Wissenschaftliches Arbeiten (WIA)

Vorlesung – Hochschule Mannheim

Philosophical Foundations and Theory of Science

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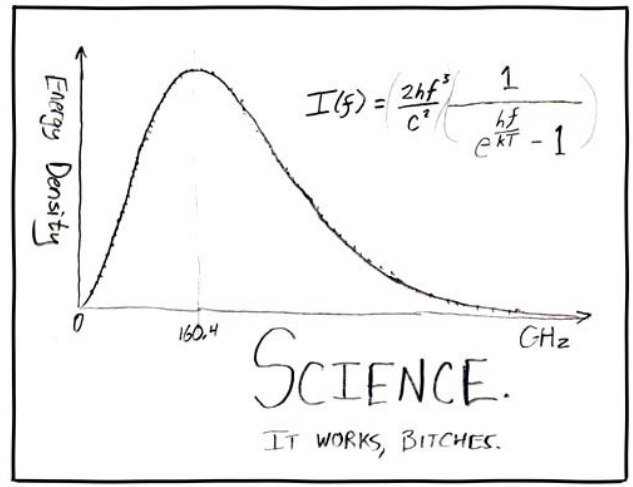

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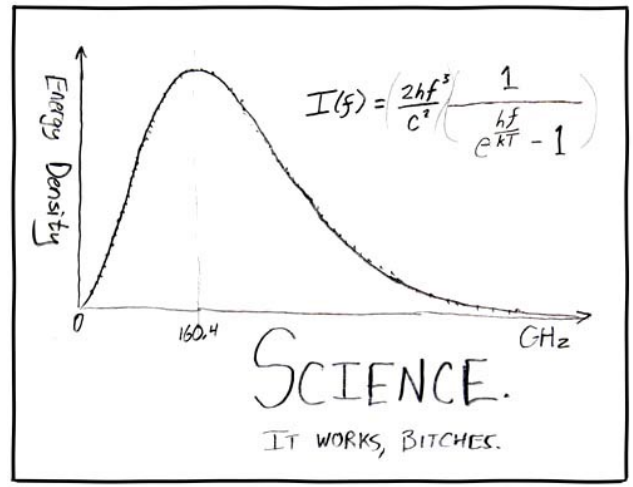
Objectives


Energy Density
$I(f) = \frac{2hf^3}{c^2} \left(\frac{1}{e^{\frac{hf}{kT}} - 1} \right)$
0
160.4
GHz
SCIENCE.
IT WORKS, BITCHES.

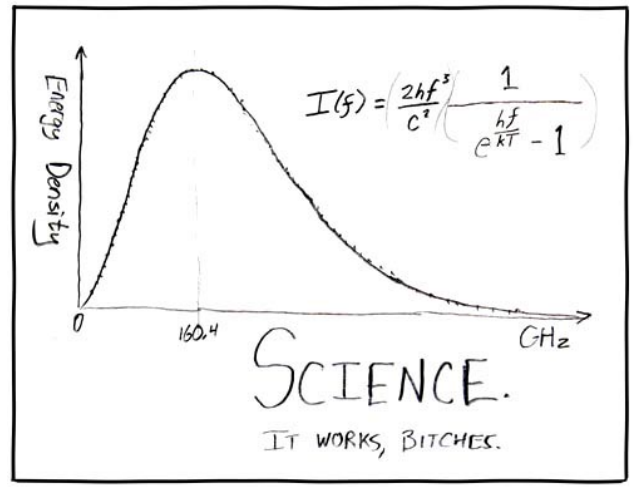
Key Questions

- What is the theory of science?
- How do we gain scientific knowledge?
- How can we find proof for theories?

Learning Objectives

- Understand the fundamental problems in gaining knowledge
- Know the basic ideas of Realism and Anti-Realism
- Understand the importance of experiments in science
- Distinguish good from bad theories
- Know the problem of induction
- Understand how Falsificationism works

Statements and Proof



Example

- What is the difference between the following statements?
- How can we prove them correct?

There are unicorns.

There are no unicorns.

General vs. Special Statements

Two kind of statements

- *Universal Quantification (Allaussage)*:
  A statement about all objects in a specific context,
  e. g. „all humans are mortal“
- *Existential Quantification (Existenzaussage)*:
  A statement about the existence of at least one object or phenomenon,
  e. g. „there is cheese on the moon“

Negation

- Statements about non-existence (negation of a existential quantification) are universal quantifications
  e. g. „there is no cheese on the moon“
- Statements about non-universality (negation of universal quantification) are existential quantifications
  e. g. „there is one human who is not mortal“

Examples

- „There are unicorns“ is an existential quantification
  $\Rightarrow$ „In the world there is at least one unicorn“
- „There are no unicorns“ is an universal quantification
  $\Rightarrow$ „All objects in the world are not unicorns“

Proof

How can we derive proof for existential and universal quantifications by observation of the world?

- Existential quantification: ...
- Universal quantification: ...

Proof

How can we provide proof for existential and universal quantifications by observation of the world?

- Existential quantification: Find one example of the object with the described quality,
  e. g. fly to the moon and find one piece of cheese
  $\Rightarrow$ there is cheese on the moon
- Universal quantification: No proof possible,
  e. g. you cannot know if there is somewhere a human who is not mortal

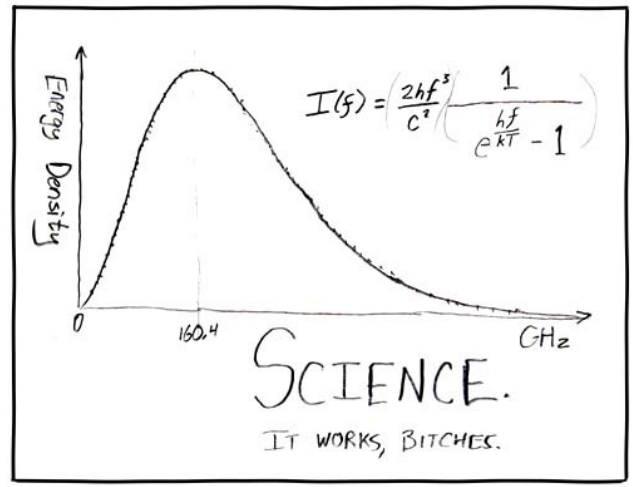
Back to the unicorn

- You cannot provide proof for the non-existence of something
  e. g. it is impossible to proof that unicorns do not exist
- You can provide proof for the existence of something
  e. g. find one unicorn

„There are unicorns“ $\rightarrow$ existential quantification, provable

„There are no unicorns“ $\rightarrow$ universal quantification, not provable

Philosophy of Science



Philosophy as the Foundation of Science

- Scientific reasoning must itself be based on a model and theory: *Theory of Science*, which is developed by Philosophy
- The central question is „How can humans gain knowledge (Erkenntnis) about the world surrounding them?“
- Philosophers are working on this questions for thousands of years
- *Logic (Logik)*:
  What conclusions can be correctly derived from premises?
- *Metaphysics (Metaphysik)*:
  How we can describe and analyze the world?
- *Epistemology (Erkenntnistheorie)*:
  How can we gain knowledge about the world?

Two Philosophical Schools

Two philosophical schools are important for the scientific approach

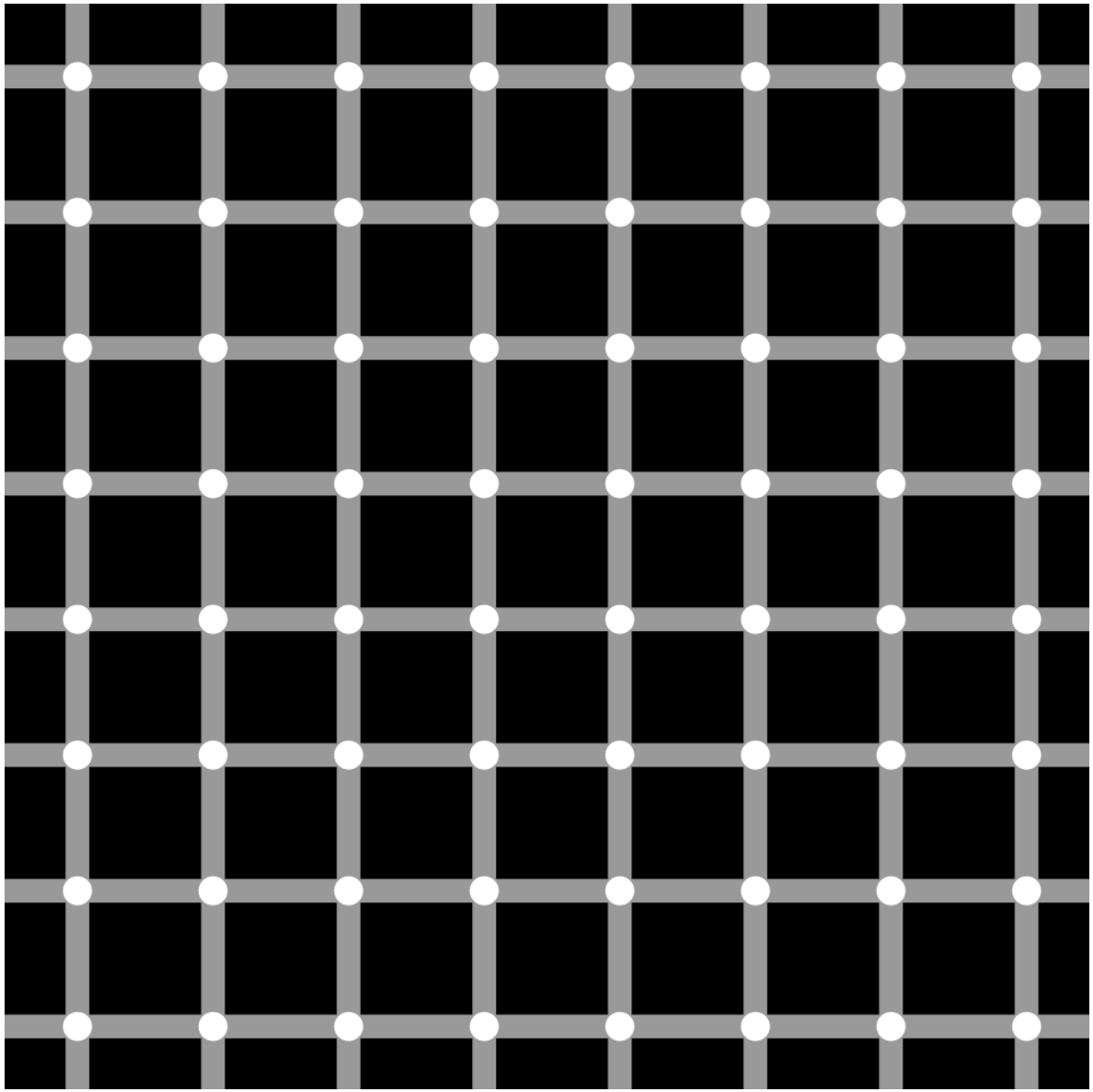
- *Empiricism (Empirismus)*
  - knowledge comes only or primarily from sensory experience
  - emphasizes the role of experience and evidence, especially sensory experience, in the formation of ideas, over the notion of innate ideas or traditions
- *Positivism (Positivismus)*
  - knowledge is based on natural phenomena
  - Information derived from sensory experience, interpreted through reason and logic, forms the exclusive source of all authoritative knowledge

Facts

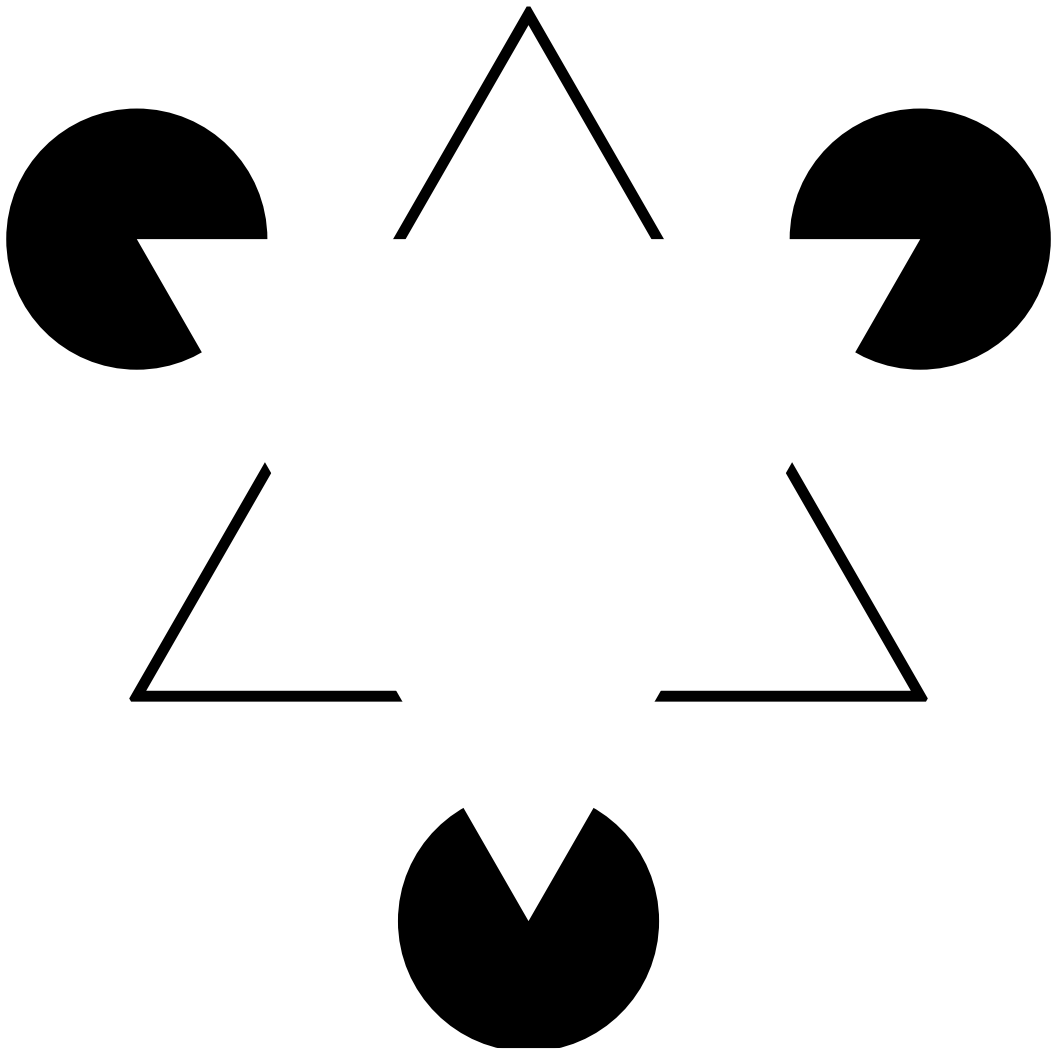
Assumptions about *facts* *(Tatsachen)*

- facts can be directly observed
  $\rightarrow$ issues with the sensory system (see below)
- facts are there before the theory is built
  $\rightarrow$ observations are not independent from the theory
- facts are a stable and reliable foundation of scientific knowledge
  $\rightarrow$ knowledge and facts are fallible and mutually depend on each other

The Fundamental Problem



The Fundamental Problem



The Fundamental Problem

- All observations of the world happen through our sensory system (Sinne)
- There is no way to distinguish
  - genuine perceptions of the world
    e. g. there is a red car and I can see a red car
  - misperceptions or hallucinations
    e. g. there is a black car but I think it is red or there is no car at all but I have a hallucination of a red car

$\Rightarrow$ all observations are *fallible (fehlbar)*

The Fundamental Problem

Is it possible to gain trusted knowledge regarding the world if all observations may be just misperceptions or hallucinations?

How can we do science if there is no means to perform objective observations of the world?

Two Contradicting Positions

Realism (Realismus)

- Most perceptions of reality are correct and capture the world as it is
- Statements about reality deliver a true descriptions about the world
- Given ideal circumstances, there is only one true description of the world
- Every statement is either true or false (*principle of bi-valence*)

Two Contradicting Positions

Anti-Realism *(Antirealismus)*

- Perceptions of reality are highly subjective
- There is no single description of the world. It is possible to have many different (inconsistent) descriptions at the same time
- The truth of a statement is a result of an agreement between humans
- Statements can be true and false at the same time (no bi-valence)

A Possible Argument

- Our sensory system's main purpose is to ensure our survival in nature
- Survival depends on correct mental representations of the environment
- Evolution has optimized the system over million of years
- Nearly all of our sensory perceptions must be correct, otherwise our species would had no chance to survive
- We have survived
- $\Rightarrow$ Therefore, our perceptions give a (mostly) correct perception of reality

Fact and Observation

- Observations must be
  - *objective*: you can test them with reproducible procedures
  - *fallible*: new methods may show that they were wrong

A *fact (Tatsache)* is an observation you can test it using your senses

Experiment

- Science requires relevant facts, not arbitrary facts
- In nature different causes tend to overlay each other
- Just observing will not reveal if many causes are affecting each other

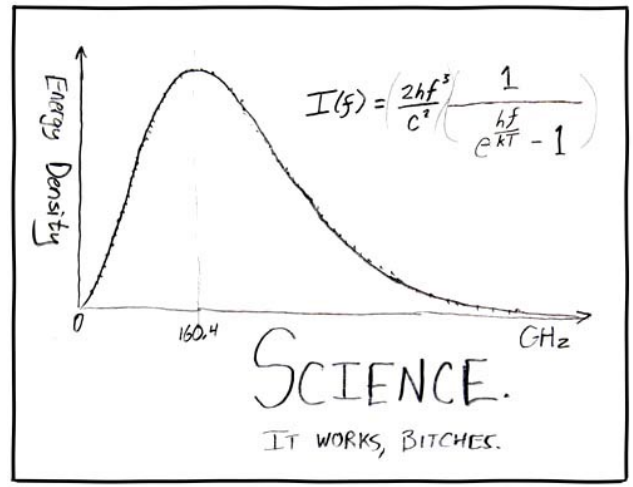
$\Rightarrow$ *Experiments (Experimente)* are required to separate different causes

Experiments are Fallible

Experimental results are also fallible

- Advances in technology
- New knowledge
- Irrelevant due to new theoretic models

Deduction and Inductivism



Deduction

Deduction (Deduktion): Deriving special statements from general statements using logic with (general $\rightarrow$ special)

1. All lectures about the theory of science are boring
2. This lecture is about the theory of science
3. $\Rightarrow$ This lecture is boring

1. and 2. are the *premises (Voraussetzungen/Prämissen)* and
3. is the *conclusion (Schlussfolgerung)*

If the premises are true, the conclusion is also true

Truth of the Conclusion

Truth of the premises cannot be derived by deduction or logic at all

1. All pigs can fly
2. Babe is a pig
3. $\Rightarrow$ Babe can fly

> Logic is not the source of new truth!

Induction

Induction (Induktion): Deriving general statements from observation of special cases (special $\rightarrow$ general)

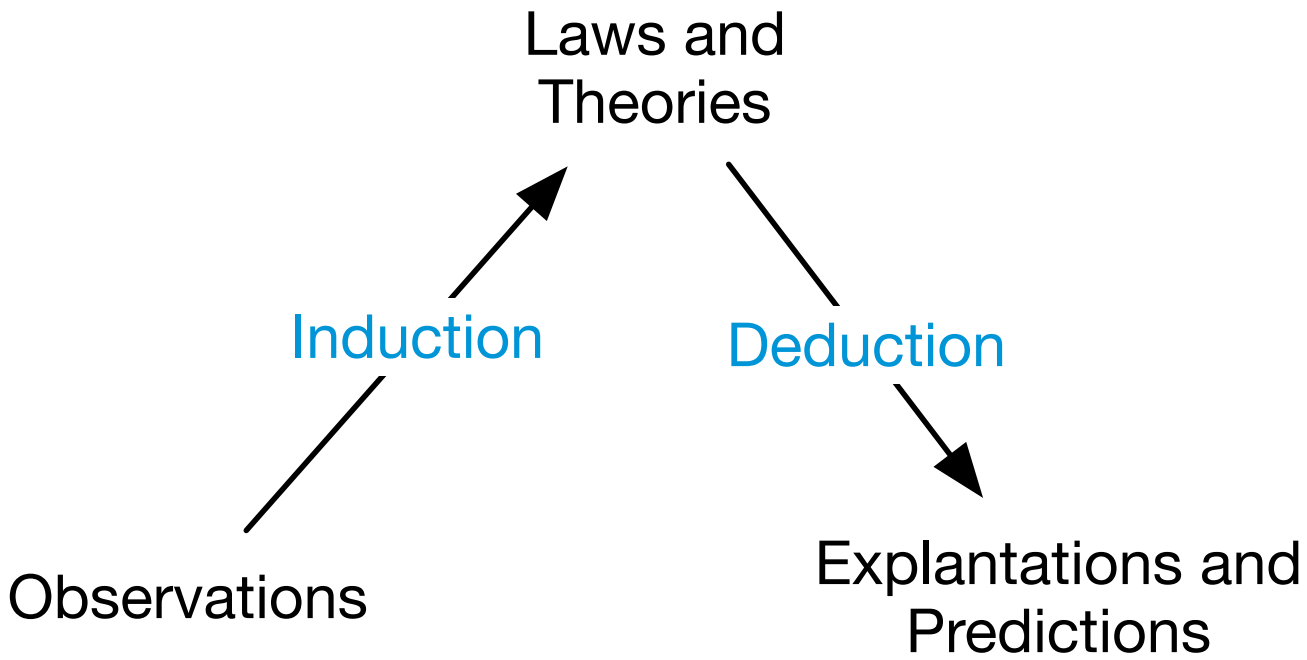
- If a large number of A observed under different conditions show, without any exception, the quality X
- $\Rightarrow$ all A have the quality X

Example

- I have seen a white swan
- I have seen a white swan
- ...
- All swans I have ever seen are white
- $\Rightarrow$ All swans are white

Inductivism

Inductivism (Induktivismus): Scientific knowledge can be gained by induction using observable facts



Predictions based on induction

Induction

Source: Wikipedia

Problem of Induction

Problem of Induction *(Induktionsproblem)*

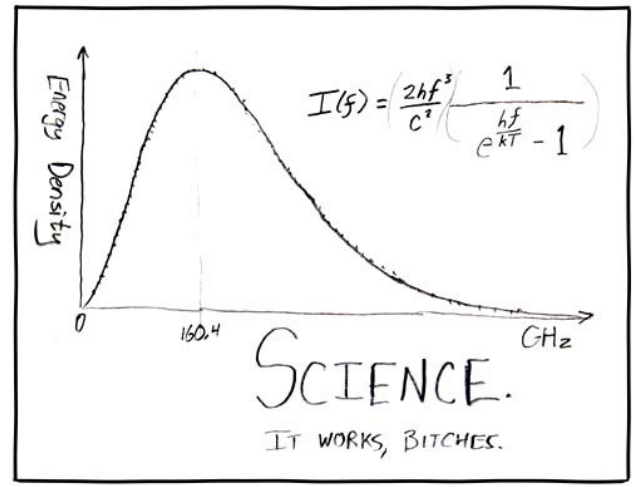
- A large number of observations is regarded as proof for the theory
  e. g. I have never seen a black swan $\Rightarrow$ they don't exist
- A theory makes statements about general terms
  $\Rightarrow$ it consists of universal quantifications
  $\Rightarrow$ single observations cannot provide proof for universal quantifications
  $\Rightarrow$ you cannot prove a theory using single observations
- Any inductive argument uses facts that are based on knowledge gained by inductive arguments
- Many theories deal with things you cannot observe: DNA, atoms, ...
- Induction is justified by the fact that it worked many times before
  (do you see the problem?)

Summary

Induction

- can provide valuable insights
- can support the creation of theories
- is not sufficient to gain scientific knowledge

Falsificationism



Basic Idea

- It is impossible to logically deduct general theories from observations and experiments (regardless of their number)
  $\Rightarrow$ All theories are speculations and may be wrong
- It is possible to test theories by observations and experiments
  $\Rightarrow$ A bad theory will fail
  $\Rightarrow$ A good theory has to survive this tests
  $\Rightarrow$ The more tests a theory survives, the more we regard it as correct

The scientific approach to test theories using predictions made by the theory is called *Falsificationism* *(Falsifikationismus)*

Requirements for the Theory

A good (scientific) theory must be *falsifiable (falsifizierbar)*: It must be possible to make observations that do not fit to the theory

Asses the following statements:

> *All matter expands if heated.*

> *There may be luck involved in betting on horses.*

> *All points of an euclidean circle have the same distance from the center.*

Good Theories

Good theories should be

- highly falsifiable
- as exact as possible

A theory is never true but only not falsified

Ad-hoc Modifications

Changes to a theory that prevent it from being falsified are called *Ad-hoc modifications* *(Ad-hoc Modifikation)*

- does not allow new ways to falsify the theory
- reduces the scope of the theory and therefore the possible falsifications

Example

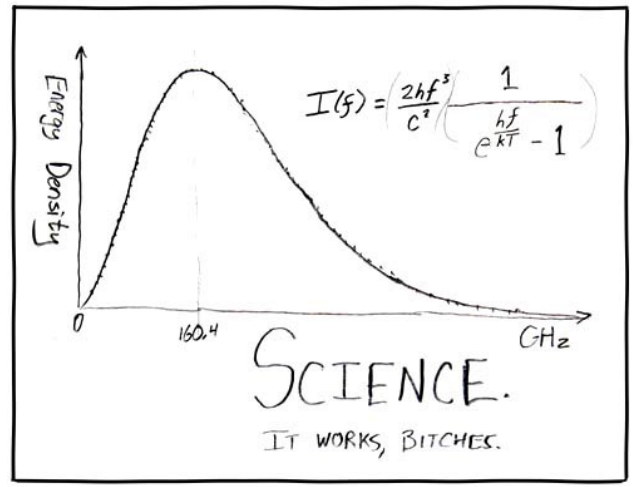
- Aristoteles' theory is that all celestial objects are perfect spheres
- Galileo observed with his telescope that the moon has craters and the surface is not smooth
- Supporters of Aristoteles' theory proposed that the moon is covered with an invisible substance that fills all the craters and provides a smooth surface

Limits of Falsificationism

Although a very powerful model, falsificationism has some limits

- Observations that falsify a theory can also be wrong
  $\rightarrow$ Is it the theory or the observation we have to regard as wrong?
- Experiments require instruments and a theory describing their working
  $\rightarrow$ Is the falsified theory wrong or the theory describing the instruments?
- Historically, theories were not dropped due to single falsification but modified and expanded
- It does not describe how science can learn from errors, i. e. falsification

Beyond Popper



Kuhn's Model of Progress in Science

Kuhn points out the revolutionary character of progress in science and crises as driving forces:

- normal science
- $\Rightarrow$ crisis
- $\Rightarrow$ revolution
- $\Rightarrow$ new normal science
- $\Rightarrow$ new crisis
- $\Rightarrow$ ...

Paradigm and Normal Science

- A *paradigm* (*Paradigma*) consists of
  - general theories and assumptions
  - techniques for their application
  - which are accepted by the „science community“
- All scientists working inside the paradigm practice *Normal Science*
- At some point, issues and falsifications drive the normal science into a *crisis*
- Proponents of the old paradigm lose their faith in it
- A new paradigm emerges and causes a *Scientific Revolution*
- A new Normal Science is based on the paradigm

Learning from Kuhn's Theory

Revolutions are required

- There is no means to decide a-priori whether a given paradigm is the most adequate
- Revolutions are required to get to a new paradigm
- It takes more than one falsification to reject a theory $\Rightarrow$ the issues with a theory need to accumulate to cause a revolution

Lakatos' Theory of Research Programmes

- Scientific activity is performed in specific environments, which Lakatos calls *Research Programmes (Forschungsprogramm)* ($\rightarrow$ Kuhn's paradigm)
- Not all aspects of a science have the same relevance
  - *hard core (harter Kern)*
    $\rightarrow$ broad hypotheses which are central for the science, fix
  - *auxiliary hypotheses (Schutzgürtel)*
    $\rightarrow$ can be adapted and modified to support the hard core

Progressive / Degenerative Programmes

- Falsifications will not destroy the hard core but lead to extensions of the auxiliary hypotheses
- *progressive research programmes* withstand falsifications and stay coherent
- *degenerative research programmes* loose their coherence

Heuristics

A *heuristic* is a set of rules and hints supporting discoveries and inventions

- *negative heuristic* defines what not to do (e. g. modifying the hard core)
- *positive heuristic* defines what to do and how to extend the hard core and modify the auxiliary hypotheses

Issues with Lakatos' Theory

- Model works only in retrospective
- It cannot be used to judge on an existing science

Feyerabend's Anarchistic Theory of science

Paul Feyerabend (1924-1994), Austrian-born philosopher of science

- Scientific approach is not superior to other means knowledge
  - Different approaches are *incommensurable (inkommensurabel)*: there are no theoretical overlap allowing a comparison
  - In the past, important scientist broke the rules to gain new knowledge
- Science should be separated from the state (like religion)
- Scientist follow their own, subjective needs not a general method
  $\Rightarrow$ „*anything goes*“

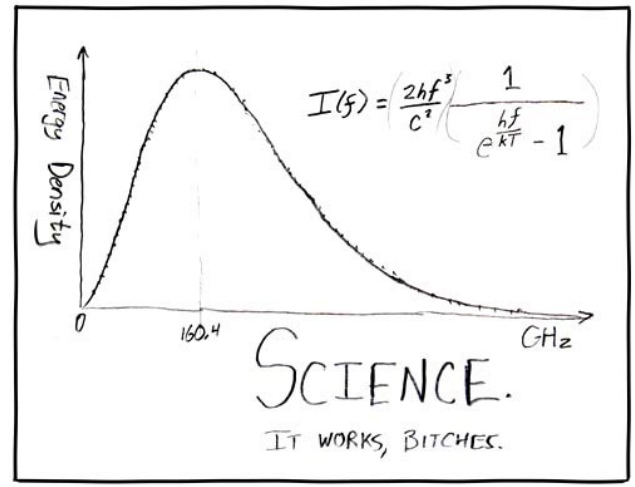
New Experimentalism

New Experimentalism: The basis of science is not the observation but the experiment

- Experiments allow to examine reality without large theories as background
- Experiments can show effects the theories must be able to explain
- Experiments can test theories
  $\rightarrow$ falsification (Popper)
  $\rightarrow$ causing scientific revoltions (Kuhn)
- Experimental results are not fallible, they are permanent

$\Rightarrow$ Requires that experiments have their own practices ($\rightarrow$ theory-agnostic)

Scientific Knowledge



Scientific Knowledge and Theory

Scientific Knowledge consists of true, justified (begründet) opinions

- they do not only show facts but also their causes
- they make statements about general facts, not only singular ones
- they deal not only with visible but also with invisible parts of the world
- they are presented in a logical ordered form
- they can be tested and controlled intersubjectively
- they can be criticized and improved
- they form a *scientific theory*

Formal vs. Empirical Sciences

- *Formal sciences* *(Formalwissenschaften)*
  - are concerned with formal systems and characterize abstract structures described by sign systems
  - can provide a formal proof for their statements
  - support empirical sciences with structures these use to describe the world
- *Empirical sciences* *(Empirische Wissenschaften)*
  - research the physical, social or psychological world
  - cannot provide proof for their statements but can only corroborate or invalidate them

Empirical Theory

Empirical Theory (Empirische Theorie)

- Describes general laws of nature or other regularities
- Allows the logic deduction of statements about observable facts
- Can be corroborated *(bestätigt)* or invalidated *(invalidiert)* using observable facts $\rightarrow$ can be *falsified (falsifiziert)*

Therefore, an empirical theory should not only give explanations (Erklärungen) but also be able to make predictions (Vorhersagen)

Examples

Asses the following statements:

> *Traumatic events in our lives cause nightmares. If the nightmares do not occur, they have been suppressed by the subconscious.*

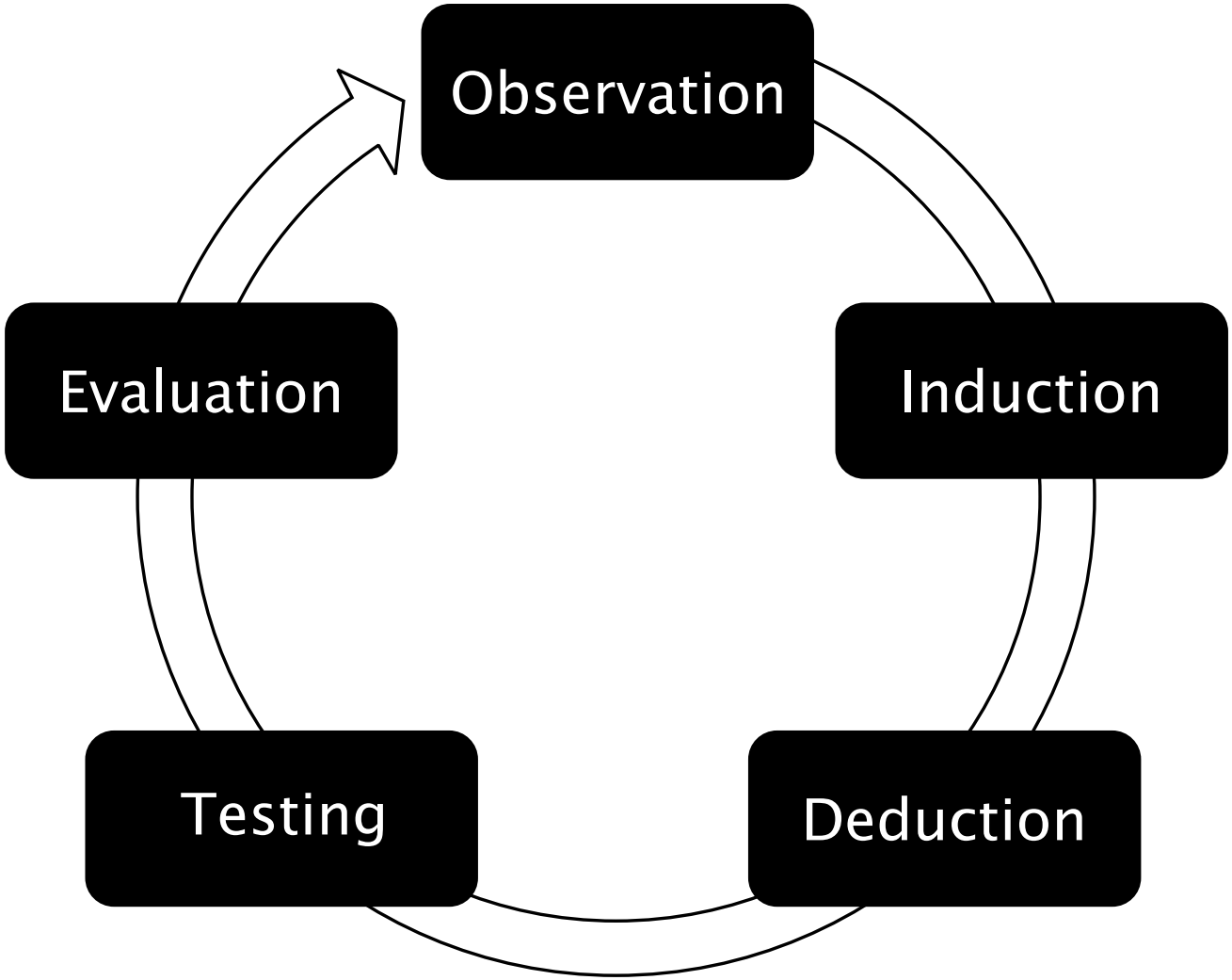
> *Rust is caused by oxygen corroding the surface of iron.*

> *The planets are revolving around the sun on elliptic paths.*

Examples

- „Traumatic events in our lives cause nightmares. If the nightmares do not occur, they have been suppressed by the subconscious.“
  $\rightarrow$ no empirical theory, cannot be falsified
- „Rust is caused by oxygen corroding the surface of iron.“
  $\rightarrow$ empirical theory, can be falsified by experiments
- „The planets are revolving around the sun on elliptic paths.“
  $\rightarrow$ empirical theory, can be falsified by observation

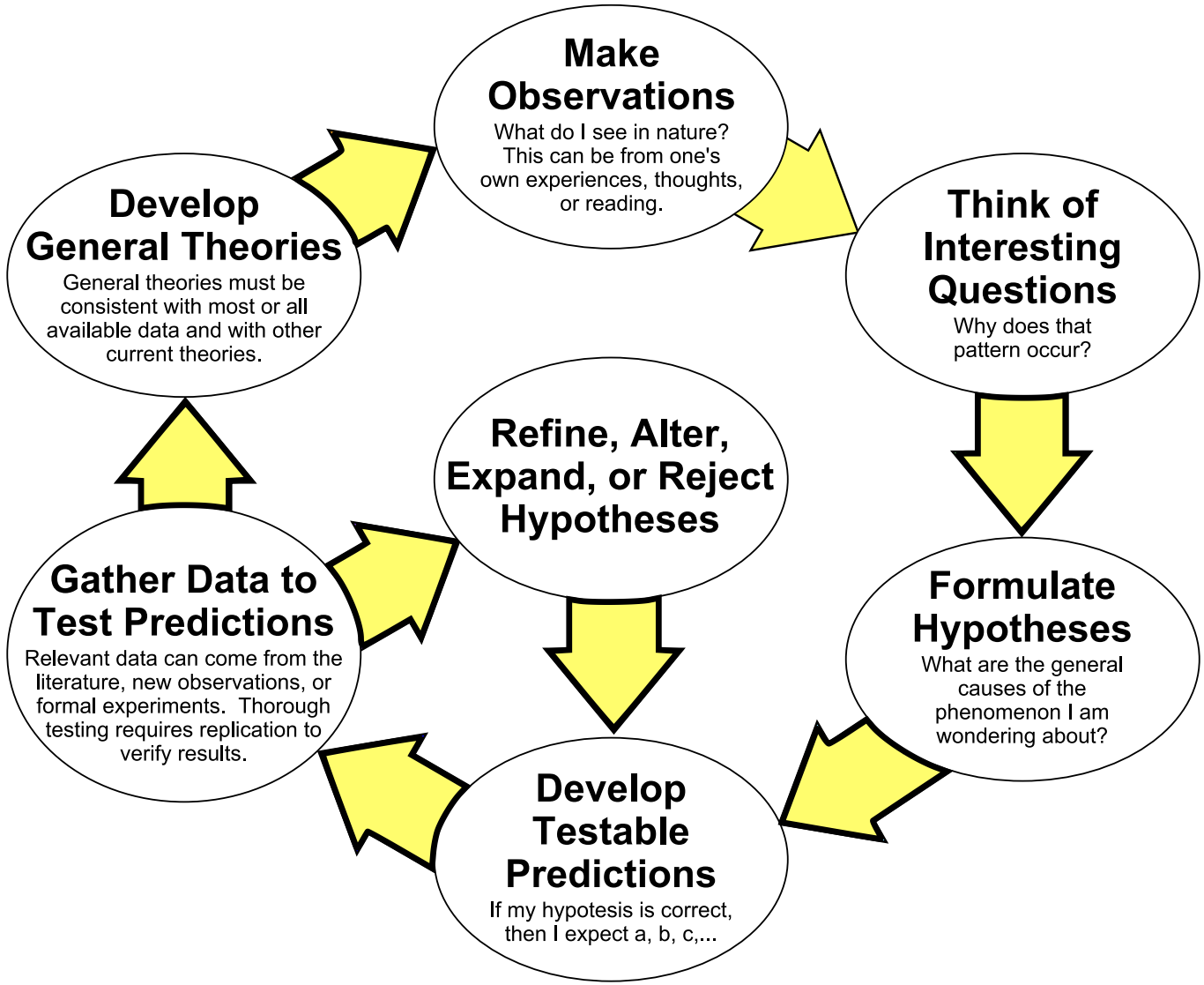
Empirical Cycle



Empirical Cycle

- *Observation*: Make observations about the world
- *Induction*: Using induction to derive general laws from the observations and formulate a theory
- *Deduction*: Derive predictions from the theory
- *Testing*: Test the predictions by observation or experiments
- *Evaluation*: Evaluate the results of the tests to falsify the theory

Scientific Method



Source: Wikipedia, ArchonMagnus