Falsification

Don’t prove, *disprove*!

Karl Popper

- Austrian philosopher of science (1902 – 1994)

A hypothesis is never *probable*

- Popper agreed with Hume that inductive inferences are not logically justifiable.
- Popper's response was to say that *science does not make inductive inferences*.
- I.e. science does not (or should not) say that a hypothesis H is probable, given evidence E. Such assessments of inductive strength/probability are subjective and have no place within science.
- The only probability we can (perhaps) assign to a scientific theory is *zero*

Confirmation vs. Falsification

- Inductive logic can be described in terms of *confirmation*. Evidence E "confirms" hypothesis H when E *increases the probability* of H. I.e. E supports H, at least in some small way.
- Popper says that no hypothesis is ever confirmed (in this sense) by empirical evidence. (Such "probabilities" have no place in science.) Instead, evidence can only *falsify* (refute or disprove) a hypothesis.

Induction/Confirmation

H predicts E
E occurs
(H is plausible, etc.)

So H is (probably) true

Falsification/Refutation

H predicts E
In observation, ~E occurs

So H is (surely) *false*

- **Falsification does not rely on background assumptions**, in the way that induction does.

- Consider the hypothesis “All swans are white”.
- Inductive argument:

1. “all swans are white” predicts “all observed swans will be white”
2. All observed swans are white

So, all swans are probably white

This relies on an assumption that *swans are likely to be similar in certain ways*, e.g. colour. Otherwise why would you form beliefs about objects you have never seen?

- By contrast, the falsification argument:

1. H= “all swans are white” predicts E = “all observed swans will be white”

2. Here is a black swan

So, not all swans are white

is deductive, and **needs no background assumptions**.

What happens when a hypothesis isn't falsified?

- Suppose someone proposes the hypothesis that all swans are white, and then observes only white swans. The data then *do not refute* the hypothesis, of course.
- Can we then say that the hypothesis is confirmed?
  - Popper says no. The hypothesis is "not yet falsified". It can also be described as "corroborated" by the data.

What counts as a *scientific* hypothesis?

- Apart from solving the problem of induction, the idea of scientific reasoning as falsification also gave Popper a **criterion of demarcation** between science and non-science (metaphysics).

  A scientific hypothesis is one that is (highly) *falsifiable*.

  I.e. the hypothesis makes definite *predictions* that could turn out to be false.

What counts as a *scientific* hypothesis?

- Popper notes that in astrology, Marxism, Freudian psychoanalysis, social science, etc. there are few (if any) robust predictions.
  - Instead, the general plan is to get the data first, and then think up hypotheses to explain them, in terms of unconscious desires, etc.
  - This is sometimes called *post hoc theorizing*.

- Popper's criterion of demarcation *strongly* resonates with many scientists, especially physicists.

Robust, precise predictions

- *Robust* = firm, unchangeable, you can’t wriggle out of it

- *Precise* = involves a narrow range of values
  - E.g. between 4.8926 and 4.8927, rather than “around 5”.

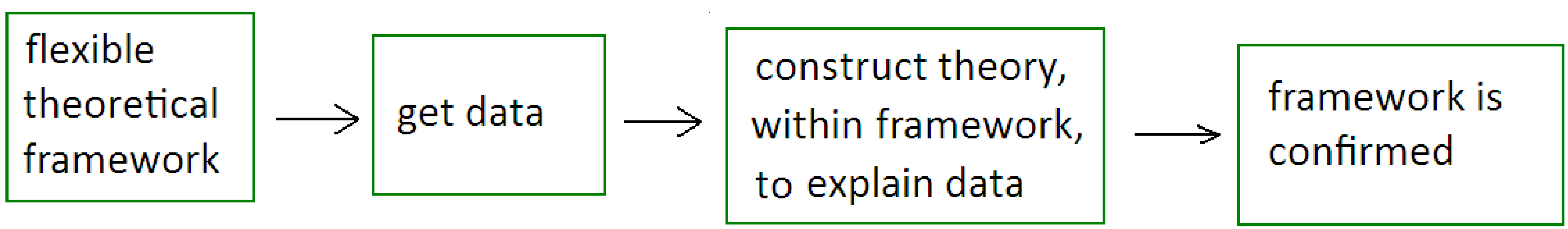
“I found that those of my friends who were admirers of Marx, Freud, and Adler, were impressed by a number of points common to these theories, and especially by their apparent *explanatory power*. These theories appear to be able to explain practically everything that happened within the fields to which they referred.

… Once, in 1919, I reported to [Adler] a case which to me did not seem particularly Adlerian, but which he found no difficulty in analyzing in terms of his theory of inferiority feelings … Confirmations should count only if they are the result of *risky predictions*”

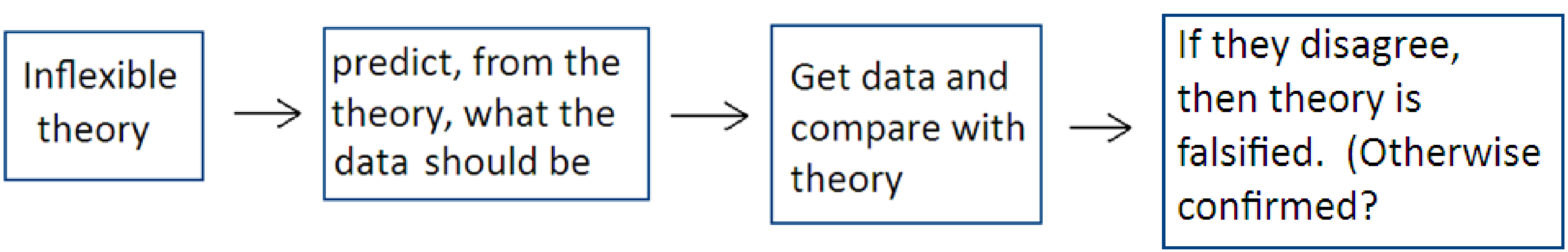
Popper, “Science as Falsification”, 1963.

- I think Popper has a very important insight here. But I'm not convinced that *falsifiability* is the key idea. Perhaps *prediction* is?

Post hoc "science"



Predictive/falsifiable science



E.g. Case of Little Hans

- Little Hans was a 5-year-old boy with a phobia of horses. Hans said that he was especially afraid of white horses with black around the mouth who were wearing blinkers. He was afraid that the horse would bite him.
- By 1909 Freud's ideas about the Oedipus complex were well-established and Freud interpreted this case in line with his theory.
- Freud thought that, during the phallic stage (approximately between 3 and 6 years old), a boy develops an intense sexual love for his mother. Because of this, he sees his father as a rival, and wants to get rid of him. The father, however, is far bigger and more powerful than the young boy, and so the child develops a fear that, seeing him as a rival, his father will castrate him.

- Freud believed that the horse was a symbol for his father, the black bits were his moustache, and the blinkers his spectacles.
- Freud theorised that Hans feared that the horse (father) would bite (castrate) him as punishment for the incestuous desires towards his mother.

- (The father and child had often played at 'horses' together. During the game the father would take the role of horse, the son that of the rider.)

Thomas Kuhn (1922-1996)

"The paradigm guy"

- His best-known book is *The Structure of Scientific Revolutions*, in which he argues that 'normal science' occurs within a fairly rigid orthodoxy, defined by the paradigm.

- Kuhn also wrote *The Copernican Revolution*, describing the transition from Ptolemaic to Copernican astronomy. This is his favourite example of a 'paradigm shift', or 'scientific revolution'.

Kuhn on the demarcation problem

- Kuhn says that science is demarcated from non-science in that science:

  (i) has a *shared paradigm* which is used to solve problems, and

  (ii) problems that persistently remain unsolved within the paradigm create a *sense of crisis*.

  In philosophy, for example, there is no shared paradigm. And problems can remain unsolved for centuries, and yet there is no crisis! ☹

Prediction is shared ground

- Kuhn and Popper actually agree that precise and robust *prediction* is an important part of science.
  1. Falsification requires a prediction. (It occurs when a prediction contradicts the empirical data.)
  2. Puzzles occur when a phenomenon cannot be predicted, or (even worse) a prediction contradicts the data.

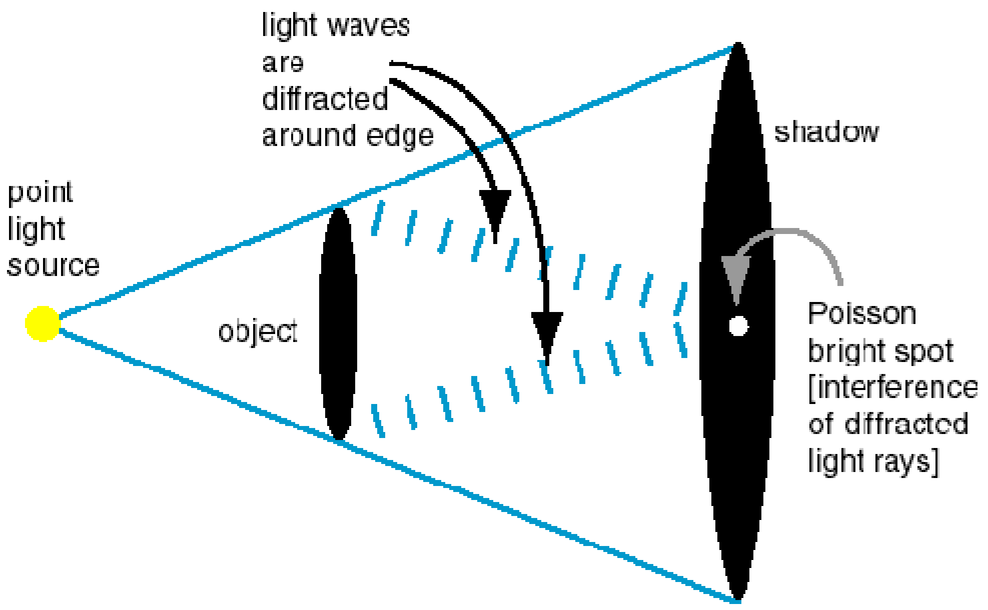
Qu. Can a theory make predictions, and yet not be falsifiable?

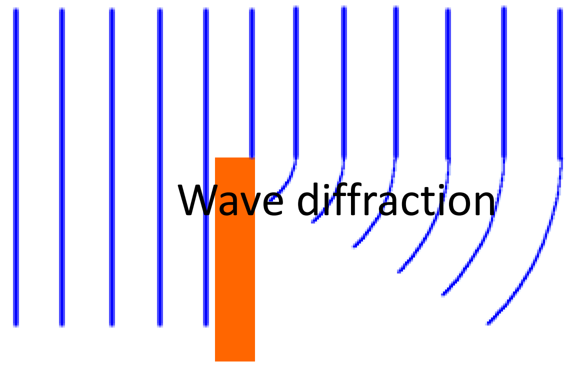
Answer: Yes. (See later criticisms of Popper.)

Surprising Predictions

- Popper is especially impressed by a theory that makes *surprising* (improbable) predictions (i.e. ones that seem to have virtually no chance of being right) that turn out to be true.
- E.g. in 1812 Fresnel proposed a wave theory of light. His opponent Poisson, aiming to refute the theory, showed that Fresnel's theory predicted that the shadow of a circular disc should have a bright spot at the centre. "Of such no such spot exists!" thought Poisson.

Poisson's hostile prediction, using diffraction and interference of waves

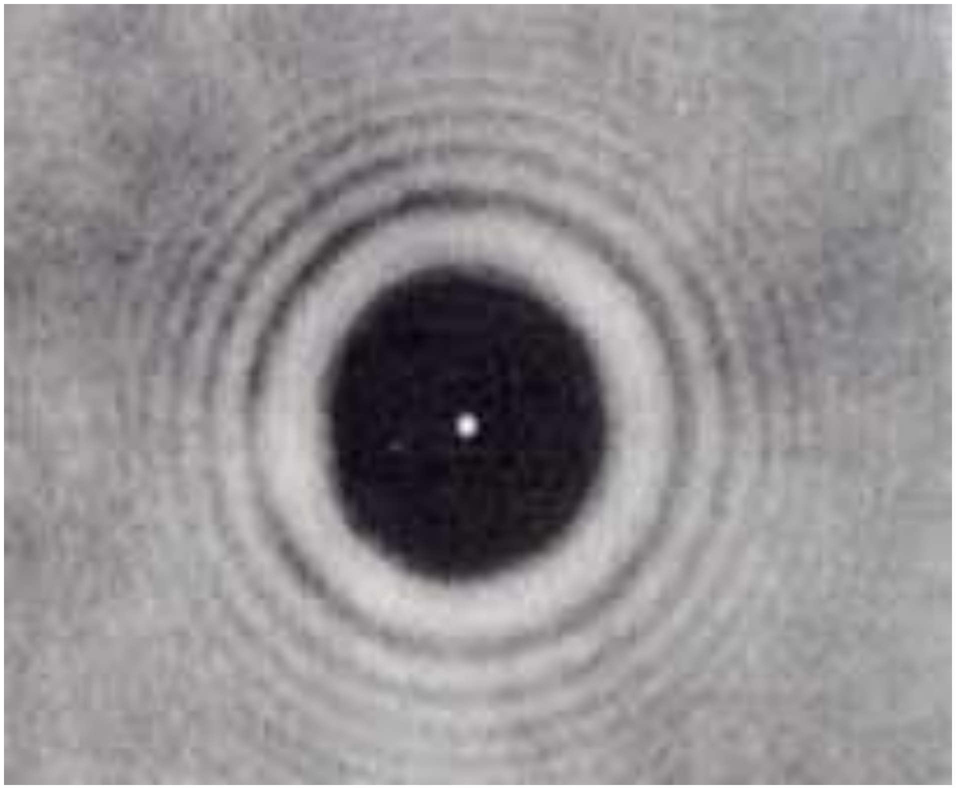


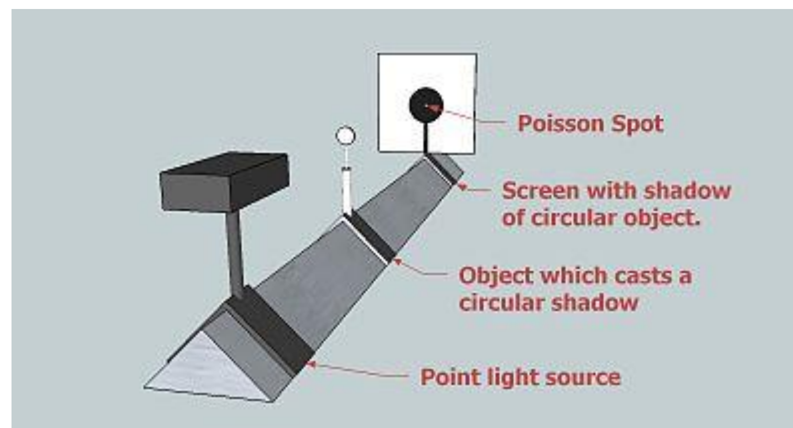


Diffraction is the spreading of waves when a piece is chopped off.

Interference is the ability of waves to add up or cancel each other out.

Data = Poisson/Arago Spot (!)





- Popper regards Fresnel’s theory as scientific, as it could easily have been *falsified* by experiment.

- One might instead view it as scientific due to its ability to make *robust, precise predictions*.
  – *Robust* = firm, unchangeable, can’t wriggle out of it
  – *Precise* = involves a narrow range of values

(Unscientific theories make vague, and/or loosey-goosey predictions, or none at all.)

Another “posterior cranial indentation”?

- According to Wikipedia,

  “The existence of the spot had previously been observed in 1723 by Gicomo F. Maraldi, but the work had been largely unrecognized.”

Part 2

Objections to Falsificationism

1. The Duhem problem

Falsification follows this pattern:

H predicts E

~E

~H

But Duhem says that an isolated hypothesis H never predicts anything **by itself**.

- Realistically, we have some “auxiliary assumptions” A that are used with H to make predictions. I.e.

  (H & A) predicts E

  ~E

  ~(H & A)

- Given that (H & A) is false, we infer that either H is false, or A is false, or both. *We don’t know where the falsehood lies*.

- When a hypothesis makes a false prediction, it isn't refuted. We can instead adjust the auxiliary assumptions.
  - E.g. the hypothesis that the earth moves predicts a stellar parallax. There is no stellar parallax, so Copernicus is refuted.
  - But no, wait! *Only relative to the assumption that the stars aren't too far away.* Rather than abandon the Copernican hypothesis, we can change that assumption.

H (the earth's motion) predicts E (stellar parallax)

There is no annual stellar parallax (~E)

Hence, the earth does not move (~H)

H (the earth's motion) *and the stellar sphere isn't huge* predicts E (stellar parallax)

There is no annual stellar parallax (~E)

Hence, *either* the earth does not move (~H), *or* the stellar sphere is huge.

“physical science is a system that must be taken as a whole; it is an organism in which one part cannot be made to function except when the parts that are most remote from it are called into play, some more so than others, but all to some degree.”

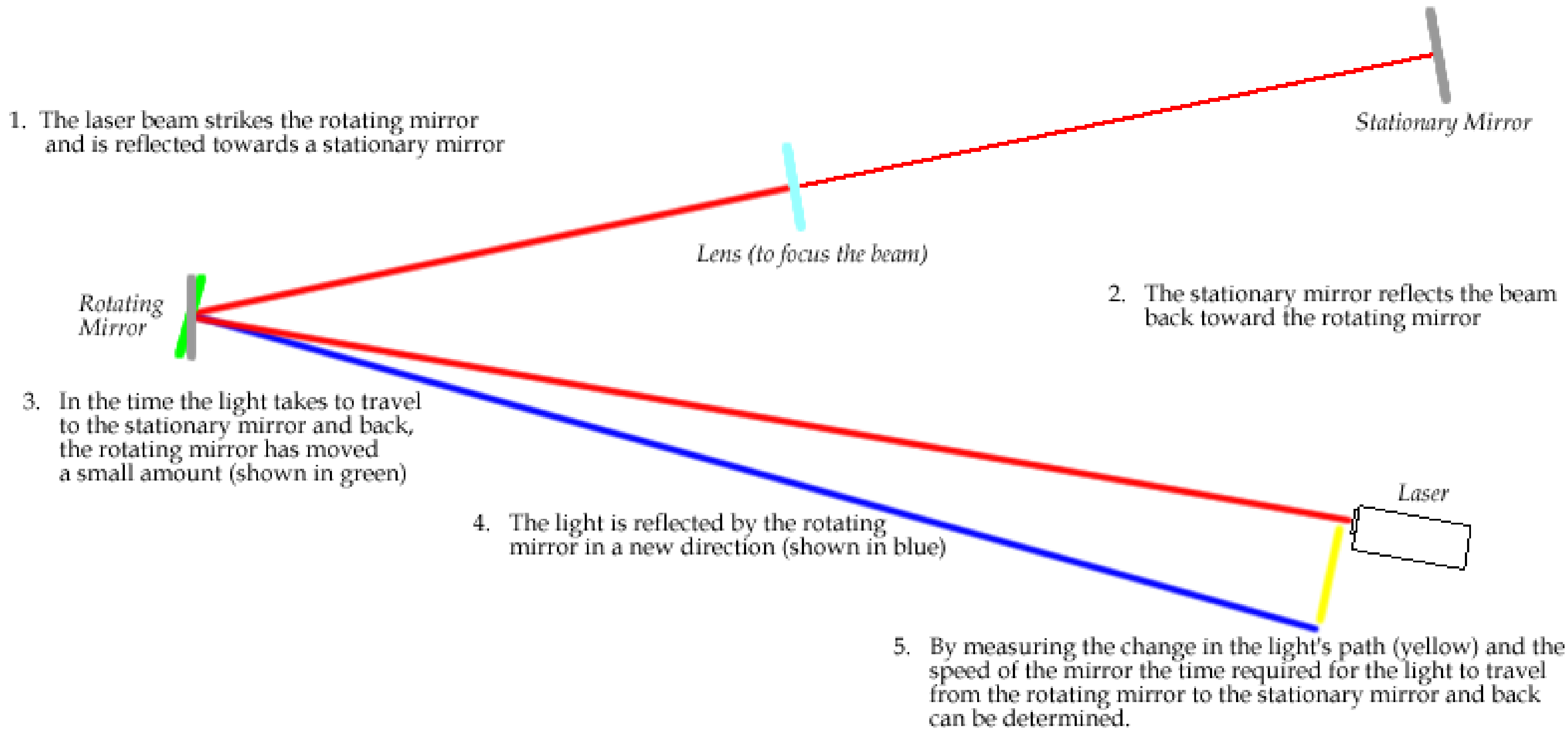
Pierre Duhem, *The Aim and Structure of Physical Theory*, 187-88.

How do scientists decide what to reject?

- When a theory makes a prediction, and this prediction turns out to be false (inconsistent with the empirical data) then how do scientists decide what to do?
  - I.e. do they reject the theory? Or reject an auxiliary assumption?
  - Copernicus kept his hypothesis, and changed the size of the universe.

- In other cases, scientists have given up on the hypothesis itself.
- For example, there was a long-running dispute between wave and particle theories of light. Biot tenaciously supported the particle theory (proposed by Isaac Newton). But after a famous experiment in 1850 by Foucault and Fizeau, Biot abandoned the particle hypothesis.
  - Could he have persisted with the particle theory?

The Foucault-Fizeau experiment



“After Foucault’s experiment had shown that light travelled faster in air than in water, Biot gave up supporting the emission hypothesis; strictly, **pure logic would not have compelled him to give it up**, for Foucault’s experiment was *not* the crucial experiment that Arago thought he saw in it, but by resisting wave optics for a longer time Biot would have been lacking in good sense.”

Pierre Duhem, *The Aim and Structure of Physical Theory* (1906) p. 218.

Quoting Blaise Pascal …

"Pure logic is not the only rule for our judgements; certain opinions which do not fall under the hammer of the principle of contradiction are in any case perfectly unreasonable. These motives which do not proceed from logic and yet direct our choices, these 'reasons which reason does not know' and which speak to the ample 'mind of finesse' but not to the 'geometric mind,' constitute what is appropriately called good sense."

(Duhem, p. 217)

Return to Induction?

- But if Duhem is right, and scientists use “good sense” to decide what to give up (in the face of a contradiction between theory and data) then that seems *awfully subjective*.
- Also, scientific reasoning starts to look like induction again, as one has to assess whether the main hypothesis (H) or the auxiliary assumptions (A) are more likely to be wrong.

Kuhn again

- Kuhn roughly agrees with Duhem here.
- False predictions are “puzzles”, or “problems”, rather than refutations of the theory.
- It’s only when puzzles are stubborn, and accumulate, Kuhn says, that a sense of crisis develops and theory change becomes possible.

Falsifiable vs. predictive

- The Duhem problem makes it difficult to say that the difference between science and non-science is that **scientific theories must be empirically *falsifiable***.

- What about a criterion of demarcation that **a body of scientific theory must make empirical *predictions***?

Objection #2

Many scientific claims are unfalsifiable?

(a) Claims about *probabilities* aren’t falsifiable.

(b) *Existential* claims aren’t falsifiable.

(c) *Fundamental Principles* aren’t falsifiable.

(Do these claims make *predictions*?)

(a) Probabilistic claims

- Fred claims that the coin he's holding is fair, so that the chance of heads is 0.5 on each toss.

- We toss it 1000 times and get 733 heads, 267 tails. "Fred, you're full of it," we say. "This coin is biased!"

  "Nonsense," Fred replies. "It's *possible* for a fair coin to produce that outcome. The fair-coin hypothesis is not refuted."

  Is Fred right or wrong here?

- Fred is unfortunately right. What outcome does the fair coin hypothesis predict, for 1000 tosses? *It makes no definite prediction*. It allows (absolutely) any outcome, simply assigning a probability to each one. Such hypotheses are not strictly falsifiable. (At best, they are rendered “probably false”.)

- Also, such probabilistic predictions are fairly common in science. A lot of scientific models involve random processes (e.g. genetic mutation in biology, radioactivity in physics).

- Popper suggested that we can regard a hypothesis as "practically" falsified, if it assigns a very low probability to an event that actually occurs. I.e.

1. E is very unlikely given H, i.e. Prob(E | H) is low
2. E occurs

$\therefore$ H is falsified, for all practical purposes

- N.B. Popper is ok with assigning probabilities to the evidence, e.g. Prob(E | H).

Example

1. 733 heads (from 1000 tosses) is very unlikely, given that the coin is fair.
2. 733 heads occurred

The fair coin hypothesis is (practically) refuted

(Does this work?)

- The problem is, if you're tossing the coin 1000 times, then *every possible outcome is unlikely*. Even the most likely outcome (assuming a fair coin), i.e. 500 heads, has a chance of only about 1/40.
- With more tosses, say one million of them, even the most likely outcome is very unlikely.
- Also, that "outcome" of 500 heads is really a (huge) *collection* of outcomes, as there are about 10^{299} distinct outcome sequences with 500 heads. So the chance of the actual *precise* outcome is really about 10^{-301}.
- According to Popper's rule, the fair coin hypothesis is refuted *whatever happens*!

- Popper’s rule for refuting probabilistic hypotheses is completely ridiculous.

- Others, such as (statisticians) Ronald Fisher, Jerzy Neyman and Karl Pearson, have proposed more sophisticated rules in the same falsificationist vein. Such rules are central in “frequentist” statistical inference.
- Do probabilistic theories make *predictions*?
  - Tentative predictions, not certain ones.

(b) Existential Statements

- Existential statements, such as “there is a black swan”, “there is a monster in Loch Ness”, “Chronic Fatigue Syndrome is caused by a retrovirus”, etc. are not generally falsifiable, but are provable.

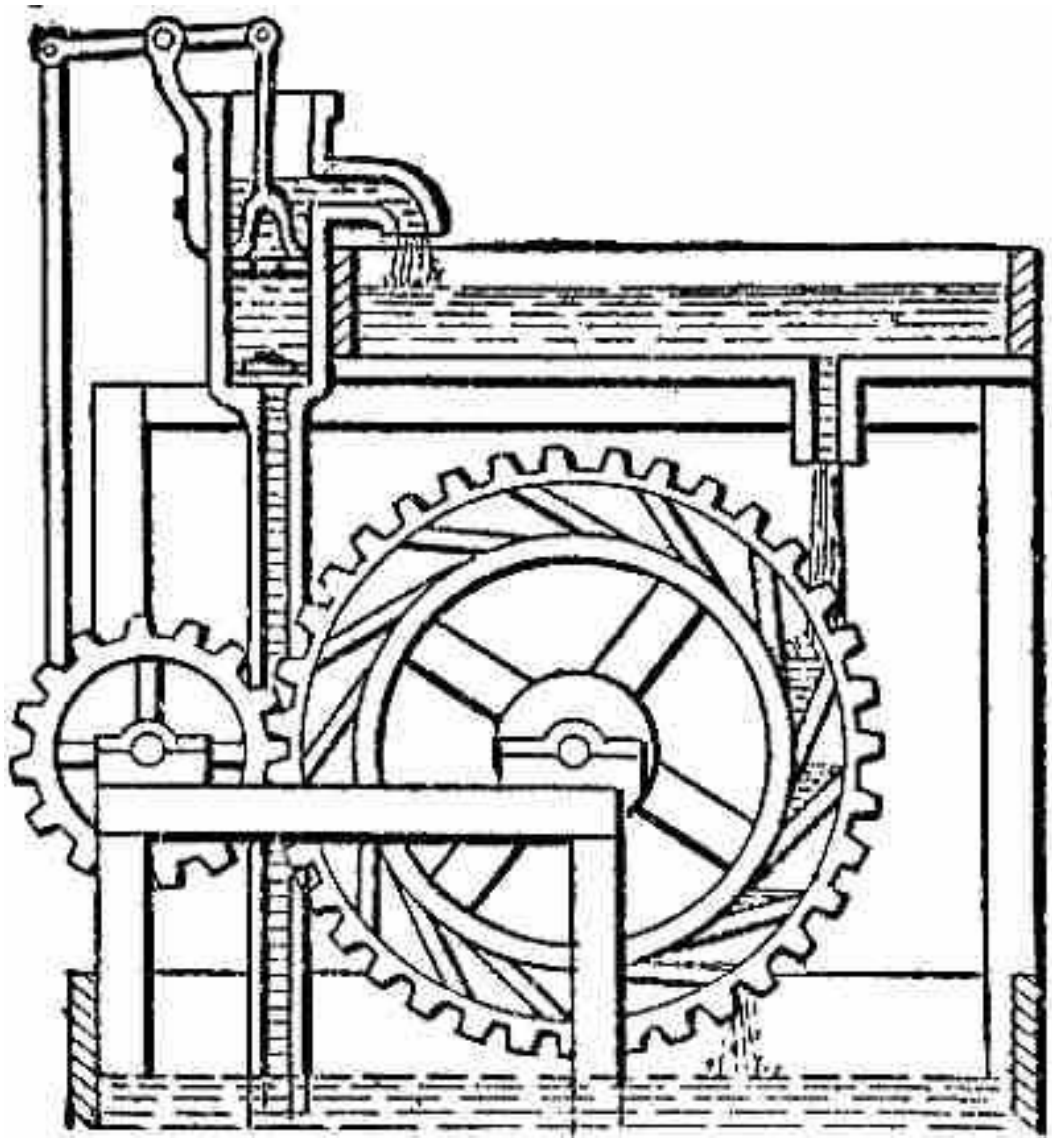
- Do they lead to predictions?
- Tentative predictions only.

(c) Fundamental Principles

- Suppose a scientist claimed to show, experimentally, that energy is not conserved:
- "This apparatus in my lab creates energy out of nowhere, since more energy comes out of the system than is going in."
  - (I.e. he claims to have a **perpetual motion machine**.)

- How would the scientific community respond to this claim?

E.g. (it goes forever!)



It turns by itself!!

- Right. They would say that ***it just can't work***.

- Or, if it does work, then there's an additional energy source that the experimenter has overlooked.

- "Indeed, the fact that the energy output exceeds the known energy inputs *proves* that an additional energy source exists, because *we know that energy cannot be created*."

- In other words, the second law of thermodynamics is now so deeply entrenched in the scientific community that it is (effectively) impossible to falsify.

- But isn’t it still a *scientific* principle?

- (Does it help to make predictions?)

"If your theory is found to be against the second law of thermodynamics I can give you no hope; there is nothing for it but to collapse in deepest humiliation"

(Physicist Arthur Eddington)

Objection #3.

Don’t we *believe* our best theories?

- Despite what Popper says (and the devotion he inspires in many scientists) it seems that scientists do (at least partially) *believe* their theories.
- When a geologist, for example, is speaking about the ice ages (a hypothesis used to explain some geological formations) does he regard the hypothesis as having probability zero?

- Consider also Michael Polanyi’s statement:

  “The physicists of the period from 1912 to 1930 considered it as **established beyond reasonable doubt** that only electrical forces could account for intramolecular attraction.”

- E.g. an article in *Scientific American,* in response to creationists who say that evolution is “only a theory” (i.e. a speculative guess),
- “The fossil record and abundant other evidence testify that organisms have evolved through time. Although no one observed those transformations, the indirect evidence is clear, unambiguous and **compelling**.

  “15 Answers to Creationist Nonsense”, John Rennie, July 1, 2002

Betting on theories

- Scientists often urge policy makers to (in effect) *bet on* scientific hypotheses.
- A bet on the proposition A, in general, is to undertake some action which will have a positive benefit if A is true, and carry some cost if A is false.
- E.g. a bet on (anthropogenic) global warming might consist of expensive measures to reduce CO_2 emissions.
  - These measures result in a net future benefit if AGW is true, but a net cost if it’s false.

Betting and Belief

- "degrees of belief" are (at least roughly) defined in terms of dispositions to accept bets at certain odds.
- E.g. a person who regards the gamble

  [$1 if Canada wins gold medal in women's hockey]

  as worth 58 cents *believes* to degree 0.58 that the Canadian women will win.

- So, betting on theories seems to require that we have a (partial) belief that they are true.

- Should a Popperian jump out of the window from the top of a building (rather than take the elevator)? After all, if he doesn't *believe* the theory of gravity …

- Popper has been accused of (epistemic) anti-realism, i.e. the view that we have no way to ever know what is true. (The truth is out there, but permanently inaccessible.) Anti-realism of all kinds is contrary to the scientific attitude.

Ignoring Falsifying Evidence

- Sometimes scientists simply *don’t worry about* inconsistencies between a hypothesis and the data. (E.g. Darwin and the distribution of marsupials.)

- The attitude is, “Oh well, it will be alright. Something will turn up.”

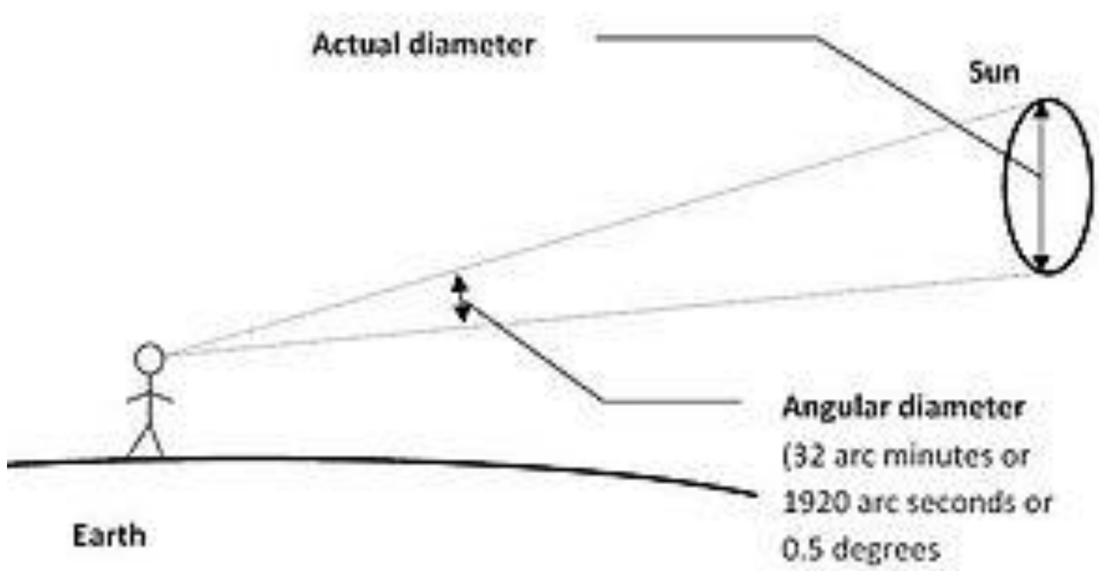
- If scientists like the theory, they will stick with it, even in the face of such problems, at least until something better comes along.

Galileo and the stellar parallax

- When Galileo looked at a star through his telescope, he didn't see a point of light. Rather, he saw a small bright disc. (Something like the image below.)

Apparent Diameter

- The *apparent* size of a sphere, for a given viewer, is its "angular diameter", measured in degrees, or fractions of a degree, as shown in the diagram below.



Angular diameter of a star

- Galileo measured the angular diameter of a bright star to be about 5 arc-seconds (i.e. 5/3600 degrees) and a dim star to be around 1 arc-second.
- (The sun is about 1920 arc-seconds, i.e. about 380 times the angular diameter of a bright star.)
- *By assuming that all stars are the same size as our sun*, Galileo calculated that bright stars are only about 380 A.U. away from earth.

- "We know that the differing stellar radii Galileo was measuring represented nothing more than a combination of a wave optics diffraction pattern/Airy Disk and the limits of the human eye".

  "Galileo used his observation of Mizar to calculate that Mizar A, being 1/300 the apparent radius of the Sun, must be 300 times more distant than the Sun (300 A.U.). In doing this Galileo assumed that stars are suns. By the same logic, Mizar B would be 450 A.U. distant."

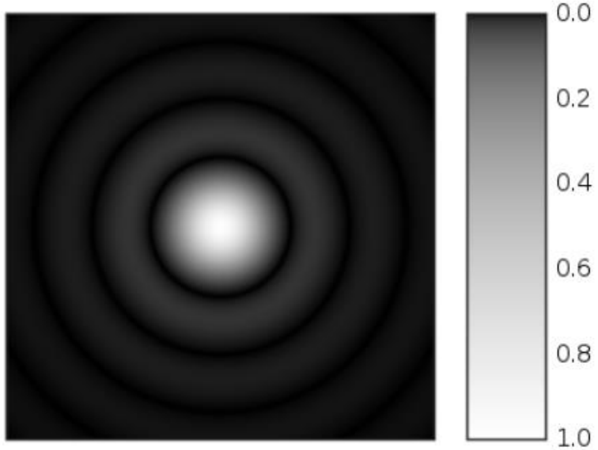
  [Quoted from "The Accuracy of Galileo's Observations and the Early Search for Stellar Parallax", Christopher M. Graney.]

  [N.B. the true distance to these stars is about 5 *million* AU!]

"At distances of 450 A.U. and 300 A.U., Mizar's two components should have had parallax angles of 7.6 arc-minutes and 11.5 arc-minutes respectively. Over the course of a year, this would mean that *the separation of the two would vary by several arc-minutes*. Since they were separated by only 15 arc-seconds and since Galileo could observe with arc-second accuracy, **the Earth's motion should have revealed itself easily after a short time**."

Mizar A and B, photographed using a telescope similar to Galileo's.

- Did Galileo tell everyone about this problem?
  – Heck no!



A computer-generated image of an Airy disk. The grayscale intensities

Airy disk

From Wikipedia, the free encyclopedia

In optics, the **Airy disk** (or **Airy disc**) and **Airy pattern** are descriptions of the best-focused spot of light that a perfect lens with a circular aperture can make, limited by the diffraction of light. The