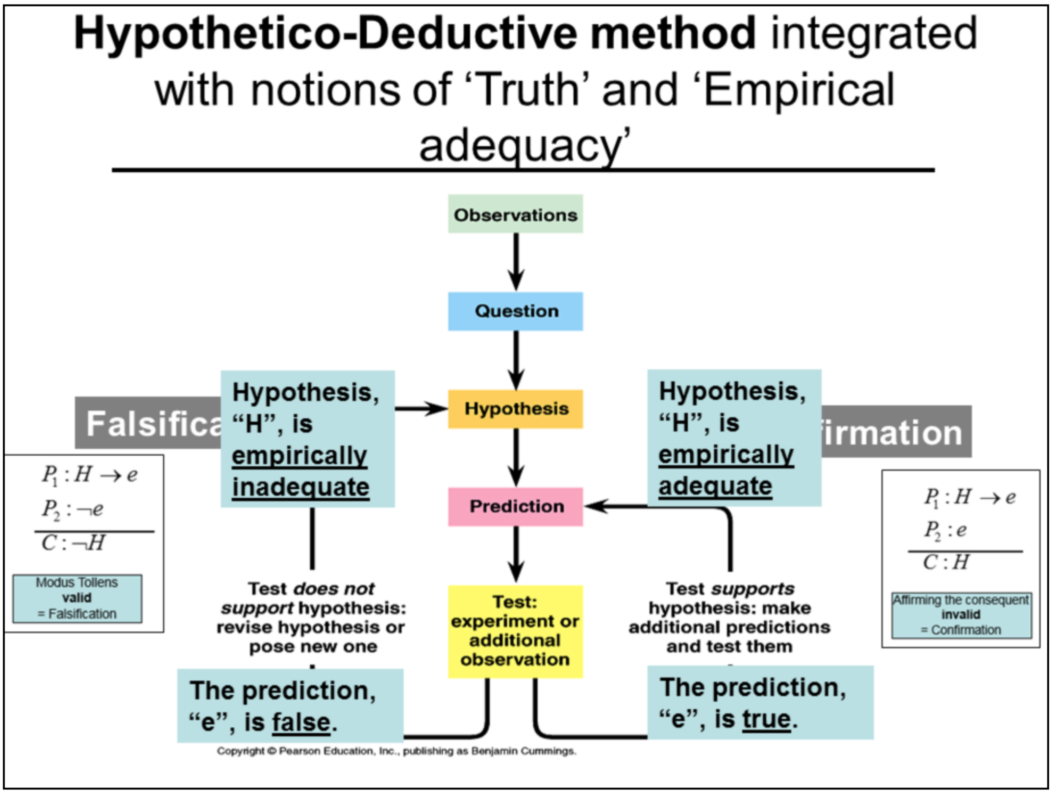
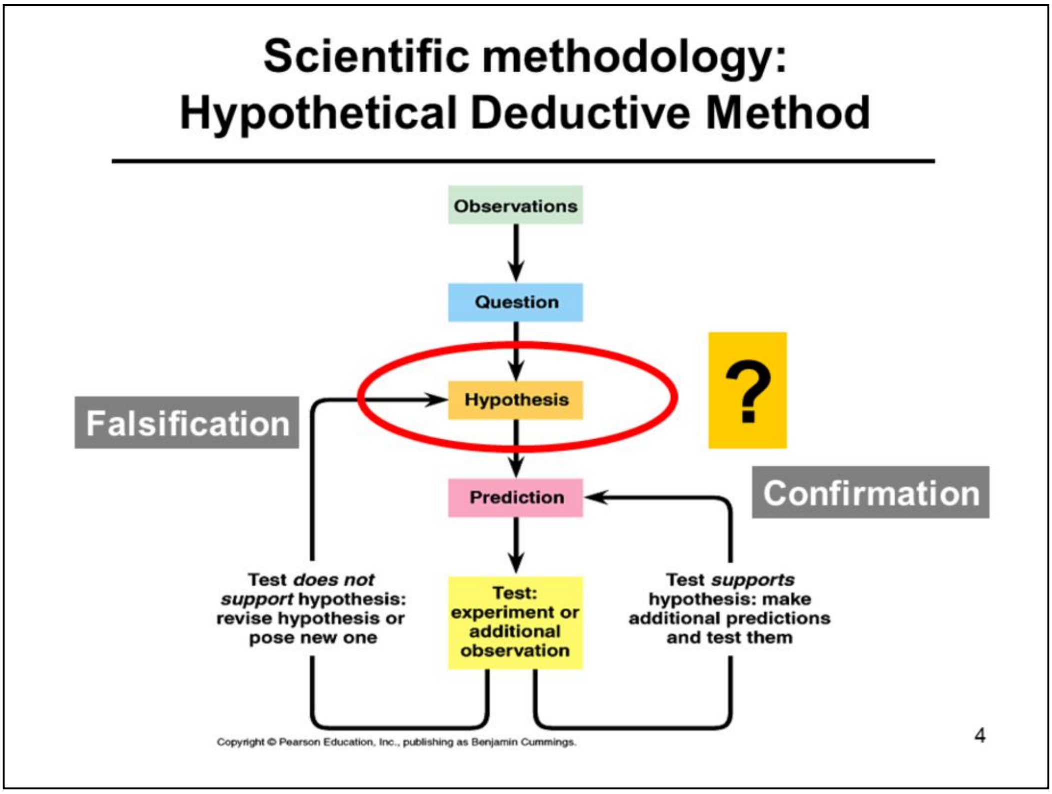
Societal role of scientists: How should we sensibly respond to such comments?



Last week: The notion 'empirical adequacy' merged with the HD-method. The prediction "e" is true or false (if the measurement, e, agrees with the "e", which is deduced from the hypothesis, H). The Hypothesis "H" (e.g., Bohr's model of the atom) is then empirically (in-)adequate.

The topic of this class will be to explore how the hypothesis in this diagram comes about. How do scientists construct a hypothesis? Especially, if the hypothesis is not attained by means of mere inductive reasoning (e.g. from observing that A1 is B, and A2 is B,…, Ai is B, to the hypothesis that All A's are B's), but if the hypothesis aims to **explain**, for instance, "Why 'All A's are B'".



The hypothesis can be achieved by inductive reasoning, e.g., as in Boyle’s or Hooke’s experiment.

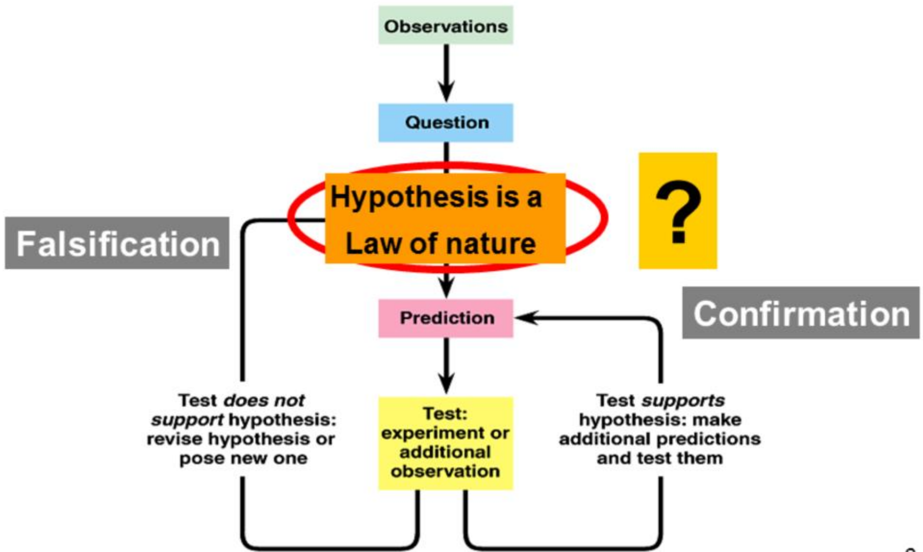
Let us firstly focus on the question how a hypothesis comes about. Especially, in cases where the hypothesis is supposed to be a <u>scientific explanation</u> of an (observed or measured) phenomenon, (rather than just a generalization).

Therefore, let us first look a little bit deeper into what we mean by ‘explanation’, and after that, at how explanations are constructed.

Hypothesis – Law of nature

- Assume that the hypothesis is an explanation, i.e., an answer to a *Why* question, e.g.: "*why does the pressure of a gas in a closed vessel increase when (in an experiment) the volume is decreased?*"
- Assume that the hypothesis is a law of nature (e.g., PV = constant).
- Laws of nature are derived from inductive reasoning & introducing new scientific concepts.
- Are laws of nature explanations / answers to a why-question?

Do laws of nature *explain* observed phenomena?



Law of nature from experiments

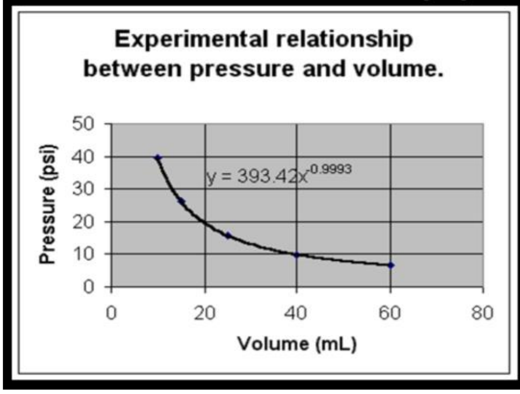
Boyle's law

Robert Boyle (1627-1691)

Induction: Inference from measured data to a law.

Scientific concept: gas constant, c(T).

$$PV = c(T)$$

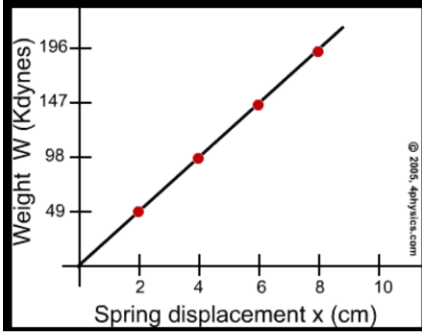


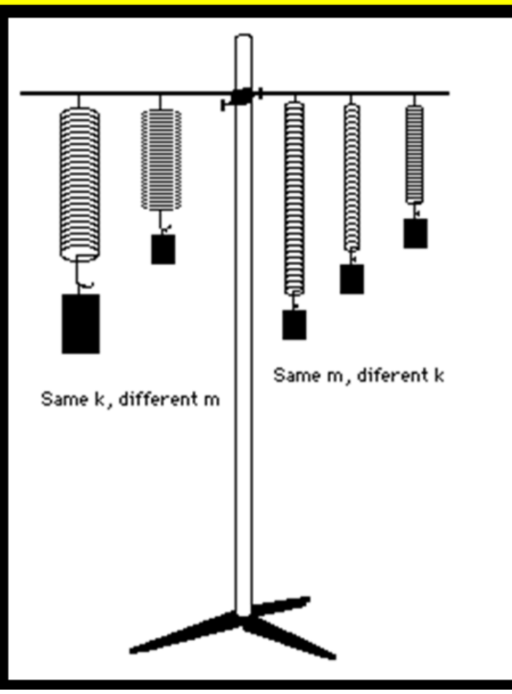
Law of nature from experiments

Robert Hooke's law (1635)

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

$F=-k.x$





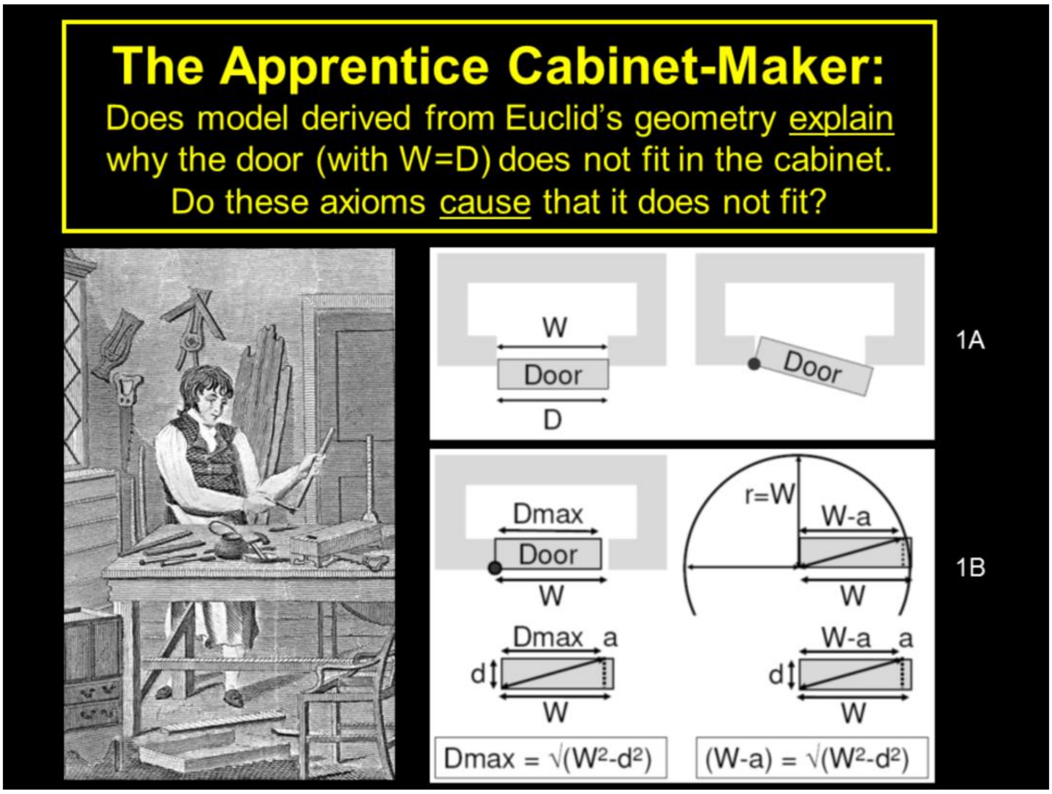


Figure 1A. Represents the observed phenomenon: a concrete, material door hanging in the hinges of the cabinet, with D = W, does not fit when closing it.

Figure 1b. The observed phenomenon is explained in terms of the axioms of Euclidean geometry (two different ways of explaining it: Picture on the left uses Pythagoras with the diagonal equal or smaller than W; Picture on the right uses the radius of a circle at length W).

(explanation of this example in former class):

- Do Euclid's axioms *describe* the phenomenon correctly?
- Do they *explain* the observed phenomenon?
- Do they *cause* the phenomenon?

Try to apply this line of reasoning to Newton's axioms (or laws of Nature?).

- Do Newton's axioms *describe* the observed phenomenon correctly? (e.g., of the orbit of the Moon, or of the trajectory of the bullet)

- Do they *explain* the observed phenomenon?
- Do they *cause* the phenomenon?

Explaining versus describing.

- Does a mathematical model (such as the model of the non-closing door, which is constructed by means of Euclidean geometry) *explain* the phenomenon that the door does not close? Certainly, it does not count as a causal explanation. In other words, the laws of Eucledian geometry are not causally responsible for this phenomenon.

- Similarly, we can ask whether a model constructed by EM theory explains EM phenomena? (and also for Newton).

The point of this question is whether you think that an explanation (a model) should describe the cause of a phenomenon, or rather, that an explanation just helps us in thinking how to intervene, predict, change, calculate the phenomenon. In the latter case, you are close to the idea that scientific models (and scientific knowledge in general) is an epistemic tool (i.e., a tool for thinking, see the slides below).

Do laws of nature *explain* observed phenomena?

1. Is Boyle's / Hooke's / Ohm's law an explanation (e.g., law explains *why the pressure goes up when the volume is decreased*)**? Yes / No**

2. Is Eucledean geometry (axioms) an explanation? Yes/No

…

5. Do you consider your own idea about laws of nature closer to Realism or anti-Realism?

Do laws of nature *explain* observed phenomena?

1. Is Boyle's / Hooke's / Ohm's law – which is derived by means of inductive reasoning – an explanation (of, e.g., why the pressure goes up when the volume is decreased)? Yes [True] / No [False]

24/43 (A) True

12/43 (B) False

Do laws of nature *explain* observed phenomena?

Does Euclid's geometry (Euclid's axioms) explain why the door (with W=D) does not fit in the cabinet. [Or, Does model derived from Euclid's geometry explain why the door (with W=D) does not fit in the cabinet.]

2. Yes [True] / No [False]

37/43 (A) True

4/43 (B) False

Do laws of nature *explain* observed phenomena?

3. Do Newton's laws explain why the moon (or the bullet) has its specific (observed) trajectory?
Yes [True] / No [False]

22/43 (A) True

18/43 (B) False

Do laws of nature *explain* observed phenomena?

4. Does a scientific explanation (e.g. the law of nature) **explain** because it **describes the cause** of the observed phenomenon?
Yes [True] / No [False]

12/43 (A) True

28/43 (B) False

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Do laws of nature *explain* observed phenomena?

5. Do you consider your own idea about laws of nature closer to Realism or anti-Realism? A realist (according to Van Fraassen) believes that theories are literal, true stories or picture of how ‘the world behind the phenomena' is => what would the law describe according to the realist? Conversely, if you are more inclined towards an anti-realist position => what would the law [e.g. PV(at constant T) is a constant] describe according to the anti-realist?

What do we determine in experimental research (e.g., such as in Boyle's or Hooke's experiment)? What does the equation (such as Boyle's law PV = k(T); Hooke's law F=-k.x; Ohm's law V=I.R) describe?

Question 1:

Is Boyle’s / Hooke’s / Ohm’s law – which is derived by means of inductive reasoning – an explanation

(of, e.g., why the pressure goes up when the volume is decreased)?

Yes: 24

No: 12

Question 2:

Does Euclid’s geometry (Euclids axioms) explain why the door (with W=D) does not fit in the cabinet.

[Or, Does model derived from Euclid’s geometry explain why the door (with W=D) does not fit in the

cabinet.]

Yes: 37

No: 4

Question 3:

Do Newton's laws explain why the moon (or the bullit) has its specific (observed) trajectory?

Yes: 22

No: 18

Question 4:

Does a scientific explanation (e.g. the law of nature) explain because it describes the *cause* of the

observed phenomenon?

Yes: 12

No: 28

See PDF in BB for answers to Q 5.

Do laws of nature *explain* observed phenomena?

5. Do you consider your own idea about laws of nature closer to Realism or anti-Realism? A short selection of answers:

- I’m closer to realism. If I’m not it is not useful to study engineering that is based on theories.
- Realist, most of the current scientific knowledge cannot be explained by just 'observable' phenomena.
- Keep it real.
- Realist; laws describe the unobservable world to a degree of precision. An infinite amount of laws would be needed if it is described 100% precise.
- Realism: I think that physics can be described by formulas which cannot be observed. Gravity is an unobsevable thing and I believe in this kind of thing.

Do laws of nature *explain* observed phenomena?

Laws of Nature are derived from inductive reasoning & introducing new scientific concepts.

- **Realism**: e.g. *laws of nature* are literal, true descriptions of 'the world behind the phenomena,' explaining it.
- **Anti-realism**: e.g. *laws of nature* describe observable regularities produced at specific (type of) physico-technological conditions (e.g., P, V of gas in closed vessel).
- Or, a *law of nature* is an operational definition that relates mutually dependent measurable variables (e.g. V, I, R).

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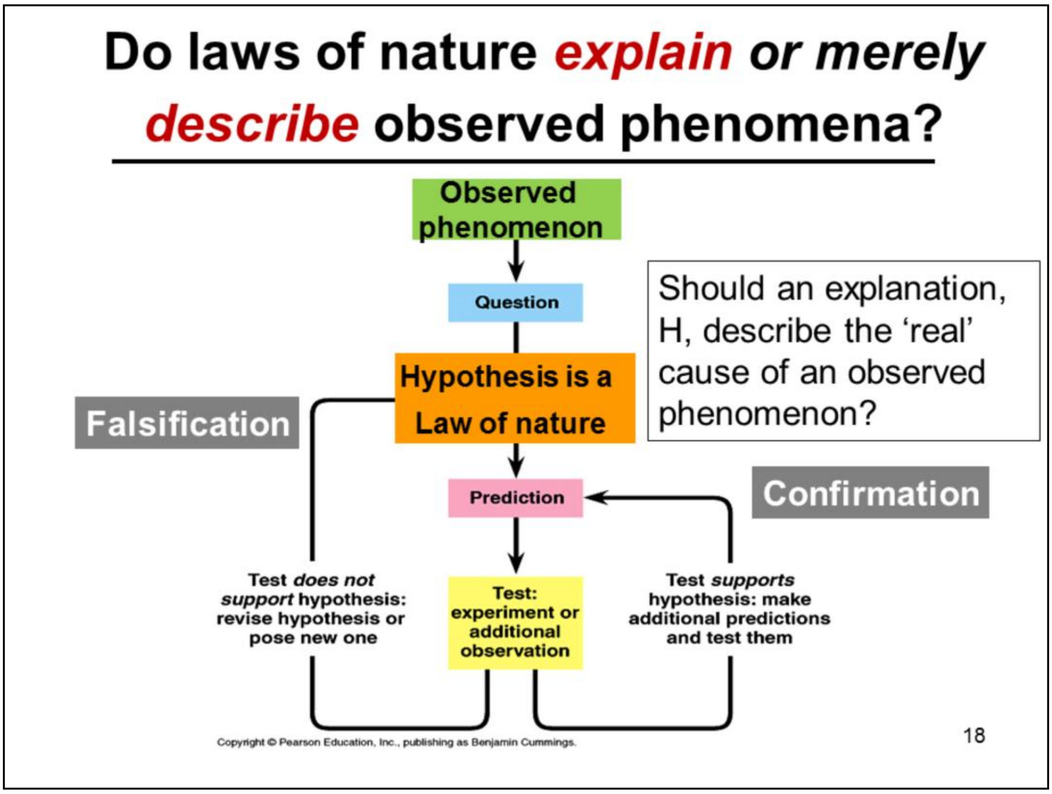
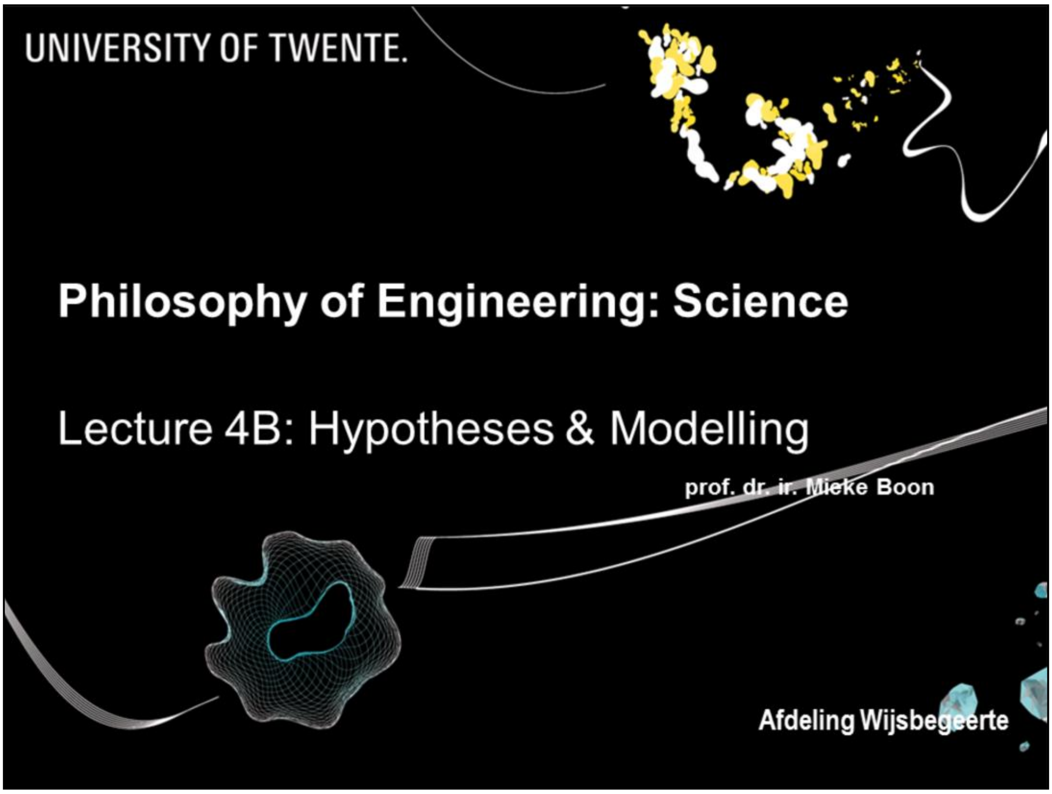
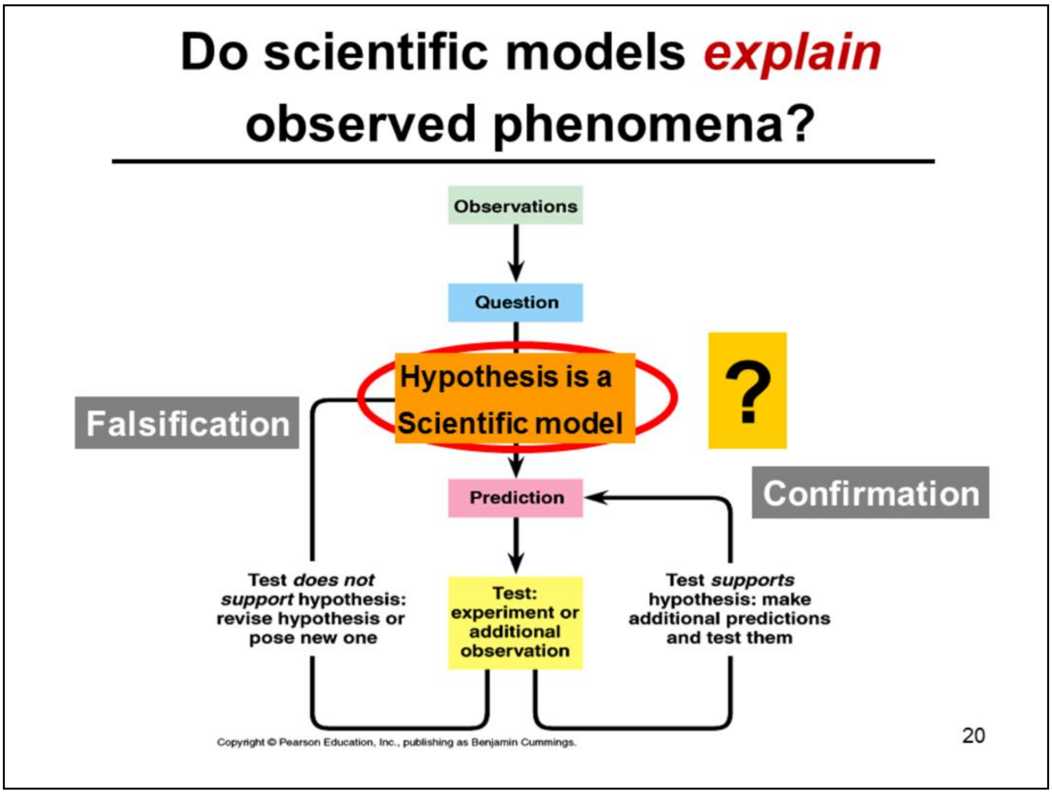


The realism / anti-realism enters when we consider what an explanation is:

Is the hypothesis, when the hypothesis is meant to be an explanation (answer to a why question), a <u>description</u> of an unobservable phenomenon (e.g. a process) that can be held responsible for (i.e., that *causes*) the observed phenomena? This is close to a realist position about scientific knowledge.


UNIVERSITY OF TWENTE.
Philosophy of Engineering: Science
Lecture 4B: Hypotheses & Modelling
prof. dr. ir. Mieke Boon
Afdeling Wijsbegeerte



How do scientists get from an the observation + question to an explanation (= a hypothesis)? For instance, how do they get from the observation of absorption / emission spectra of Hydrogen gas, and the question "What is the cause or mechanism 'behind' these phenomena" to an explanation of the observed phenomena (emission and adsorption spectra).

The hypothesis cannot be deduced from the observations, for instance by means of inductive reasoning.

The point of this lecture is that it is often suggested (e.g., in high-school teaching) that the explanation (e.g., Bohr's model of the Hydrogen atom) was 'somehow' *discovered*, as if the atom was 'directly observed'. In this lecture, an alternative philosophical 'account' of successful explanations is proposed: the scientific model (or hypothesis) is *constructed* such that it explains (or 'accounts for') the observed phenomena.

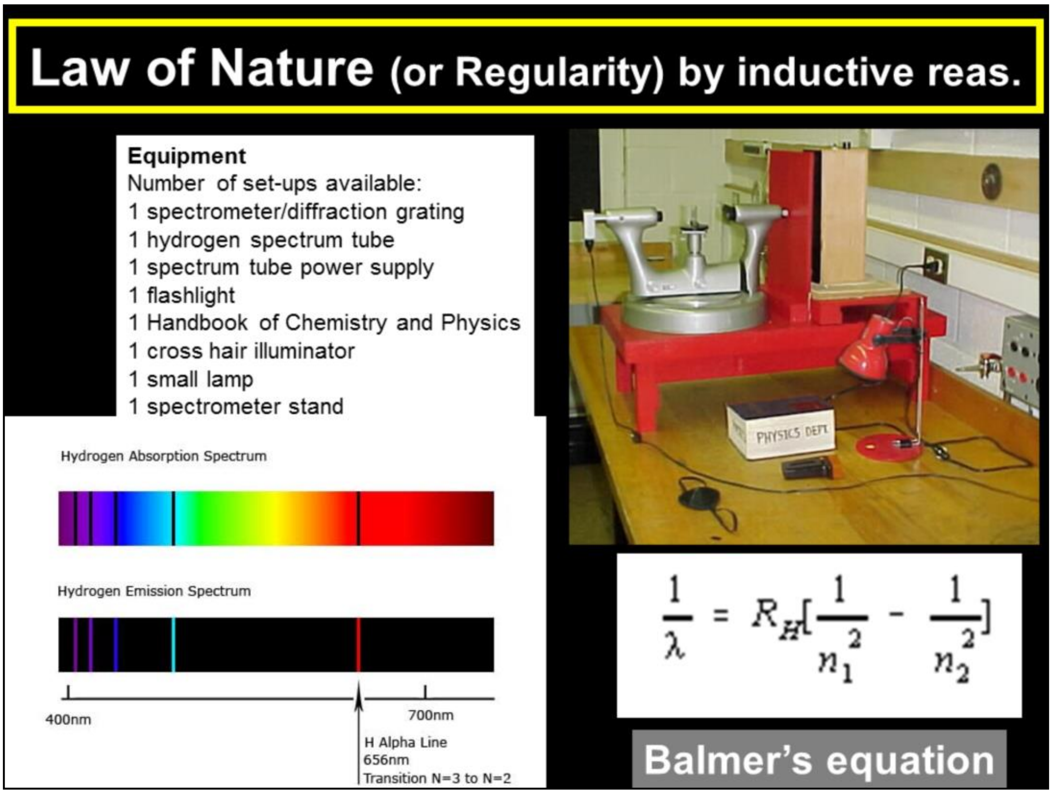
The methodology for testing remains the same: the hypothesis is put to test by deducing observable events from it, which are tested in experiments, which leads to either confirmation or falsification of the hypothesis.

Note: in this course, the words 'hypothesis', 'explanation', 'model', 'mechanism' (and 'theory') are often used interchangeably.

The model (e.g. Bohr's model of the atom) is an explanation of the observed phenomena.

The model (e.g. Bohr's model of the atom) represents the structure of the real Hydrogen atom. Or, in naïve realist language: The model (e.g. Bohr's model of the atom) literally describes (or pictures) the structure of the real Hydrogen atom.

The model (e.g. Bohr's model of the atom) is a hypothesis that must be put to test.

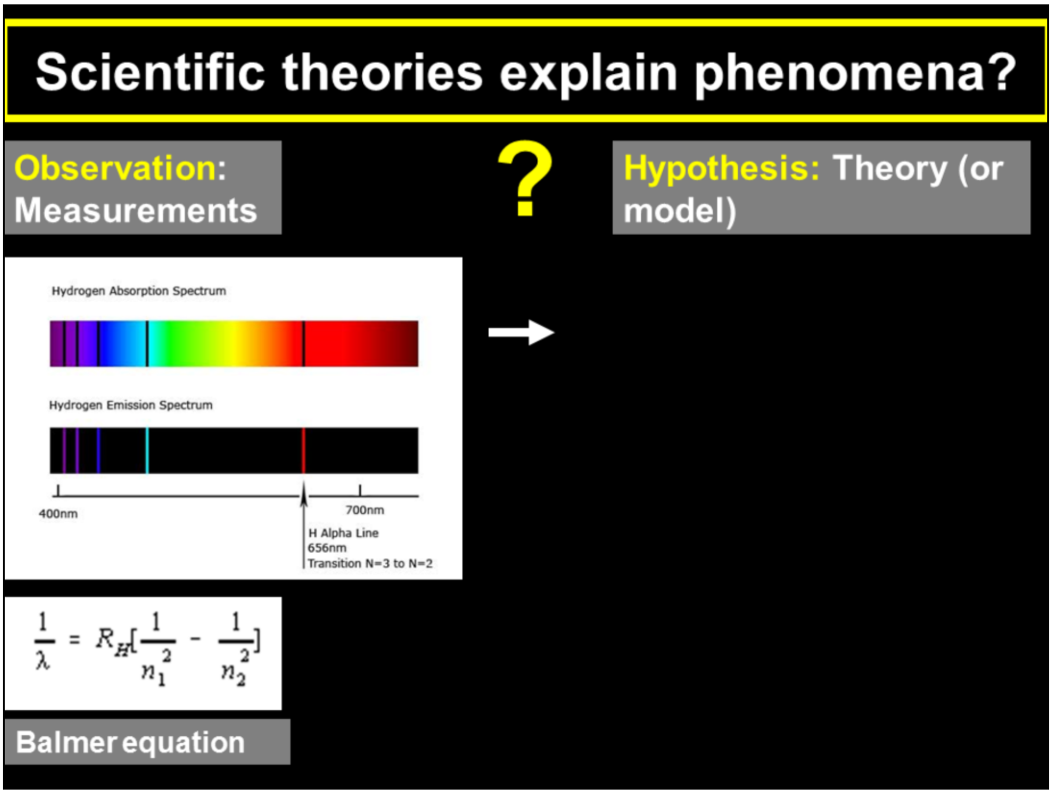


Assume for instance the phenomenon observed in this experimental set-up, namely the Absorption or Emission spectrum of hydrogen gas. The Balmer equation mathematically ‘describes’ the observed phenomenon, but we usually do not assume that this equation <u>explains</u> the observed phenomena.

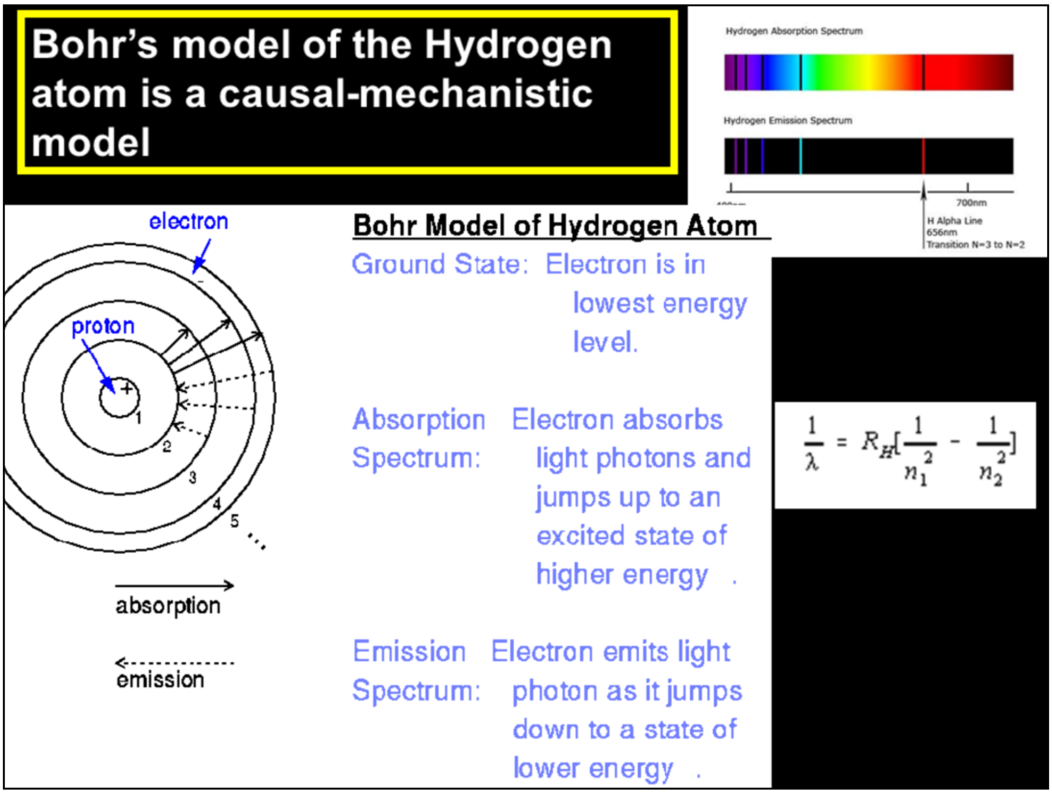
In this experimental device, the absorption or emission spectrum of a gas, such as hydrogen gas, is measured. In this measurement several absorbtion, respectively, emission lines are measured (meaning that a very specific wavelength in the light-spectrum is being absorbed or produced). The axis is the wave-length in nanometers, from which the wave-length of absorption / emission lines can be determined (note that emission and adsorption wave-length are the same, from which scientists will conclude that some kind of reversible process is responsible for the observed phenomenon). A scientist, such as Balmer, aims at a mathematical description of these lines (which is an example of inductive reasoning). This equation describes the wavelength of emission or absorption lines, and it is assumed that this process is reproducible, so it will also predict future outcomes of the same kind of experiments.

This is the Balmer equation. Similar to Hooke, who used different kinds of springs in his measurement (finding that Hooke’s law applied with varying values of the elasticity coefficient), Balmer used different kinds of gasses and found that this equation applied, with varying values of R, which is gas-specific.

In sum, this equation is not considered as an explanation of why hydrogen absorbs or emits light at specific wave-length. Scientists will aim at a ‘deeper’ explanation.



Scientists will aim at a ‘deeper’ explanation, and ask: Why does hydrogen emit / absorb light at specific wave-length?



Bohr's model of the hydrogen atom is supposed to <u>explain</u> the observed (measured) phenomenon.

The explanation of the observed phenomenon (Bohr's model of the atom) tells that electron jump between levels, emitting (when jumping from high to low) or absorbing (when jumping from low to higher energy levels) photons (= light particles, which have a specific wavelength).

But the question is now: what does this model represents?

Do scientific models *explain* observed phenomena?

Scientific models are not derived through mere inductive reasoning, but rather explanatory reasoning (IBE = Inference to Best Explanation).

Realism: e.g. models are literal, true descriptions of 'the world behind the phenomena,' explaining phenomena => models are true: the model corresponds with real world..

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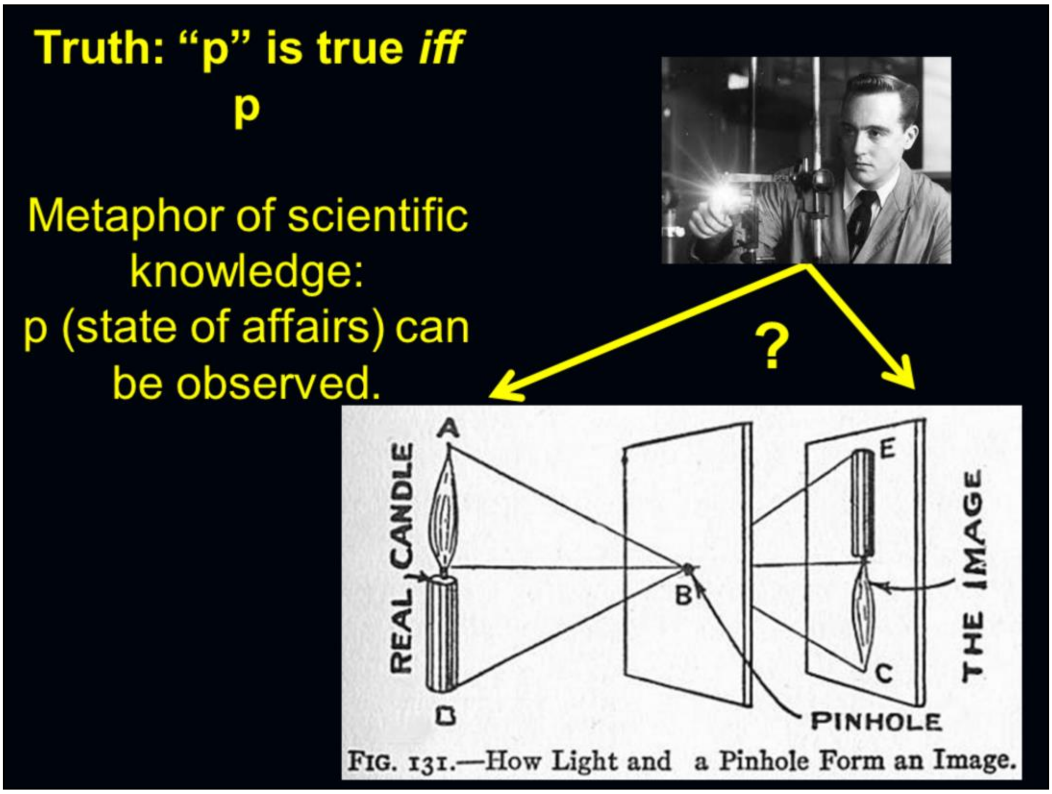
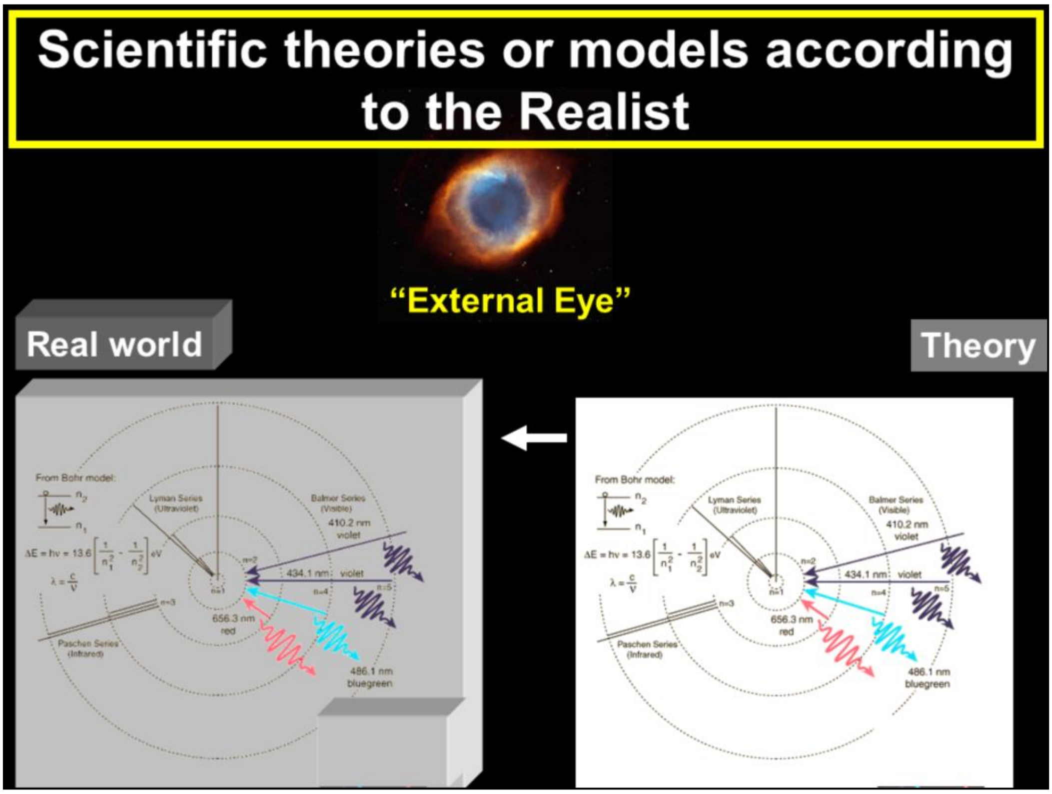


Recall: So-called 'scientific realism' adopts the 'mirror image' of knowledge.

This idea can be explained by the following metaphor: Determining whether a claim or a picture or representation is true requires that the claim or the picture or representation can be compared (by means of observation or 'direct perception) with the real object it is a representation off.

In this metaphor, the external observer position is possible: the scientist can compare in an unproblematic manner the real, material candle with the image at the back of the Camera Obscura, and decide that the image corresponds (or, 'is sufficiently similar') to the real object.

Is this metaphor ('the mirror image of knowledge') adequate for scientific knowledge?



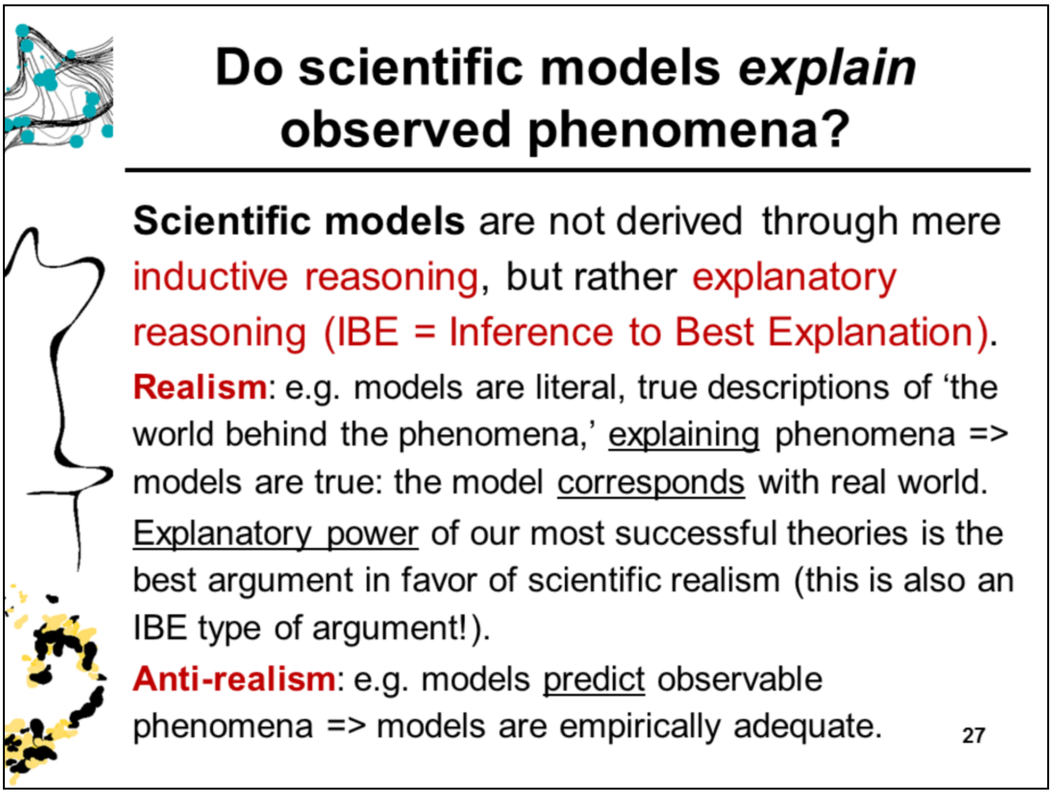
If we use this metaphor to analyze what many people have in mind when it comes to scientific knowledge, the model (or theory) would be a literal description or picture of a real (but unobservable) object and/or process. On this philosophical view, the scientific model or theory is a kind of photograph; it corresponds to an ‘unobservable phenomenon’ that exists in the world. This is the position of a scientific realist.

One philosophical problem of this idea is that it is impossible for scientists to compare in an unproblematic manner the supposed real, material object or process with the scientific model. A comparison similar to how the scientist compares the real, material candle with the image at the back of the Camera Obscura is not possible in principle.

Clearly, this is not to say that the world is *not* as the theory tells! The critical philosophical point made here is that *we cannot know whether this is the case*.

Scientific realists invoke the so-called ‘Miracle argument’ to underpin their believe that the model is approximately true: They admit that the truth of scientific theories cannot be proven. However, scientific theories are the best explanation for the occurrence of the phenomena, and the successes of at least some theories would be unintelligible, unless we assume that they are approximately true! ... says the scientific realist

Anti-realists such as Van Fraassen argue that there may be other possible explanations for the ‘empirical adequacy’ and ‘explanatory power’ of these theories.



Realism: scientific model describes or depicts 'world behind the observable phenomena' + explanatory power of the model can only be understood if we assume literal truth / correspondence between model and world.

This position, although not fully coherent, seems to be intuitively attractive and plausible.

Anti-realists reject it for several reasons. One of those reasons is that it does not have a plausible reply too 'have-baked' anti-realists, science critics and science-haters, who, based on a very superficial understanding of science can claim that "science has often been proven wrong, so we should not trust it." This kind of critique can be found in society. On the one hand, there are good reasons to be critical and cautious with scientific claims; on the other hand, it is the best we seem to have for the production of knowledge that is used for all kinds of societally relevant purposes (e.g., detecting and solving problems; developing technologies; ..)

Therefore, we are in need of a more refined understanding of the possibilities and the limits of science. This is what some 'anti-realist' philosophers of science aim at.

So, the question that will be addressed in the remainder of this lecture is, whether philosophers can present us with a plausible anti-realist ‘picture of science.’

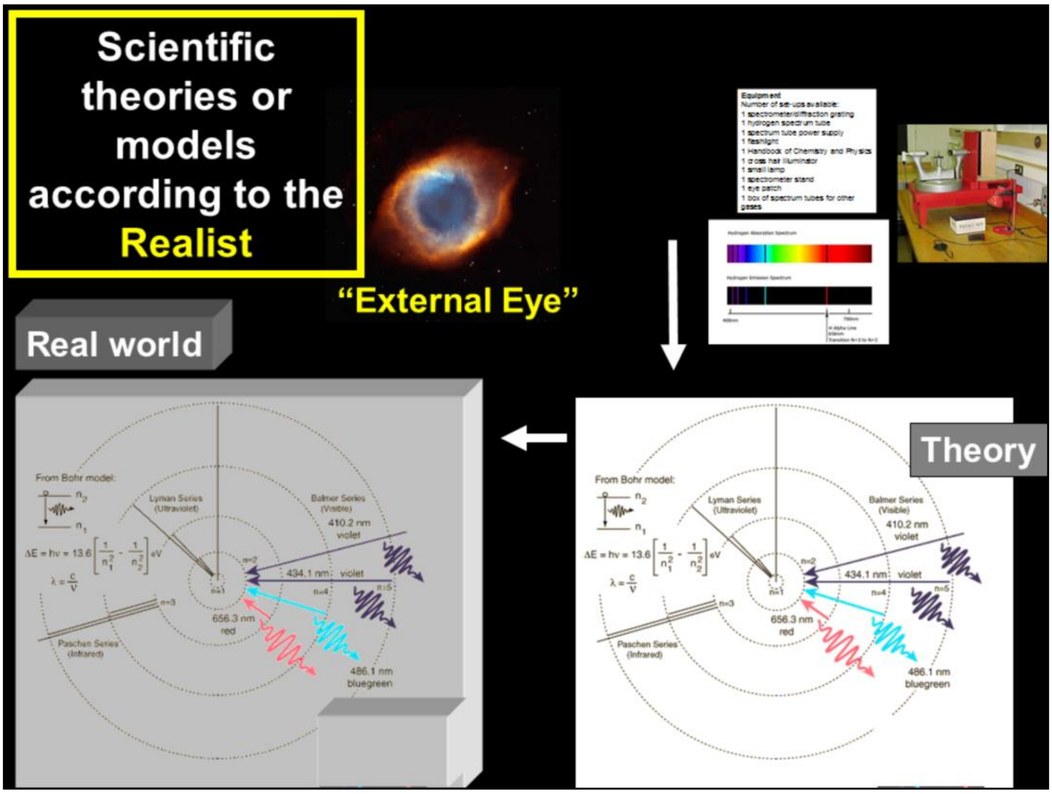
How do we construct and test a scientific model that explains the observed phenomenon?

A naive picture of scientific discoveries.

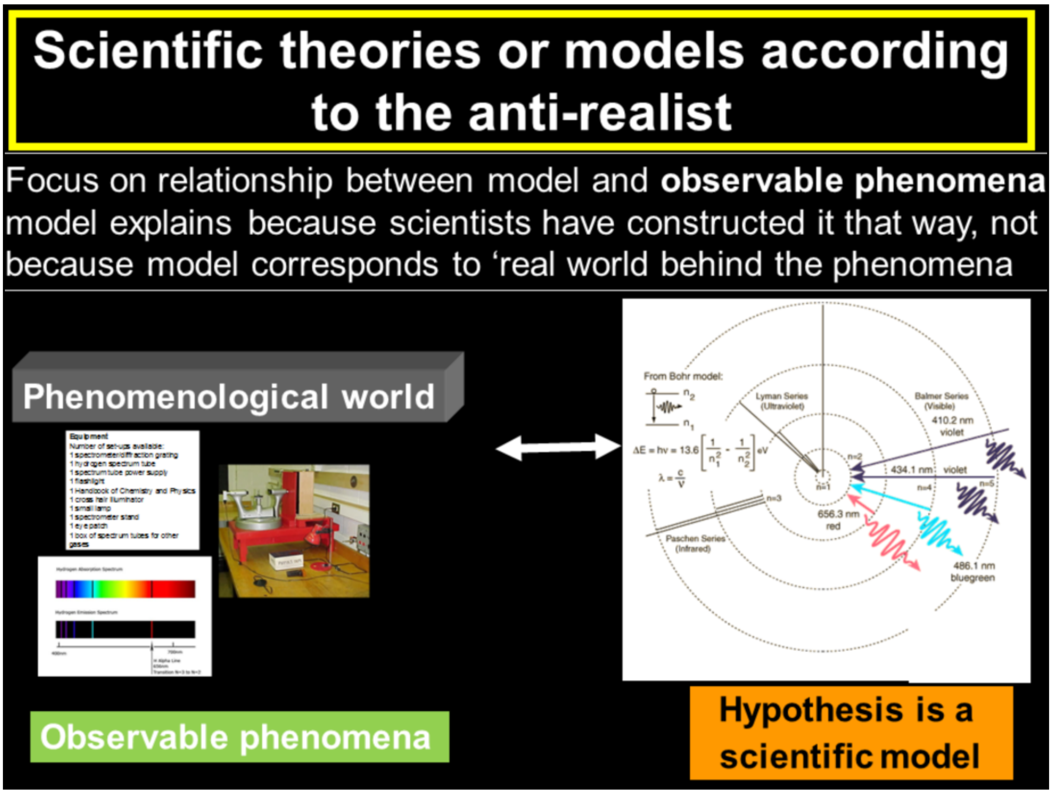
Dutch quote says: Searching the Higgs-Boson.

Scientific language often is suggestive, as if they discover particles in the sense of actually having observed it.

Another cherished explanation is that great scientists do their discoveries in ‘blind flashes of inspiration’, and sometimes happen to be correct (say, as in ‘clair-voyance’).



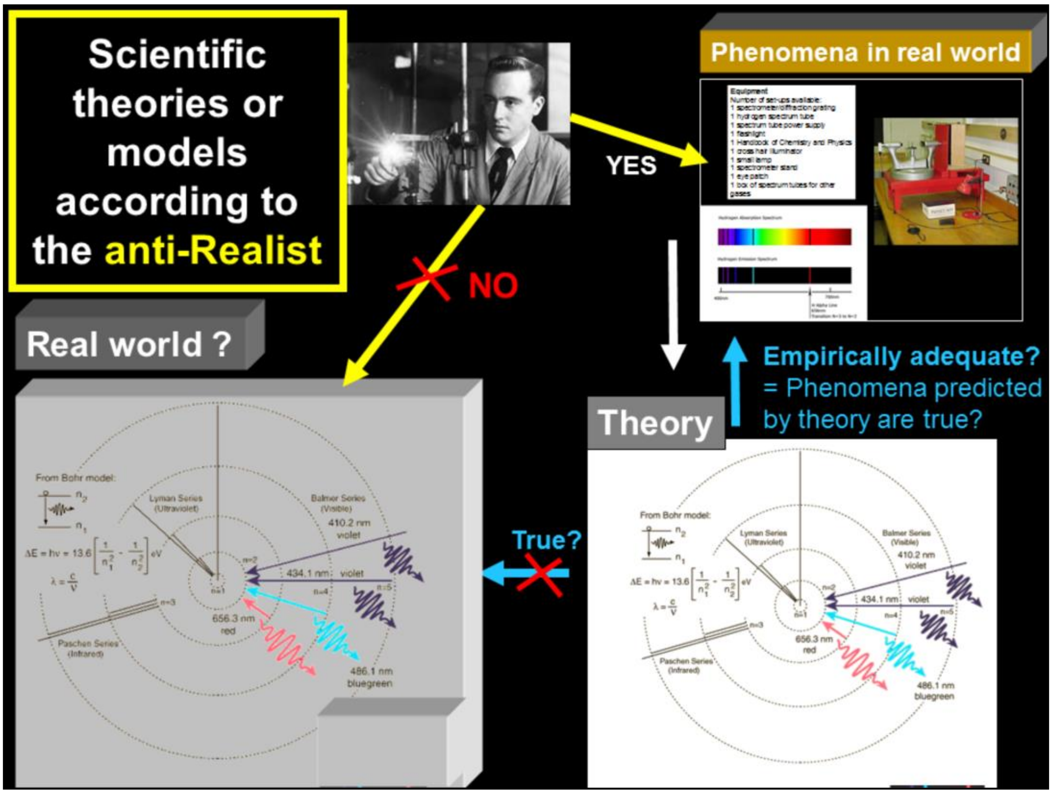
Scientific theories or models according to the realist: models or theories that explain observed phenomena supposedly present a literally true story about the real world. Hence, models tell 'what the real world is like', which is why we can trust these models.



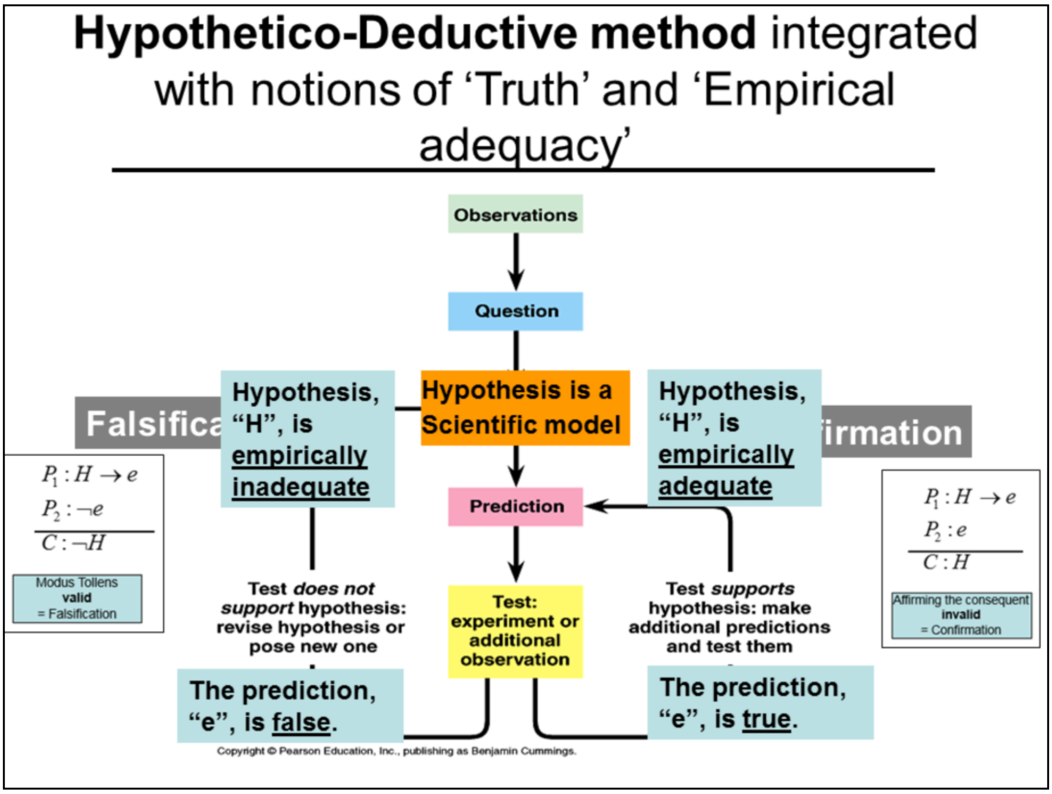
Recall: *Empirical adequacy* of Bohr's model, means that the <u>predictions</u> made by this theory are *true*. So, the model correctly predicts the absorbtion and emission spectra produced in spectrometry.

The <u>alternative explanation</u> (of the empirical adequacy and explanatory power of successful scientific theories) proposed in anti-realism (also called 'epistemological constructivism' – Boon 2015), is that scientists <u>construct</u> theories such that they are explanatory, and empirically adequate for certain epistemic uses. Crucial to this alternative is that the 'link' (i.e., the semantic relationship) between theory and world is not firstly between the theory and the real (unobservable) object or process, but between the theory (or model) and the observable phenomena that are usually produced through instruments and measurements in an experimental set-up (see horizontal white arrow, and not the 'unobservable' real world has been removed from the scene.

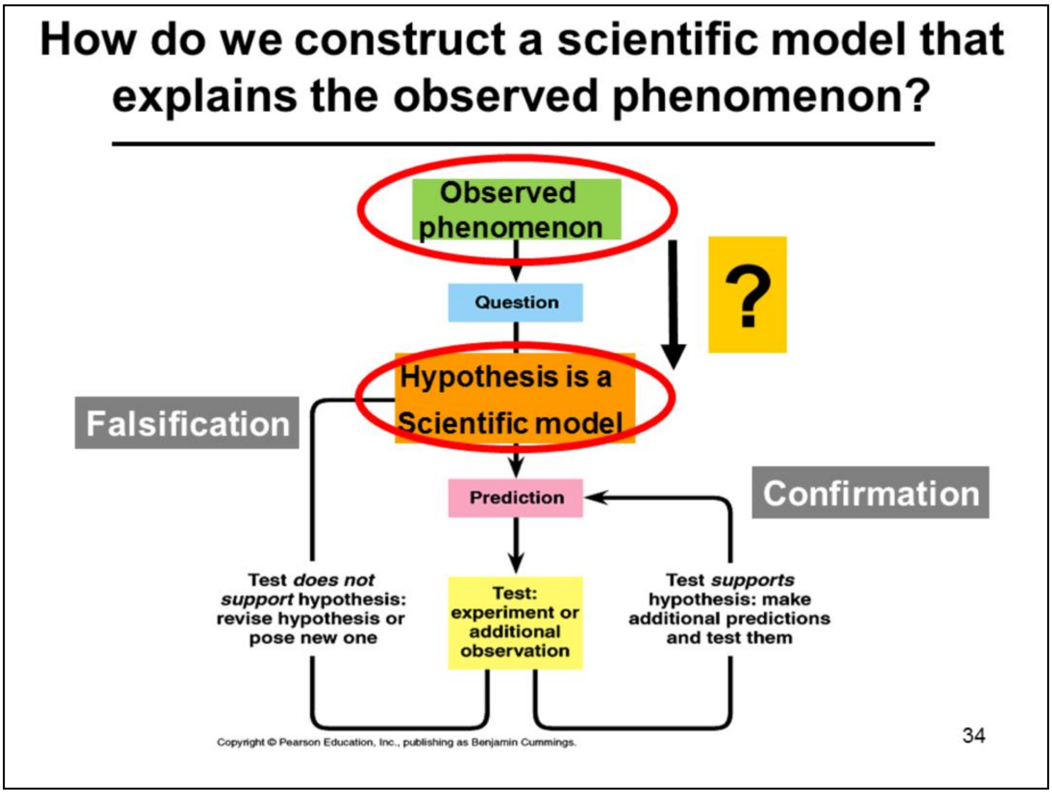
This idea may be more plausible than it seems at first. Try to imagine, for instance, how scientists 'manipulate atoms.' Scientific models (pictures of molecules) often suggest that there is a direct manipulation with, in this case, the atom. However, on a closer look, we all know that these manipulations (or, technological interventions) often are by means of the very same kinds of instruments that lead to the discovery of that theory (model of the atom).



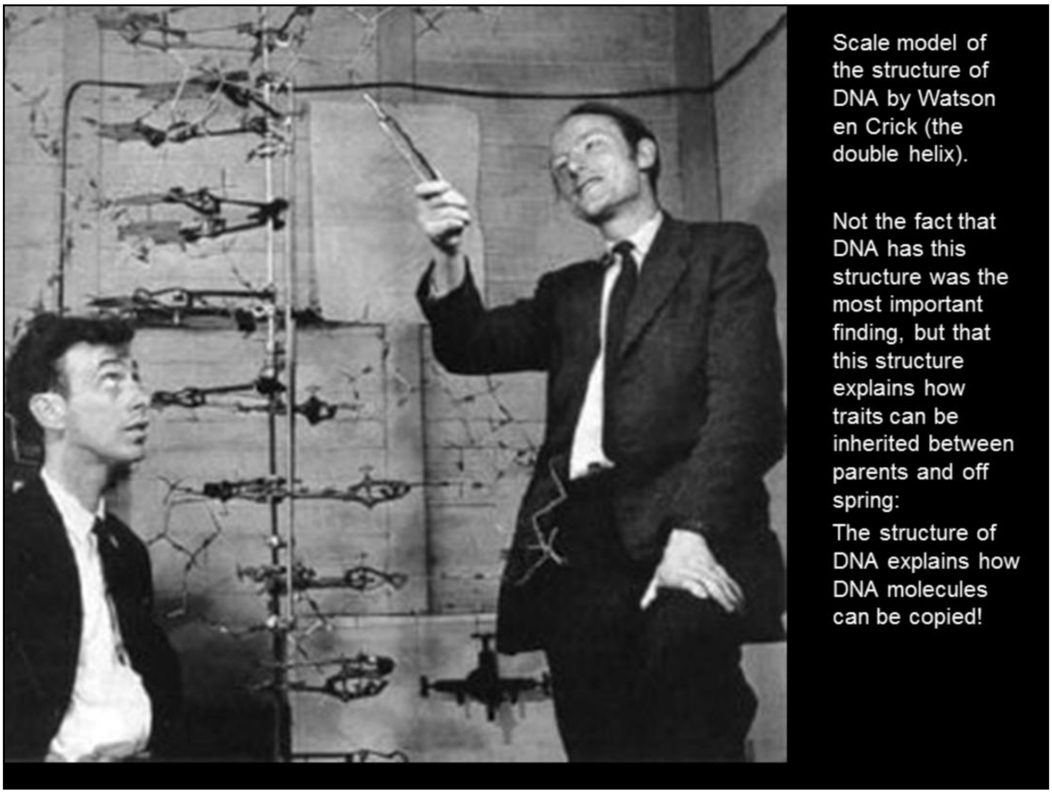
Empirical adequacy of Bohr's model means that only the predictions made by this theory are true. So, the model correctly predicts the absorbtion and emission spectra produced in spectrometry. This does not imply that the model itself is necessarily true. True predictions do not proof the truth of the model (recall how this was explained by means of the logical analysis of the HD method).



The logical structure of testing a scientific model according to the anti-Realist.

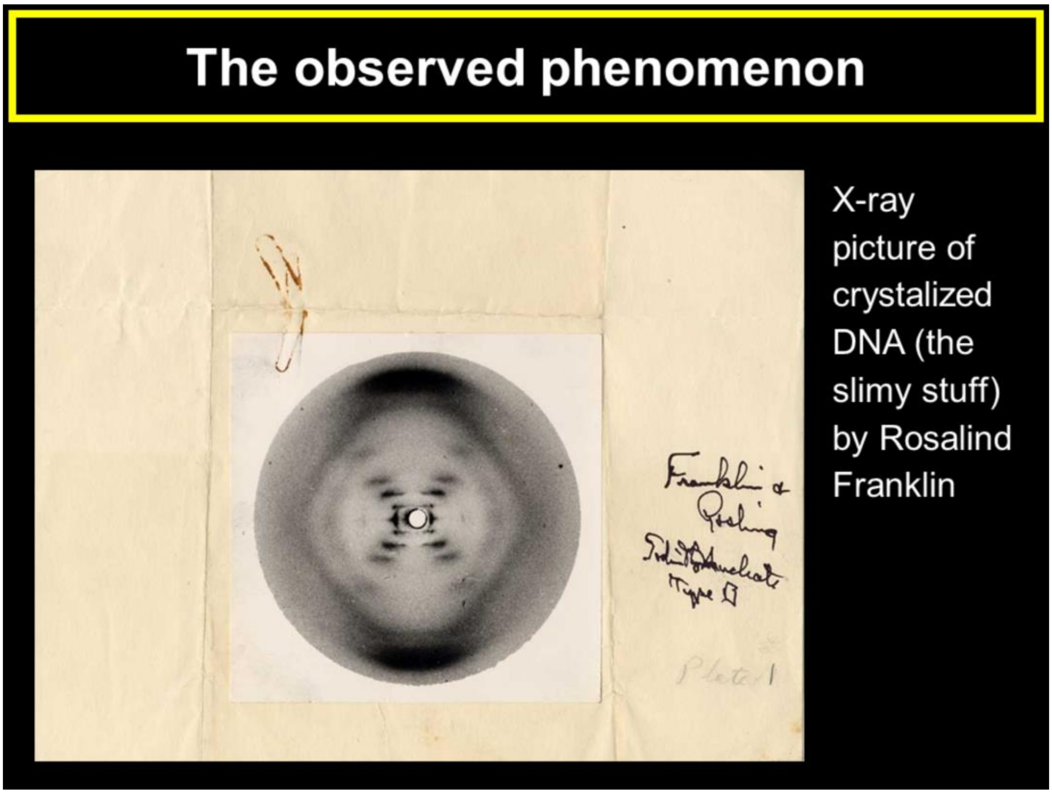


How do we get from observed phenomena to a hypothesis that answers the why question. As was said, in case of models, this is not by means of mere inductive reasoning.



Another example of a scientific discovery:

The way in which this scientific model was constructed can be analysed by means of the B&K theory that will be proposed below.



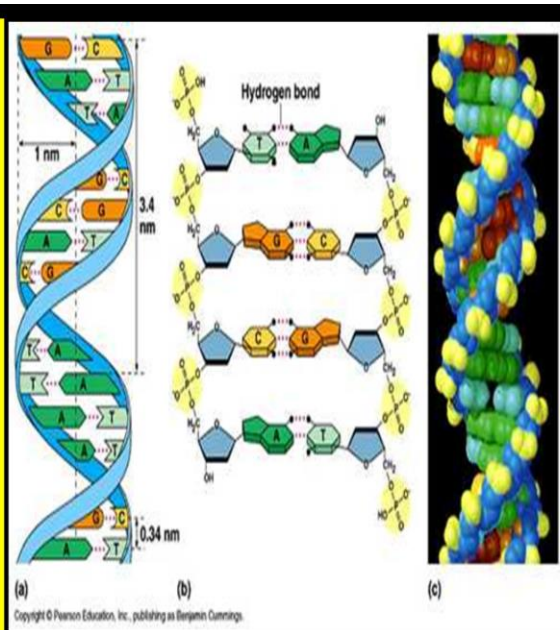
This X-ray picture of crystalized DNA (the slimy stuff) played a crucial role in the discovery of the structure of DNA held responsible for inheritance of traits.

Following the diagram:

- Observed phenomenon: Inheritance of traits between parents and off-spring
- How is ‘information’ transferred from parents to children.
- Observations in scientific research: A nucleic acids in cells, called DNA, of which the function is not understood; X-ray pictures of DNA.
- Hypothesis: Maybe DNA is the carrier of inheritance, but if so, why / how?

Double helix structure of DNA (a causal-mechanistic model) for how information can be transferred from parents to off spring.

Note that scientifici models often are ‘suggestive’ as if this is what has been observed (e.g. through a microscope). When reading scientific articles, be aware of whether a picture presents an observation (photograph), a measurement, a calculation, a computer simulation, etc..



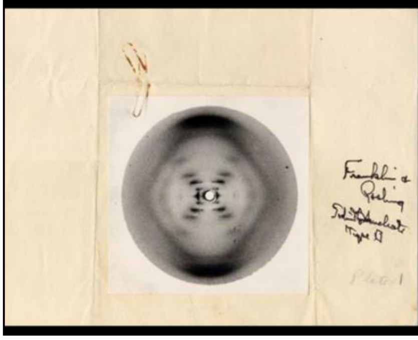
Explaining these phenomena?

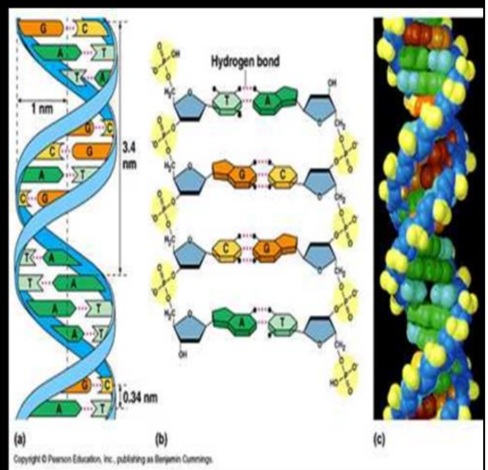
Observation: Measurements

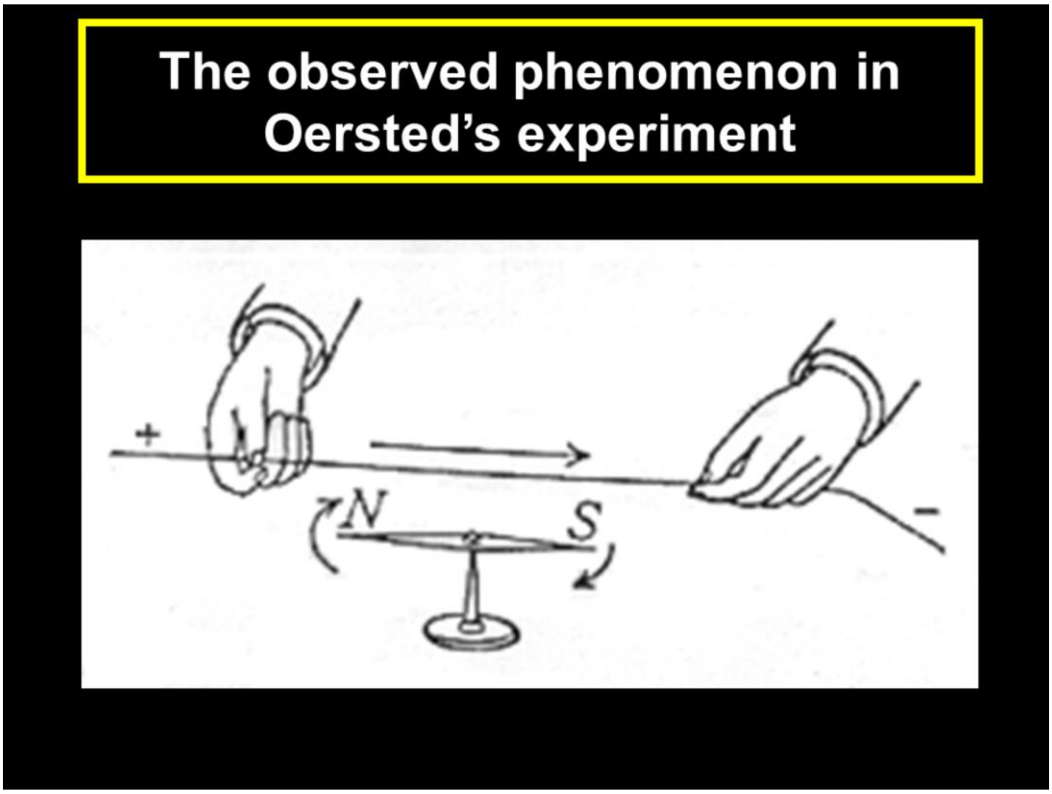
?

Hypothesis: Theory (or model)

Phenomenon: the inheritance of traits + X ray →

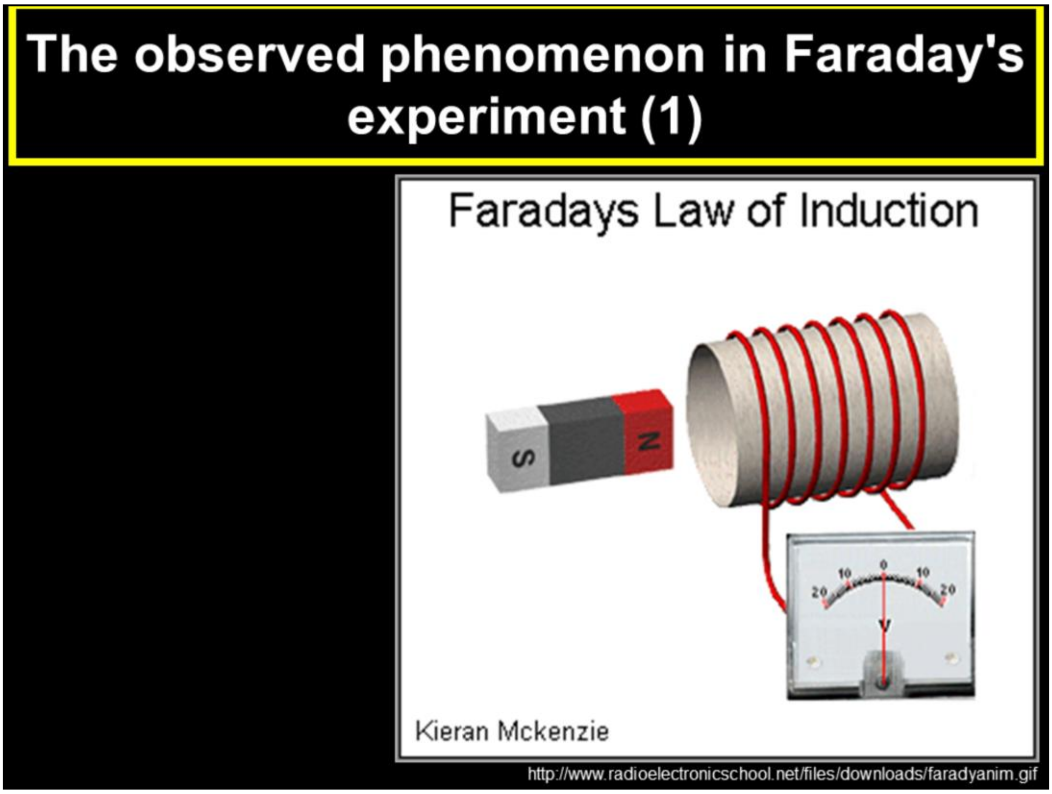






These few slides illustrate the observed phenomena for which Maxwell's EM theory was constructed. Initially, Maxwell and other physicists in the 19th century aimed to explain the observed phenomena in a mechanical (causal-mechanical) manner.

[Hans Christian **Ørsted** (* 14 augustus 1777, Rudkøbing, † 9 maart 1851)]



Faraday’s law of induction

Michael Faraday (AD 1791-1867),

Moving a conductor (such as a metal wire) through a magnetic field produces a voltage. The resulting voltage is directly proportional to the speed of movement

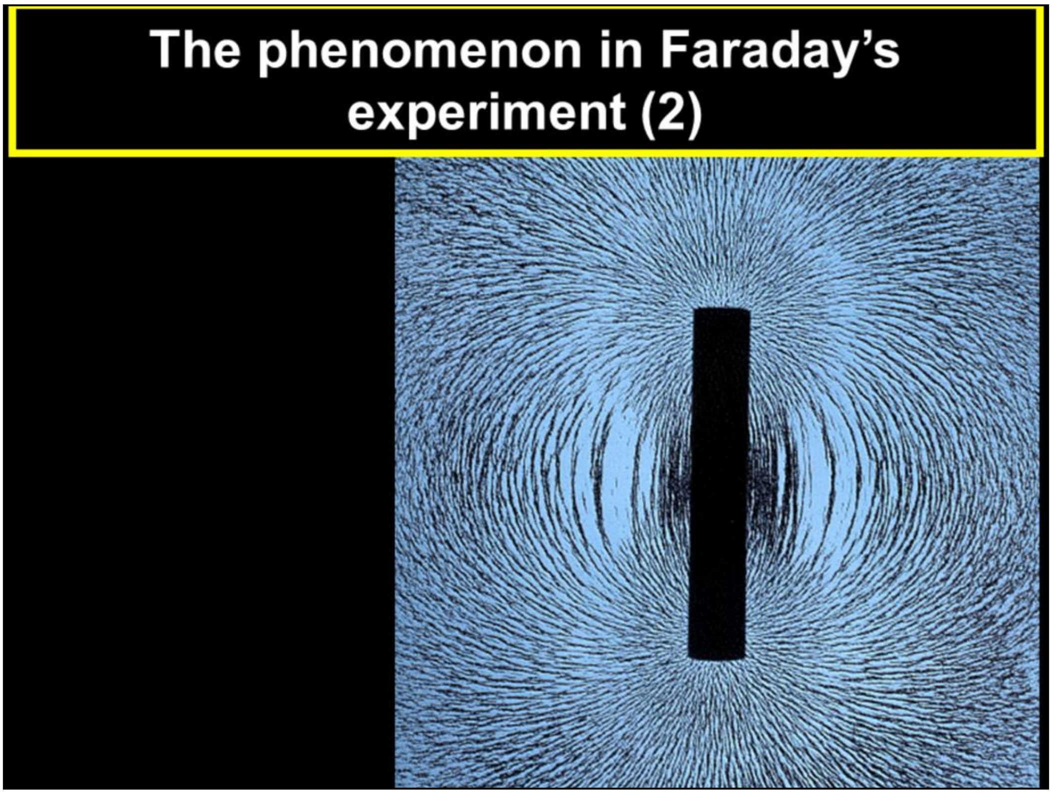
Faraday's law of induction (more generally, the **law of electromagnetic induction**) states that the induced emf (electromotive force) in a closed loop equals the negative of the time rate of change of magnetic flux through the loop.

Integration

Observed behaviour is described by means of phenomenological laws

Moving a conductor (such as a metal wire) through a magnetic field produces a voltage. The resulting voltage is directly proportional to the speed of movement

The relation between the rate of change of the magnetic flux through the surface *S* enclosed by a contour *C* and the electric field along the contour where **E** is the electric field, d**l** is an infinitesimal element of the contour *C* and **B** is the magnetic field. The directions of the contour *C* and of dA are assumed to be related by the right-hand rule.



Circa 1830. This picture is Faraday's depiction of the arrangement of iron filings in the vicinity of magnetic poles.

[Source of text below: The intelligibility of Nature by Peter Dear, Chapter 5.]

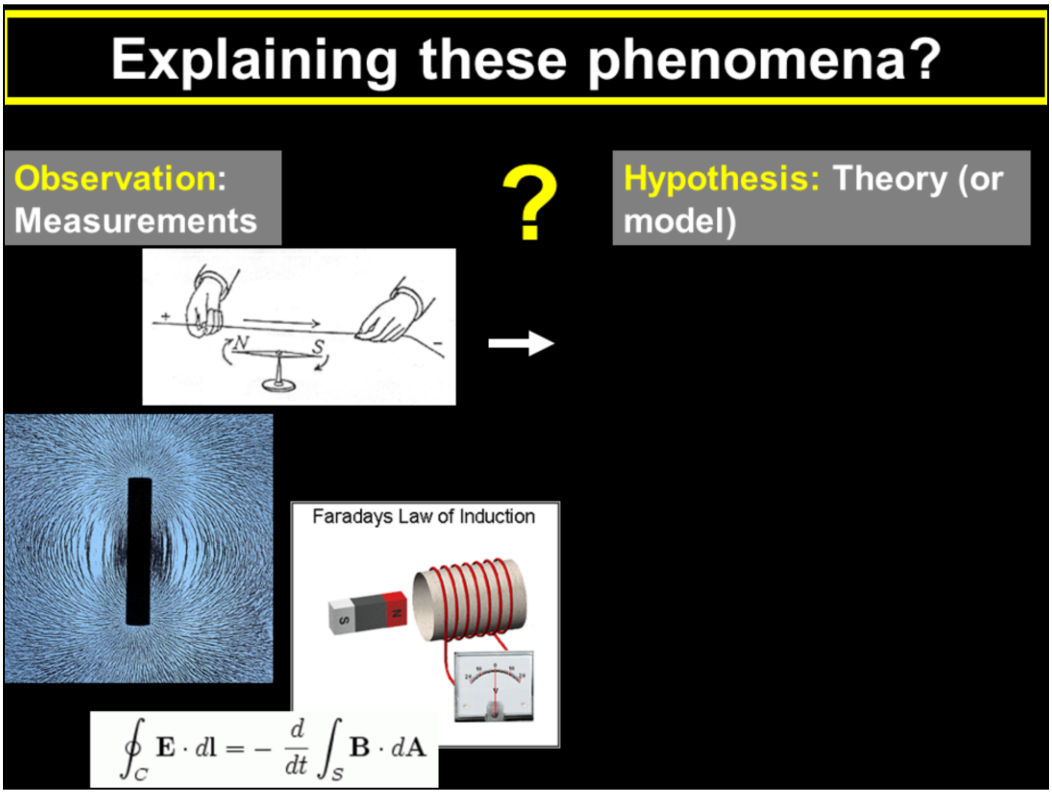
Michael Faraday (1791-1867) introduced the notion of magnetic fields on the basis of these observations.

Faraday performed work on electricity and magnetism. Between 1820 and 1850 he developed the idea of 'lines of force' as a way to make sense of magnetic and electrical forces in the space around magnets and current carrying wires. [Note that J.J. Thomson's discovery of the electron was only 50 years or so later, in 1897].

In the 1830th, Faraday had used this idea to conceptualize the three-dimensional reality of electrical and magnetic behaviors, but at that time he made no claim that the 'lines' were literally present in space: they were simply a helpful way of thinking about experimental setups. In the 1840s and '50s, however, Faraday became convinced that these lines were real things, not just fictions. So, according to Faraday, the disposition of the iron filings to arrange themselves in the vicinity of magnetic poles 'shows' the existence of independently existing magnetic 'lines of force', to which the filings orient themselves.

But, what *are* ‘lines of force’? William Thomson defended that making sense of electromagnetic phenomena should involve a mechanical model. Het believed that “every phenomenon in nature is a manifestation of *force*.”

Physicists in the 19th century, such as Thomson (Lord Kelvin) and Maxwell assume the existence of a medium, the aether (also spelled *ether*), which is a space-filling substance, thought to be necessary as a transmission medium for the propagation of electromagnetic or gravitational forces. The medium is often conceived of as a fluid. In the slide below, it is explained how properties of smoke where used as a metaphor for understanding aether as a fluid.



In class 7 & 8, this will be used as an example:

Is there a physical explanation for these phenomena? i.e., an explanation in terms of more fundamental physical features of reality?

Crucial to the physical explanation is that the transmission of forces or waves requires a medium. Phycisists in the 19th century (e.g., Helmholz, Thomson, Maxwell) supposed this medium was aether. On the one hand, these phenomena pointed at the existence of aether; on the other hand, the existence of aether was presupposed for explaining the forces of electricity and magnetism.

Physicists aimed to devise models of aether that could account for the forces of electricity and magnetism.

Eventually, no such 'causal-mechanistic' explanation was found. Instead, Maxwell came up with an axiomatic theory, which allows for the construction of models for EM systems.

NOTE: So far, we did not talk about cases where mathematical models for describing the observable behaviour (= observable phenomena) are derived from (= constructed by means of) scientific theories such as Newton’s or Maxwell’s theories. Also, in the slides below, we will not talk about models that are in a more or less straightforward manner derived from such theories (and as illustrated in our physics textbooks).

Problem (of realism versus anti-realism) solved for these (axiomatic) theories and the mathematical models derived from them? No! We may still ask what these (axiomatic) theories actually describe? For further thinking, recall the example about the model derived from Euclid’s axioms. Is the situation with Newton’s and Maxwell’s axiomatic system analogous or different?

Maxwell's Fundamental Laws for EM

Name	Differential form	Integral form
Gauss's law:	$\nabla \cdot \mathbf{D} = \rho$	$\oint_S \mathbf{D} \cdot \mathrm{d}\mathbf{A} = q = \int_V \rho \mathrm{d}V$
Gauss' law for magnetism (absence of magnetic monopoles):	$\nabla \cdot \mathbf{B} = 0$	$\oint_S \mathbf{B} \cdot \mathrm{d}\mathbf{A} = 0$
Faraday's law of induction:	$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$	$\oint_C \mathbf{E} \cdot \mathrm{d}\mathbf{l} = -\int_S \frac{\partial \mathbf{B}}{\partial t} \cdot \mathrm{d}\mathbf{A}$
Ampère's Circuital Law (with Maxwell's extension):	$\nabla \times \mathbf{H} = \mathbf{J} + \frac{\partial \mathbf{D}}{\partial t}$	$\oint_C \mathbf{H} \cdot \mathrm{d}\mathbf{l} = \int_S \mathbf{J} \cdot \mathrm{d}\mathbf{A} + \int_S \frac{\partial \mathbf{D}}{\partial t} \cdot \mathrm{d}\mathbf{A}$

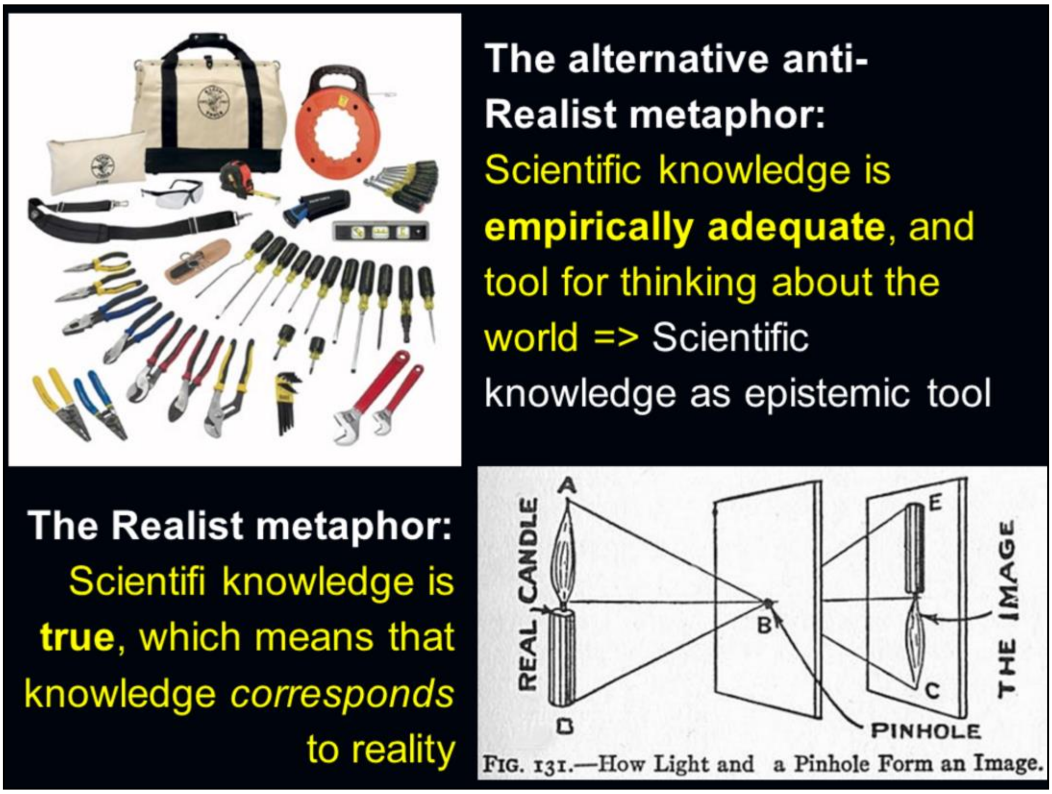
Maxwell's EM theory by means of which mathematical models of EM systems can be constructed.

The notion of explanation is problematic here. It depends on what you mean by explanation. There are several possibilities:

1) An explanation must describe (or 'represent') the physical causes or the physical mechanism 'behind' the observed phenomenon.

2) The (mathematical) structure explains the observed phenomenon (as in the example of the apprentice cabinet maker).

Instead of claiming that Maxwell's laws explain EM phenomena, you could also say that Maxwell's laws are tools for constructing empirically adequate models for EM systems. Below it will be proposed that models and theories can be understood as 'tools for thinking' (in the philosophers language: 'epistemological tools'). Instead of firstly being related to 'the world behind the observable phenomena' (which would mean that the model is a description or literal representation of the world behind the observable phenomena), it is propose that models and theories are firstly related to the observable phenomena: they are empirically adequate in regard of the observable phenomena.



The question addressed in this lecture is, whether philosophers can present us with a plausible anti-realist 'picture of science.'

One approach to the development of this alternative is to abandon the so-called representational view of scientific knowledge. On this 'traditional' view, scientific knowledge is a description or picture of 'the world behind the phenomena'. As a metaphor, knowledge (which is in the domain of language) mirrors the real world, similar to how a real object is mirrored on the back of a Camera Obsura. On this view, the objectivity is warranted because it does not involve any human (subjective) contribution. The picture is passively (physically) produced.

However, from the analysis of examples above, we now know that the formation of scientific models involves human epistemic activities such as imagination, mathematization and categorization, which are not guided by logic alone.

The alternative (anti-realist) philosophical view proposes to consider scientific knowledge as 'epistemic tools'. The idea is that humans construct scientific knowledge for epistemic purposes. That is, scientific knowledge such as models allow for and 'guide' scientific reasoning in producing new knowledge, e.g., reasoning in making predictions and calculations about a target object;

reasoning in making computer simulation models; and reasoning about how to design or improve technological devices. On this philosophical view, knowledge is not firstly a representation of the (unobservable) world, but a tool for thinking about, for instance, (technological) possibilities to intervene with that world (e.g., as in technological R&D). Scientific knowledge (such as laws of nature, scientific models and theories) is constructed such that it can be used for this task. For instance, a scientific model is constructed for calculating how a process can be optimized. Or, how we can technologically produce a material property (e.g., a material that is superconductive at high temperatures). To use another metaphor: scientific knowledge has the character of a design. A design is an epistemic tool for building something. The design helps us to think of how to built it. The design is constructed before the thing is actually built. Only when that thing has been built, the design is a representation of it; before, it is an epistemic tool for building it and for the whole building process. The epistemic tool allows engineers to think about possible improvements, safety-matters, material-costs, constructive feasibility of the design, etc. The design as an epistemic tool ‘guides and constrains’ the reasoning of engineers, but it is not an algoritm that determines just one outcome.

REMARK. Although the construction of scientific models involves subjective aspects, it is not somehow arbitrary. Important epistemological criteria for the building and acceptance of a model are: empircal adequacy (which is why models are tested in experiments), logical consistency, coherence (both between the elements of the models, and with accepted knowledge), and also more subjective norms such as simplicity, generality, explanatory power (see also next few slides).

The B&K theory of scientific modeling
=
A theory of how we construct models of / for phenomena

- Scientists produce scientific models of / for an observable phenomenon (e.g., a cauliflower = bloemkool).
- The same phenomenon can be modelled in different ways, depending on the epistemic purpose of the model.
- The epistemic purpose of the model connects Research with Design and Development.

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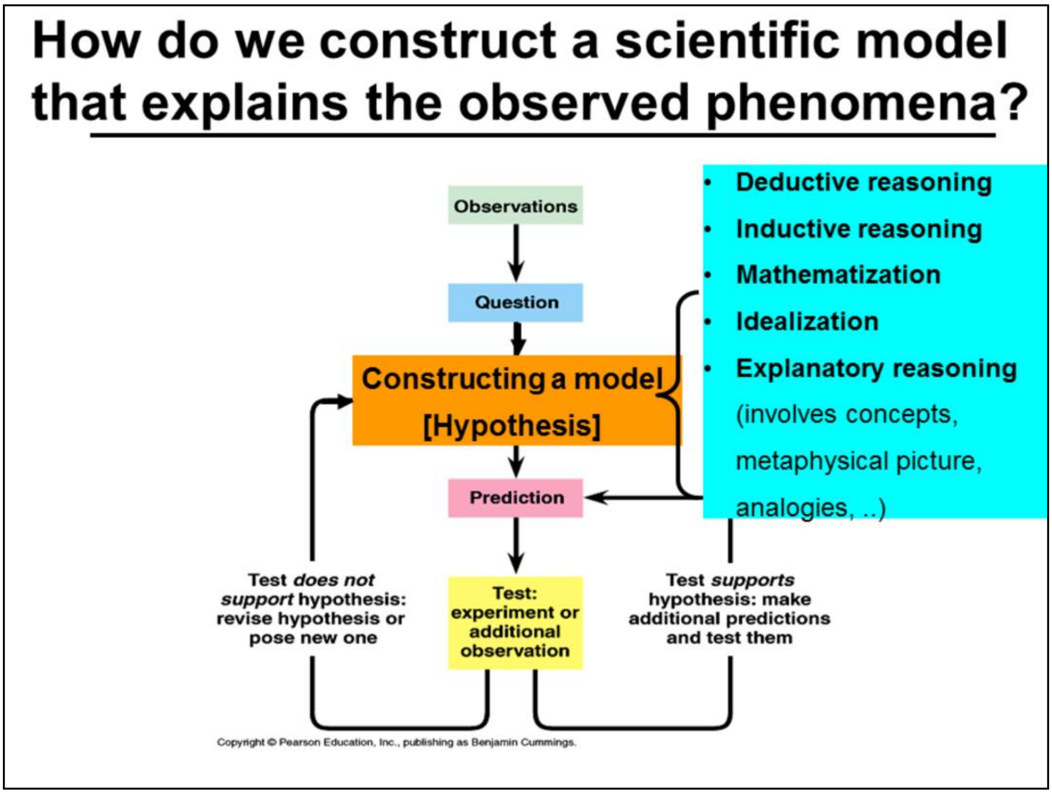


The point we are working on is understanding how a hypothesis comes about. The approach we take is that, although it involves a lot of creativity and imaginative power of the scientists, the formation of the hypothesis also is a rational and structured process that draws on scientific knowledge that scientists already have and on specific ways of reasoning (listed in the blue box). Note that this list is not complete. Other important ways of reasoning are categorization, conceptualization, abstraction, ... These ways of reasoning overlap. When looking at this list, you see that it involves the traditional logical forms of reasoning (deductive and inductive), but also other forms. The point of these other forms is that no algorithms can be given for them. These ways of reasoning involve the skills and imaginative power of scientist.

The B&K theory that will be explained below expands on the Hypothetical-deductive method as a description of scientific methodology. It puts more emphasis on how models are constructed. Therefore, the B&K theory of scientific modeling encompasses general aspects that usually play a role in the activity of scientific modelling.

However, when admitting that the construction of a scientific model (or theory) goes beyond the strict rules of logic, and, as was already pointed out, also beyond what can be observed in an unproblematic manner, science can be criticized of being subjective. This point of critic has been played out between ‘admirers’ of science and those who dislike science. The philosophical insight that scientific knowledge is not objective (observability + logic only), has been crucial to the decline of scientific authority in the past decades.

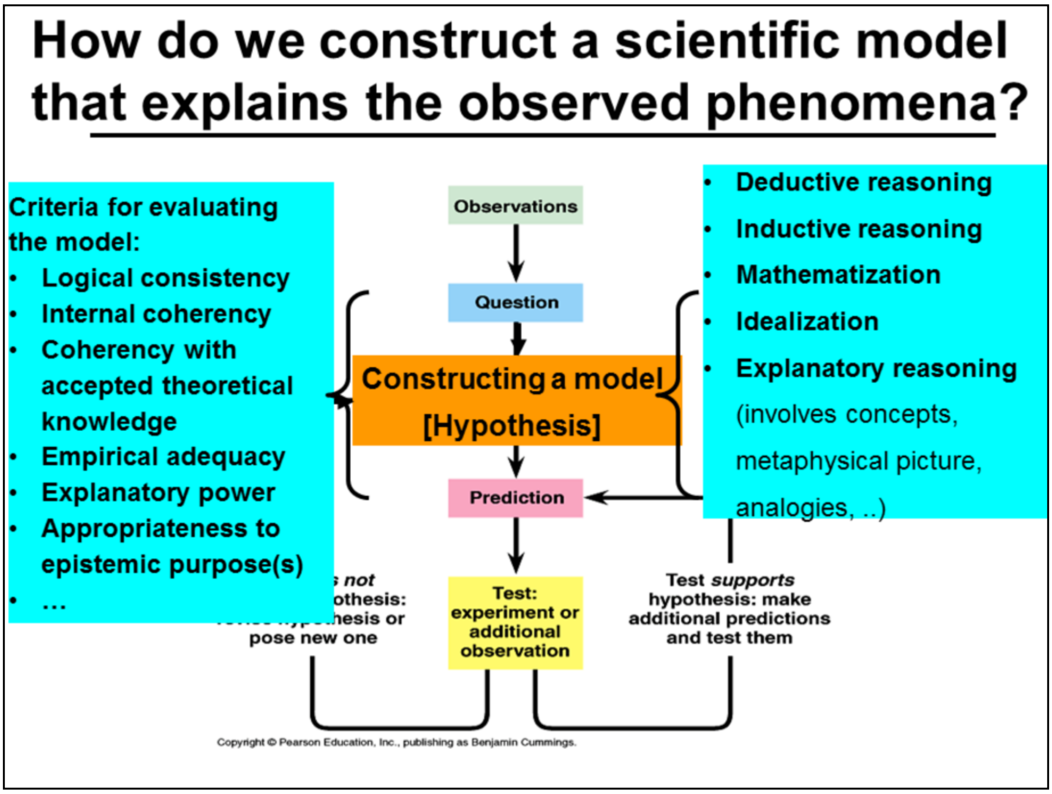
Some of the current philosophy of science aims to develop balanced solutions, which will be briefly presented in this course (and which are not found as yet in Philosophy of Science textbooks such as Ladyman). The challenge of this solution is reconciling the insight that scientific knowledge involves subjective aspects, with the idea that scientific knowledge and scientific methodology has some rigor to it that transcends just personal preferences.

The B&K theory of scientific modelling. (Re-)construction of a model (e.g., as presented in scientific articles) involves asking: “What is ..”:

- i. Specific phenomenon (X) for which the ‘model of/for X’ is produced.
- ii. Model type (e.g. morphological, logical, functional, mathematical, causal-mechanistic, statistical, ..).
- iii. ‘Epistemic purpose’ of the model.
- iv. Relevant (physical) circumstances and properties.
- v. Measurable (physical) variables.
- vi. Idealizations, simplifications, and abstractions.
- vii. Theoretical and empirical knowledge, and principles, used in the construction of the model.
- viii. Justification of the model.

Conceptual tool for (re-)constructing models. Scientific models comprise several aspects. These aspects are ‘build-in’ the model. Therefore, (re-construction of a model presented in scientific articles involves asking: “What is ..”:

This conceptual tool is called the B&K theory of scientific modelling. Also see the handout (in Course Materials): “The B&K theory of scientific modeling.” This handout also provides references to the theoretical background (can be downloaded on Campus through the links in the document).



Alternative to 'discovery' (as if we just saw the Higgs boson). An 'anti-realist alternative' to the realist explanation of why scientific theories and models are successful:

In constructing a model:

- Scientists (must) make use of several aspects ('ingredients') summarized in the B&K theory of scientific modelling (listed on the former slide), which are eventually part of the model (i.e., these aspects are 'built-in' the model.
- Constructing a model involves different kinds of reasoning (listed in the blue box on the right): not only logical ways of reasoning such as deductive and inductive reasoning, but also more constructive kinds of reasoning such as mathematical reasoning and explanatory reasoning. Explanatory reasoning makes use of analogies (e.g., billiard balls as an analogy for bouncing molecules) and scientific concepts used in other contexts (e.g., force, initially used in Newton's theory is now used in all kinds of other context as some kind of originator of change).
- Next to empirical adequacy (as proposed in Van Fraassen's anti-realist position), several other criteria play an important role in constructing and evaluating the model. In other words, these criteria (listed in the blue box on the left) play a role in accepting or rejecting a model. 'Explanatory power' may sound strange in the anti-realist context, as we usually assume (in a realist mode) that a model can only be an explanation if it describes more or less correctly how 'unobservable physical phenomena'

bring about the observed phenomena. The anti-realist ‘knowledge as epistemic tool’ position does not take ‘what the model says about the real world’ as firstly a true or literal description, but rather as an ‘as if’ description – that is, ‘as if’ the world that generates the observable phenomena is as depicted or described in the model. [Note that it requires quite a bit of philosophical work to underpin this idea, which is the kind of research that philosophers of science do.]

- Back to the idea of ‘inference to the best explanation’: this position can also be read in an anti-realist fashion, namely, the model as ‘the best explanation’ for observed phenomena is achieved when a model has been constructed that fits together all the relevant element (in B&K list) thus meeting ‘in the best possible manner’ those multiple criteria.

Take home - Overview

- What are Laws of nature (descriptions, explanations, definitions)?
- Are explanations descriptions of 'hidden' causes / causal-mechanisms?
- How does realism – anti-realism about scientific knowledge play a role (in our understanding of science)?
- What are models and how do we construct them?
- Can a plausible anti-realist alternative be formulated?
- Scientific models as 'epistemic tools' = tools for thinking.