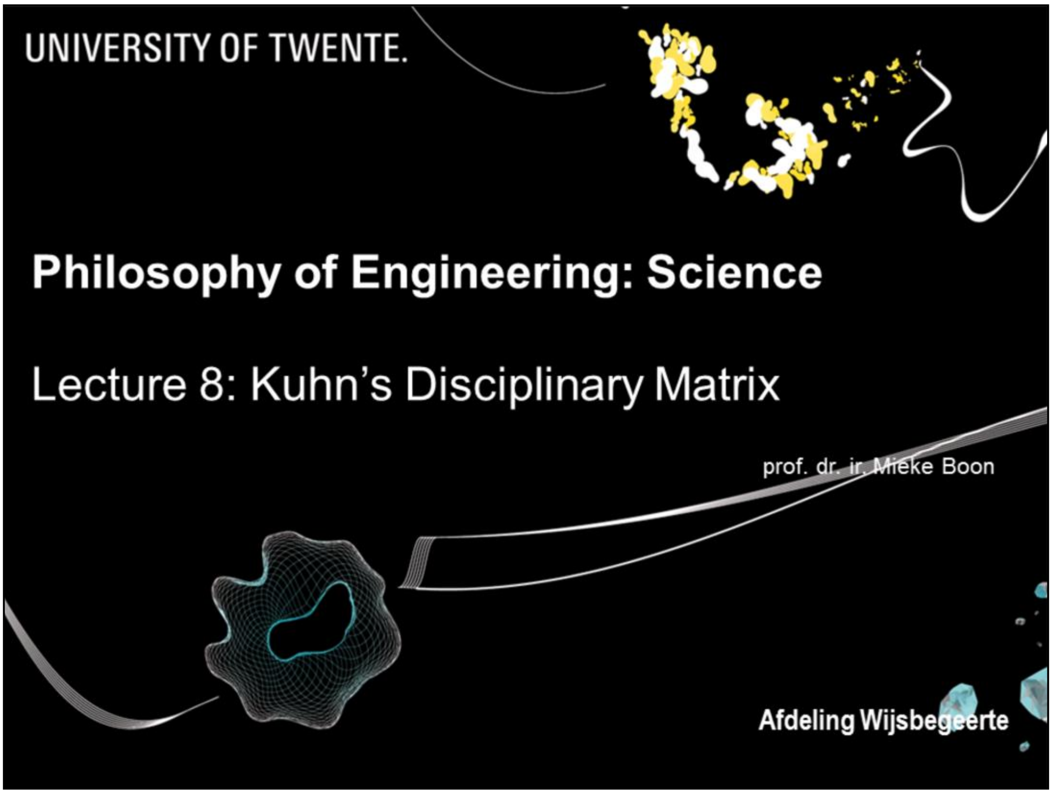
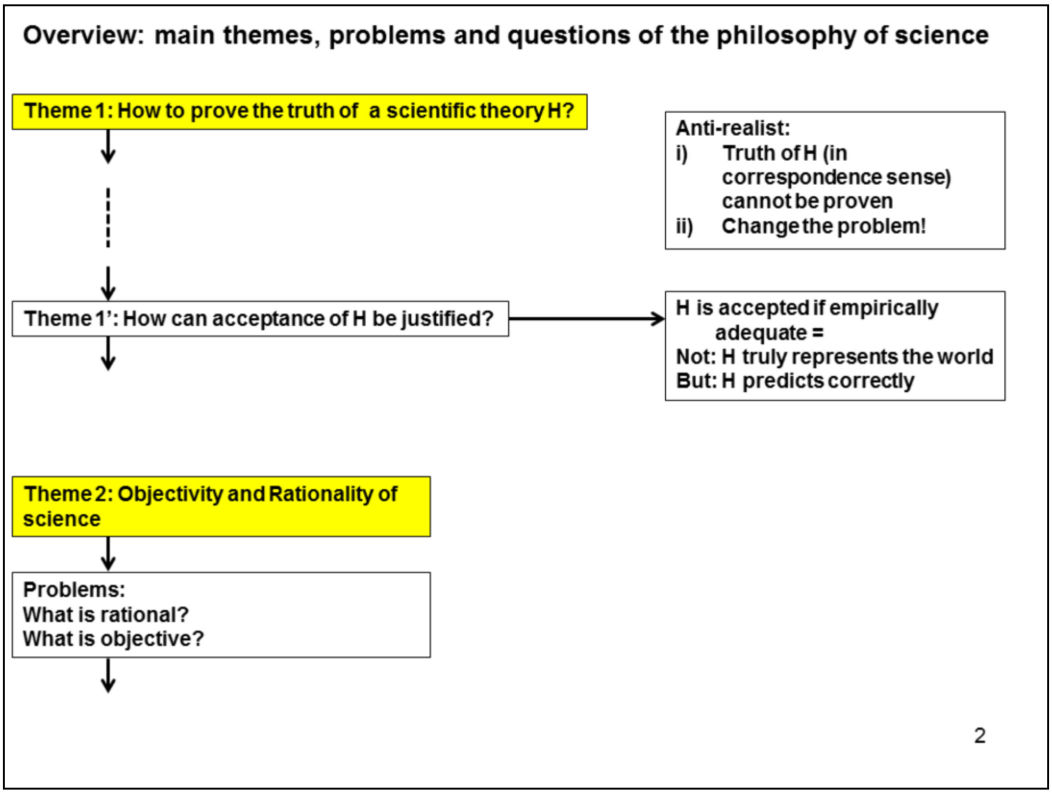
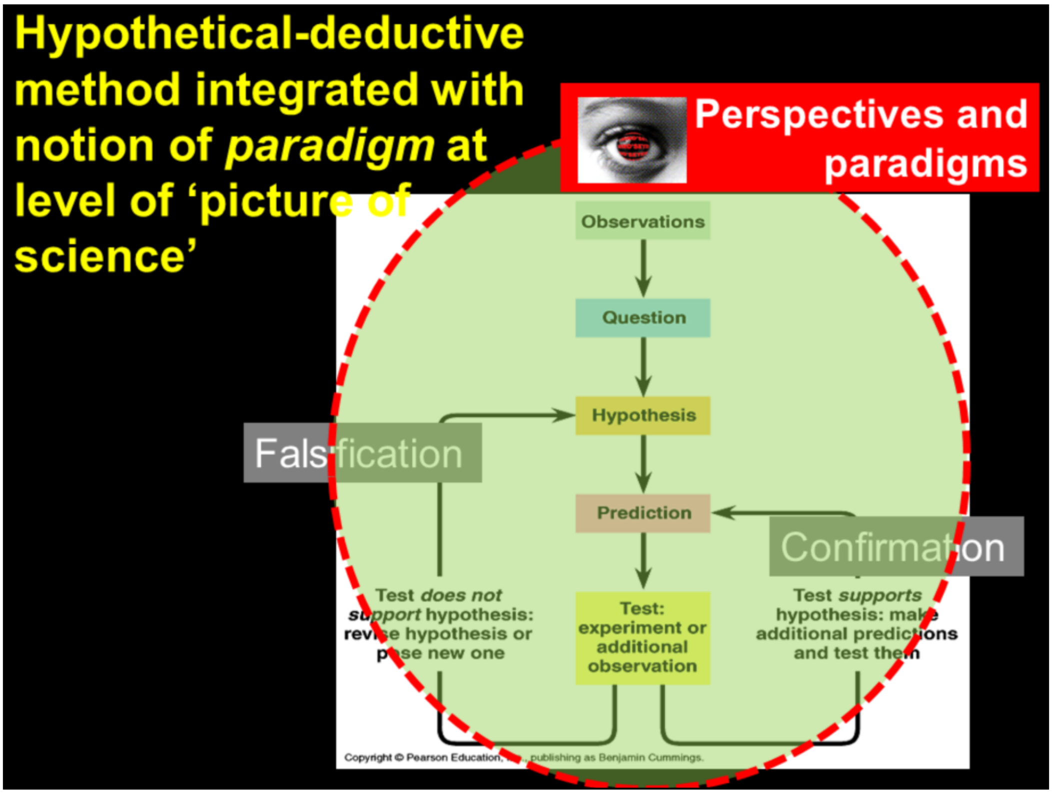


This lecture aims at explaining Kuhn's notion of disciplinary matrix, and to give several examples, in particular of 'metaphysical pictures of the world' (which is one aspect of the disciplinary matrix).



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



This schema pictures how Kuhn's notion of **paradigm** (and his more specific notion '**disciplinary matrix**') can be integrated with scientific methodology as described by the HD method. The disciplinary matrix is the (often implicit) background within which scientific research (in a specific field or discipline) is being done. In a sense, this background 'governs' and enables scientific research. Without such a 'disciplinary matrix' a scientist would hardly be able to observe something interesting, and he would not know how to formulate a significant research question, or how to formulate an explanation (hypothesis).

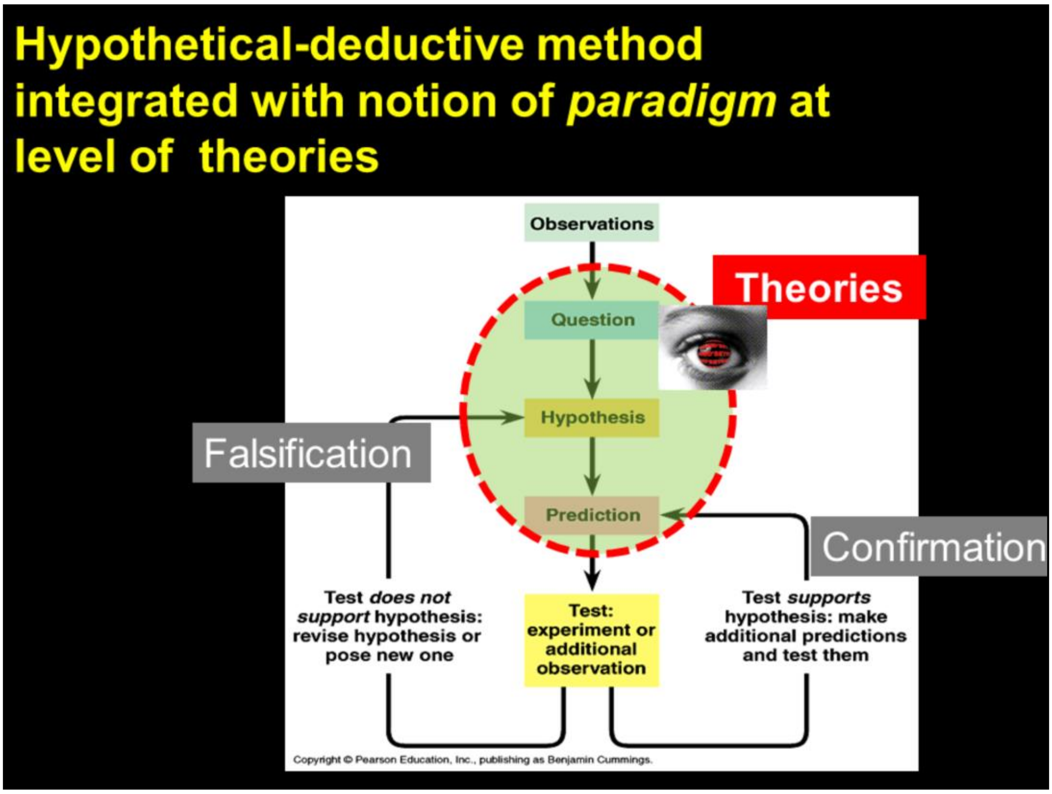
Although such aspects (of the paradigm or disciplinary matrix) often are implicit, making it explicit pays off. It makes you aware of the confines within which you do your research. In this way, you will understand more of the character of your own discipline. [Such an analysis of your own discipline is somewhat similar to what people do in psycho-analysis: they become aware of deeper, hidden layers that, without them noticing, govern their behavior – recognizing these patterns that govern emotional and behavioral responses may help in changing those that are unproductive or even harmful. Also, through understanding the background of your own emotional behavioral responses may raise awareness of different patterns determining the behavior of other people]. Also see notes on interdisciplinary research on the last slide of this lecture.

An example is the disciplinary matrix that enabled Newton to construct 'Newtonian mechanics'. Part of the new perspective that enabled Newton to construct this theory was articulated by Newton himself [Also see slide 9-18 in Lecture 2]. [Note that it is not always possible to make a strict distinction between these five aspects]:

1. The epistemological values mentioned on the next slide apply, but this list is not exhaustive.
2. Newton's metaphysical picture of the world is quoted on the slide below (every phenomenon should be explained in terms of particles and forces between them). Another important change in Newton's metaphysical world picture (already mentioned in Lecture Two) involves giving up on the (philosophical/metaphysical) assumption of his predecessors that there is a fundamental difference between the (chaotic) terrestrial [= on Earth] and (perfect) celestial world [=Heaven], resulting to the ideas that the same laws of nature hold everywhere in the Universe. This new metaphysical assumption (which at that time could not be proven!) enabled Newton to construct his theory [Note that Newton's construction of a mathematical model for the orbit of the moon, was grounded on this assumption]. Furthermore, the conception of 'Laws of Nature' as universal laws that govern nature, was a new kind of conception emerging in that age. Additionally, also new to Newton's approach was the idea that physical phenomena could be described in 'the language of mathematics.'
3. [In part, the core principles coincide with the methodology and also with the metaphysical picture]. Newton articulated several 's core principles which guided his modeling approach. See his 'rules of philosophizing' on slide below.
4. Newton's general methodology is new. He took a mathematical approach to modeling (explaining) physical systems (moving objects). This approach involves the initial mathematical definition of core concepts such as force and acceleration.
5. Exemplars: The kind of phenomena Newton aimed to understand focused on moving objects such as already described by Kepler and Galilei. E.g., the regular (and reproducible) motion of the planets and moon.

Understanding this background picture (the paradigm) helps us in understanding how it was possible that Newton (and not his predecessors) constructed this 'revolutionary' theory (also see Sadi Carnot as another example of constructing a revolutionary theory).

We can now see, how important such philosophical ideas are in doing science. Usually the role of a 'disciplinary matrix' is implicit – usually, we are not aware that it 'governs' us (i.e., that it guides the ways in which we look and reason in science). In scientific revolutions and 'breakthroughs' those ‘great scientists’ have reflected on ‘common sense’ and ‘self-evident’ assumptions; challenging these ‘commonly accepted ideas’ and creatively trying out ‘odd’, ‘implausible’ and ‘counter-intuitive’ alternatives. This is where philosophical and scientific thinking meet.



Paradigms that guide us in doing science may be less encompassing. Actually, the basic theories of a discipline play a similar role. The way in which a discipline phrases its questions and constructs its hypotheses is guided by the theory that is central to the discipline. An example is the evolutionary theory: all observations in this field are firstly interpreted in terms of variation and selection. And the presupposition that each trait or behaviour must be explained in terms of its contribution to the survival of a species.

In the former slide, the broad role of a paradigm in doing science was sketched. In this schema it is illustrated that a broad and general scientific theory may function in a similar way. In this case, we are usually aware of the role a theory plays in the way we look at and think about the world, ask questions, and explain observed phenomena.

For instance, if you see a tennis ball thrown by a child towards a glass-window, you may immediately interpret this situation in terms of Newtonian mechanics: you 'observe' an object having momentum and foresee its curved trajectory; you will ask questions such as whether it will hit the ground before it hits the window, and whether its momentum will break the glass. Furthermore, you know how this occurrence can be mathematically modeled. Hence, your looking at and thinking about this situation is 'guided' by that theory (Newtonian mechanics). [Note that a psychologists may 'see' and interpret and explain this situation very differently! – Also see notes on Interdisciplinarity in the last slide.]

Hence, also Newtonian mechanics itself (i.e., the theory) can be analyzed in terms of the five aspects of a disciplinary matrix. The theory can be considered as a ‘framework’ in terms of which physical systems that consist of moving objects are interpreted and mathematically modeled:

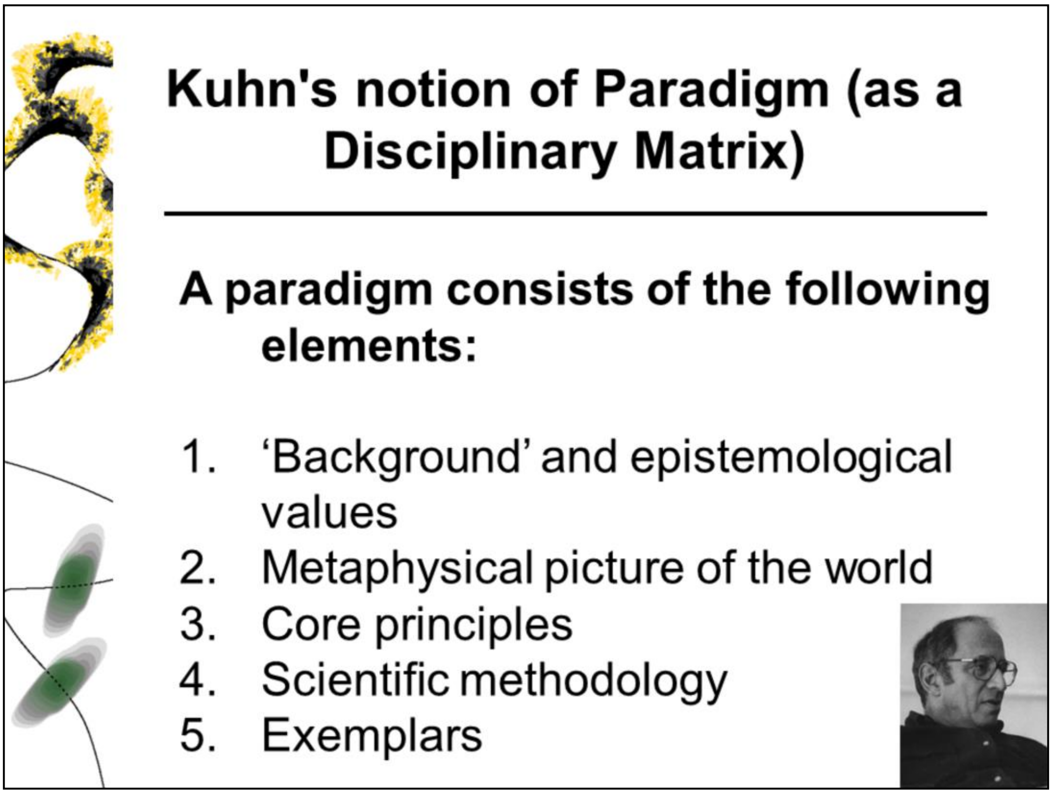
(1) Epistemological values: Mathematical consistency and coherency are crucial. Empirical adequacy as an epistemological value in this field is debatable: In most cases, quantitative predictions made by means of a mathematical model constructed for a Newtonian system will disagree with measurements made of the real, physical system. In other words, strictly speaking the constructed model is empirically inadequate. Our common solution is to explain why the theoretically predicted values disagree with the measurements. Scientists say then that the real system is not ideal. (e.g., due to friction, or elastic behavior, or because it is not a point-mass). Note that this also implies that Newton’s theory can hardly be falsified: The theory actually always applies for Newtonian system (but we know that it leads to incoherencies when applied to ‘relativistic systems’), and anomalies must be explained by other physical phenomena that affect the behavior of the system.

(2) Metaphysical picture: Physical behavior of moving bodies as described in Newton’s axioms. [Suggestion: read the axioms (e.g. “Every body continues in its state of resting or of moving uniformly in a straight line, except insofar as it is driven by impressed forces to alter its state.”) as a metaphysical picture.

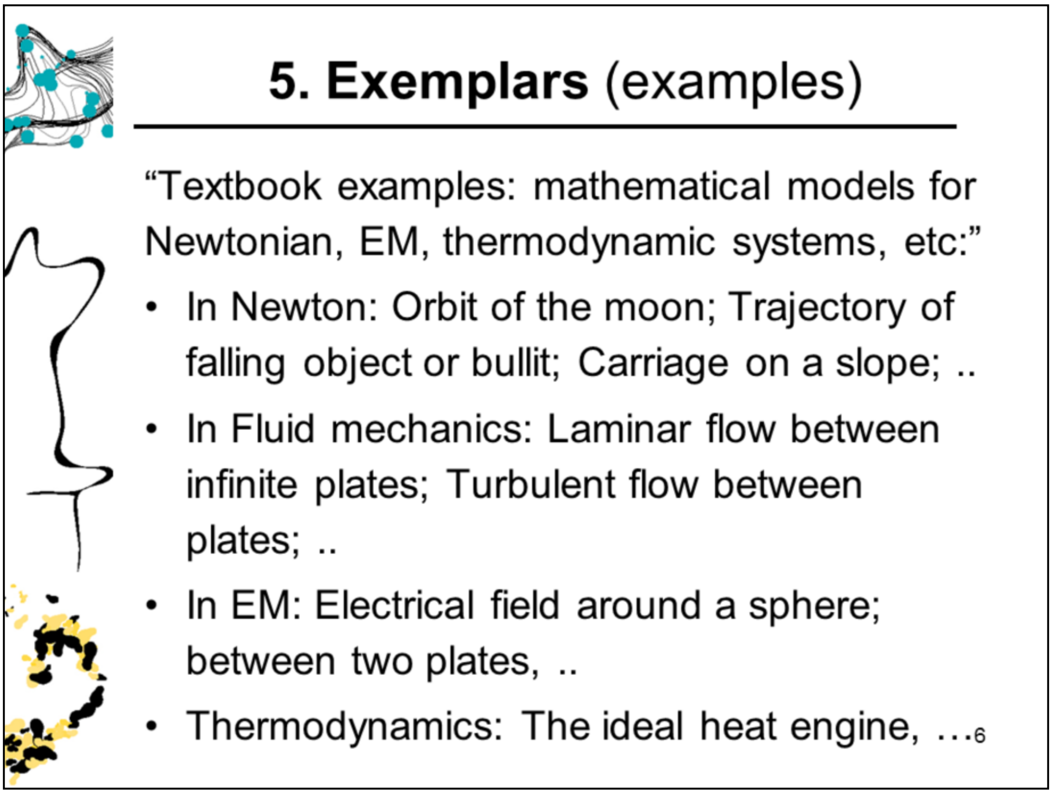
(3) Core principles: Newton’s laws, and several of the laws derived for typical Newtonian systems (e.g., the behavior of elastic objects; the oscillating pendulum).

(4) Scientific methodology: The mathematical approach to modeling a Newtonian system (e.g., trajectories of moving objects).

(5) Exemplars: The examples you have seen in your physics textbooks on Newton’s theory at high school (trajectory of a bullet, orbit of the Moon, oscillating pendulum).



Kuhn's initial notion 'paradigm' was obscure and seemed to have many different meanings. In his post-script to the second edition of his book, Kuhn therefore specified this notion, and calling it a **disciplinary matrix**. A disciplinary matrix consists of these five aspect. In the next slide, examples are given of (1) background and epistemological values that guide in selecting and accepting theories. This lecture will focus on examples of (2) metaphysical pictures of the world.



Core principles and methodology guide how scientists reason. These are firstly the rules of logic (which forbid logical inconsistencies in our reasoning). However, these rules are necessary but not sufficient in scientific reasoning. On the next slide, you find Newton’s ‘rules of philosophizing’. Newton articulated some additional rule that guides his reasoning.

4. Methodology (examples)

- Deductive reasoning (derivation from first principles)
- Inductive reasoning (observation & experimentation + generalization)
- Falsification
- Statistical reasoning
- Hypothetical-deductive reasoning (including: testing of hypothesis by means of experiments).
- Explanatory reasoning (IBE)

7

Core principles and methodology guide how scientists reason. These are firstly the rules of logic (which forbid logical inconsistencies in our reasoning). However, these rules are necessary but not sufficient in scientific reasoning. On the next slide, you find Newton's 'rules of philosophizing'. Newton articulated some additional rule that guides his reasoning.

1. Epistemological values, e.g.:

- Truth (?!)
- Internal (logical) consistency of theory.
- Coherence with accepted knowledge and facts, or empirical adequacy of theory.
- Accuracy or predictive power.
- Simplicity.
- Explanatory power.
- Generality or scope.
- Fruitfulness in finding new aspects of world and how to manipulate it.

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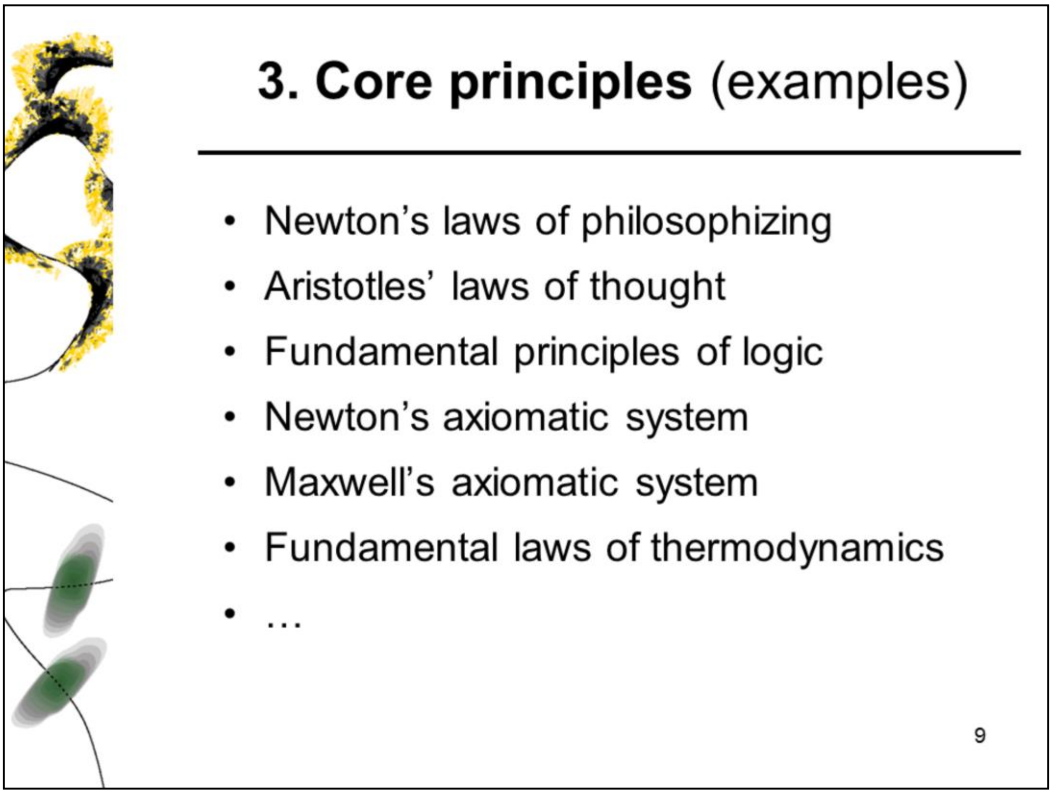
Examples of the first aspect of Kuhn’s disciplinary matrix, as mentioned by Kuhn.



Core principles and methodology guide how scientists reason. These are firstly the rules of logic (which forbid logical inconsistencies in our reasoning). However, these rules are necessary but not sufficient in scientific reasoning. On the next slide, you find Newton’s ‘rules of philosophizing’. Newton articulated some additional rule that guides his reasoning.

Newton's rules of philosophizing
(Ontology and Methodology)

Rule 1: That there ought not to be admitted any more causes of natural things than those which are both true and sufficient to explain their phenomena. [Simplicity – or, Ockam's raizor].

Rule 2: Accordingly, to natural effects of the same kind the same causes should be assigned, as far as possible. [Same effect, same cause].

Rule 3: The qualities of bodies ... are to be taken as qualities of bodies universally. [Parts have same properties as whole].

Rule 4: In experimental philosophy, propositions gathered from the phenomena by induction are to be taken as true, .. [Falsification – or, Explanation is true as long as not counter-example has been found.]

Core principles that guided Newton in his construction of Newtonian mechanics were articulated by him in his 'rules of philosophizing.'

- Rules of philosophizing are rules used in 'showing' that the established mathematical principles 'apply to' or 'constitute' the real world.
- They are rules that describe the way we actually think if we are thinking philosophically.
- They are standards of sound reasoning about phenomena, causes, and properties of matter.
- They describe the working of the mind of a careful thinker; what we would call scientific thinking.

Think of the following: How can these rules be justified. Are these rules correct from a logical point of view? Are these rules necessary in the sense that their denial leads to a contradiction? Do these rules involve other metaphysical presuppositions? [Here you see that a sharp distinction between core principles and a metaphysical picture is not always possible. For instance: Every event has a cause, is part of an ontological picture of the world, but also a rule of reasoning.] Note, for instance, that Rule 2 is false from a logical point of view, and also it can be falsified empirically as counter-examples to this rule can be easily found.

Newton probably articulated these rules by careful philosophical reflection on how he reasons himself.

Note that philosophy and science used to be closely connected. Scientists used to reflect on their own presuppositions (= fundamental principles).

Aristotle's laws of thought:
Fundamental principles of logic (Methodology)

	Natural language:	**Formal language**
Law of identity	An object is the same as itself. Everything is 'the same with itself and different from another'	A ≡ A "A is A and A is not ~A"
Law of excluded middle	Contradictory propositions cannot both be true in the same sense at the same time.	"No one thing can simultaneously be a member of both A and ~A"
Law of non-contradiction	Either proposition is true, or its negation is.	"Every single thing must be a member of either A or ~A"

Yet, Newton was not the first to articulate rules of thinking. Aristotle, already in the 4th Century BC, articulated 'laws of thought', which are the fundamental principles of logic.

Basic principles of logic. At any particular time, in any particular context:
http://en.wikipedia.org/wiki/Principle_of_contradiction

"The law of non-contradiction and the **law of excluded middle** are not separate laws *per se*, but correlates of the law of identity. That is to say, they are two interdependent and complementary principles that inhere naturally (implicitly) within the law of identity, as its essential nature. To understand how these supplementary laws relate to the law of identity, one must recognize the dichotomizing nature of the law of identity. By this I mean that whenever we 'identify' a thing as belonging to a certain class or instance of a class, we intellectually set that thing apart from all the other things in existence which are 'not' of that same class or instance of a class. In other words, the proposition, "A is A and A is not ~A" (law of identity) intellectually partitions a universe of discourse (the domain of all things)into exactly two subsets, A and ~A, and thus gives rise to a dichotomy. As with all dichotomies, A and ~A must then be 'mutually exclusive' and 'jointly exhaustive' with respect to that universe of discourse. In other words, 'no one thing can simultaneously be a member of both A and ~A' (law of non-contradiction), whilst 'every single thing must be a member of either A or ~A' (law of excluded middle)."

Fundamental principles of logic ('ontological')

	Natural language:	**Formal language**
Existence	Every thing ***is*** some thing.	For every x there is an y such that x=y
Identity	A thing ***is*** the thing it is.	For every x, x=x
Uniqueness	No thing ***is*** another thing than the thing it is.	For every pair of things, x and y, not (x=y)
Specificity	Every thing ***has*** some property.	For every x , there is a property Z such that Z(x)
Excluded middle	A thing ***has** or does not have* a particular property.	For every x and every Z, Z(x) or not Z(x)
Non-contradiction	No thing ***has** and does not have* a particular property.	For no x and no Z, Z(x) *and* not Z(x)

Basic principles of logic.

Note that the sentences in Natural language are about the world, whereas the principles in the formal language are rules of logic. The two are closely connected and seem to support each other.

Can these principles be challenged?

Challenging the paradigm of logic and math: Intuitionistic logic (L.E.J. Brouwer, 1907)

http://plato.stanford.edu/entries/intuitionistic-logic-development/

- In "*The untrustworthiness of the principles of logic*" Brouwer challenged the belief that the rules of the classical logic have an absolute validity, independent of the subject matter to which they are applied.
- Problems and concepts:
- "The present King of France is bald" is true or false?
- Realism versus Anti-realism (Constructivism, *mental constructs*).
- *Provability* = constructing a mathematical proof.
- **Brouwer rejects the principle of the excluded middle**. "*A* or not *A*", is not accepted as a valid principle.

Basic principles (axioms) are constructed such that they account for certain 'insights' that are 'intuitively clear', 'obvious', self-evident and relevant to us. For instance, the **law of the excluded middle** as it was explained on the former slide.

Yet, major scientific breakthroughs often result from reflection on basis principles:

- By introducing or articulating new principles for specific fields (e.g. Euclid, Aristotle, Newton, L.E.J. Brouwer, E.W. Dijkstra).
- By challenging existing, well-accepted and 'self-evident' principles such as the **law of the excluded middle** (e.g., L.E.J. Brouwer).
- By thought-experiments, testing our presuppositions at 'extreme conditions' or 'at the limits'. (e.g., Albert Einstein's though-experiments).

[Note: Explanation of this example in mathematics is not part of my common expertise and draws on several sources mentioned below. Consult sites and literature referred to, if you wish to understand it in more depth.]

The example addressed here is L.E.J. Brouwer, who challenged the law of the excluded middle.

Why?

Consider this problem in logic:

Since the law of excluded middle tells us that every statement is either true or false, the sentence “The present King of France is bald” must be either true or false. Which is it?
Since there is no present King of France, it would seem quite unusual to claim that this sentence is true. But if we accept the law of excluded middle, this leaves us only one option - namely, to claim that it is false.

Source:
http://www.stanford.edu/~bobonich/glances%20ahead/IV.excluded.middle.html

“Early in his career, Brouwer proved a number of theorems that were breakthroughs in the emerging field of topology. The most celebrated result was his proof of the topological invariance of dimension.

Brouwer in effect founded the mathematical philosophy of intuitionism as an opponent to the then-prevailing formalism of David Hilbert … (cf. Kleene (1952), p. 46–59). As a variety of constructive mathematics, intuitionism is essentially a philosophy of the foundation of mathematics. It is sometimes and rather simplistically characterized by saying that its adherents refuse to use the law of excluded middle in mathematical reasoning.”

In the philosophy of mathematics, **intuitionism**, or **neointuitionism** (opposed to preintuitionism), is an approach to mathematics as the constructive mental activity of humans. That is, mathematics does not consist of analytic activities wherein deep properties of existence are revealed and applied. Instead, logic and mathematics are the application of internally consistent methods to realize more complex mental constructs.

http://plato.stanford.edu/entries/intuitionistic-logic-development/

“There is a special case […] which really seems to presuppose the hypothetical judgment from logic. This occurs where a structure in a structure is defined by some relation, without it being immediately clear how to effect its construction. Here one seems to *assume* to have effected the required construction, and to deduce from this hypothesis a chain of hypothetical judgments. But this is no more than apparent; what one is really doing in this case is the following: one starts by constructing a system that fulfills part of the required relations, and tries to deduce from these relations, by means of tautologies, other relations, in such a way that in the end the deduced relations, combined with those that have not yet been used, yield a system of conditions, suitable as a starting-point for the construction of the required system. Only by this construction will it then have been proved that the original conditions can indeed be satisfied. (Brouwer 1907, 126–127)/(Brouwer 1975, 72 (modified))”

Does intuitionistic logic have any practical relevance? Intuitionistic formal logic is used in informatics. For instance, in correctness proofs of an algorithm. http://en.wikipedia.org/wiki/Intuitionism

2. Metaphysical picture
(examples)

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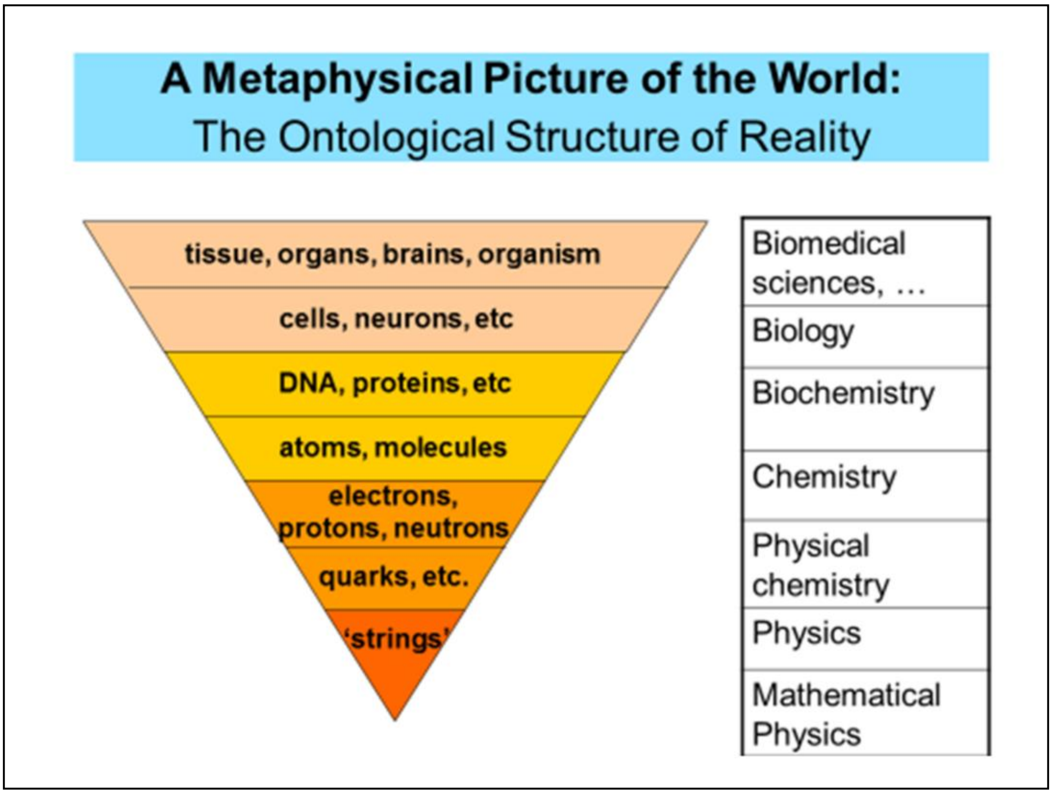
Fundamental ontological principles (examples)

1. There exists a fundamental order in the world.
2. There exists a fundamental matter of which everything else is being built => determinism, reductionism, materialism, scientism => problematic for notion of ‘mind’ (our mind emerge from matter), and the notion of ‘God’.
3. There exists only one fundamental kind of cause => problematic for notion of ‘mind’ (our minds cannot be a cause of anything but must be reduced to material cause).
4. ‘Linear time’ => The Universe must have a beginning in time => problematic in cosmology / astronomy.
5. ‘Linear space’ => The Universe must be finite => problematic in cosmology / astronomy.
6. Every occurrence (or, change) has a cause => problematic in quantum mechanics.
7. Same cause, same effect.

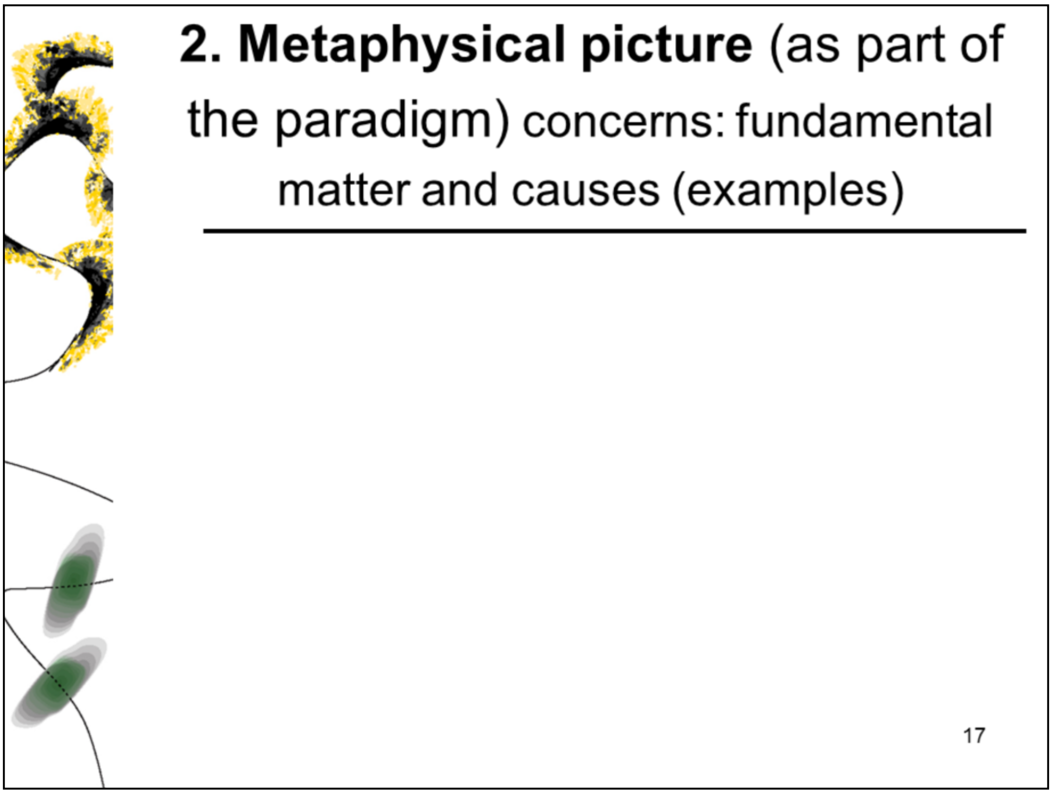
This is a metaphysical picture that many physicists currently hold. These ontological principles (ideas about what the world ‘fundamentally’ is like), cannot be proven or disproven, but guide the way in which scientific research in physics is being done.



This metaphysical picture (which assumes this ontological structure in which higher level entities and processes result from lower level entities and phenomena) may be part of our 'Picture of Science.' This structure is called a reductionist ontology. It motivates reductionist approaches (= a reductionist methodology) in science. It also motivates an ordering between more and less fundamental sciences.

These assumptions – of a basic ontology – are reflected in how we conceive of the relationships between the sciences. This pyramid reflects this a so-called reductionist picture of the Universe and of the sciences studying that Universe. Mathematical physics is considered the fundamental science, and is about the (theoretically postulated) entities that supposedly inhabit the real world and form the building-blocks of everything that exists. Theoretically postulated entities and laws at a more fundamental level are supposed to be the building-block and cause of physical phenomena and objects at a higher level of complexity. Therefore, the sciences shall explain phenomena at a higher level in terms of phenomena, objects and laws at a lower, more fundamental level.

The point is not to claim that this metaphysical picture of the world – the supposed ontological structure of reality – is true or wrong, but rather, that it cannot be proven (nor disproven). Instead, this picture is presupposed and guides the ways in which we do scientific research. We assume, for instance, that processes in the brain consist of, and are to be explained in terms of bio- and electrochemical processes occurring in neuro-physiological structures. It is only more recently, that scientific researchers have become aware that in some cases explanations must go the other way around: processes at a ‘lower’, more fundamental level are affected by the more complex system they are part of. For instance, DNA is not only the cause of biological structures such as cells, but also affected by this environment.



The ‘ontological structure of the world’ just mentioned is one example of a ‘metaphysical picture’ in Kuhn’s notion of ‘disciplinary matrix’. It is the modern metaphysical picture maintained in science. It is the background picture that makes scientific approaches possible – it guides and enables scientific reasoning. Also, a metaphysical picture of the world closes-off alternative approaches. For instance, astrology, homeopathy and intelligent design are rejected (i.e., supposed to be falsified) not on the basis of empirical findings, but on the basis of the ‘commonly accepted’ metaphysical background pictures. [You may ask whether it would be possible to do research into the phenomena claimed by these so-called ‘pseudo-sciences’. Notice that even the mere possibility of these phenomena is already rejected by the metaphysical background picture, which means that the metaphysical background picture even prevents us from *observing* these phenomena (as was already suggested by Kuhn: observation is theory-laden).]

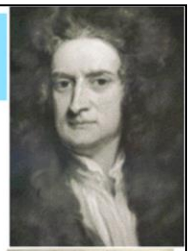
However, this widely accepted metaphysical picture of science may change due to new developments in science. A current change is due to the notion of *information*, which differs from the notion of physical building-block and laws of nature as the primary causal and explanatory entities. DNA, for instance, is understood as a carrier of information (a blue-print) rather than the physical building-block of cells. Another example is new ideas and concepts developed in *complexity* and *self-organization* research, which also may result to radical changes in the metaphysical picture of the ontological structure of the world (think of the example just mentioned: DNA being the blue-print of the biological system it is part of, but also, DNA is affected itself by this biological system).

Another important aspect of this metaphysical picture is the concept of reductionism itself. The reductionistic ontological picture suggests ‘simple’ explanations (such as DNA as a straight-forward blue-print of an organism, and ‘variation & selection’ as a straight-forward mechanism of evolution). However, in real scientific practice, it usually appears that these initial ‘beautifully simple’ explanations are far too simplistic, and the more phenomena scientists aim to explain by such theories, the more additional aspects are to be introduced.

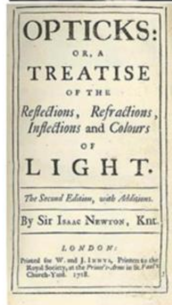
In these examples we have been looking at possible changes in the current metaphysical picture that guides scientific research. We can also look at the history of science. Did scientists in the past have the same metaphysical picture we have today? Clearly not, as they didn't know many of the theoretical entities that feature in the ontological structure shown above.

Also scientists in the past needed a metaphysical picture that guided them in their ways of finding scientific explanations of observable phenomena. A very explicit example can be found in Newton’s *Optics*.

Newton's Metaphysical picture:



that we could "derive the rest of the phaenomena of Nature by the same kind of reasoning from mechanical principles [as in the case of gravitation] for I am induced by many reasons to suspect that they may all depend upon certain forces by which the particles of bodies ... are either mutually impelled towards one another .. or are repelled and recede from another.."



Many writers followed Newton and attempted to account for diverse phenomena by combinations of attractive and repulsive forces between particles or point atoms.

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In the *Optics* (1718), Newton explicitly states how, according to him, every phenomenon should be explained (carefully read this quote by Newton!). The metaphysical picture Newton expresses here is a '**corpuscular' world view**: Newton believes that all phenomena are to be explained in terms of (unobservable!) particles and the forces between these particles. So, to spell this out a little bit further, Newton suggests that explanations of observable (perceivable) phenomena should be found in terms of a limited set of different kinds of particles. The specific properties of a specific kind of particle, then, is responsible for the observed behavior. Do you think that Newton's metaphysical picture is 'fundamentally' different from the current metaphysical picture (the pyramid just shown)?

1) Newtonian objects in Newtonian mechanics are masses that attract each other, which explains the phenomenon of gravity.

2) Also air and light were considered to consist of particles (see notes on the next slide). [The way I understand Newton's metaphysical picture more precisely is that (he believes that) the world consists of **particles of matter**, *and* particles that interact with these particles of matter and which are responsible for the attraction and repulsion forces. I do not know whether or how Newton explained gravity. In any case, he did not explain it in terms of 'gravity particles', but I am not certain whether he considered

gravitational attraction as a property of the particles of matter themselves, or whether he remained silent on this issue.]

3) In the *Optics*, Newton aims to explain (the transfer of) light in terms of **aether particles**.

4) Maxwell, in his *On physical lines of Force* (1860), which he wrote almost 150 years after Newton's *Optics*, aimed to explain the observed phenomena of electricity and magnetism in terms of these particles, called aether. On the next slide, the properties of aether as they were articulated by Newton in his *Optics* (which aims at explaining the behavior of light), are summarized. Note that these properties were attributed to aether, <u>not</u> because aether itself was studied, but instead, these properties of aether were postulated in order to make sense of (= explain) the observed behavior (e.g. of light) for which aether was supposed to be causally responsible.

5) An example of <u>another kind of 'fundamental' particle</u> is **caloric particles**. This kind of particle is held responsible for the phenomenon of heat. Again, postulating this particle can be understood as being guided by the metaphysical picture of the world (articulated by Newton): all phenomena must be explained in terms of particles that attract or repel each other. Note that, apparently, heat could not be explained in terms of aether. Can you, from comparing the properties of these two kinds of particles (on the next two slides) understand why not?

Compare the descriptions (i.e., the properties) of the two different kinds of fundamental particles on the next two slide (aether and caloric), and imagine whether, if you were a scientific researcher in the 18th century after Newton, explanations of phenomena such as light and heat in terms of these particles would have been plausible / convincing for you? Was it then plausible to believe in the <u>existence</u> of these particles?

Kuhn's point is that, at that time, it was <u>rational</u> to believe in the <u>existence</u> of these kinds of unobservable particles, as the existence of these particles was supported by a lot of evidence: more and more observable phenomena could be explained by them. 'Apparent' anomalies sometimes required to adapt the conception of these particles (i.e., required the introduction of auxiliary hypothesis). Yet, this approach (the introduction of auxiliary hypothesis) is not really a problem, as it is a process of refining our knowledge of these particles – we learn to know more and more of its detailed properties, which is never a reason to discard of the postulated object! [An example is the introduction of 'latent' versus 'sensible' heat of caloric].

Note that this way of reasoning does not come across as odd or irrational! This is how we reason all the time in scientific practices – also in current scientific research. The broad, fundamental theory (such as caloric and aether) is maintained if ‘strange things’ (incoherencies) come up that are not easily explained by it (= anomalies). Usually our scientific solution is not to consider this anomaly as a falsification, but instead, scientists aim to refine and adapt the theory. Kuhn pointed at ‘revolutions in science.’ These occur when indeed the fundamental theory is replaced. This happens in different ways: (1) Scientists say they have proven that aether and caloric do not exist (which is actually incorrect – instead, what actually happened is that better explanations have been found). (2) The metaphysical picture itself radically change. So, the metaphysical picture of Newton, which says that all phenomena are to be explained in terms of particles is replaced by an alternative metaphysical picture. The history of science article by Smith “*From force to energy*” (file in Blackboard, and also summarized below), describes how this metaphysical picture was replaced in the history of science: the idea of particles and forces as the primary cause, was replaced by the notion of energy as the primary cause.

Aether, or Luminiferous ether
(e.g. Newton in *Optics*, 1718)

1. Aether is an all-pervading substance (permeating all matter and space), the particles of which repel each other (which explains action at distance).
2. Particles of aether are smaller than those of air.
3. Aether acts as the medium for transmission of electro-magnetic waves (e.g. light), much as sound waves are transmitted by elastic media such as air.
4. Aether is weightless, transparent, frictionless, chemically and physically undetectable.

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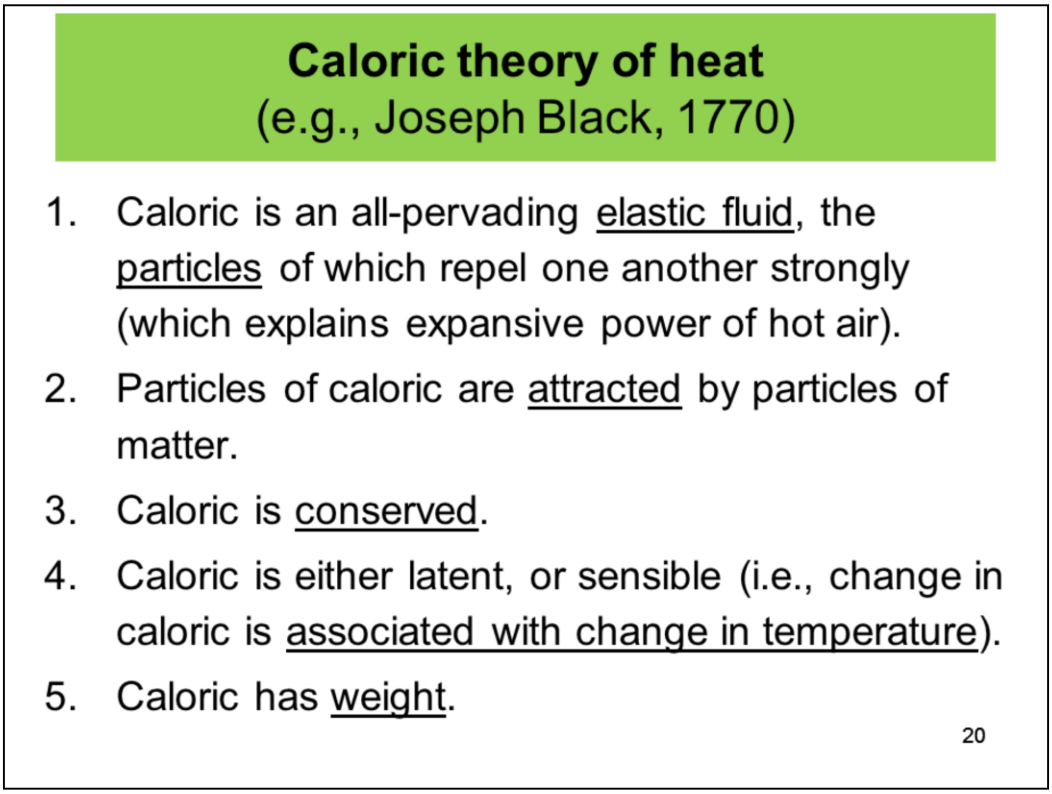
http://en.wikipedia.org/wiki/Timeline_of_luminiferous_aether

Newton wrote, "I do not know what this Aether is", but that if it consists of particles then they must be "exceedingly smaller than those of Air, or even than those of Light: The exceeding smallness of its Particles may contribute to the greatness of the force by which those Particles may recede from one another, and thereby make that Medium exceedingly more rare and elastic than Air, and by consequence exceedingly less able to resist the motions of Projectiles, and exceedingly more able to press upon gross Bodies, by endeavoring to expand itself."

Note that nothing is said about the interaction between particles of aether and particles of matter (compare with caloric below).



Note that this description of caloric accounts for the interaction between caloric and ‘particles of matter’.

Reasoning within a paradigm:

Metaphysical picture concerns fundamental matter and causes

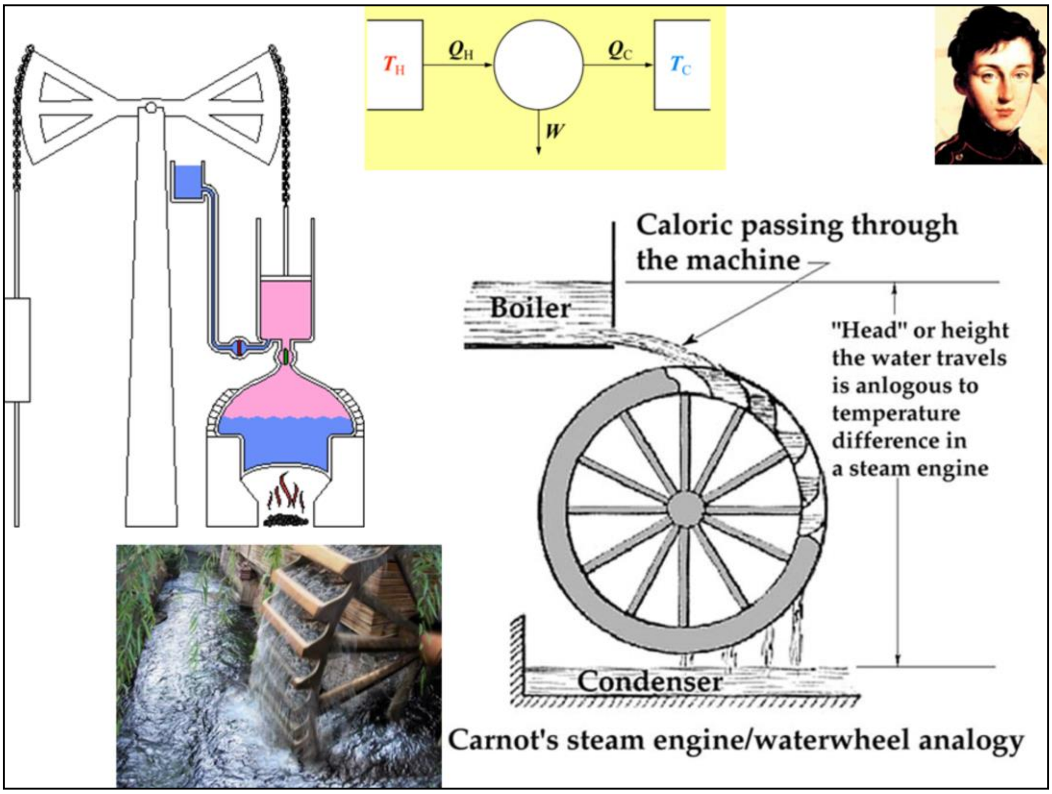
21

Wiki:

Nicolas Léonard Sadi Carnot (1 June 1796 – 24 August 1832) was a French physicist and military engineer who, in his 1824 *Reflections on the Motive Power of Fire*, gave the first successful theoretical account of heat engines, now known as the Carnot cycle, thereby laying the foundations of the second law of thermodynamics. He is often described as the "Father of thermodynamics", being responsible for such concepts as Carnot efficiency, Carnot theorem, Carnot heat engine, and others.

The prevalent theory of heat was the caloric theory, which regarded heat as a sort of weightless, invisible fluid that flowed when out of equilibrium.

In his ideal model, the heat of caloric converted into work could be reinstated by reversing the motion of the cycle, a concept subsequently known as thermodynamic reversibility. Carnot however further postulated that some caloric is lost, not being converted to mechanical work. Hence no real heat engine could realise the Carnot cycle's reversibility and was condemned to be less efficient.



http://www.uh.edu/engines/epi1958.htm

http://www.uh.edu/engines/epiindex.htm

Lazare Carnot pointed out that, in an imaginary *perfect* waterwheel, none of the water's energy would go to waste. None would be dissipated, and all the motion would be completely reversible. If the perfect waterwheel were run backward, it would become the perfect pump. And here Lazare's son Sadi claimed his inheritance.

He said, let us conceive a perfectly reversible *steam engine.* If we could build such a thing, we could run it in reverse and pump heat from a condenser to a boiler. Refrigerators wouldn't appear until thirty-six years later, but Sadi Carnot had pointed the way.

Hence, Sadi Carnot used the mechanism of how in a water-wheel, motive power was produced as a metaphor / analogy for explaining how motive power is produced in a steam engine:

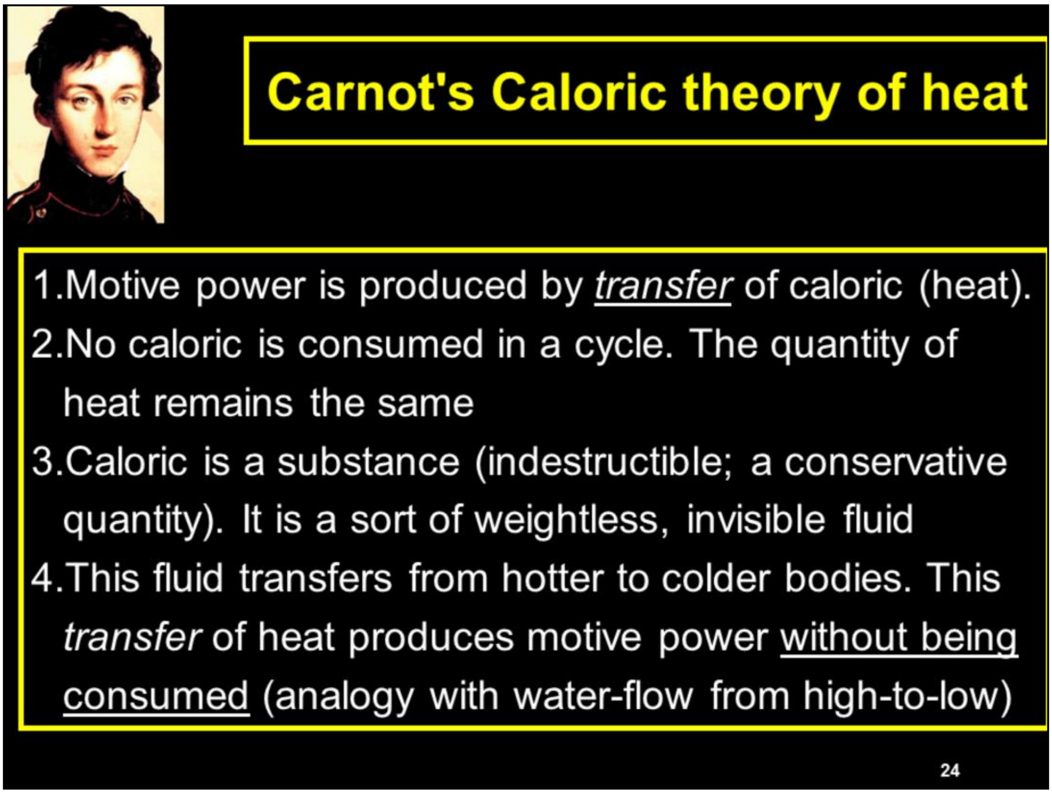
- Mechanism of the water-wheel: Water moving from high to low level produces motive power.
- Steam engine: Steam 'changing' from a high to a low temperature produces motive power.

The crucial question is: How could Sadi Carnot employ the mechanism of the water-wheel for explaining the mechanism of the steam-engine? The point to make here is that this reasoning is ‘guided and enabled’ by the accepted metaphysical background picture, which assumes that ‘changes’ should be explained in terms of particles and forces exerted by these particles. In case of the water-wheel, this can be experienced in a straight-forward manner, but not in case of the steam-engine. Carnot used the analogy to come up with an explanation in terms of caloric particles and their forces. Part of the metaphysical background picture is that we already know that particles cannot appear or disappear, but are *conserved*; and that particles exert forces:

a) Similar to the fact that water is not consumed, caloric is not consumed when producing motive power.

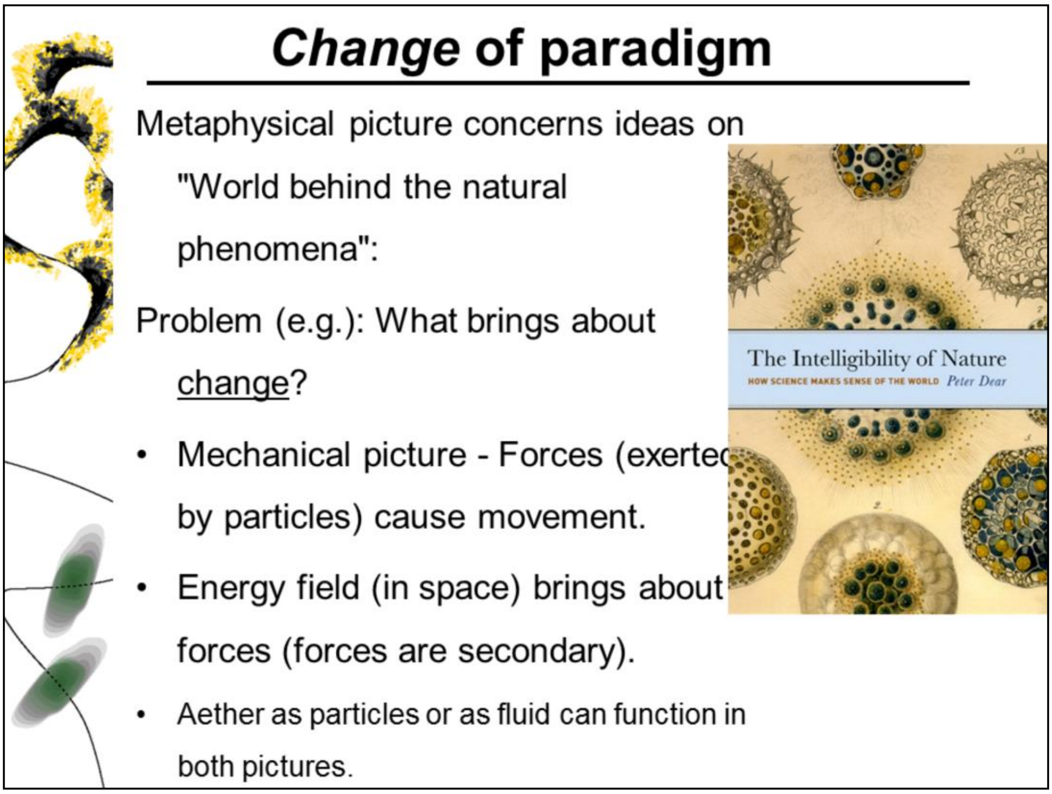
b) Similar to how motive power is produced when a water-flow transfers from a high to low level (through interaction with the machinery of a water-wheel), motive power is produced when a caloric flow transfers from a high to a low temperature (through interaction with the machinery of a steam-engine).

c) Similar to the fact that motive power is produced because water particles exert a force (or pressure), motive power is produced by the pressure of steam for which caloric particles are held responsible.



"The most probable opinion concerning the nature of caloric, is, that of its being an elastic fluid of great subtilty, the particles of which repel one another, but are attracted by all other bodies. ..." (Dalton, 1842, p.1; first edition, 1808).

This concept of caloric is enriched with **the idea that temperature is the density of caloric**. In a further theoretical elaboration, it was postulated that caloric exists of two different states: sensible and latent. In its free state, caloric was conceived of as sensible, being able to affect the thermometer and our senses, whereas in its latent state, caloric is combined with matter and deprived of its characteristic repulsive force, thus being unable to effect the expansion of thermometric substances. This refinement of the caloric theory allowed for explaining e.g., that addition or withdrawal of (latent) heat causes a change of a state (e.g., melting, freezing, boiling, condensation, etc.) without change of temperature (cf. Chang, 2003 and 2004).



An example of a change of paradigm is the change of the Newtonian metaphysical background picture (here called the <u>mechanical picture</u>).

This book of Peter Dear is about the history of science and puts emphasis on the idea that the accepted paradigm determines what counts as intelligible in science. Changing the paradigm involves that other standards of intelligibility emerge. For instance, before Newton, ‘action at a distance’ was unintelligible. After Newton, explanations in terms of particles that exert ‘forces at distance’ became the ruling paradigm, and was considered as intelligible (although, if we really start to thinks how that works, we accept it, but we still do not feel that we really understand it….).

The ‘history of science’ article *Energy* (or, *From Force to Energy*) by Crosby Smith, describes in much more detail how a new ‘metaphysical picture of the world’ developed. Newton’s picture (summarized in the quote on slide 9, and quoted in this article of Smith on page 326-327), in which physical explanations were cast in terms of particles and forces, was slowly and gradually replaced by explanations in terms of energy and fields.

In my lectures so far, this development has been described in a ‘rough and dirty’ manner. Nevertheless, this preparation will facilitate your understanding of the article by Smith.

The next slide quote’s the introductory sentence of Smith’s article:

> “Between Isaac Newton and Albert Einstein no development in physics is more significant that the replacement of the concept of force by the concept of work.”

Change of paradigm
Example I: From 'force' to 'energy'

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ENERGY

CROSBIE SMITH

"Between Isaac Newton and Albert Einstein no development in physics is more significant than the replacement of the concept of force by the concept of work."

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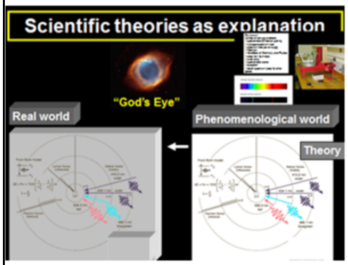
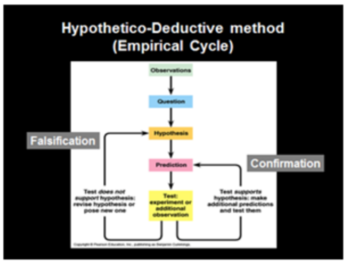
Note that in this article by Smith, a new mathematical approach is described (starting with Fourier, see p. 327), which is similar to what will be said about Maxwell's turn to a mathematical approach (after 1861 "On physical lines of force") when he appeared not to have succeeded in constructing a coherent mechanical model (based on the behavior of aether particles) for explaining EM phenomena. As will be explained below, after the apparent failure of the vortex model (the 'bundle of spaghetti model') Maxwell refrained from further attempts of finding a physical explanation. Similarly, Smith writes about Fourier:

> "By contrast, the approach of Joseph Fourier (1768-1830) marked a decisive shift away from the force physics of the Laplacians [who had refined Newton's approach, starting a program in which all physical phenomena were reduced to the action of inverse square forces between point atoms]. He [Fourier] continued the Laplacian priority on mathematical analysis, but at a practical rather than at a hypothetical level. Fourier therefore treated heat conduction as though it were a phenomenon of continuous flow, without regard to its true physical nature. His technique brought the power of mathematical analysis to bear directly on empirical laws without any appeal to microscopic models of the Laplacian kind. His theory of heat was essentially macroscopic, geometrical and practical [rather than 'micro-physical' and mechanistic or 'explanatory']."

Debate at level of paradigm *Force* – *Energy* (1)

Particles had different kinds of properties: Newton's inelastic atoms lost motion at every collision, Laplace's atoms could never lose *vis viva* which he defined as mass times the square of the velocity (conservation of kinetic energy). Laplace's universe had no need of Newton's God who acted continually to replenish motion in a world which would otherwise run down.





$$\frac{P_1 : H \rightarrow e \qquad P_2 : e}{C : H}$$

Affirming the consequent
invalid
= Confirmation

One of the ways in which metaphysical pictures are examined and refined is by means of thought experiments. In this example (Smith, p. 327), Newton's conception of particles was criticized and refined by Laplace.

At some point, as in the case of Newton and Laplace, scientists do have debates at the level of their metaphysical pictures. How does this go about. You now understand that scientists cannot compare their conception (e.g., of particles responsible for observable phenomena) with the real world (see familiar schema on the left). Usually, they cannot test it in real experiments, which would be in accordance with the HD method (see familiar schema in the middle). Instead, they examine the (im)plausibility and consistency of a metaphysical picture in thought-experiments, which may lead to contradictions. In though-experiments, scientists make use of **HD reasoning**.

Debate at level of paradigm *Force – Energy* (2)

Thomson (1845) Total force became total work contained in the system, with attention focused not on summing over elementary forces among the parts but on the work entering or leaving the system (Smith p. 331).

Mechanical effect was now located *in the field rather than in the forces exerted on magnetic* matter. Here he advanced the mathematical basis of field theory.

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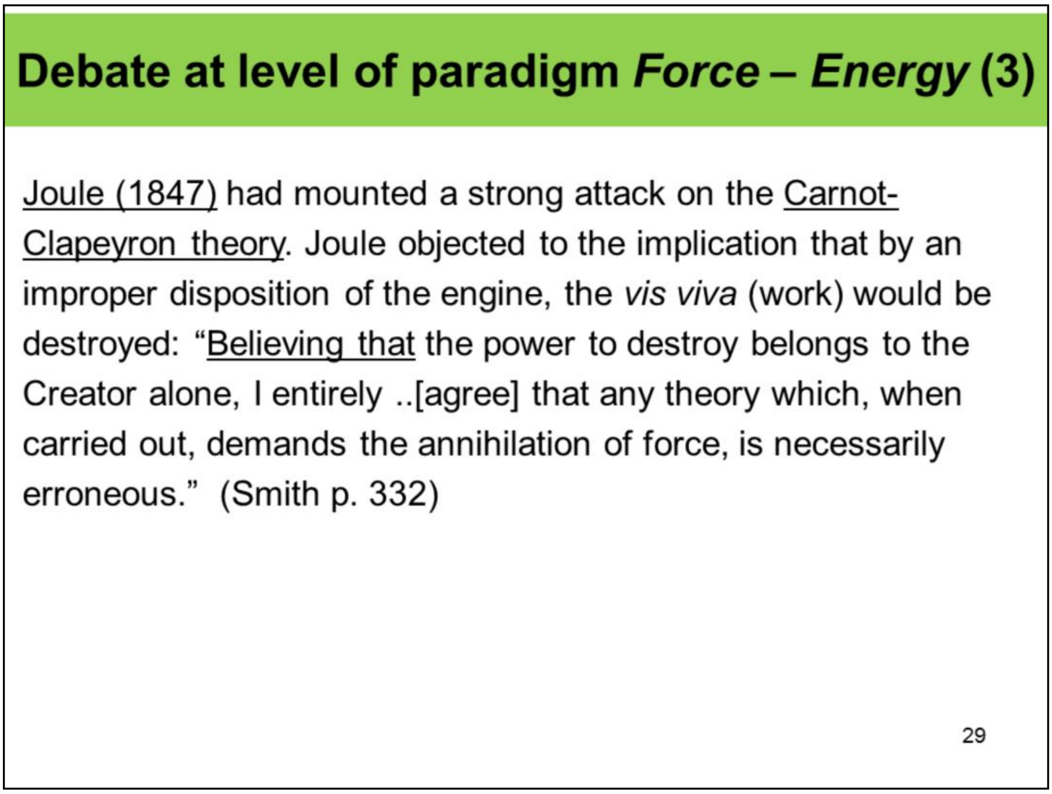
Smith p. 331: Thomson’s new view, centered on the concept of mechanical effect, expressed the work expended or absorbed by an electrical system in "exactly the same way as a waterfall or steam engine, with electrical potential analogous to the height of a waterfall or temperature difference between boiler and condenser, and quantity of electricity analogous to mass of water or quantity of heat. **Total force became total work contained in the system**, with attention focused not on summing over elementary forces among the parts but on the work entering or leaving the system. Total mechanical effect thus became a potential (soon to be potential energy) for the gross forces exerted by the system. ….

Mechanical effect was now located *in the field rather than in the forces exerted on magnetic* matter. Here he advanced the mathematical basis of field theory.

Thomson's new perspective, then, originated within the context of the Carnot-Clapeyron theory of heat engines in which the passage of heat from a hot to a cold body produced mechanical power (work or *vis viva).*



Note that the development of a mathematical description of heat and work after Carnot (1827), as described by Smith (328-330), is well before Maxwell developed his (mathematical) axiomatic system for EM phenomena (1871).

Smith p. 332. In 1847, however, he [Thomson] met Joule (1818-89) for the time and discovered that three years earlier Joule had mounted a strong attack on the Carnot-Clapeyron theory. Joule objected to the implication that by an improper disposition of the engine (leading to waste by conduction or collision, for example), the *vis viva would be destroyed:* ‘Believing that the power to destroy belongs to the Creator alone, I entirely coincide with Roget and Faraday in the opinion that any theory which, when carried out, demands the annihilation of force, is necessarily erroneous. Joule’s own theory substituted for the temperature difference a straightforward conversion of the heat (contained in the steam expanding in the cylinder of a steam engine) into an equivalent quantity of mechanical power [see next slide].

This view involves a broader, shared metaphysical presupposition:

Smith p. 332: They certainly shared his theology of nature whereby an omnipotent God created and held in being a

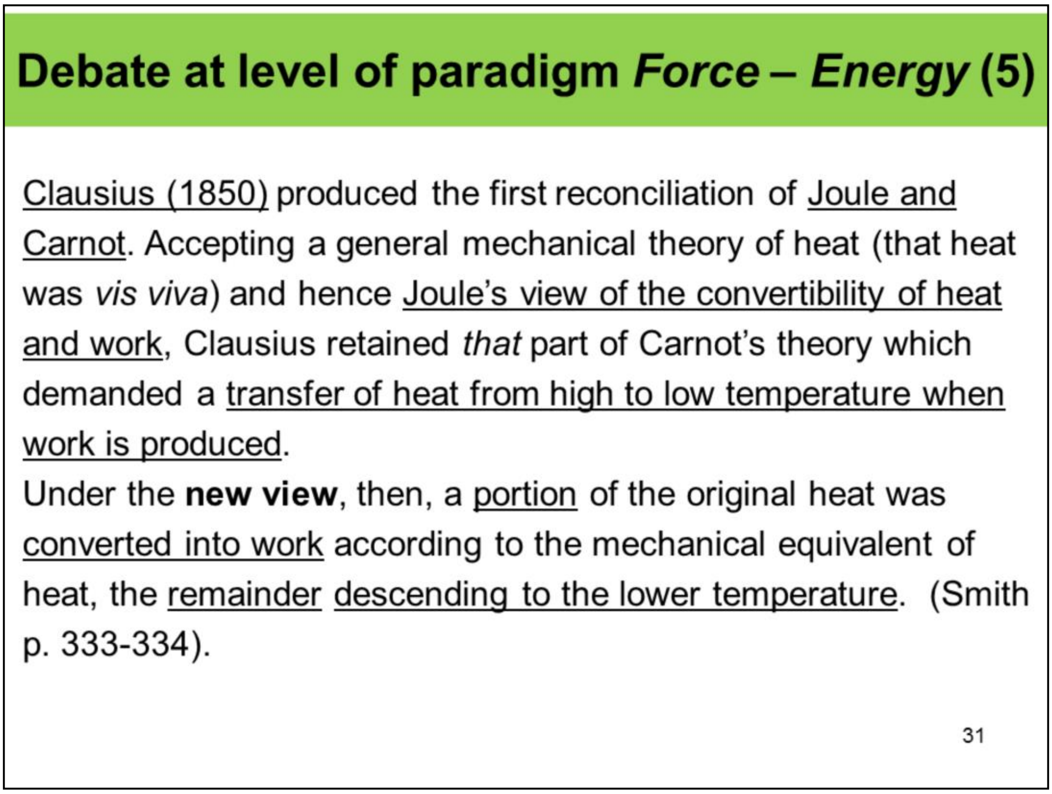
universe whose basic building blocks (matter and other agencies such as 'force' or 'energy' discovered by experiment) could not be increased, annihilated, or otherwise altered by any human or natural agency. Such a metaphysical belief was one to which all Christians, irrespective of denomination or status, had to give allegiance. It made possible the wide acceptance of the new conservation of energy doctrine on account of its perceived non-sectarian, non-speculative and non-hypothetical character. Thus William entirely admitted Joule's specific objection to the Carnot-Clapeyron theory.

Smith p. 333. For Thomson, as for Joule, energy (measured as mechanical effect) had to be conserved: '**Nothing can be lost in the operations of nature - no energy can be destroyed**'. In this 1849 footnote to his exposition of Carnot's theory, Thomson introduced the term 'energy' into mathematical physics.

Debate at level of paradigm *Force* – *Energy* (4)

Joule's own theory substituted for the temperature-difference [between which transfer of caloric produces motive power], a straightforward conversion of the heat (contained in the steam expanding in the cylinder of a steam engine) into an equivalent quantity of mechanical power (i.e., mutual conversion of heat and work) =>
Displaced the Carnot theory with the conversion [rather than transfer] of heat into work.

30



Smith p. 334.

In this short paper [by Thomson, 1852] published in the *Philosophical Magazine,* the new term 'energy' achieved prominence for the first time. It was no longer a mere footnote; instead **the shared theology of nature emphasized the primary status of energy**. Here the dynamical theory of heat, and with it a whole programme of dynamical (matter-in- motion) explanation, went unquestioned. And here too, the universal, cosmological primacy of the energy laws opened up new questions about the origins, progress and destiny of the solar system and its inhabitants,

["In the history of science, vis viva (from the Latin for living force) is an obsolete scientific theory that served as an elementary and limited early formulation of the principle of conservation of energy. It was the first (known) description of what we now call kinetic energy or of energy related to sensible motions."]

Disciplinary Matrix (Paradigm**):**

Metaphysical picture, core principles & scientific methodology:

Concerns / guides how we model (e.g. explain) the phenomena

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Change of paradigm
Example II: Discarding '**aether**'

Maxwell (and his successors) were unsuccessful in developing a **causal-mechanistic model** of EM phenomena, for instance in terms of **aether**.

Instead, he developed a **mathematical model**, which is an axiomatic system that describes and predicts observed/observable patterns.

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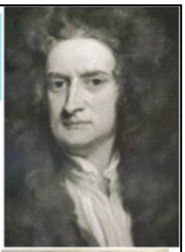
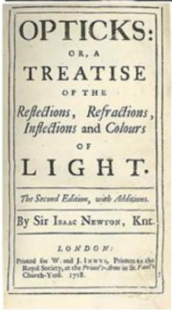
Newton's paradigm (1704):





OPTICKS:
OR, A
TREATISE
OF THE
Reflections, Refractions, Inflections and *Colours*
OF
LIGHT.

The Second Edition, with Additions.

By Sir ISAAC NEWTON, Knt.

LONDON:
Printed for W. and J. INNYS, Printers to the Royal Society, at the *Prince's-Arms* in St. *Paul's* Church-Yard. 1718.

that we could "derive the rest of the phaenomena of Nature by the same kind of reasoning from <u>mechanical principles</u> [as in the case of gravitation] for I am induced by many reasons to suspect that they may all depend upon certain <u>forces</u> by which the <u>particles</u> of bodies ... are either mutually <u>impelled</u> towards one another .. or are <u>repelled and recede</u> from another.."

Many writers followed Newton and attempted to account for diverse phenomena by combinations of <u>attractive and repulsive forces between particles or point atoms</u>.

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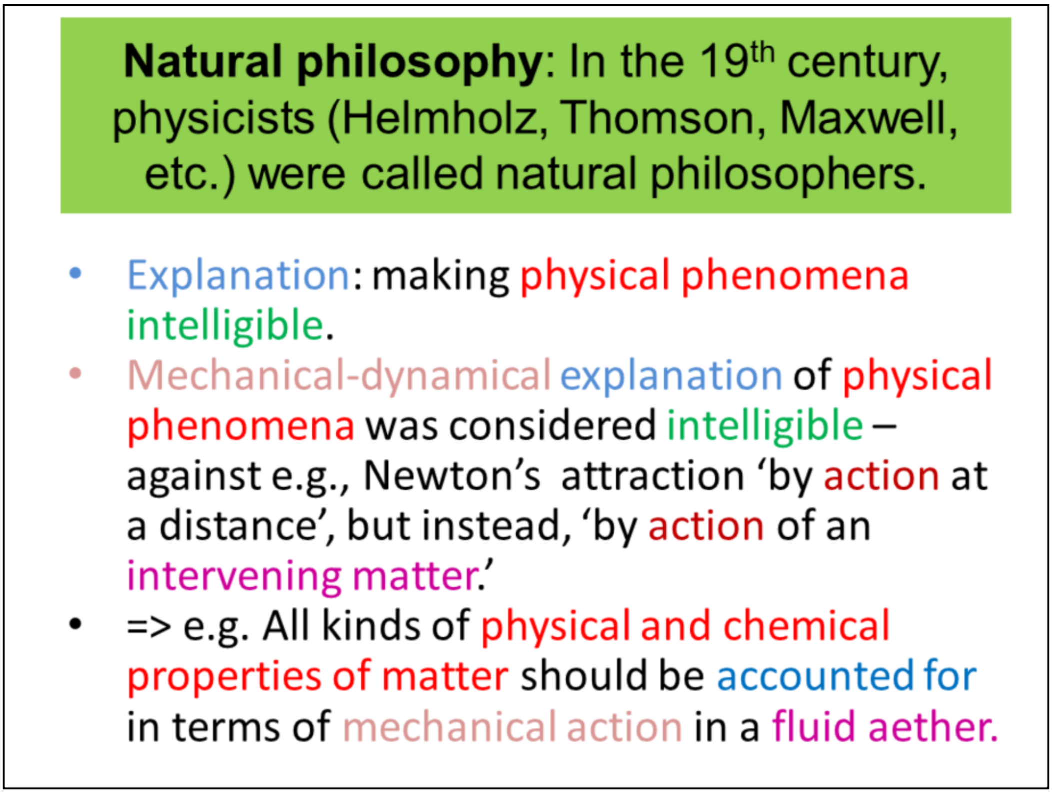
Repetition

Aether, or Luminiferous ether
(e.g. Newton in *Optics*, 1718)

1. Aether is an all-pervading substance (permeating all matter and space), the particles of which repel each other (which explains action at distance).
2. Particles of aether are smaller than those of air.
3. Aether acts as the medium for transmission of electro-magnetic waves (e.g. light), much as sound waves are transmitted by elastic media such as air.
4. Aether is weightless, transparent, frictionless, chemically and physically undetectable.

Repetition



- Explanation: making physical phenomena intelligible.
- Mechanical-dynamical explanation of physical phenomena was considered intelligible – against e.g., Newton's attraction 'by action at a distance', but instead, 'by action of an intervening matter.'
- => e.g. All kinds of physical and chemical properties of matter should be accounted for in terms of mechanical action in a fluid aether.

Peter Dear p.127 on intelligibility:

"For these physicists, intelligibility resulted from being able not just to manipulate (e.g. manipulating 'lines of force' in experiments), but to account for (=explain) field lines in a mathematical-mechanical language. This language would ground physical phenomena in what they took to be more **fundamental features of reality**. ... These explanations are **imaginary physical models designed to account for natural phenomena**, which Thomson called "dynamical illustrations". The point of a dynamical illustration was to show that a given phenomenon (such as magneto-optic rotation) could be accounted for (=explained) by an imagined material aether that obeyed the basic laws governing ordinary mechanical systems.

Whether nature really was like that– whether the particular model was just like the natural phenomenon (MB i.e., whether the model is <u>true</u>) – might be an ultimately undecidable question. The important feature of such illustrations was that they showed a consistency between the phenomenon's actual existence and the possibilities inherent in "dynamical" principles (MB, roughly, this consistence means that the model is <u>empirically adequate</u>): if it was possible to account for (= explain) a phenomenon in dynamical terms, then that phenomenon had been shown to be dynamically intelligible."

Smoke rings

How did these physicists go about in explaining EM phenomena?

An important aspect is that they use analogies, such as the behaviour of smoke.

Below, smoke (and the behavior / features of smoke) is considered as a fluid. This behaviour is used for developing a conception of aether.

Thomson (Lord Kelvin)'s (1867) atomic vortex theory: Atoms are nothing more than knotted and linked tubular vortices in the all pervasive fluid called **aether**.

After reading Helmholtz's paper, the Edinburgh University physicist[1] Peter Guthrie Tait gave a series of lectures on Helmholtz's paper. To demonstrate Helmholtz's result in his lectures, he used an apparatus of his own design that produced vortex rings of smoke. His presentations illustrated quite vividly and dramatically that:

- The vortex rings behaved as independent solids.
- On collision with one another, the vortex rings rebounded as if they were quivering elastic solids, like rings of rubber.
- The smoke rings exhibited fascinating vibration modes about their circular form.
- On each attempt to cut the smoke rings with a knife, the smoke rings would simply wriggle around the knife. The rings were indivisible!

The behaviour of smoke rings, on the one hand, added to a newly developing mathematical theory (namely, the **knot theory**, which studies mathematical properties of knots; later called **topology** *), and to a new physical theory (namely, a new mechanical-dynamical way to explain 'unintelligible action at a distance' such as gravity and electro-magnetic properties:

http://www.csee.umbc.edu/~lomonaco/kelvin/kelvin23.pdf

The first few pages of this articles nicely illustrate the close interaction between the development of the mathematical and physical theory. The mathematician, Guthrie Tait, studied (experimentally and conceptually) the behaviour of tubular (fluid) vortices: Experimentally by studying the behaviour of **smoke rings (= vortex rings).** Conceptually by **considering them as fluids**, and conceiving of their fundamental properties pointed out on the slide. [Consider these fundamental properties of vortex rings of smoke as conceived of by means of looking at the specific behaviour of smoke rings.]

Tait developed this mathematical theory. He was inspired by Helmholtz, who proved that within an incompressible, inviscid (inviscid flow = the flow of an ideal fluid that is assumed to have no viscosity) and constant density fluid, fluid vortices are actually permanent and indivisible (also see p. 128 in Peter Dear: "The intelligibility of Nature").

At the other end, considering the observed behavior of smoke rings also resulted to a powerful metaphor in the construction of a physical theory (the **atomic vortex theory**). Sir William Thomson (Lord Kelvin) was struck by the evident permanence and indivisibility of “water twists”, as illustrated by Tait’s smoke rings. It was into this lecture that Thomson conceived of and created his atomic vortex theory, i.e., that atoms were nothing more than knotted and linked tubular vortices in the then postulated all pervasive fluid called ether. Starting in 1867, Thomson published a series of papers that explained his theory.

Peter Dear (p 129) writes about Thomson’s (1867) “On Vortex Atoms”: “This was a very ambitious vision for physics, one in which all kinds of physical and chemical properties of matter would be accounted for (= explained) in terms of mechanical action in a fluid aether.” ... “In a sense, Thomson wanted to develop a version of what is now sometimes called a ‘theory of everything’. In 1870 he wrote: ‘Is action at a distance a reality, or is gravitation to be explained, as we now believe magnetic and electric forces must be, by action of intervening matter?’ His implied answer was clear: only the latter was acceptable.”

*) http://en.wikipedia.org/wiki/Knot_theory

Knot theory, later called topology. A mathematical theory of knots was first developed in 1771 by Alexandre-Théophile Vandermonde who explicitly noted the importance of topological features when discussing the properties of knots related to the geometry of position. Mathematical studies of knots began in the 19th century with Gauss, who defined the linking integral (Silver 2006). In the 1860s, Lord Kelvin's theory that atoms were knots in the aether led to Peter Guthrie Tait's creation of the first knot tables for complete classification. Tait, in 1885, published a table of knots with up to ten crossings, and what came to be known as the Tait conjectures. This record motivated the early knot theorists, but knot theory eventually became part of the emerging subject of topology.

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

Topology: A non-Eucledian geometry:

(Part 1) http://www.youtube.com/watch?v=p2ofJPh2yMw

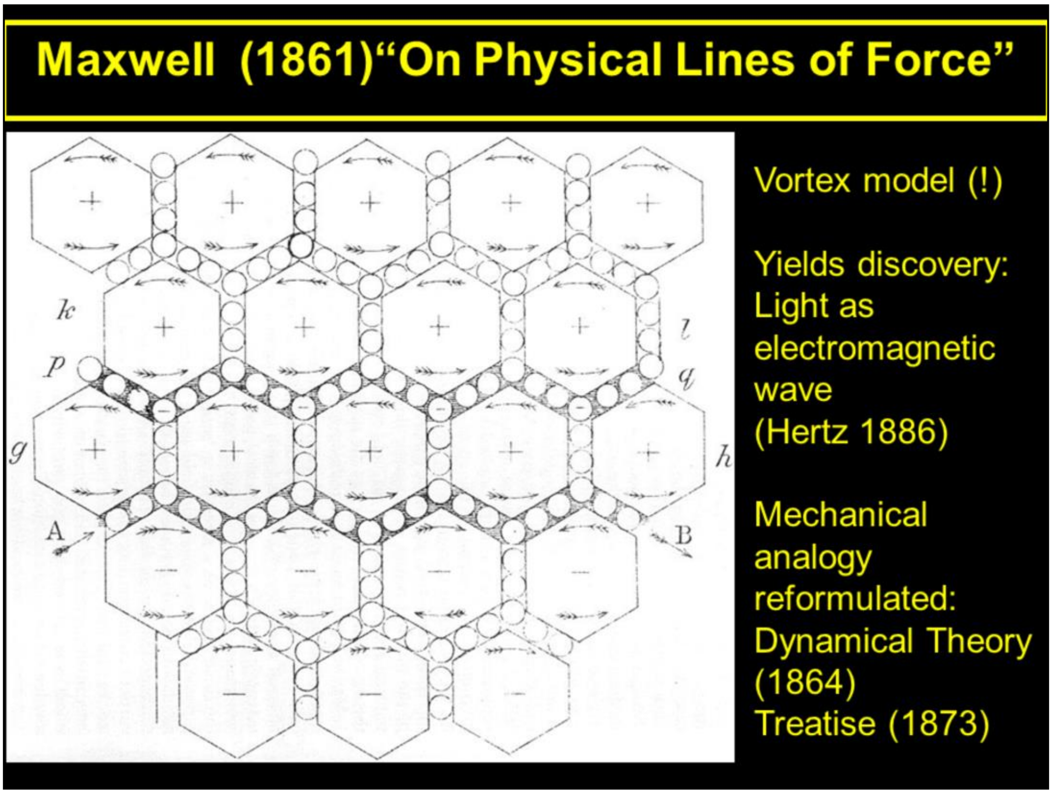
(Part 2) http://www.youtube.com/watch?v=n8Sb29BSZcY

(Part 3) http://www.youtube.com/watch?v=29LoQVbEa7w

Current application of this mathematical theory (topology) is in biochemistry e.g., the folding behavior of Proteins and DNA:

http://www.newton.ac.uk/programmes/TOD/todw02.html

http://cmgm.stanford.edu/biochem201/Handouts/Topology.pdf



Also see Dear p.131 and further, and extra materials in Blackboard for Maxwell’s original articles. “On Physical Lines of Force” (1861).

Recall: An <u>explanation</u> aims at an answer to a why question.
E.g. [Dear, p. 130]: “Maxwell wrote that the physical problem of gravitational attraction between bodies really amounted to asking ‘<u>Why</u> does the energy of the system increase when the distance increases?’ ”

Faraday’s discussion of magnetic lines of force had focused on the medium between bodies .. Maxwell accepted that “Thomson ... proved, by strict dynamical reasoning, that the transmission of magnetic force is associated with a rotary motion of the small parts of the medium.’ ”

Maxwell (“On Faraday’s Lines of Force,” 1856) proceeded by setting up a physical analogy between Faraday’s lines of force and the motion of an incompressible fluid flowing through tubes. Maxwell writes: “My object in this paper is to clear the way for speculation in this direction [i.e. Lines of force as physical states or actions of a medium] by investigating the mechanical results of certain states of tension and motion in a medium, and comparing these with the observed phenomena of magnetism and electricity. By pointing out the mechanical consequences of such hypotheses, I hope to be of some use to those who consider the phenomena as due to the action of a medium, but are in doubt as to the relation of this hypothesis to the experimental laws already established, ..

Mechanical model of the aether

[Dear p. 132:] “Maxwell now proceeded to design a mechanical model of the structure of the aether (*) that would be consistent with the electromagnetic phenomena (see figure on slide). He first represented magnetic lines by rotating tubes, or vortices. The direction and rate of rotation of the vortices corresponded to the direction and strength of the magnetic field in that region of space; the vortices were all packed together like a bundle of uncooked spaghetti, with no variation in the density of their packing. In asking himself how to fit the empirically known relationship between magnetism and electric currents into this picture, Maxwell then appealed to an additional consideration: the limits of his own understanding ☺:

Maxwell writes: “I have found a great difficulty in conceiving of the existence of vortices in a medium, side by side, revolving in the same direction about parallel axes. The contiguous portions of consecutive (opeenvolgend) vortices (**) must be moving in opposite directions; and it is difficult to understand how the motion of one part of the medium can coexist with and even produce, an opposite motion of a part in contact with it.

The only conception which has at all aided me in conceiving of this kind of motion is that of the vortices being separated by a layer of particles, revolving (roterend) each on its own axis in the opposite direction to that of the vortices, so that the contiguous (aangrenzende) surfaces of the particles and of the vortices have the same motion.”

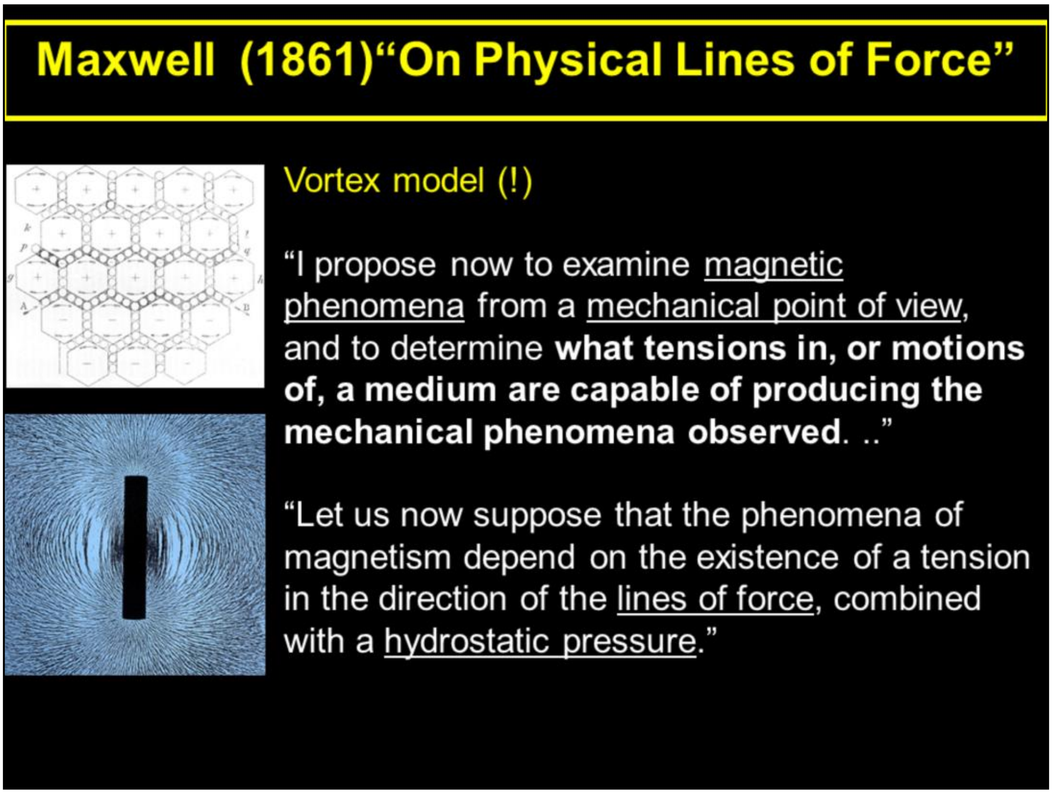
He subsequently called these particles ‘idle (nutteloze) wheels’.

Maxwell’s diagram on this slide (in On Physical Lines of Force 1861), presents a cross-section of his electromagnetic aether (the magnetic lines of force represented by the rotating tubes, or vortices), and the layer of revolving particles between these tubes, which, when in motion, represent electrical current. In this manner, the connexion between magnetic line of force and electrical current is mechanically conceivable.

*) In the 19th century, luminiferous aether (or ether), meaning light-bearing aether, was a theorized medium for the propagation of light (electromagnetic radiation). In 1864, when Maxwell wrote “A Dynamical Theory of the Electromagnetic Field”, Maxwell still took for granted that a material aether existed to sustain and transmit forces (the medium he refers to in the quote above). In his “Treatise on Electricity and magnetism (1873), Maxwell, like Faraday before him, invoked Newton as an authority on the implausibility of genuine action at a distance and reaffirmed his own view that electromagnetic action is a property of “the medium in which the propagation takes place.”

Also see: http://en.wikipedia.org/wiki/Luminiferous_aether#cite_note-newton-3.

**) Vortex is spin (circulaire werveling).



[See extra materials in Blackboard for Maxwell’s original articles. “On Physical Lines of Force”]

Maxwell writes: “I propose now to examine magnetic phenomena from a mechanical point of view, and to determine what tensions in, or motions of, a medium are capable of producing the mechanical phenomena observed. If, by the same hypothesis, we can connect the phenomena of magnetic attraction with electromagnetic phenomena and with those of induced currents, we shall have found a theory which, if not true, can only be proved to be erroneous by experiments which will greatly enlarge our knowledge of this part of physics.

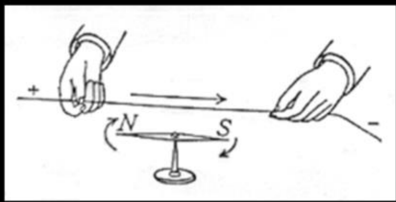
..

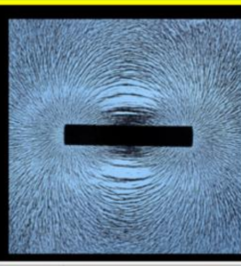
Let us now suppose that the phenomena of magnetism depend on the existence of a tension in the direction of the lines of force, combined with a hydrostatic pressure; or in other words, a pressure greater in the equatorial than in the axial direction: the next question is, what mechanical explanation can we give of this inequality of pressures in a fluid or mobile medium? The explanation which most readily occurs to the mind is that the excess of pressure in the equatorial direction arises from the centrifugal force of vortices or eddies in the medium having their axes in directions parallel to the lines of force.”

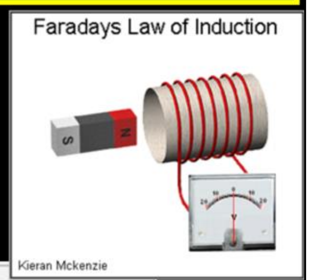
Also see: http://en.wikipedia.org/wiki/History_of_Maxwell's_equations

While Maxwell’s mathematical formalism certainly seemed to work instrumentally (see next slide), they were never enough to satisfy his understanding. Also after his death in 1879, physicists continued attempts to devise more satisfactory models of aether that could account for the forces of electricity and magnetism.

Maxwell's Fundamental Laws for EM



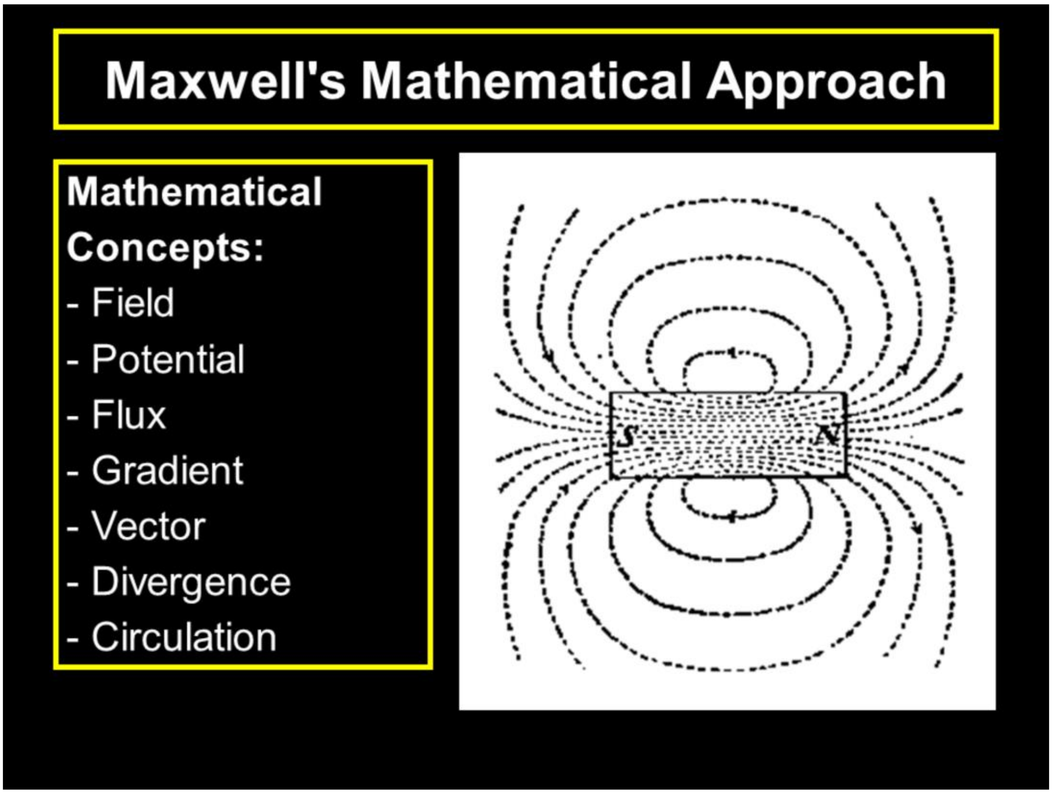




Name	Differential form	Integral form
Gauss's law:	$\nabla \cdot \mathbf{D} = \rho$	$\oint_S \mathbf{D} \cdot \mathrm{d}\mathbf{A} = q = \int_V \rho \mathrm{d}V$
Gauss' law for magnetism (absence of magnetic monopoles):	$\nabla \cdot \mathbf{B} = 0$	$\oint_S \mathbf{B} \cdot \mathrm{d}\mathbf{A} = 0$
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.

This axiomatic system does not present a physical, mechanistic explanation of EM phenomena.



Integration:

Mathematical tradition “explains” patterns produced by means of experiments and instruments. This requires the introduction of mathematical concepts. Maxwell constructed an axiometic system, using these mathematical concepts (invented by mathematicians like Gauss). The patterns that were observed in experiments of scientists such as Faraday and Orsted are ‘explained’ in terms of fundamental laws (axioms).

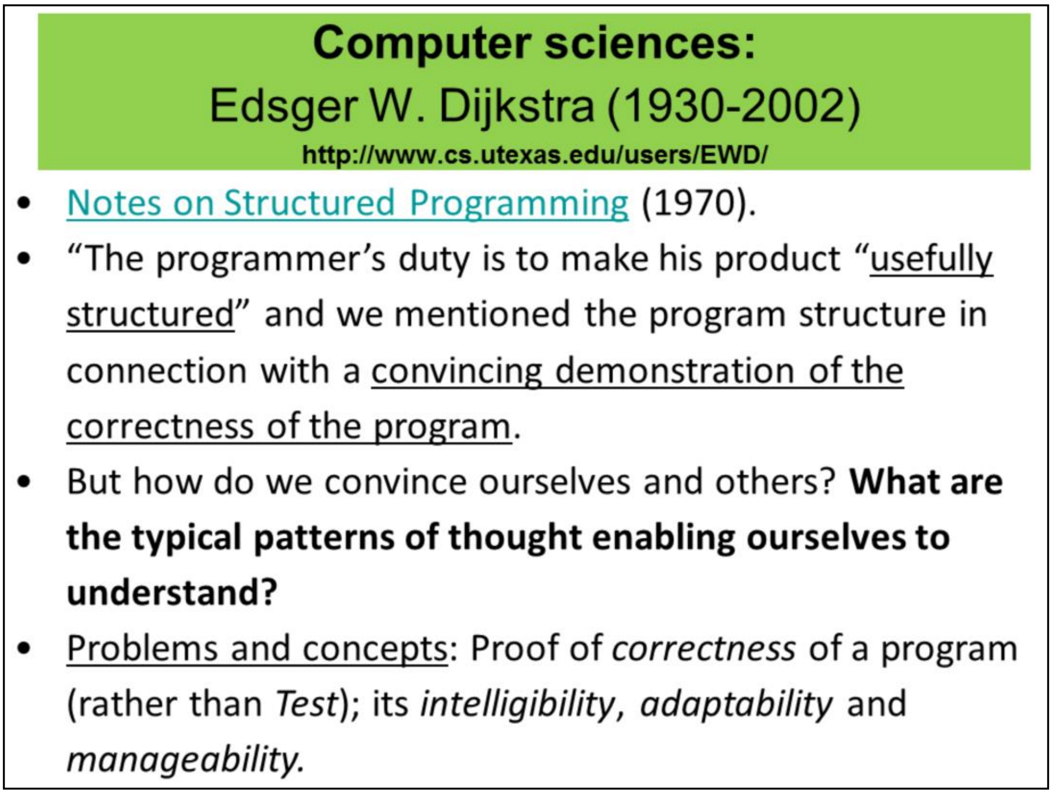
Change of paradigm in Mathematics:
Example III: New concepts in numerical reasoning

What is a number?

- Natural numbers
- Prime numbers
- The number Zero (and pi, and e)
- Rational numbers
- Real numbers
- Irrational numbers
- Imaginary numbers
- Geometry => Algebra

[Note: Needs additional explanation]

The Parrots theorem – A novel by Denis Guedj



[Note: needs more explanation]
http://en.wikipedia.org/wiki/Computer_science

- Notes on Structured Programming (1970).
- Problem of composition of large computer programs => problem of increasing size cannot be solved by induction (e.g., increasing speed of crawling child to speed of super sonic jet) => be explicit about size of the computation: it involves the amount of information and the number of operations.
- It is not only the programmer's task to produce a correct program, but also to demonstrate its correctness in a convincing manner. (also adaptability and manageability).
- The art of programming is the art of organizing complexity, of mastering multitude and avoiding its bastard chaos as effectively as possible. => how can we optimize while keeping the program manageable?

Kuhn's notion of Paradigm (as a Disciplinary Matrix)

A paradigm consists of:

1. ‘Background’ and epistemological values
2. Metaphysical picture of the world
3. Core principles
4. Scientific methodology
5. Exemplars

The construction of scientific models / hypotheses / explanations (of unobservable world) involves a 'paradigm'

- A 'picture' of what unobservable world is like (= metaphysics).
- Ideas about the qualities a good explanation (or theory) should have, e.g., empirically adequate, simple, .. (= core principles, methodological ideas & values).
- Ideas about things or systems (e.g. observed phenomena / experimental findings) that should be explained by it (= exemplars & values).

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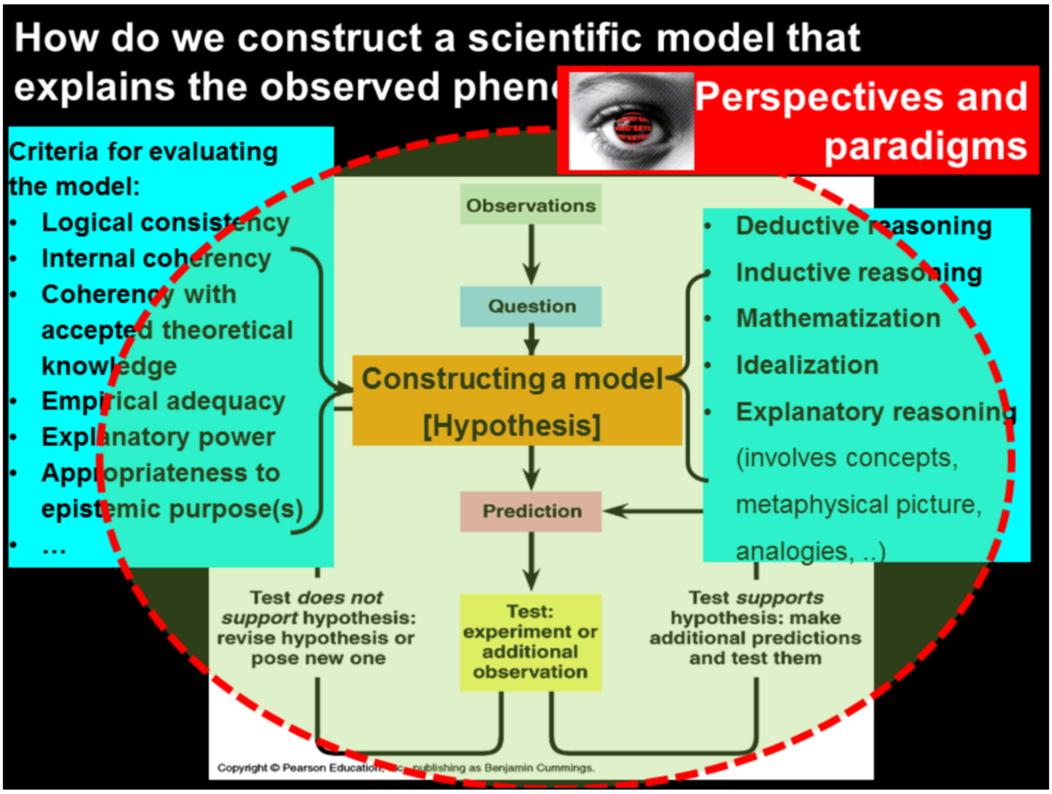
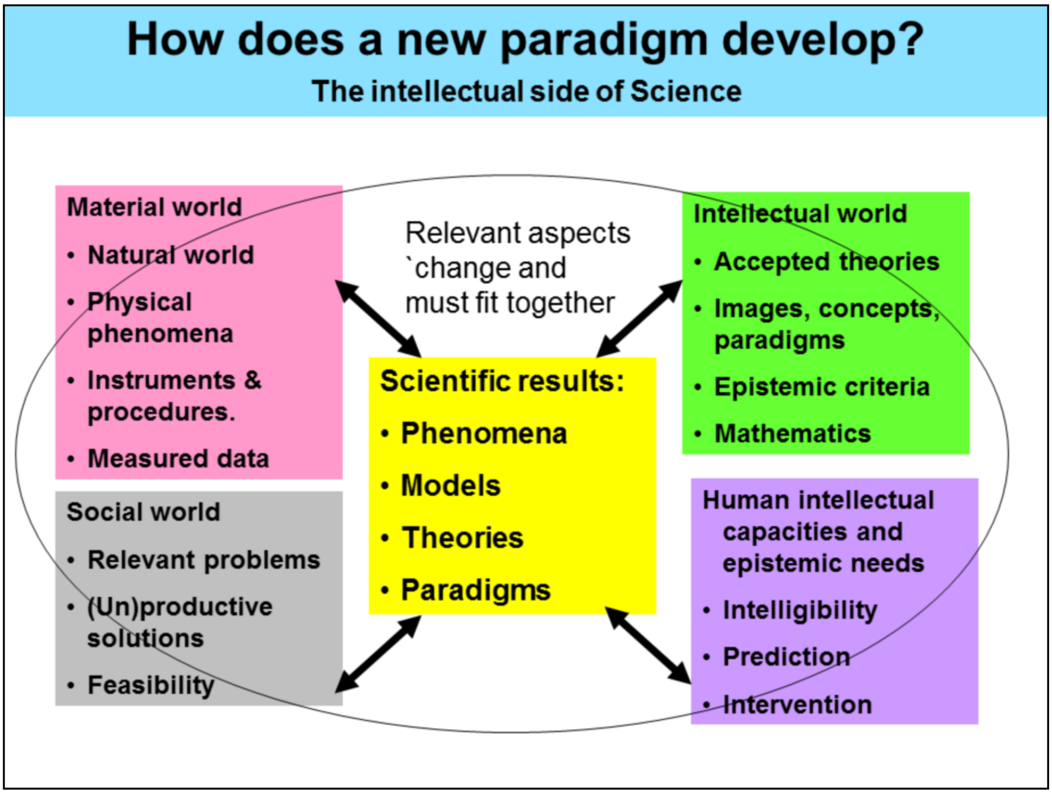


The point we have been working on is understanding how a hypothesis comes about. The approach we have taken is that, although it involves a lot of creativity and imaginative power of the scientists, the formation of the hypothesis also is a rational and structured process that draws on scientific knowledge 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 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 personal preferences.



[Note: This slide has not been addressed in the lecture. It is not part of the compulsory curriculum.]

The scientific enterprise is not an isolated activity. Science and new ideas and concepts (including new paradigms) affect society in different ways. Conversely, science is affected by its intellectual, societal and material environment, and by the human intellectual abilities. These interactions is what this schema aims to show.

The formation of concepts and ideas, but also technologies and methodologies in concrete scientific practices is affected by:

- The ‘material world’: Within scientific practices new technological instruments (such as the instruments and experiments in EM by Ampere, Faraday and Orsted, or the thermometer) are developed, which produce new kinds of physical phenomena and data to be studied. But also new technologies developed in the outside world are brought into scientific practices (such as the telescope and microscope, the hourglass and mechanical clock, the weight balance, the magnet and compass, the water-wheel and steam-engine). These technological devices not only provide new possibilities for measuring and experimenting, but often, also new metaphors for understanding ‘how things work’.
- The ‘intellectual world’: A scientific discipline is also affected by ‘intellectual’

ideas and concepts developed in other disciplines or in 'broader society'. Examples of overarching new concepts that emerged in one field and have entered scientific disciplines (of the natural sciences) are: (in)deterministic processes, statistical processes, (ir)reversible processes, dynamic equilibrium, history, evolutionary processes, feedback, 'blue-print', information, complexity, self-organization, and function. These are the kind of concepts that have affected paradigms. Also, consider concepts used in mathematics: there seems to be an exchange of concepts used in mathematics and in the natural sciences. The emergence of such concepts have affected paradigms in science.

- The 'social world': Problems and challenges in society clearly enter scientific practices. Especially in the engineering sciences, scientific research is explicitly performed in the context of technological applications in society. In the historical article by Crosby Smith (Energy), it becomes clear that scientific conceptualization and scientific modeling of physical phenomena that are of technological relevance is affected by their utility. Both the concept of 'work' and the 'simple' mathematical modeling of work and energy use, for instance, aimed at practical use and not firstly at a theoretical / physical understanding of these processes. Smith, then, suggests that the paradigm-shift of force to energy ('work') was also affected by these practical needs.
- 'Human intellectual capacities and epistemic needs': Related to the former, scientific models, scientific concepts and mathematical formalisms must be constructed such that they can be utilized by humans. In this course, the notion of (scientific) knowledge as epistemic tool has been introduced as an alternative to the idea that (scientific) knowledge is an objective representations independent of human intellectual capacities. In other words, this alternative assumes that (scientific) knowledge is constructed such that it enables humans to think by means of it, for instance, about possible (technological) interventions with a system. In such practical uses of knowledge, it must be intelligible, which in a sense is subjective as it is 'supported' by a paradigm. Also, for this reason, it must be 'simple'. In other applications, the predictive power of knowledge is more important than intelligibility, which implies that 'unintelligible' mathematical descriptions (and computer simulations) are appropriate. In yet other cases (e.g., in cases where knowledge is complex and must be adapted to new situations all the time, such as in information technology), pragmatic criteria such as testability and manageability is crucial.

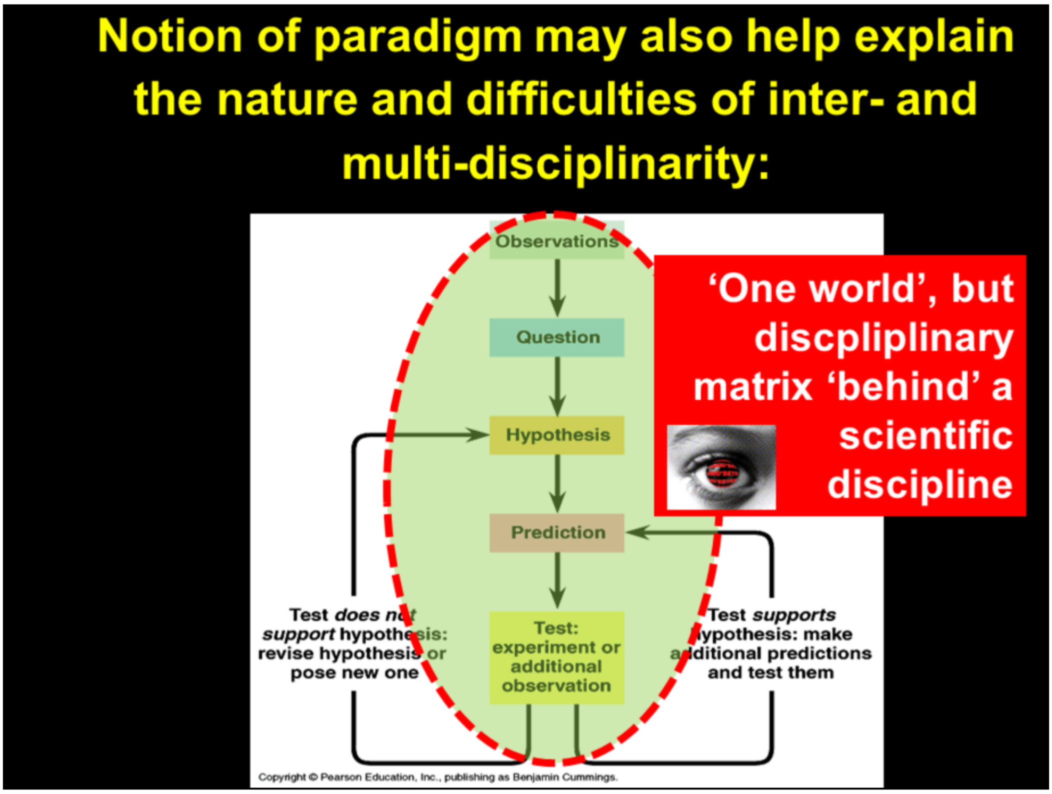
One of the message of this course in the philosophy of engineering science is that scientific research is not an algorithmic process (which would be a warrant that science is objective and rational), but instead, a thoroughly human enterprise. In the past few decades, the insight that science is not objective and rational in an algorithmic sense has supported (and motivated) attacks on scientific authority. Some of the critique on science is justified, but these attacks also have unjustly harmed the image of science. The second half of this course, has aimed at an alternative picture of science – especially the engineering sciences, that may provide us with alternative ideas on 'what science is', and why science should be taken seriously and still be given an important role in solving societal problems.

A central notion in this alternative picture of science is '(scientific) knowledge as epistemic tool.' Additionally, in this last lecture, it has been explained that paradigms (which involves several different aspects) play a crucial and indispensable role at the background. An important message, however, is that the central role of constructive and creative activities of humans, both at the level of paradigms (as illustrated in this schema), and at the level of theories, models, concepts and methodologies, does not imply that 'anything goes.' The results of science are not arbitrary. All of us should be very aware of the fact that constructive and creative activities are also thoroughly constrained by 'hard' criteria, although not in an algorithmic sense. Relevant aspects must be fitted together, and this is an important part of the intellectually demanding, constructive and creative work of scientific researchers. 'Fitting things together', both at the level of the paradigm, and at the level of theories etc., involves criteria such as coherency, consistency and adequacy, and also decisions on what is relevant and what not.

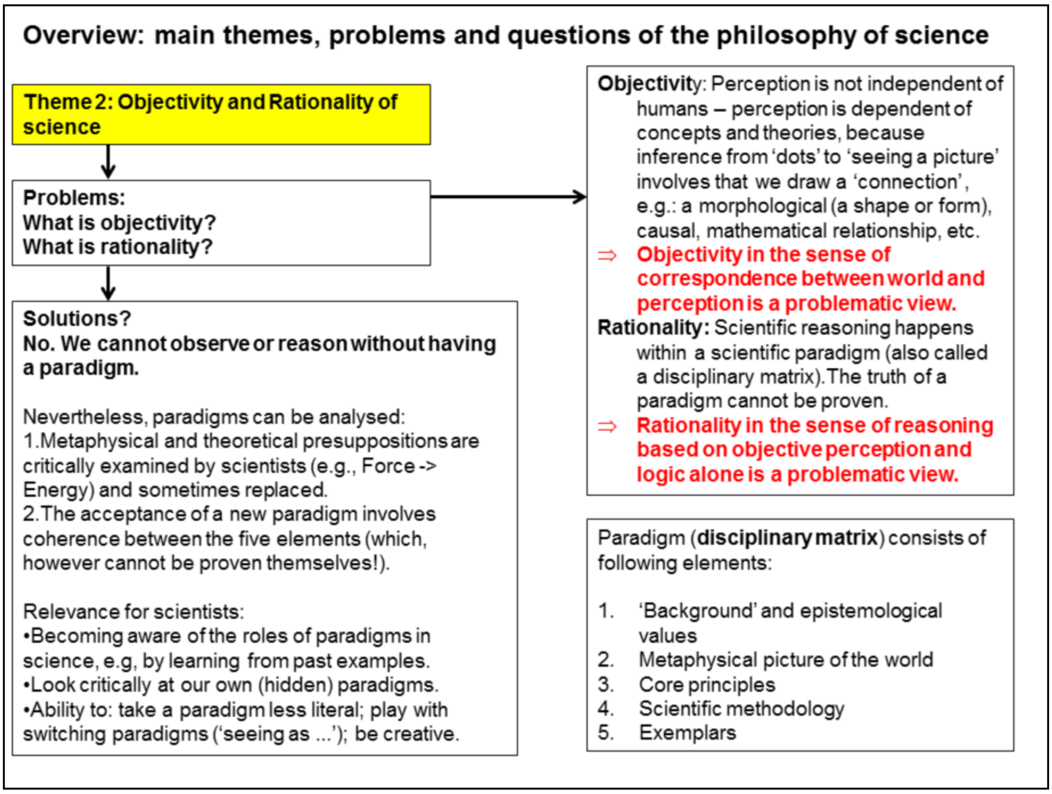
This alternative also opens the possibility of understanding interdisciplinary research somewhat better. We all know that the same 'target system' (e.g., a problem) can be scientifically described and/or explained in different ways, which cannot be reduced to each other. These 'different ways' of, say, scientifically modeling a system, are guided by distinct disciplinary perspectives. In other words, different disciplines (each having their own disciplinary background / disciplinary matrix) will model the system in different ways. This results to models that are 'incommensurable' as Thomas Kuhn puts it. [Theories are incommensurable if they cannot be assessed by the same measures – there is no way in which one can compare them to each other in order to determine which is more accurate.] Often, descriptive or explanatory scientific models produced in distinct disciplines cannot be compared to each other, nor can they be reduced to each other. [Note that the possibility of reduction of theories is strongly suggested by the metaphysical picture of the world as a pyramid of simple to complex building-blocks, illustrated above.]. As a consequence of the distinct disciplines (and disciplinary matrix 'governing' them) the theories involve: different 'observations' and different research questions, core concepts and methodologies. Moreover, the results (the 'epistemic tools' constructed in the scientific research of a discipline) enable to do different kinds of things (e.g., different ways of thinking about solutions).

Does this situation force us into relativism or skepticism about science? Not at all! The situation is that the knowledge produced within a discipline is, roughly speaking, ‘governed by’ a specific disciplinary perspective, which probably is one of the many possible scientific perspectives on a problem.

As a metaphor, you may think of this ancient Indian parable, in which three blind man investigate an elephant. The one ‘observes’ that it is a thick tapestry. The second discovers that it is a flexible pipe. The third finds that it is a big, heavy pillar. From our external (“God’s eye”) perspective, we know that they are all correct, but that each description is determined by a limited perspective on the elephant (the ‘target system’). Therefore, each of these man only describes what has been found within that perspective: the ear, the trunk, and the leg. In scientific research, we are all blind man and nobody can step out of that. Knowledge production occurs within disciplines, and is enabled (and governed) by specific ‘disciplinary matrices’ (including its epistemological and pragmatic values, its metaphysical pictures, its core principles and theories, its methodologies, and its exemplars). Knowledge produced in different disciplines often cannot be reduced to each other, nor does it make sense to compare their correctness. Instead, in solving real problems, knowledge from different disciplines often adds to each other. The challenge is to integrate these parts of knowledge into a richer and more complex whole, similar to how the thick carpet, the flexible pipe and the big pillar, at some point, may result to the concept of an elephant.



Affinity as well as hostility between scientific disciplines may be explained at the level of aspects of the disciplinary matrix 'behind' the discipline.



‘Objectivity and rationality’ in science is the second philosophical theme addressed in this course. The structure of the philosophical approach (or, ‘philosophical analysis’) is similar to how the first theme (‘truth’) was analyzed. It develops in several steps:

1) A combined philosophical and conceptual analysis of both concepts (by asking “What is objectivity?” “What is rationality?” Note that the words (‘objectivity’ and ‘rationality’) are placed between quotes if we mean to refer to the *concept*, that is, to the meaning of these words.
2) By means of the conceptual and philosophical analysis, problems of these notions (that, problems of what we consider them to mean) become obvious.
3) In furthering the philosophical analysis, solutions are explored, but happen to fail.
4) This analysis involves articulation of the ‘fundamental’ philosophical issue such that it <u>explains why the problem cannot be solved</u>. This may result to the recognition that the problem cannot be brought in accordance with ‘traditional’, commonly accepted ideas, intuitions and presuppositions (e.g., recognizing that ‘truth of scientific theories’ is an untenable, or at least, philosophically very problematic idea.
5) This insight may lead to exploring whether these ‘traditional’ ideas could possibly be changed or adapted. In other words, can these notions be re-interpreted – can they be given a more refined meaning?

6) Sometimes, this results to asking a different kind of philosophical question (e.g., shifting focus from how to *prove* that a scientific theory is *true*, to the question *why* scientific researchers *accept* a scientific theory – where the answer ‘because the theory is true’ is no longer allowed). Another possibility is shifting to an alternative philosophical approach. Clearly, in the example of ‘true theories’, looking for an alternative kind of question involves looking for ‘what really is at stake’. Why is the issue important for us? What do we aim to achieve by this concept? What do we wish to claim when using it? What do we want to preserve when using that concept (e.g., truth, objectivity or rationality).

7) The alternative approach in the case of ‘objectivity’ and ‘rationality’ makes use of the insights gained on *why* objectivity and rationality in the traditional sense cannot be maintained. Rough and dirty, Kuhn’s explanation (of why the traditional meanings of objectivity and rationality of science cannot be maintained) says that all aspects of scientific methodology – i.e., (a) the way in which observations are initially interpreted; (b) the way in which a question in science is asked, and (c) the way in which a plausible hypothesis is constructed, and also (d) what is accepted as confirming or falsifying the hypothesis, including, the kind of auxiliary hypothesis that are acceptable in repairing anomalous results of a test – are embedded in a broader perspective, a so-called paradigm or ‘disciplinary matrix’. **The message of this lecture is that a disciplinary matrix is indispensable. Nonetheless, although this ‘perspective at the background’ cannot be tested in a straightforward manner, it can be articulated, explored and revised.** This lecture aims to give some examples, especially of the second aspect of the disciplinary matrix, by briefly illustrating: (1) some different metaphysical pictures of the world, and (2) how such pictures indeed play an indispensible role in scientific reasoning (and related to the aspects a,b,c,d above of scientific methodology), and also (3) how metaphysical pictures of the world have changed as an effect of development of science in the history of science.

Standard Picture of Science (e.g.)":	Alternative Picture of Science (e.g):
• Scientific realism • Aim of science is true theories. • **Context of *discovery* versus *justification***. ○ Science is rational and objective. ○ Scientific results (truthfully) represent (unobservable) aspects of the world. ○ Mere deductive and inductive reasoning.	• Anti-realism / Pragmatism • Aim of science is useful knowledge. • Empirical adequacy (and other epistemic values) rather than truth. • **Context of *construction***: ○ Reflect on disciplinary matrix ○ Epistemic results (e.g., theories, models, concepts, equations) as tools for thinking about world. ○ Importance of scientific and mathematical concept formation. ○ Different kinds of reasoning.

Zooming out further:

In this philosophy course, we have been thinking about the question what science is. We have reflected on 'common' or 'standard' pictures of science, and discussed difficulties of these pictures. Such pictures of science are articulated and analysed by philosophers of science; philosophers also propose **alternative pictures** that aim to solve specific philosophical difficulties of the standard picture. In this course, one such alternative has been worked out in this course. Such alternative 'pictures of science' may, in a loose sense, also be considered as a paradigm. The picture of science cannot be 'proven'. Instead, it can be assessed in regard of important values, first of all, its coherency, its adequacy about concrete scientific practices, and its fruitfulness for those practices and for society. The alternative proposed takes anti-realism (or pragmatism) rather than scientific realism as its favoured metaphysical picture. This picture has been proposed as it may be a more productive picture for understanding the engineering sciences.