UNIVERSITY OF TWENTE.

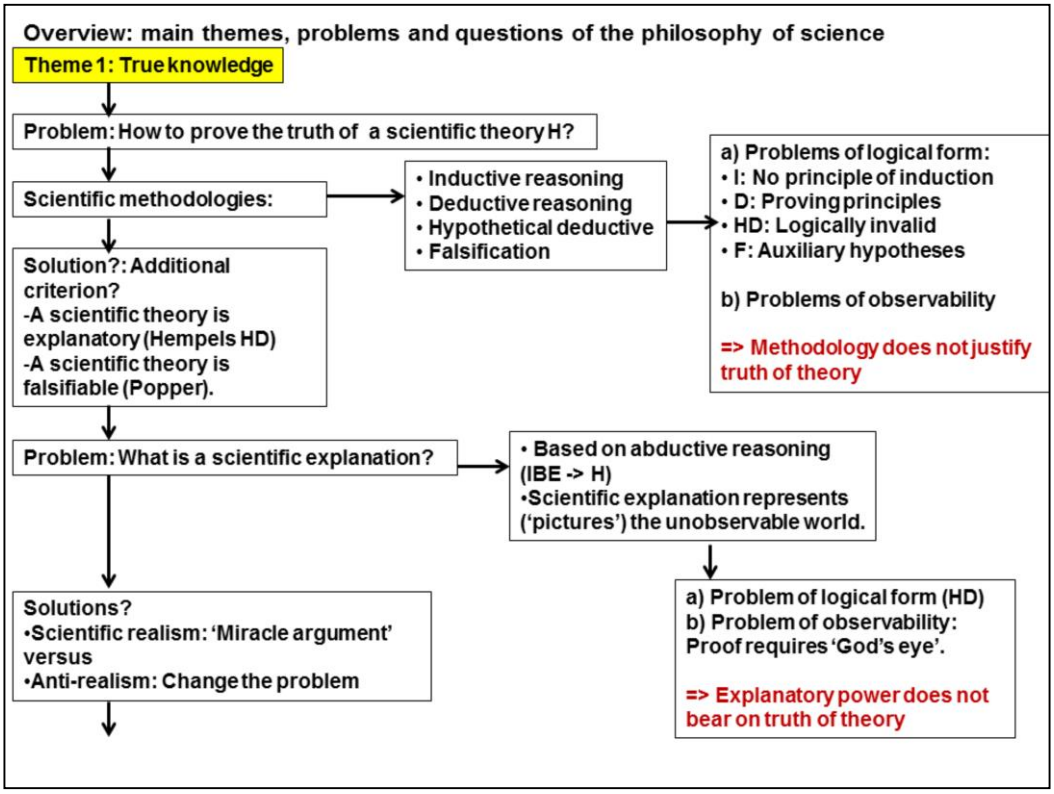
Philosophy of Engineering: Science

Lecture 7A: Overview of main themes

prof. dr. ir. Mieke Boon

Afdeling Wijsbegeerte

Theme 1: Science produces true knowledge / Acceptance of knowledge



This schema presents and overview of themes, problems and questions of the philosophy of science, and how these have been discussed during this course. The first theme was 'true knowledge'.

The philosophical problem could not be solved. 'In the end', it boiled down to two opposite beliefs: (1) Scientific Realism, which defends that the best explanation for the successes of science is that scientific theories are true (note that this is an IBE, an 'inference to the best explanation' argument). (2) Anti-realists argue that (a) there may be better explanations for the successes of science, and/or (b) that *philosophical* arguments against scientific realism force them to remain agnostic on such metaphysical claims.

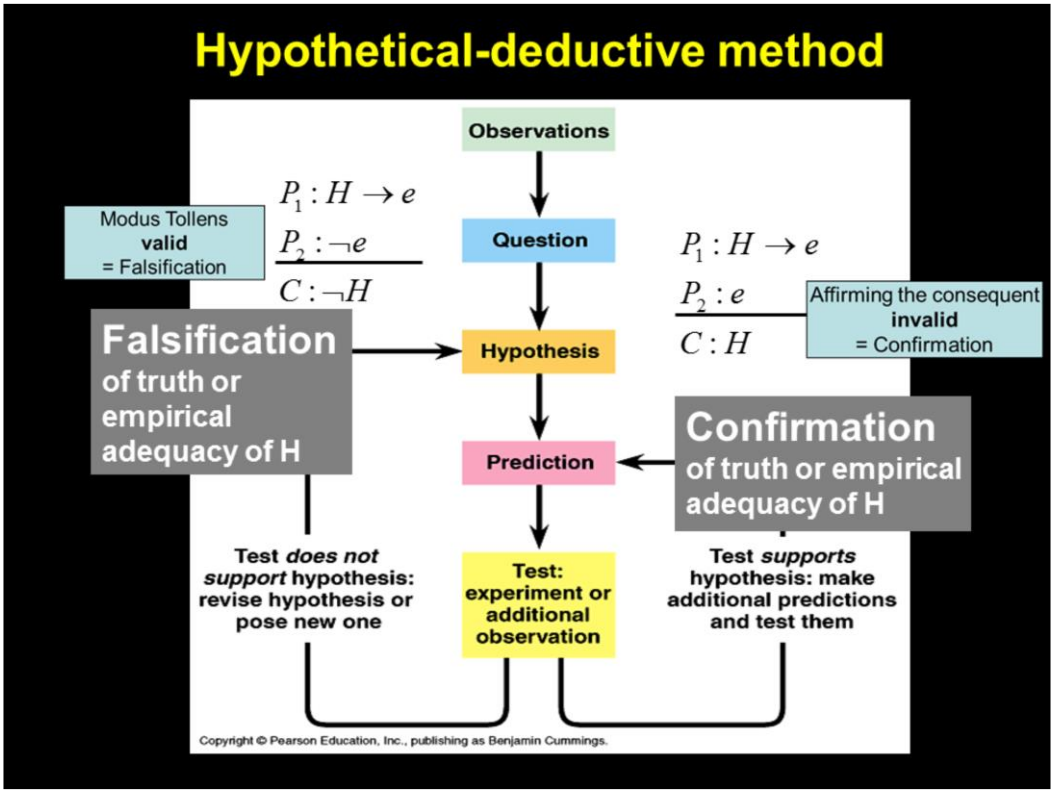
Note that claim (1) is a so-called 'metaphysical belief', which means that it can be defended by means of arguments, but there is no way to decide or proof it, for instance, based on empirical findings.

Another way of defending one of these philosophical positions is to explore which one is the most prolific, the most fruitful in its effects. This results, not in arguments as to whether the claim is true, but instead, arguments that concern the possible consequences of such beliefs.

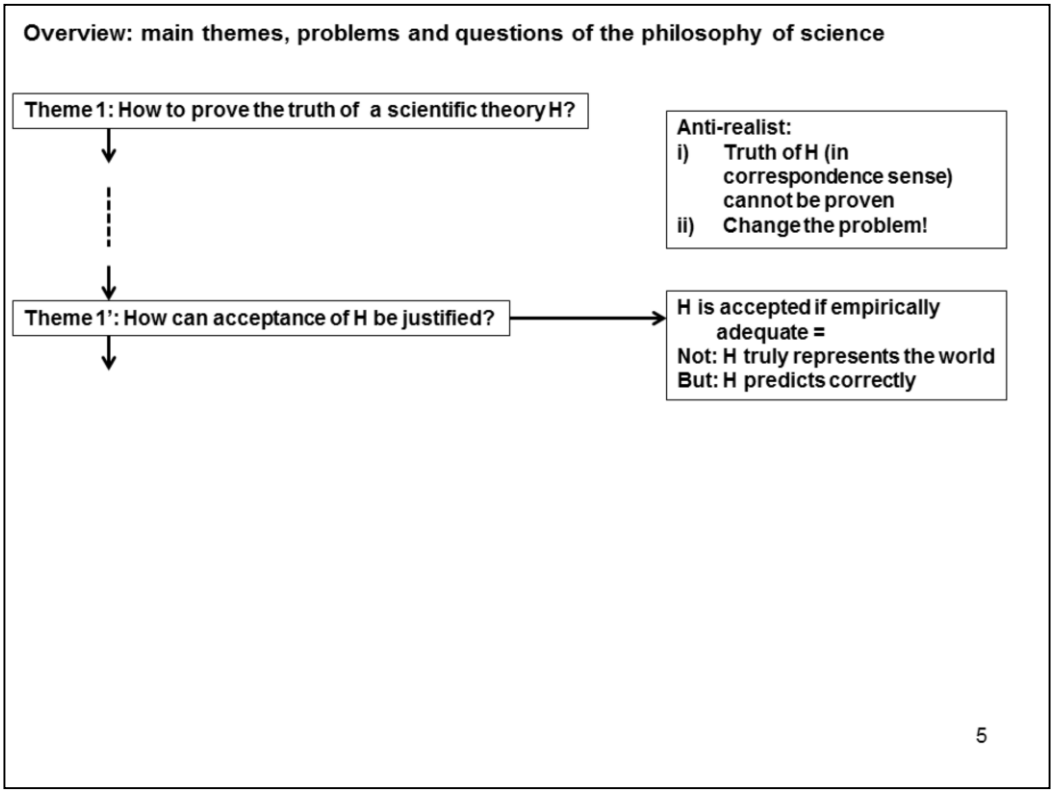
INTERMEZZO

What does it mean for a philosophical position to be 'prolific or fruitful in its

effects'? This also involves ethical concerns. Assume for instance that you believe that 'humans are good by nature', whereas your opponent believes that 'humans are bad by nature'. These are beliefs that can hardly be tested (the two claims are in the domain of the 'philosophical anthropology'), although your may discuss of course how it could be tested. But your discussion may also focus on the psychological and societal *consequences* of the one over the other belief – think of the political and social systems that may be supported by the one or the other, and what they would mean for people and welfare etc. Similarly, the position of *scientific realism* (the belief that scientific theories are – approximately – true) may be considered fruitful because it motivates scientists and the admiration and appreciation for science. Conversely, the 'anti-realist' claim that scientific knowledge firstly is constructed as epistemic tools that 'enables and guides' our thinking about the world, may downgrade the authority of science. At the same time, we may also hold that it makes us more cautious about science. Or, that it forces us to do scientific research such that it indeed provides us with valuable 'epistemic tools' (rather than holding on to the idea that every scientific research is OK in principle as it presents us with some truth and will always have some spin-off). More important, the anti-realist is more liberal towards different kinds of theories about the same target system. Contrary to the realist, who believes that there can only be one correct description (or explanation), the anti-realist recognizes that our theories are not objective descriptions (or explanations), independent of us, but that they are related to the epistemic aim and to the specific perspective, such as the disciplinary perspective. As has been stressed earlier, this is not to say that anything goes. Still, also the anti-realist holds that rigorous epistemic criteria apply for the acceptance of theories and models.

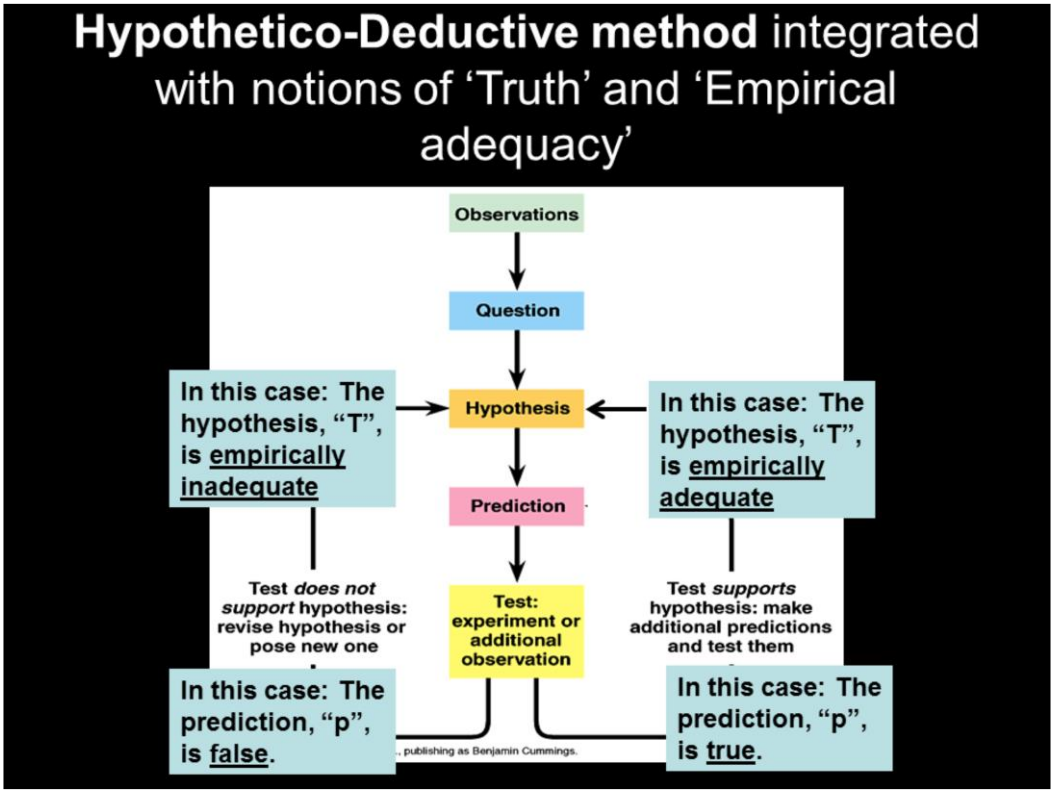


A schematic summary of the line of argument in this course. It includes the logical analysis of the two types of HD reasoning in testing the hypothesis. Note that this logical analysis concerns the 'truth' of propositions (as this is what logic is about), and does not address 'empirical adequacy'.



Note that philosophical problems often are 'solved' by asking a different kind of question. This is, by the way, also how problems raised in science are often solved. Asking the right kind of question is a very important part of both philosophy and science.

In the philosophy of science, the so-called anti-Realists (such as Bas Van Fraassen, mentioned in the class on 'Truth and Empirical Adequacy') defended that, from a pragmatic viewpoint the truth of scientific theories is not what really counts. What is important, according to Van Fraassen, is which reasons scientists 'really' have for *accepting* or rejecting a theory. This philosophical rephrasing of the problem makes explicit that 'accepting a theory' does not necessarily imply that the theory is true.

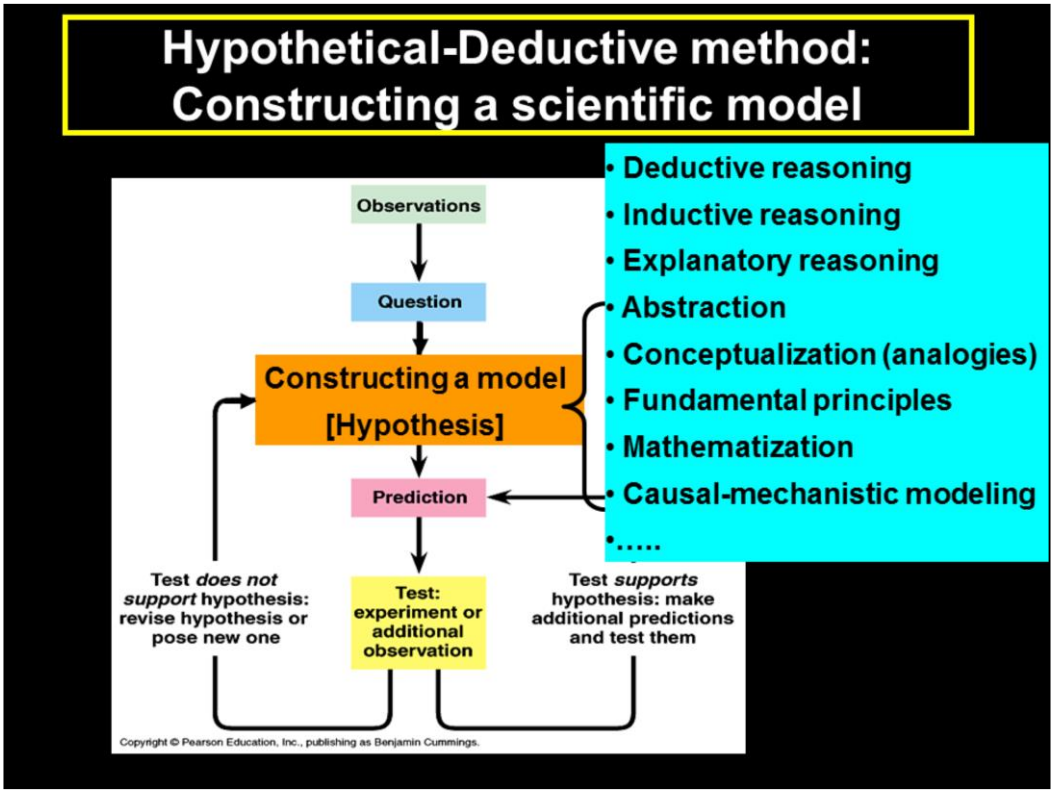


The notion 'empirical adequacy' merged with the HD-method. The prediction "p" is true or false (if the measurement, p, agrees with the "p", which is deduced from the theory). The Hypothesis "H" (e.g., Bohr's model of the atom) is then empirically (in-)adequate.

Summarizing the outcome of this lecture:

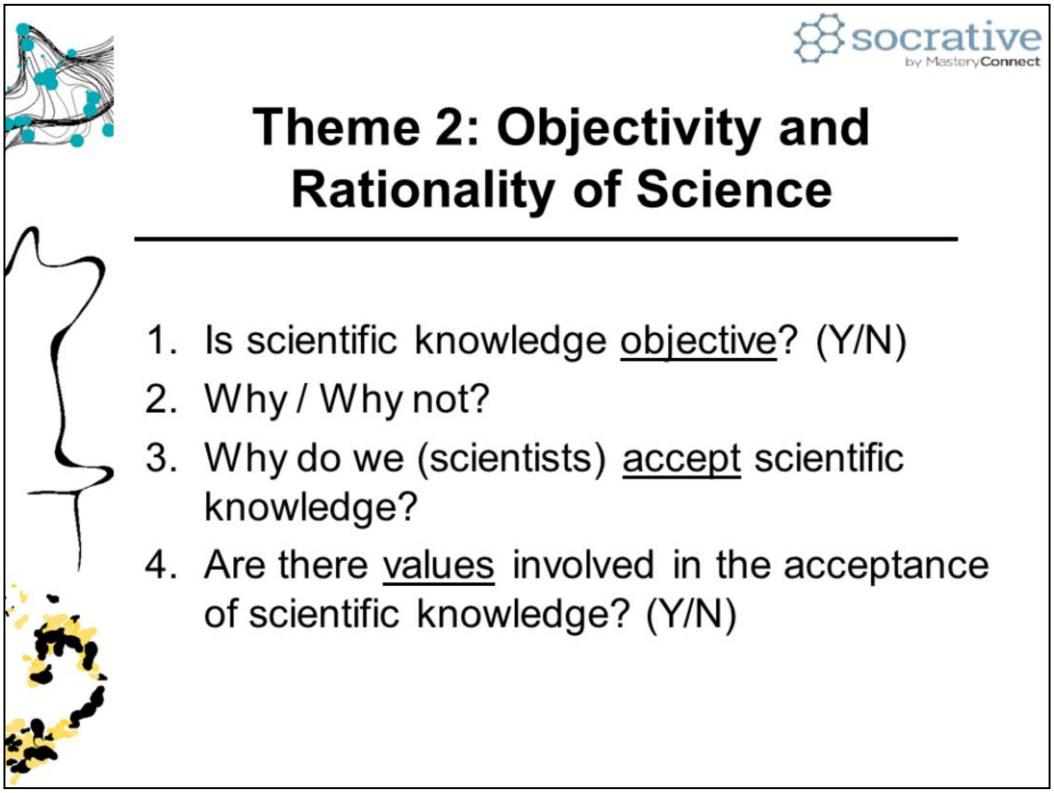
The notion 'empirical adequacy' merged with the HD-method. The prediction "p" is true or false (if the measurement, p, agrees with the "p", which is deduced from the theory). The Hypothesis "H" (e.g., Bohr's model of the atom) is then empirically (in-)adequate.

The approach in 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 HD method has been integrated with the B&K theory of scientific modeling. Constructing a model not only involves strict logical reasoning forms (deductive and inductive reasoning), but also other forms of reasoning, as listed here.

The problem is whether these additional forms of reasoning can be called rational and objective? Can the logical validity of those other forms of reasoning be proven? Only when logically valid, the rationality and objectivity of these forms of reasoning would be unproblematic.



Name of quiz: Objectivity - Kuhn

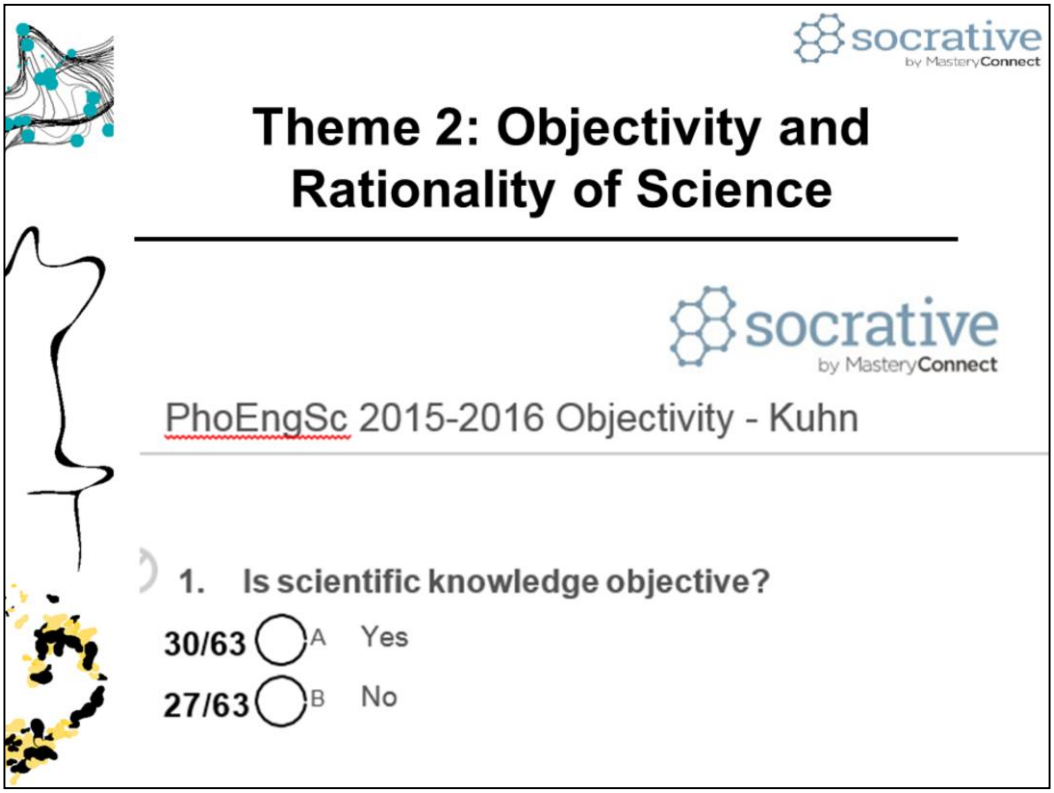
Three questions:

(1) Is scientific knowledge objective? (Y/N)

(2) Why/Why not is scientific knowledge objective? (e.g., what does 'objective knowledge' mean?) (short answer_

(3) Why do we (scientists) accept scientific knowledge?

(4) Are there values involved in the acceptance of scientific knowledge?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by MasteryConnect
Theme 2: Objectivity and Rationality of Science
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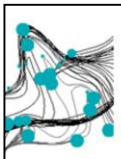
PhoEngSc 2015-2016 Objectivity - Kuhn
1. Is scientific knowledge objective?
30/63 A Yes
27/63 B No



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Theme 2: Objectivity and Rationality of Science

1. Is scientific knowledge objective? (Y/N)
2. Why / Why not?

- Yes. Objective knowledge is knowledge obtained by a scientific methodology
- No. There is still interpretation involved.
- Yes. It is objective because it is only proven with scientific knowledge and the principles are objective.
- Yes. It is objective because scientific methodology is used in gaining knowledge.
- No. I think it is not objective because for every individual an objective view is different. Again, a gods eye is necessary for an objective view.

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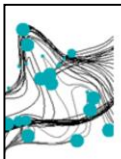
Theme 2: Objectivity and Rationality of Science

1. Is scientific knowledge objective? (Y/N)
2. Why / Why not?

- Yes. It is objective because it is based on truth-conditions
- Because gaining knowledge depends on scientists bias, knowledge is affected by its own time in history, by culture, politics...
- No. Within the selection of research subject, within inquiries, always a selection is made. Institutions, history, values, they always play a role within generating knowledge. However, within selection, everything would be an just data. We need selection and values to make sense out of the data.



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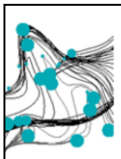
Theme 2: Objectivity and Rationality of Science

3. Why do we (scientists) <u>accept</u> scientific knowledge?

- Because it fits within their framework of problem-solving, their framework of interpretation.
- Because it is useful and has lots of applications
- Because it is closest to the truth as we see it.
- Because it gives for them a very good and logical
- explanation for a problem they have.
- Because the knowledge is not proven by fault
- Because the methodologies used to obtain the knowledge are accepted.



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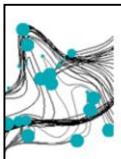
Theme 2: Objectivity and Rationality of Science

3. Why do we (scientists) accept scientific knowledge?

- So we can explain things and use that understanding to build technology.
- We need something to work with, if a piece of knowledge is empirically adequate we might be able to use it for our cause and thus make some progress.
- We don't. That is why we test everything ourselves until we do believe it enough to use.
- Many scientist (with many different not objective views) look at something, if many enough agree and can't be falsified (for now) we accept it.



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Theme 2: Objectivity and Rationality of Science

3. Why do we (scientists) <u>accept</u> scientific knowledge?

- Because subjectivity is minimized by using proper scientific methodology.
- When most people agree with the reasoning/proofs.
- They get paid to
- Because there is no 'more accurate' answer for the hypothesis that is made.

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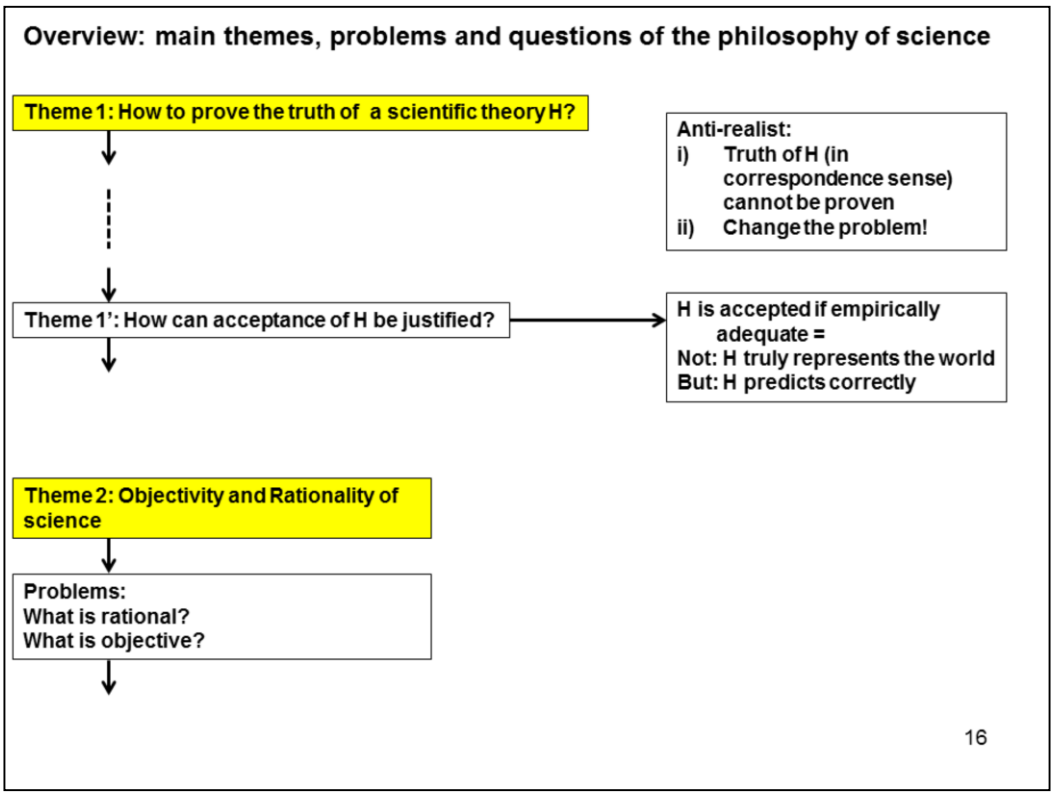
Theme 2: Objectivity and Rationality of Science

1. Is scientific knowledge objective? (Y/N)
2. Why / Why not?
3. Why do we (scientists) accept scientific knowledge?
4. **Are there values involved in the acceptance of scientific knowledge? (Y/N)**

4. Are there values involved in the acceptance of scientific knowledge (or models)?

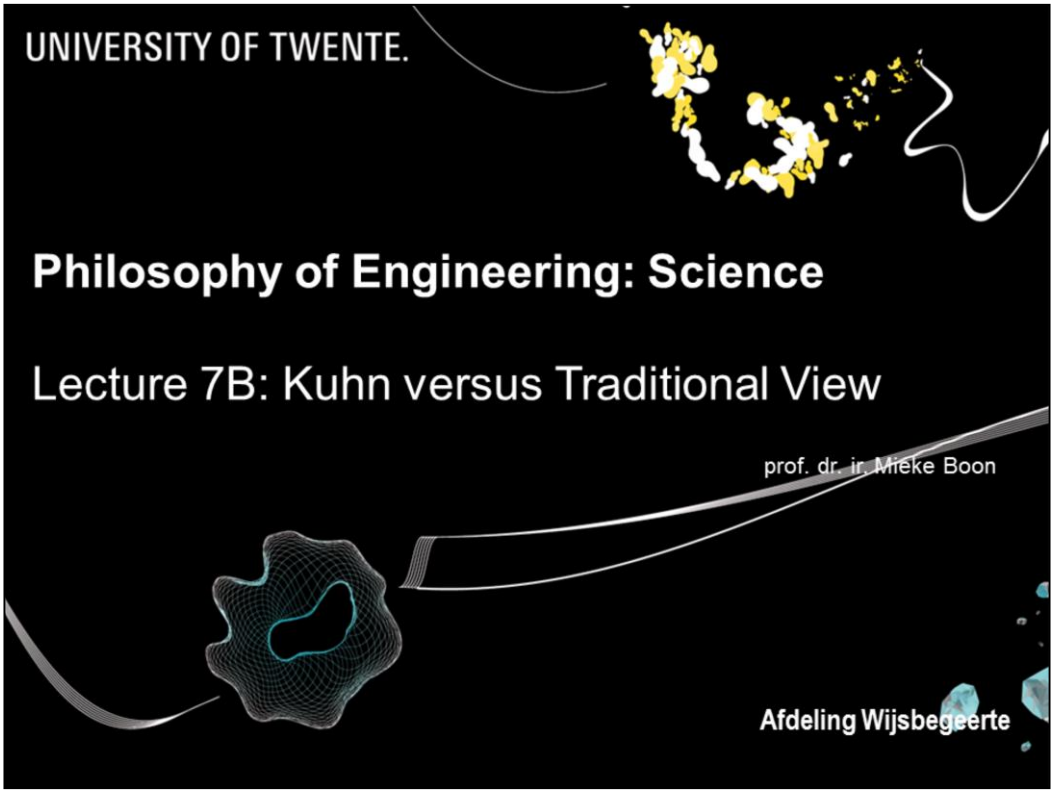
41/63 A Yes

6/63 B No

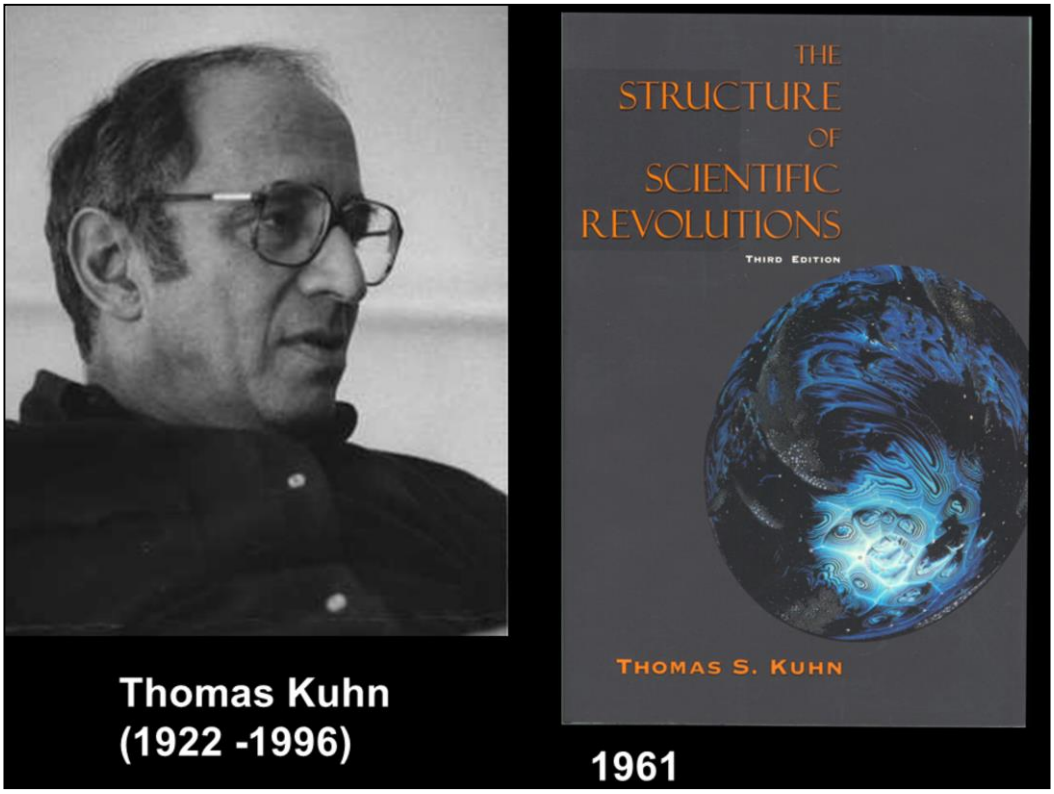


The second theme, addressed in this lecture, is rationality and objectivity. As always, we start asking what we mean to say by these notions.

For quite some time, say, since Newton at the beginning of the 18th century, until halfway the 20th century, scientists, philosophers and the educated public believed that science is rational and objective. This believe came under attack, in part due to the negative societal effects of science – in particular, the atomic bomb on Hiroshima and Nagasaki at the end of World War II in 1945, which was developed in the Manhattan project thanks to the crucial contribution of physicists; the uses of scientifically developed weapons in the Vietnam war; and the sudden discovery of huge environmental effects due to scientifically developed technology. People started to distrust science, and called into question its supposed authority and objectivity and independence and disinterestedness. Furthermore, the believe that science is rational and objective came under attack through studies of historians and philosophers of science. By means of close examination of (1) how scientific progress actually happened, and (2) how scientific reasoning goes about, they found that the common ideal picture of science held in those days, is actually inappropriate. Science is not as objective and rational as people tended to believe.



Second theme is Objectivity and Rationality of Science



Kuhn's "The Structure of Scientific Revolutions" was published in 1962, but only noticed by a broad audience in the 1970th. Probably, because only then it was understood as an explanation of some of the unarticulated but critical ideas and question marks about science.

Thomas Kuhn was a physicist, a historian and a philosopher of science. He got interested in radical changes of scientific theories, such as the replacement of the geocentric Ptolemaic world view by the Copernican heliocentric world view, and the replacement of 'phlogiston' by 'oxygen, and also, the replacement of the caloric theory of heat by 'energy' and 'conservation of energy'. Based on his close historical studies, Kuhn concluded that these changes could not be called rational. There were not – as most scientists and philosophers believed – 'crucial experiment' that proved the truth of the succeeding theory over its predecessor. Copernicus' triumphing heliocentric world view was considered as the start of scientific discovery and rationality, a triumph of reason and observation over irrationality and superstition. However, from these studies in the history of science it appeared that Copernicus' heliocentric alternative (to the geocentric world view) was not fully derived from observations and logical deduction and induction. In other words, the belief that observation, deduction and falsification are the necessary and sufficient elements for accepting an alternative theory, may be correct from a normative point of view, but appeared to be 'empirically inadequate' as counter-examples were found in

the history of science.

Rationality and objectivity of science under attack (since 1970th)

Example from the history of science: *Copernicus* (heliocentric) versus *Ptolemy* (geocentric).

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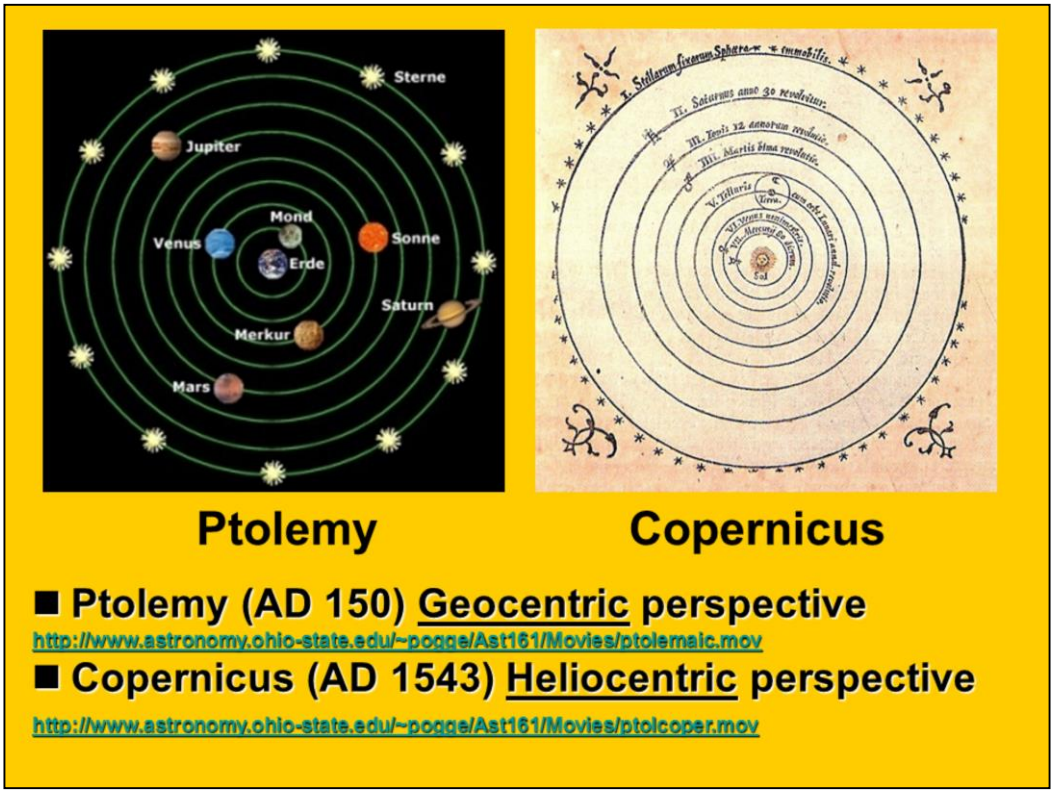
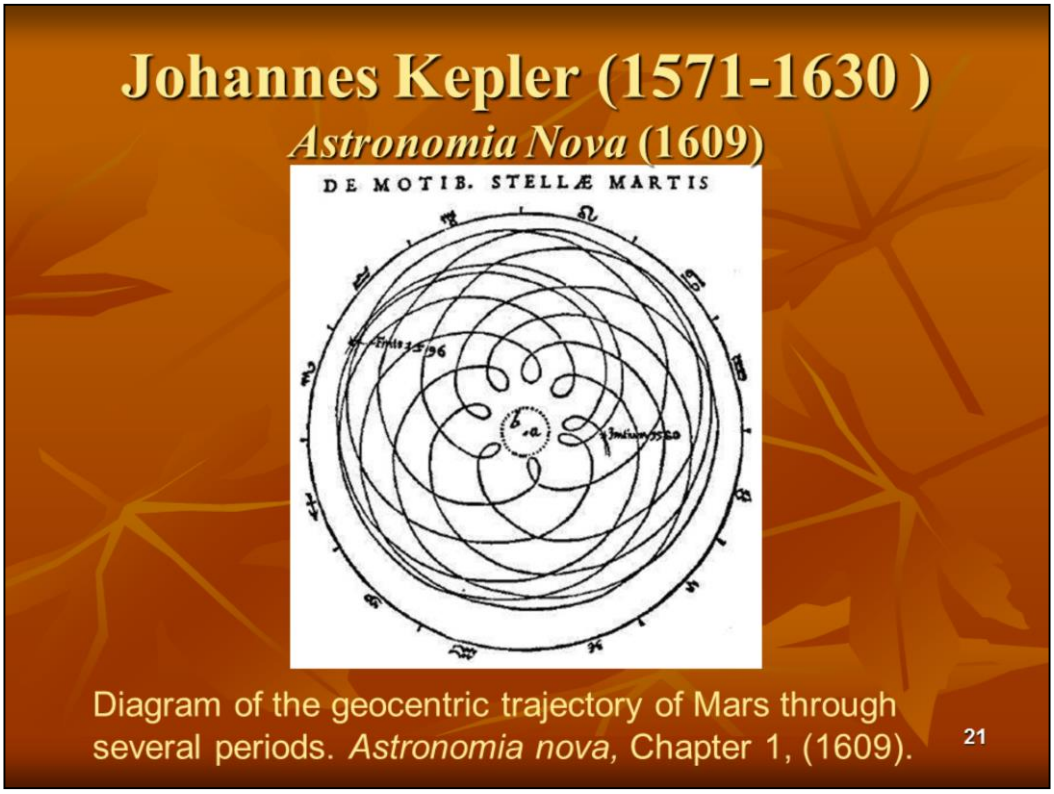


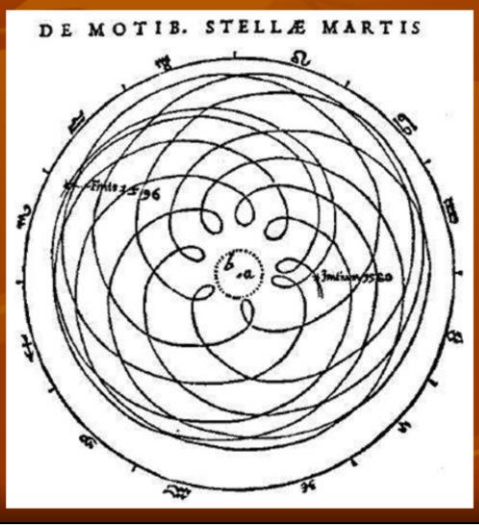
The shift from the Ptolemaic system to the Copernican system, is often considered as a paradigm shift. Furthermore, although the sky has not changed, the way in which people see the planets in the sky has changed.

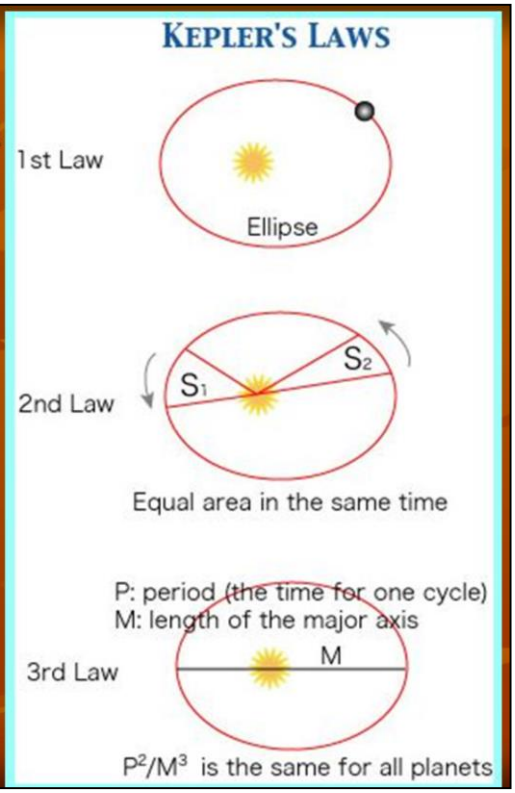
http://www.astronomy.ohio-state.edu/~pogge/Ast161/Movies/ptolemaic.mov

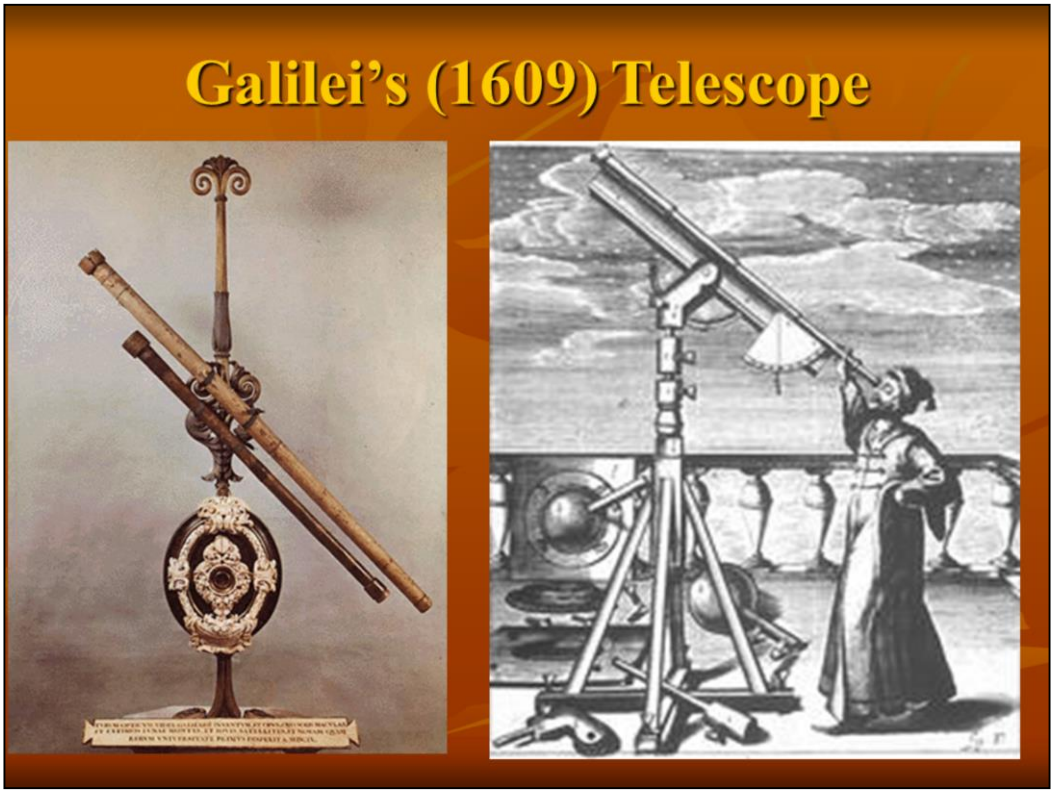


This sketch from *Astronomia Nova* offers one explanation for the apparent retrograde motion of the planet Mars when it is viewed from Earth. [*Retrograde motion* refers to the backwards motion of planets. As we now know, it is entirely an illusion caused by the moving Earth passing the outer planets in their orbits]. Specifically, it shows the path of Mars from the year 1580 (marked just to the right of center) to the year 1596 (at left, near the 10 o'clock position) according to Ptolemy's model.
http://www.maa.org/book/export/html/117541

Kepler's laws of planetary motion (1609)







Note that observations of planets by means of a telescope only became possible after its discovery: Kepler's

convex lenses to correct farsightedness are developed in the 14th century, and concave lenses to correct nearsightedness are developed in the 15th century. Also, it is claimed that in 1608, in the Netherlands, Hans Lippershey discovers that holding two lenses up some distance apart bring objects closer. He applies for a patent on his invention. This is the first documented creation of a telescope. The idea is independently developed by Jacub Metius and Sacharias Janssen.]

Kuhn: Logical positivist and Popper's traditional picture of science:

1. Cumulative growth of science
2. Unified Science
3. Science is value-free
4. Distinction between *Discovery* & *Justification*
5. Scientific proof: Confirmation or Falsification
6. Distinction between science and other beliefs
7. Distinction between observation and theory.
8. Scientific terms have fixed and precise meanings.

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Next, based on these findings in the history of science, Kuhn articulates and attacks what then come to be called the 'Received view on science'. This view is attributed to the so-called Logical Positivists, and also Popper. This slide summarizes the presuppositions of the traditional, 'received view' of science, which are rejected by Kuhn.

The next slides provide a brief explanation, but for an in-depth explanation, please read Ladyman's chapter on Kuhn.

1. Cumulative growth of Science.

- **Periods of normal science:**
  - Science is puzzle solving
- **Scientific crisis:**
  - More and more anomalies on accepted theory
  - Alternative theory
  - Scientists are willing to work on the alternative theory

=> Scientific revolution

=> Paradigm shift, so science is not cumulative.

One example is shift from geocentric to heliocentric perspective.

Another example is the 'caloric theory of heat'. An anomaly was, for instance, that objects get hot when rubbed, which disagrees with the caloric theory of heat, as this theory assumes that caloric particles cannot appear or disappear. So, this theory cannot explain heating through rubbing.

2. Unified Science

- Idea of unified science means that the scientific community beliefs that all science is reducible to physics.
- **According to Kuhn**: Is problematic because this is a *presupposition*, not grounded on empirical evidence.

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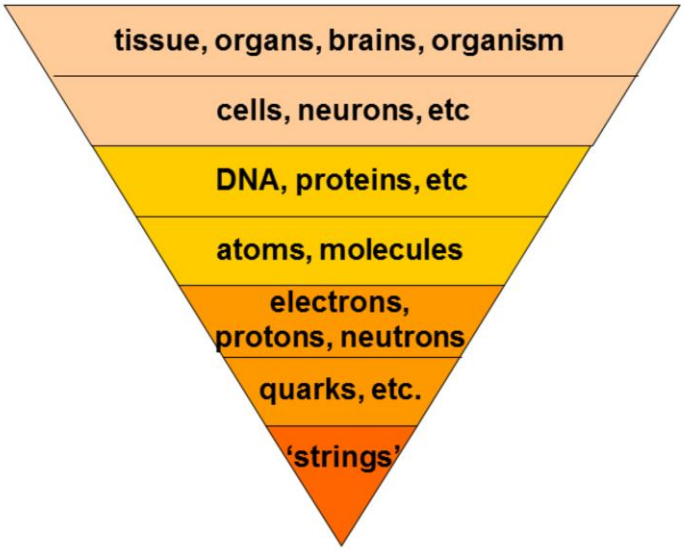
Unified Science: All knowledge is reducible to physics (also called 'scientism' & reductionism)



Biomedical sciences, …
Biology
Biochemistry
Chemistry
Physical chemistry
Physics
Mathematical Physics

3. Science is Value-free

According to Kuhn: Is problematic because:

- Science is guided by background values (e.g., on aim of science, prefered kinds of explanation).
- Science is guided by epistemological values, e.g.
    1. accuracy
    2. consistency,
    3. generality (wide scope)
    4. simplicity
    5. fruitfulness

Background values such as a preference for efficient causal explanations, or preference for theories that yield precise quantitative and testable predictions rather than general and qualitative ones.

According to Kuhn these epistemological values warrant the rationality of scientific practice. These values impose limits on what theories scientists can rationally accept. However, values may conflict.

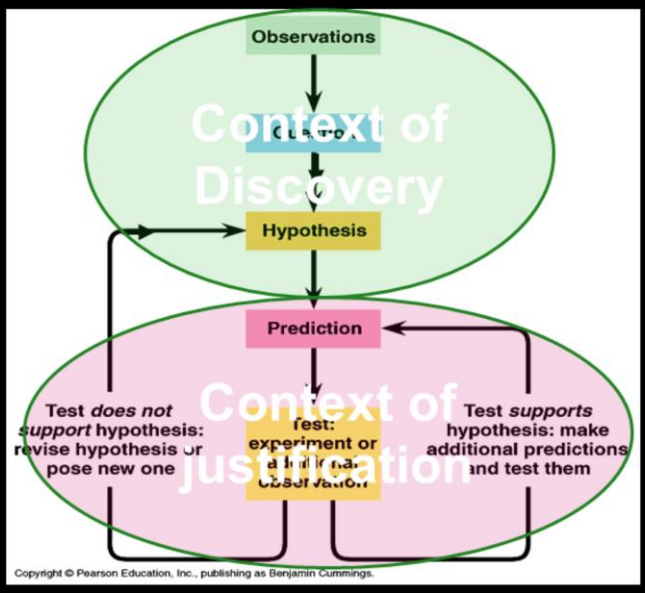
Note that there are different kinds of values: ethical values, epistemological values, esthetic values, political values, …

4. Distinction between Discovery & Justification

- Philosophy of science aimed at a clear distinction between subjective and objective elements (Context of discovery versus Context of justification).
- **According to Kuhn**: Is problematic because justification also entails subjective elements (since it involves a **paradigm**).

An important distinction made by the Logical positivists that aims to warrant the objectivity and rationality of science, is the distinction between the so-called Context of Discovery – which is outside the domain of rationality, since scientists may be inspired by their dreams, religion or metaphysical beliefs – and the Context of Justification, which is subject to the constraints of rationality, and is supposed to guarantee the objectivity of scientific knowledge. On this account, the bottom part of Hypothetical-Deductive method (where the hypothesis is being tested) reflects the context of justification, whereas the formation of the hypothesis is in the domain of the discovery (and therefore not subject to the constraints of rationality). Also see point 7 below.

Hypothetical-Deductive method:



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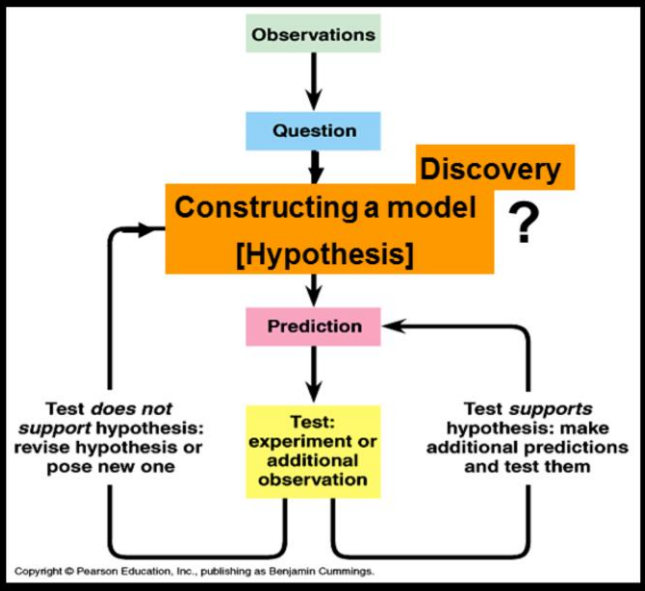

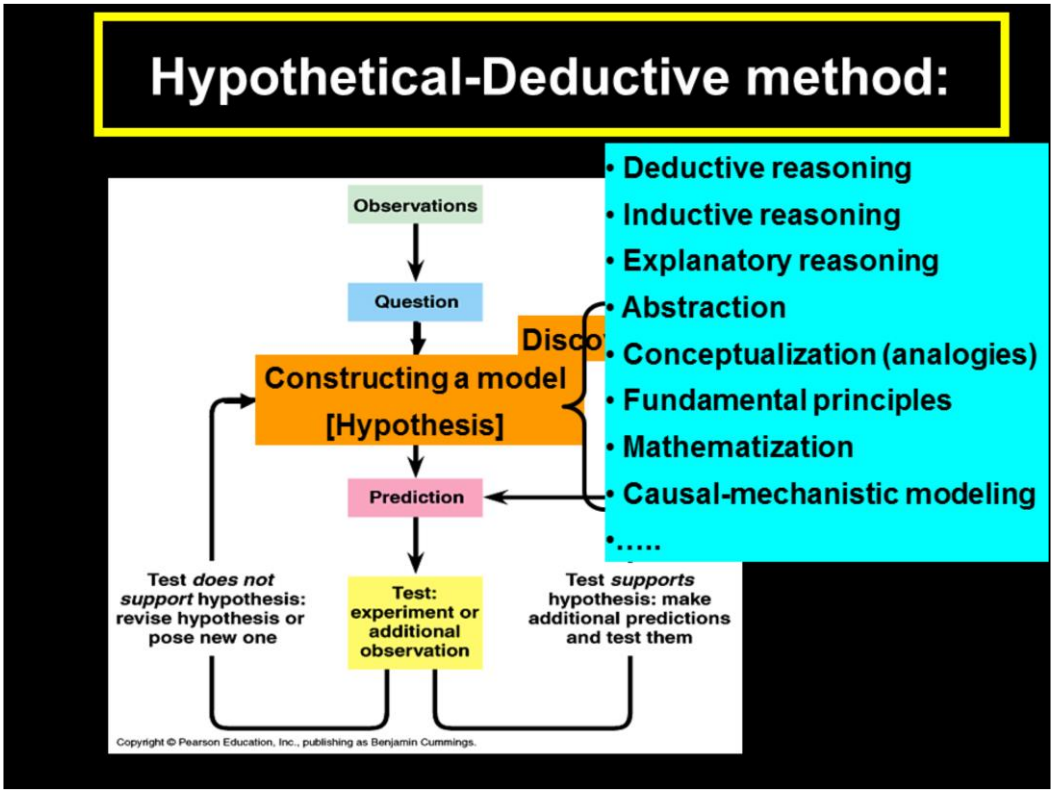

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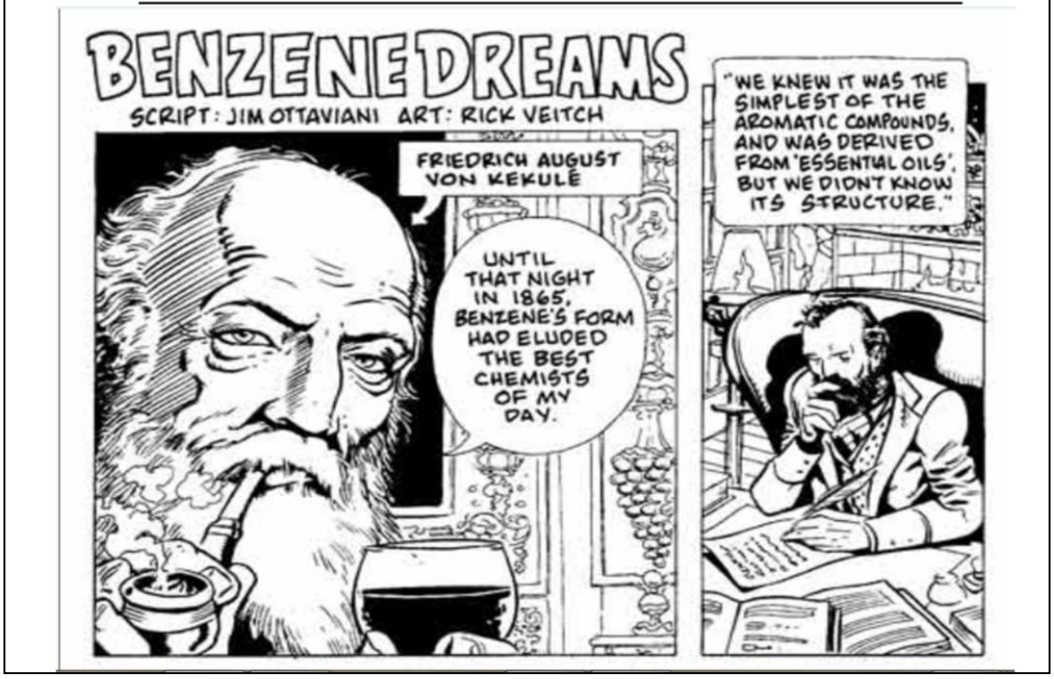
The problem is whether these additional forms of reasoning can be called rational and objective? Can the logical validity of those other forms of reasoning be proven? Only when logically valid, the rationality and objectivity of these forms of reasoning would be unproblematic.

Kekulé's discovery of the Benzene ring



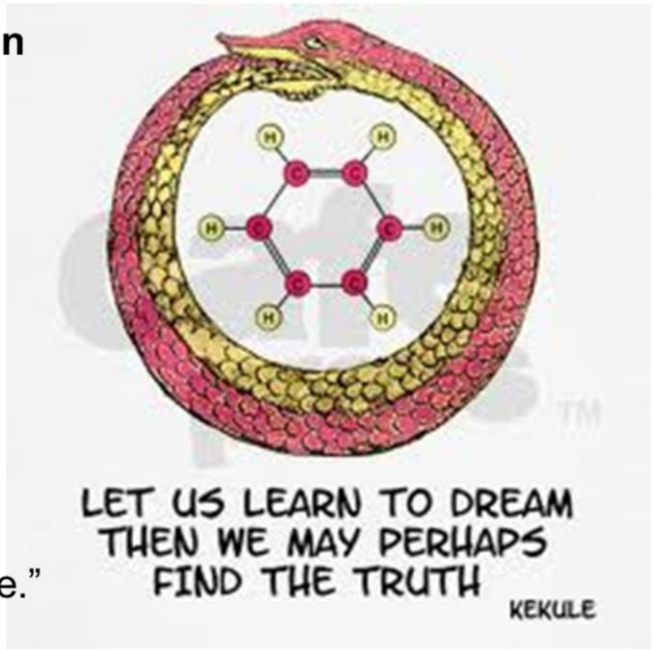
Kekule 1.

http://www.rickveitch.com/2009/05/09/

The context of discovery: Creativity in in Science

The Act of Creation

- "As if by a flash of lightning, I awoke"
- "This dream had revealed to me the truth about Benzene's structure."



http://en.wikipedia.org/wiki/Benzene

http://en.wikipedia.org/wiki/August_Kekul%C3%A9

http://www.tandfonline.com/doi/abs/10.1080/00033798500200411#.UvKxPaKYaOc

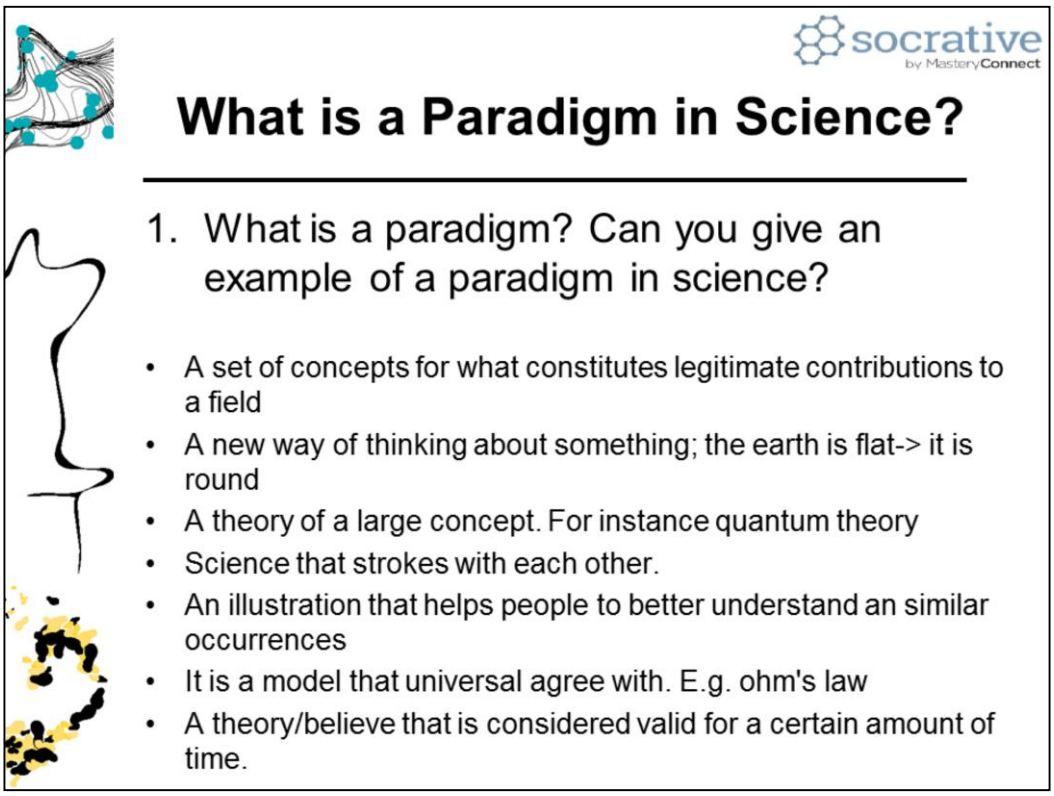
1865

Understanding of benzene, and hence of all aromatic compounds, proved to be so important for both pure and applied chemistry that in 1890 the German Chemical Society organized an elaborate appreciation in Kekulé's honor, celebrating the twenty-fifth anniversary of his first benzene paper. Here Kekulé spoke of the creation of the theory. He said that he had discovered the ring shape of the benzene molecule after having a reverie or day-dream of a snake seizing its own tail (this is a common symbol in many ancient cultures known as the Ouroboros or Endless knot).[26] This vision, he said, came to him after years of studying the nature of carbon-carbon bonds.

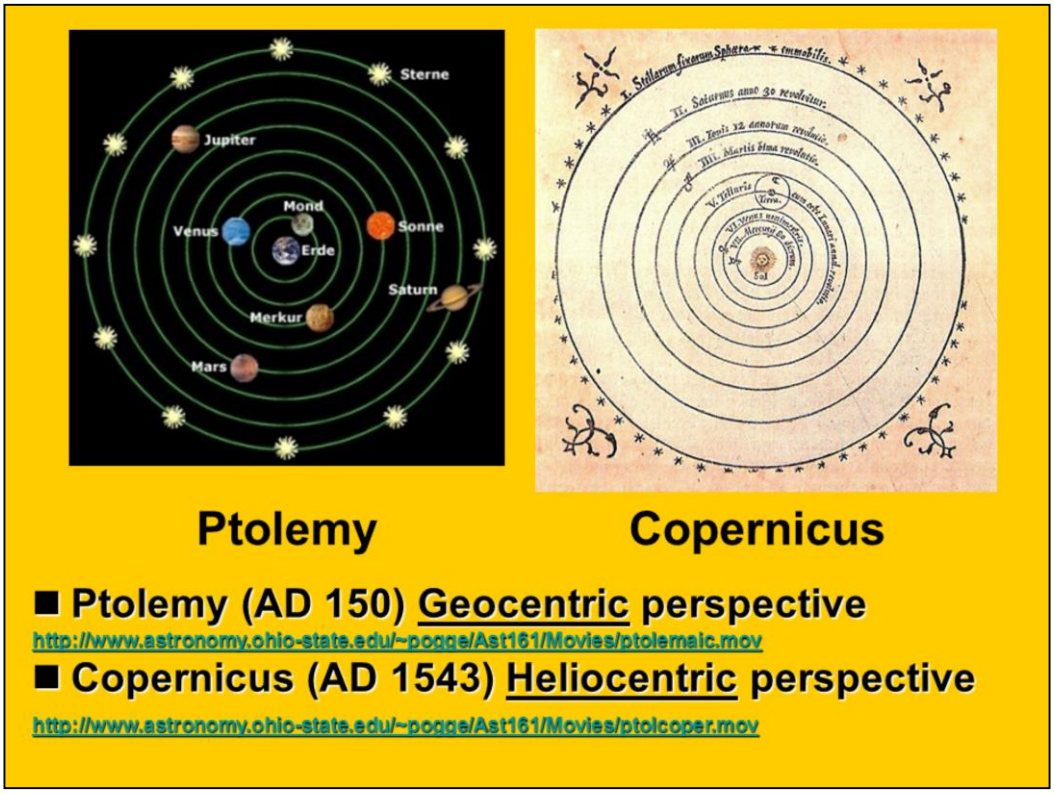
5. Distinction between science and other beliefs

According to Kuhn: Is problematic because when a theory is abandoned it is regarded as an (unscientific) belief =>

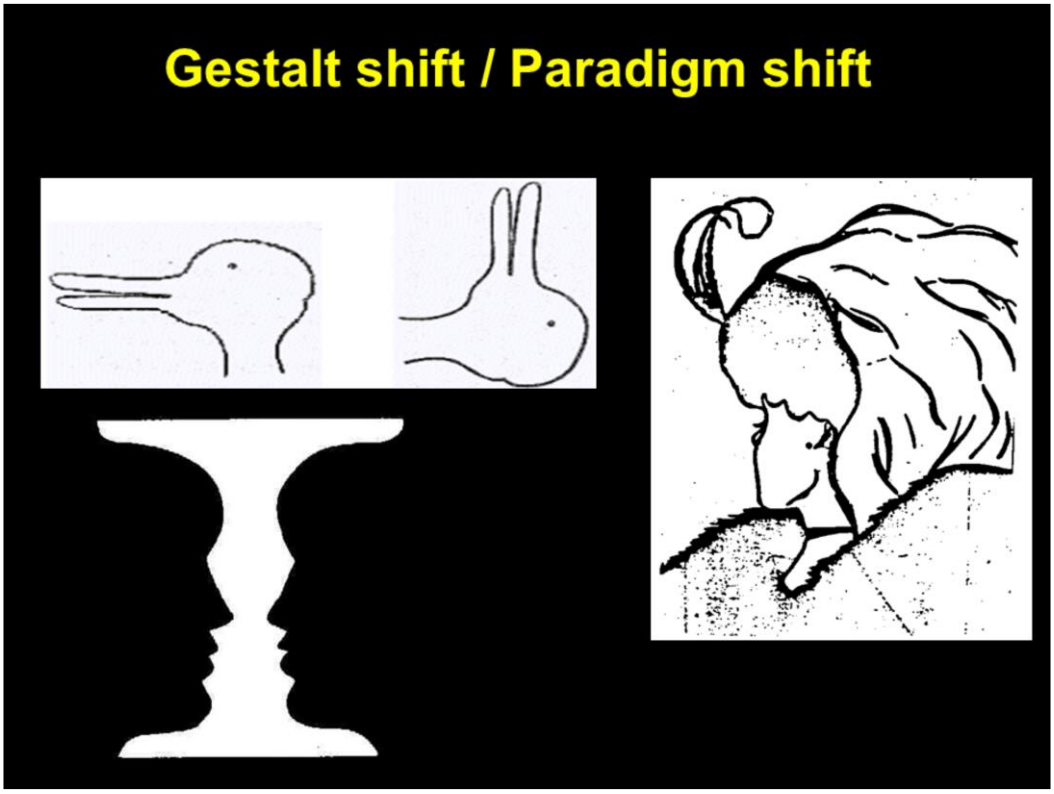
- A theory is only abandoned because of the **paradigm shift** and these shifts are seldom rational choices.
- Science is only what is considered to be science.



Name of quiz: "What is a paradigm""



The shift from the Ptolemaic system to the Copernican system, is often considered as a **paradigm shift**. People (on earth) in the center of the universe versus people no longer in the center of the univers.



The change of meaning of a concept through a change of paradigm is often related (or explained by) the notion of a ‘Gestalt switch’.

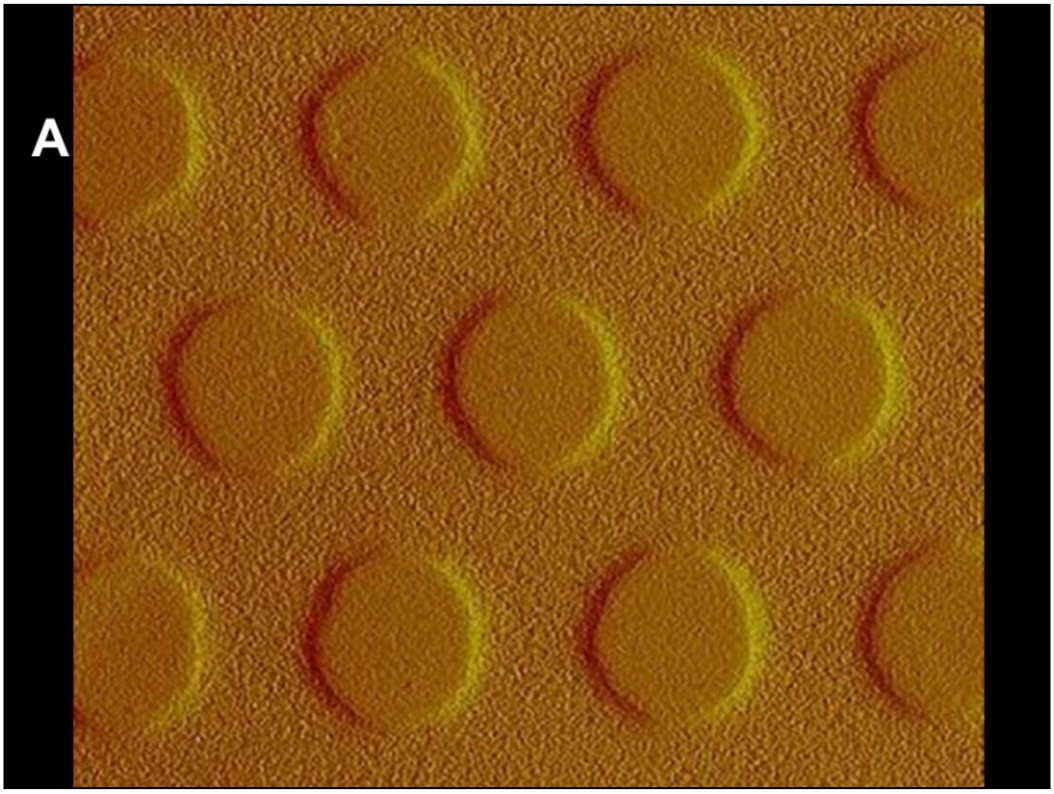
These pictures are used to illustrate that two different things can be seen in the same picture, depending on your paradigm. In other words, what you see (the meaning) is not fully determined by the picture itself, but also by how you give meaning, which, according to this view, has to do with your paradigm (or, perspective).

[1. duck and rabbit. 2. Faces and vase. 3. Young and old woman]

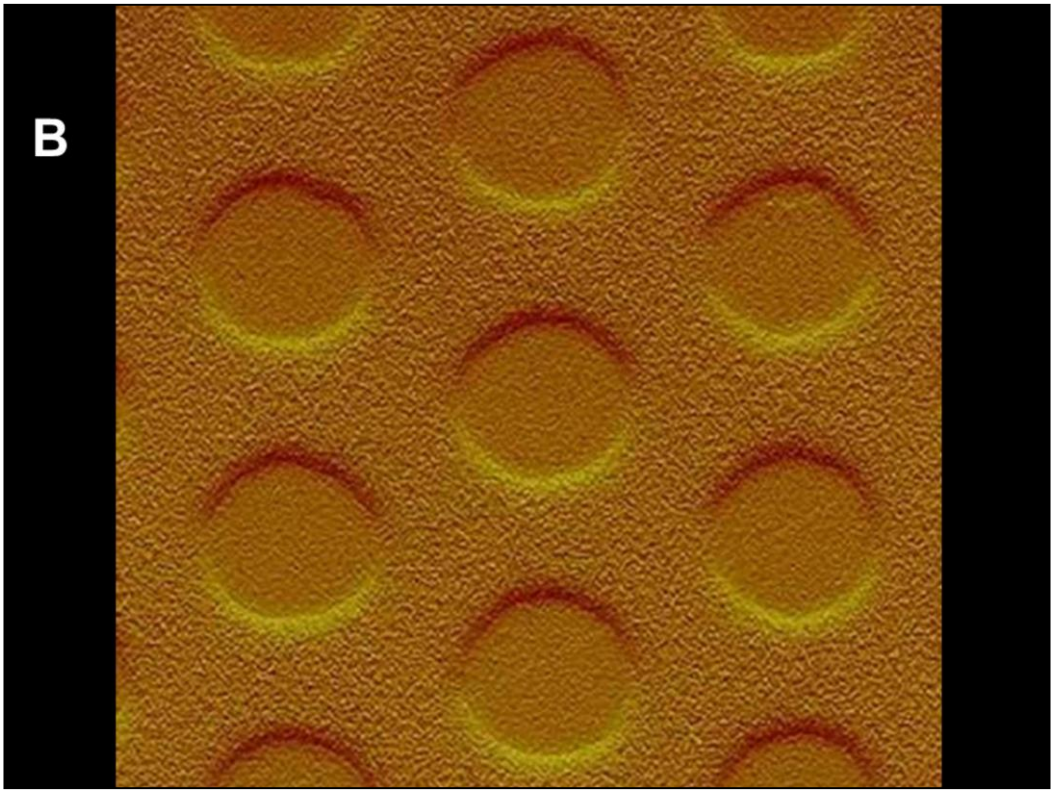
6. Distinction between observation and theory.

According to Kuhn: Is problematic because

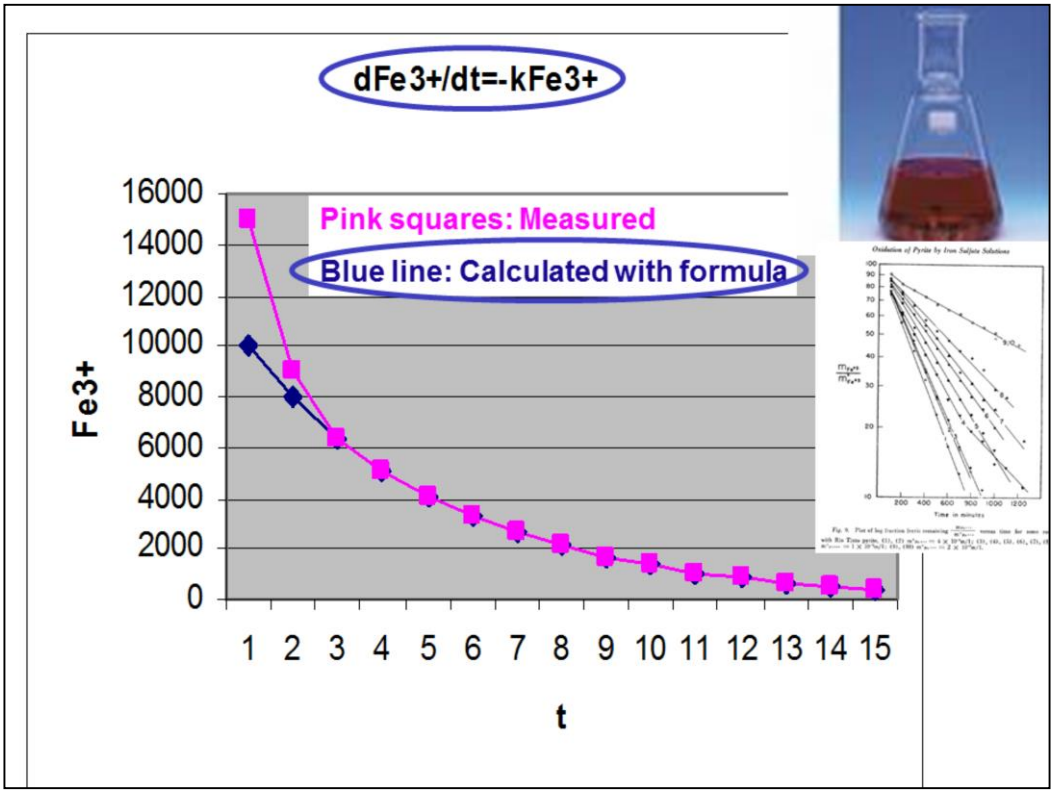
- Observation is theory-laden:
- Scientists in different paradigms actually see (observe!) a different reality.



Example of theory-ladeness of observation. One can see dots or holes on this picture. It is an AFM picture of a structure produced in nano-technology. The scientists assume that they have precipitated dots on the surface, which affects how we interpret this picture: these must be dots.



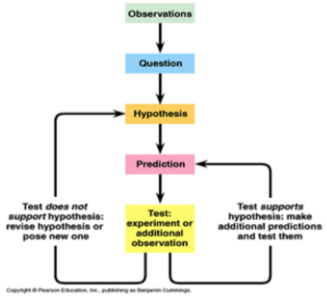
Depending on how the picture is positioned, people see dots or wholes. So even, different people can see different things in the same picture.



In this example, the pink measurement points at t = 1 and t =2 were discarded based on (a) the blue line (the first order mathematical description) fitted all measured data except of those at the start of the measurement, and (b) good arguments could be given that these initial measurement points disagreed with what would be measured in a correct measurement – they were probably due to errors in the measurement.

Hence, the formula is the theory that influences our interpretation of observations: which are correct and which are not.

7. Scientific Proof by Confirmation or Verification



According to Kuhn: Is problematic because

- when observation is theory-laden, then observation is not objective.
- Scientists in different paradigms actually see a different reality.

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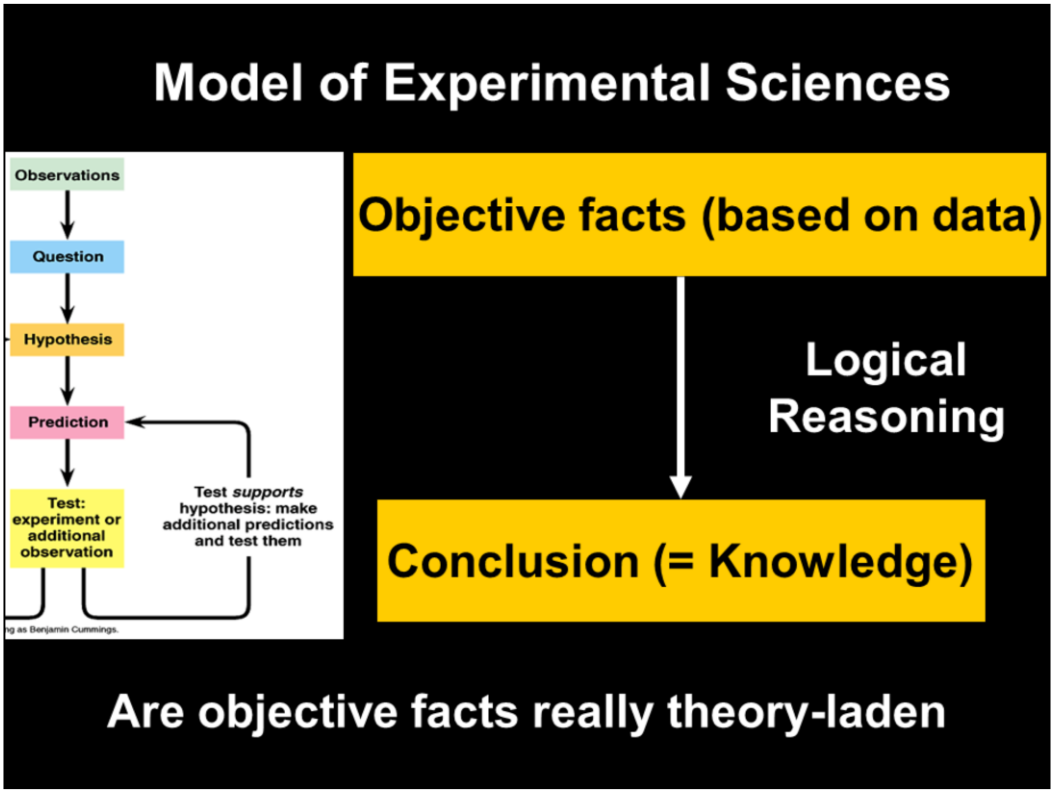
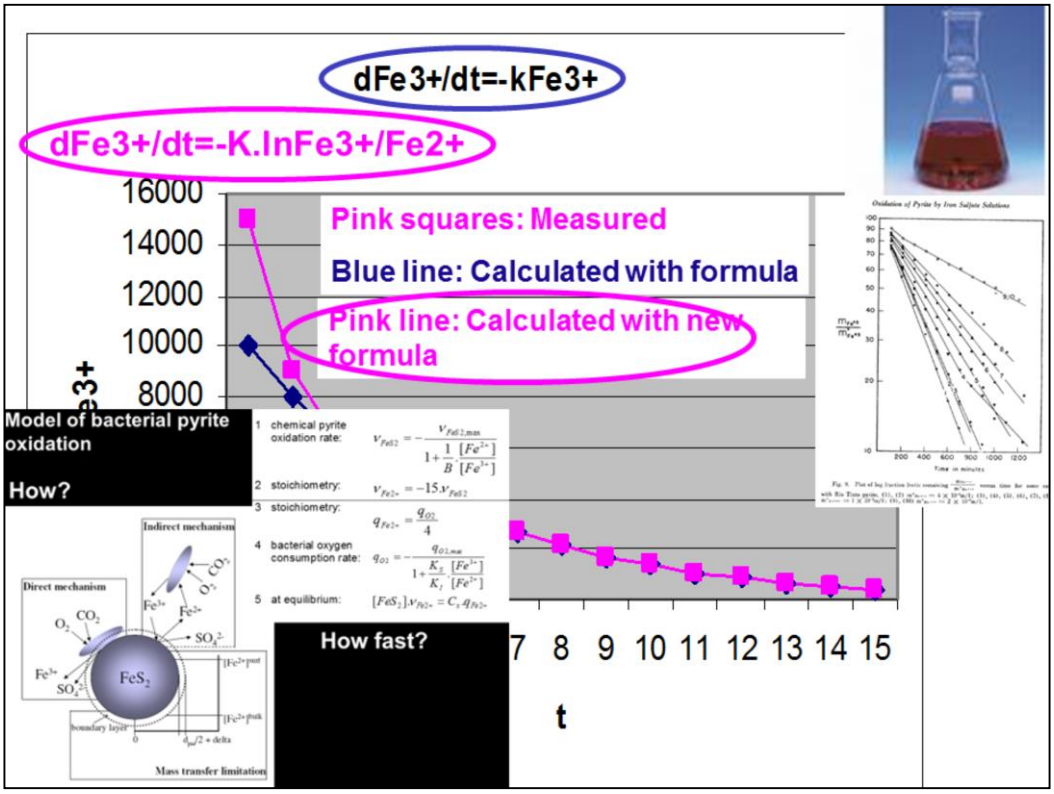


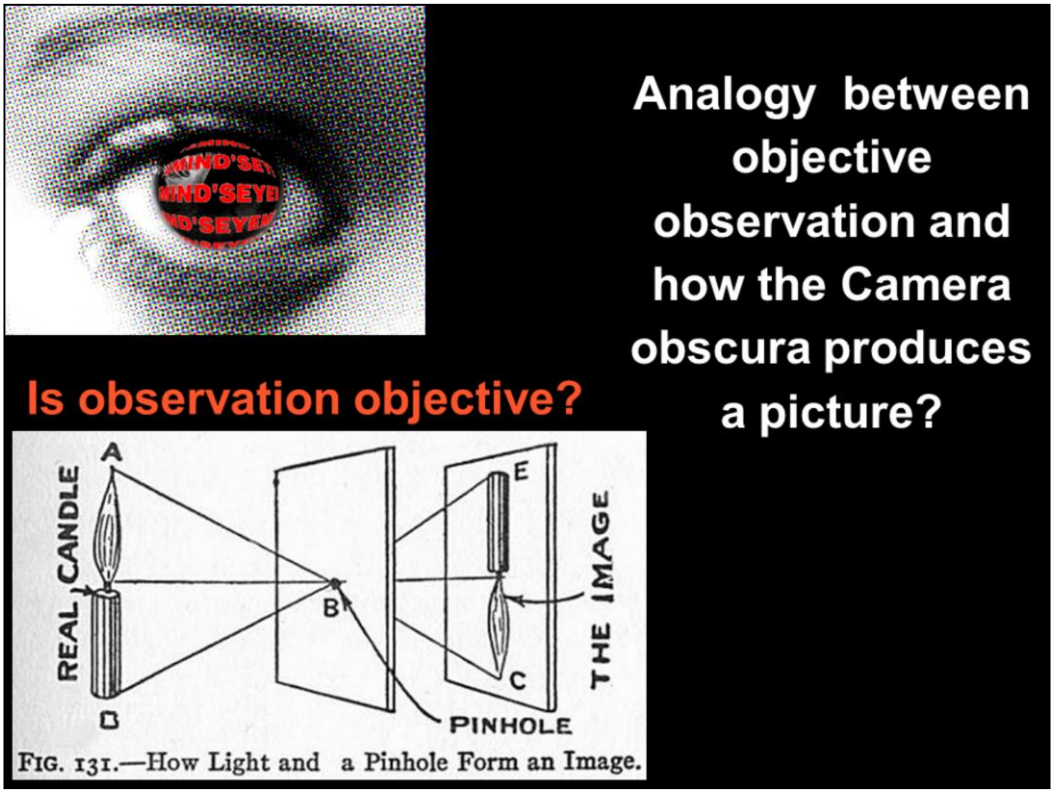
Schema of how the role of objectivity and rationality in sciences are conceived.

The question is: What is a objective? & What is an objective fact?



However, when this research continued, a more complex model was developed for the process behind the measured data. Bacteria dissolve metals from ore [resulting into a causal-mechanistic model of how bacteria do this, and a mathematical model of the measurable variables].

When applying this new theory to the initially measured data, it suddenly appears that the measured data at t=1 and t = 2 perfectly agrees with the data predicted with the new theory (the pink formula and line agrees with the measured data, rather than with the blue data predicted with the old theory). Hence, scientists now decide that these point were not due to measurement errors, but actually correct.

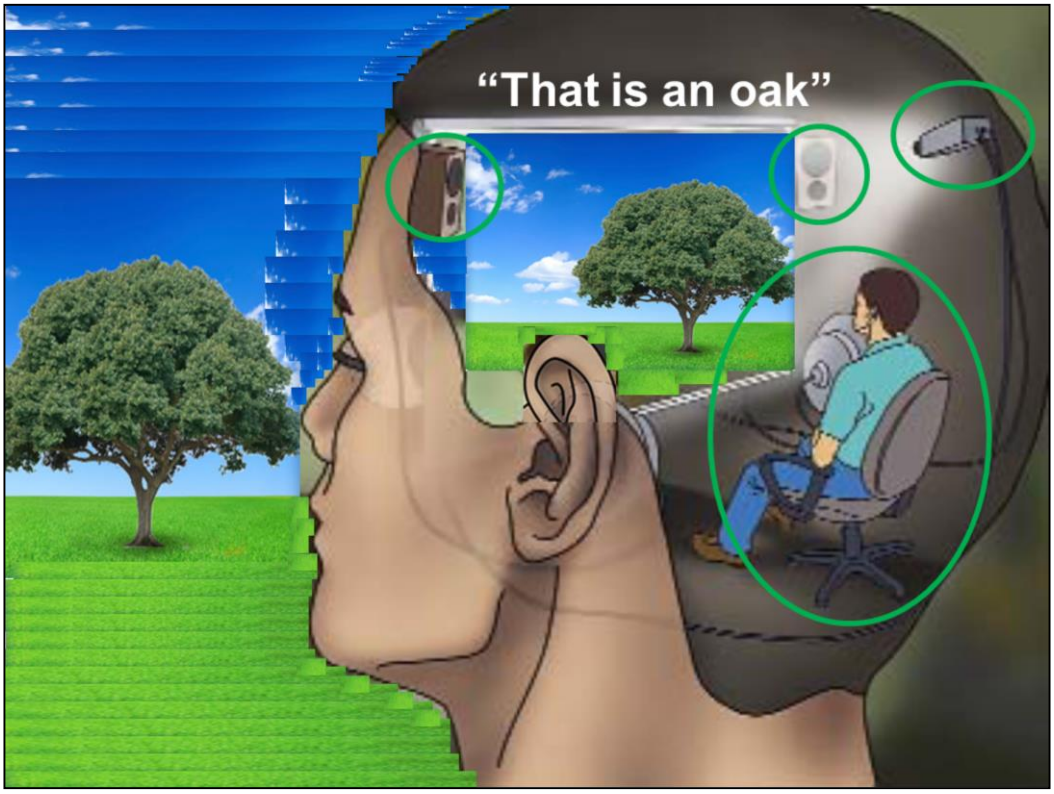


This metaphor of objective observation was explained in lecture 4. The idea is that, in order to be objective, the real object should be somehow mirrored or reflected at the back of the eye, similar to how the real object such as a candle is projected at the back of the Camera Obscura.

The point is, that in order to be objective (rather than subjective), nothing should be added or changed by the human sense organs or mind. The projection should come about passively.

Somehow as it is pictured here.

[Also this picture was explained already in Lecture 4.] In lecture 4, the point was to illustrate that we are not in the position to decide that the supposed picture in the mind *corresponds* to the real object outside. Here, the point is to illustrate that objectivity requires that the object must be mirrored in the mind without any contribution by the senses or the mind.



Yet, even if we would assume that objects are passively projected in the mind, there still is another problem, namely that a projection in the mind does not mean that it is observed by a person. [In this picture, you see how the outside world is projected by a beamer on the screen in the mind, and also the sound comes in through loud-speakers.] Seeing and hearing would require a little person in the mind, who sees and hears what is on the screen and speakers. But this happens in his mind of this little man (often called a ‘homunculus’), etc. In brief, a projection in the mind is not the same as what we consider as perceiving (seeing and hearing and describing) something.

The point made here is that, in order to arrive at a sentence such as ‘this is an oak’, we already need a concept. Where does this concept come from? It is *not* somehow delivered together with the observation! Instead, the concept is somehow added by the mind, not by the world. This situation is at the core of the problem of objective facts. In making descriptions of the outside world, humans indispensable add meaning (which is conceptual), resulting to the situation that observation is not completely passive.

8. Scientific terms have fixed and precise meaning

Kuhn claims Incommensurability:

- Meaning-incommensurability:

  The meaning of a term (e.g., a scientific concept) changes with a paradigm-shift

- Reference-incommensurability

  The world changes with a paradigm-shift.

=> **There is no objective reality and different paradigms can't be compared**

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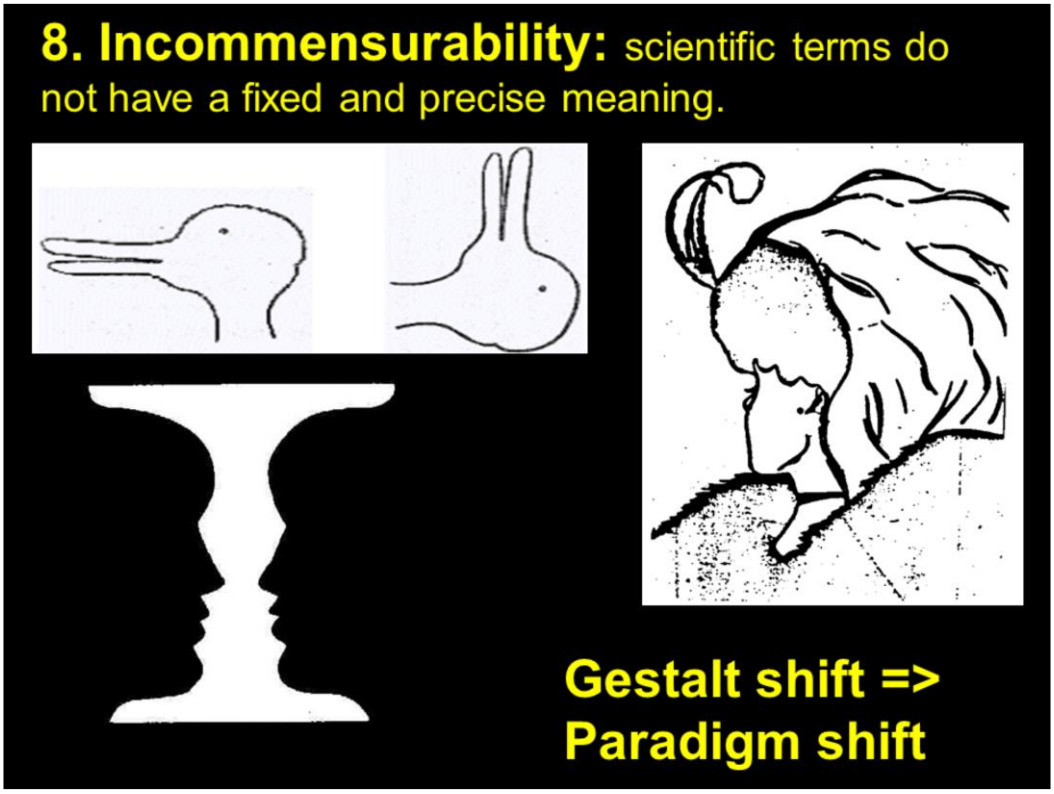
The meaning of the concept 'heat' in the caloric theory is different from the meaning of this concept in the succeeding theory of energy.

The meaning of the concept 'gravity' in Galileo's theory is different from the meaning of this concept in Newton's theory.

In other words, we remain using the same scientific concepts, but their meaning, and even their referent may change with a change of theory. [Try to think of examples yourself.]



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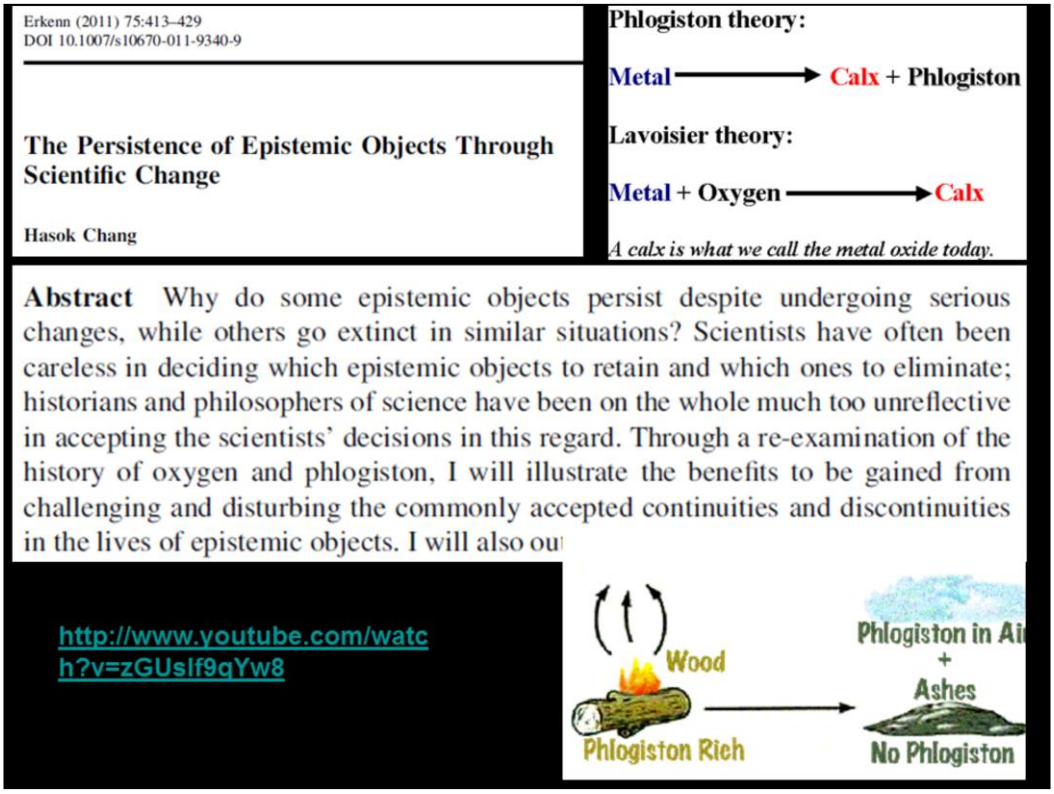
[1. duck and rabbit. 2. Faces and vase. 3. Young and old woman]

Something more can be learned from exploring what happens when we look at pictures (representations of real objects). Assume that a fox or a cat (or another animal that would love to eat a duck or a rabbit) looks at those picture. Would this predator recognize in this picture a duck (or a rabbit)? Probably not! Recognizing a duck (or a rabbit) in such pictures is typically human, and requires the ability of adding a concept to what we see. [Similarly, animals would never see constellations such as Big Dipper or Orion on the night sky.]

We always recognize patterns: we see these lines and pixels *as* something.



The victory of oxygen over phlogiston is often used as an example of how, by means of experiments, an accepted theoretical concept (phlogiston) is disproven, and replaced by another one (oxygen).

However, taking a close look at the history of science shows that there could have been reasons to keep 'phlogiston'.

This article can be used in Assignment 3.

Rough and dirty, Chang defends that the meaning of 'oxygen' (the concept) has changed over its history, and currently is much closer to the meaning of 'phlogiston' at the time 'oxygen was discovered.

Moreover, Chang defends that, had we kept 'phlogiston' for a while, it might have enabled us in thinking about energy.

Note. Currently, Hasok Chang is one of the most prolific historians/philosophers of science. Recently, he won a very prestigious prize for his last book on the 'discovery of water'. http://fernando-gil.org.pt/en/nominees/2013/winner/

Kuhn: Logical positivist and Popper's traditional picture of science:

1. Cumulative growth of science
2. Unified Science
3. Science is value-free
4. Distinction between *Discovery* & *Justification*
5. Scientific proof: Confirmation or Falsification
6. Distinction between science and other beliefs
7. Distinction between observation and theory.
8. Scientific terms have fixed and precise meanings.

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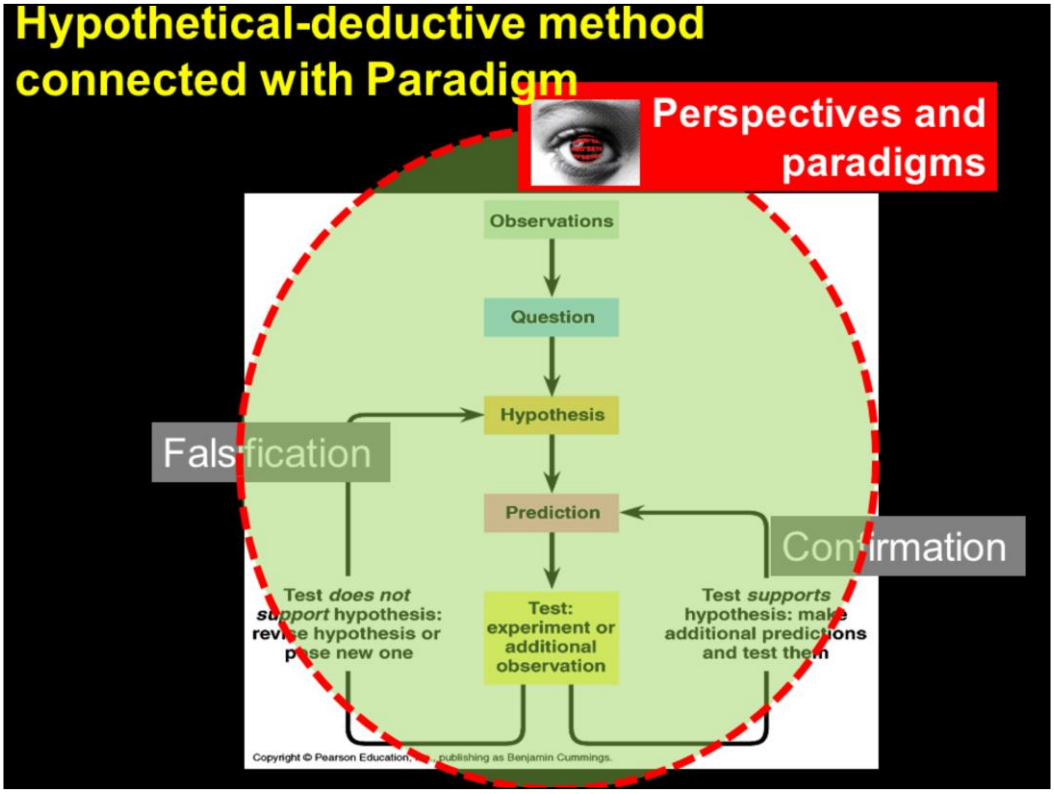
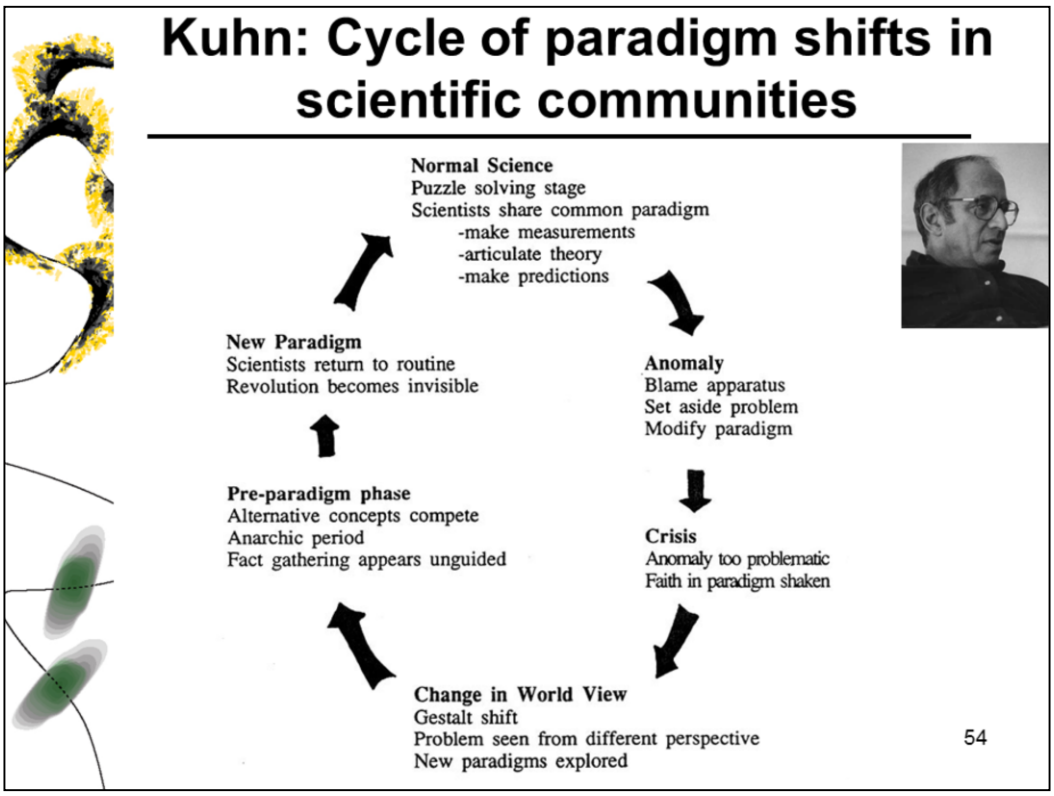
Overview



In this picture, the notion of paradigm is related to the HD method of science. The HD method applies for the construction and test of theories and models in ‘periods of normal science’. However, at the background, without them being really aware of it, scientists draw on a paradigm that guides them in how they do science. Through examples from the history of science, we can become aware of such bigger and smaller paradigms that play a role ‘at the bottom of our thinking’. Importantly, we cannot get rid of paradigms. Moreover, as Kuhn defended, a paradigm cannot be proven true or false in a straight-forward manner. Still, to some extent, paradigms held by scientists can be made explicit and explored.

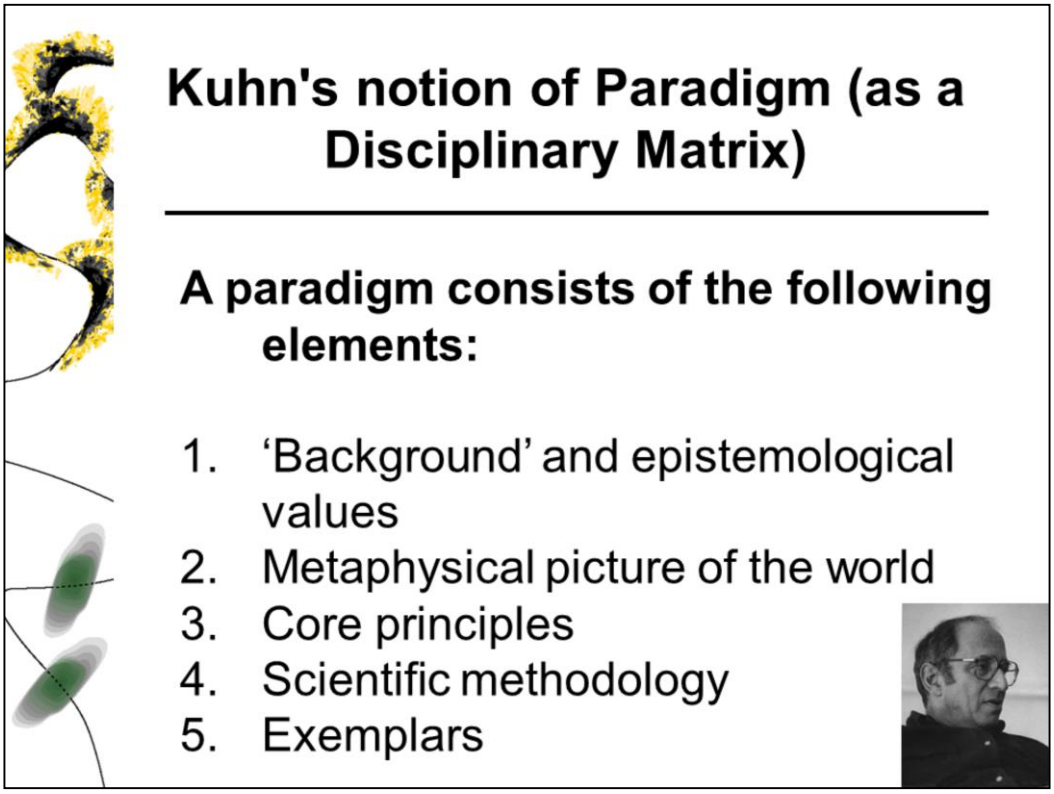


During periods of normal science, scientists do not question the fundamental principles of their discipline.

Against Popper: scientists do not easily abandon a basic theory (core principles which are part of the paradigm). Falsification is not enough.

Change of theory is not a fully rational and logical process. -> science is **less rational** than we wish to believe?

Relevance of philosophy of science is recognizing that there is a paradigm involved that may be questioned. Real breakthroughs in science are often due to changes at the paradigmatic level.



[Ladyman] Before scientific inquiry can even begin in some domain, the scientific community has to agree upon answers to fundamental questions about, for example: what kinds of things exist in the universe, how they interact with each other and with our senses, what kinds of questions may legitimately be asked about these things, what questions are central to the science, what counts as a solution to a problem, what counts as an explanation of some phenomenon, and so on. [Also see notes of slide 7].

Example: Ptolemaic world view versus Copernican world view; Alchemy versus chemistry; Vis viva ('living forces') versus biochemistry.

Exercise: Reconstruct the new paradigm that emerged when electro-magnetism became a new branch of science (as opposed to Newtionian mechanics) – also see the article by Smith: From Force to Energy (also summarized in lecture 8).