What Is Science?

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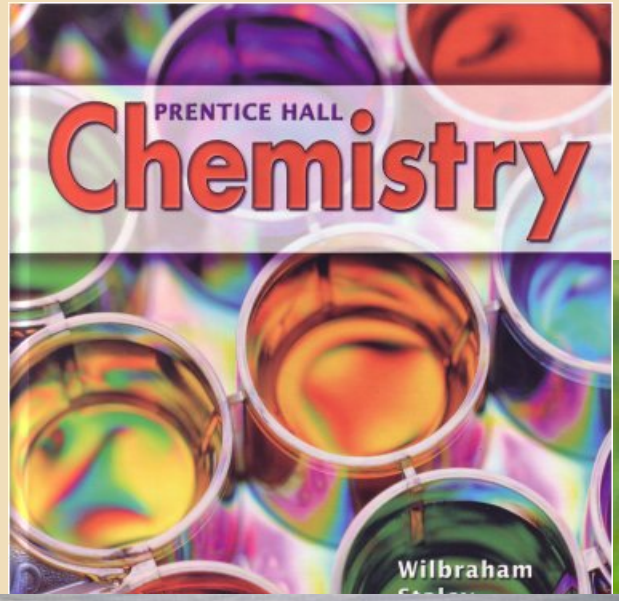
Chemistry & Society
2015 Summer Forum

June 16, 2015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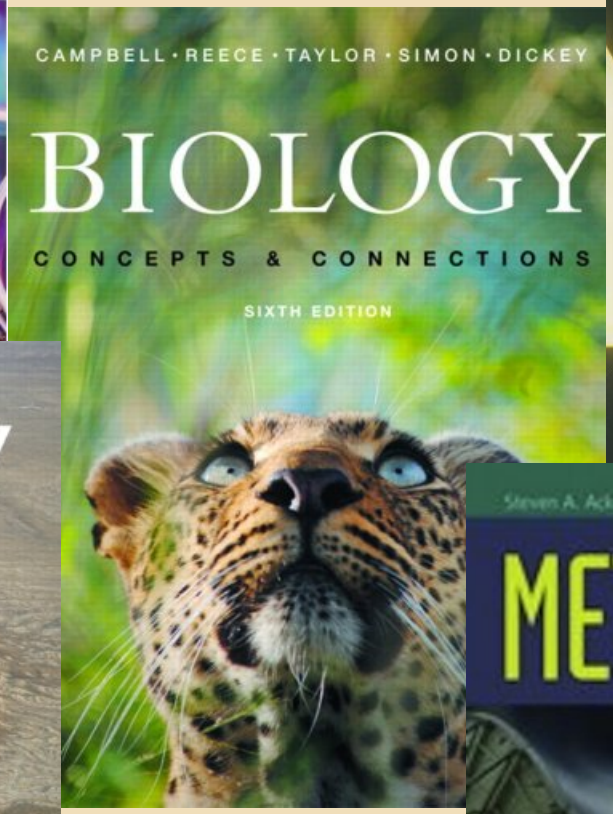
Chemistry
Wilbraham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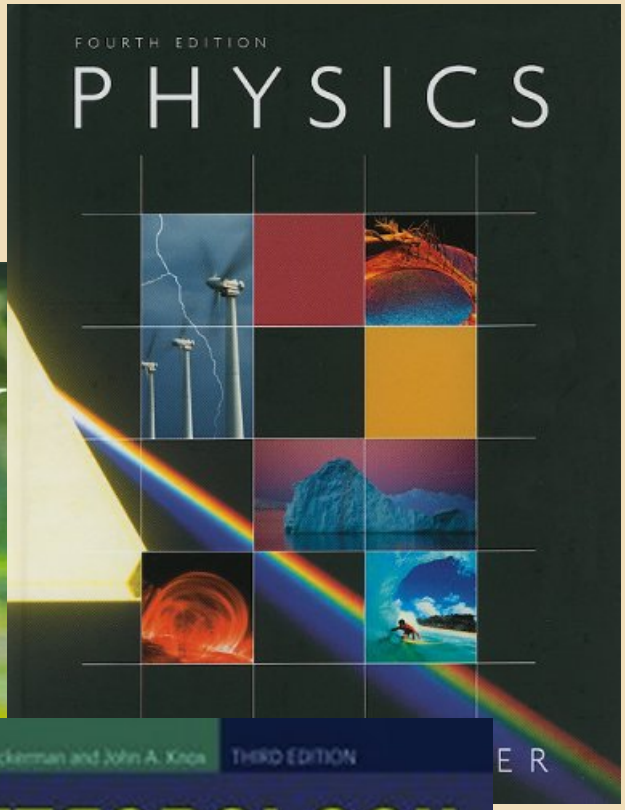
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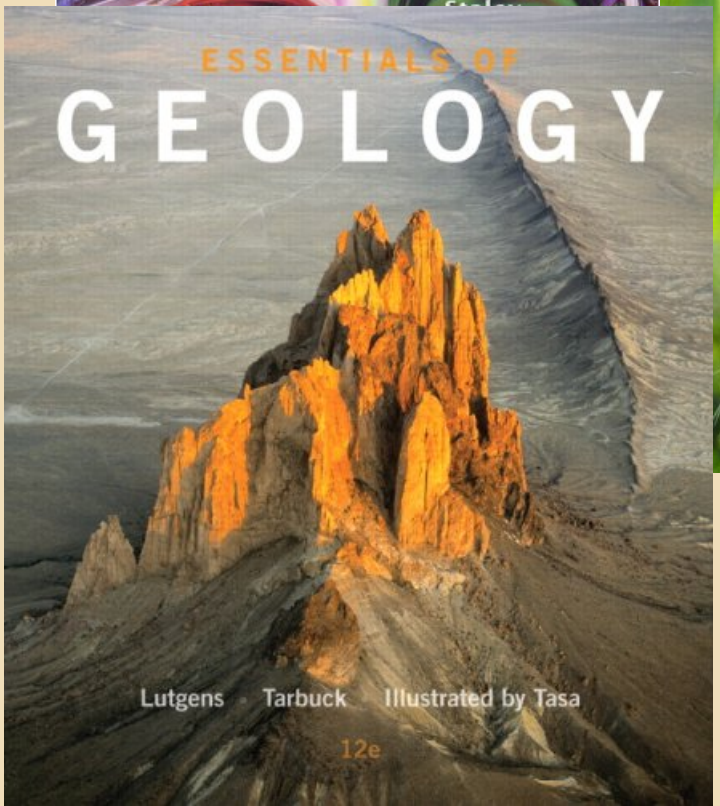
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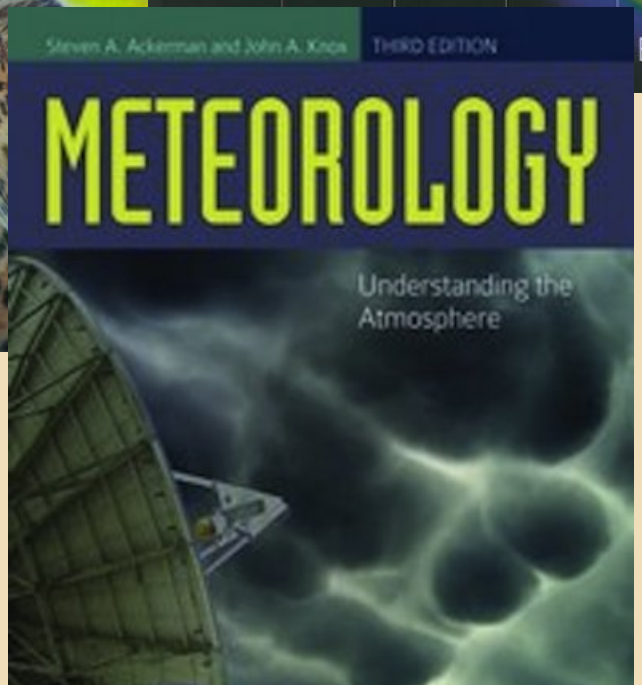
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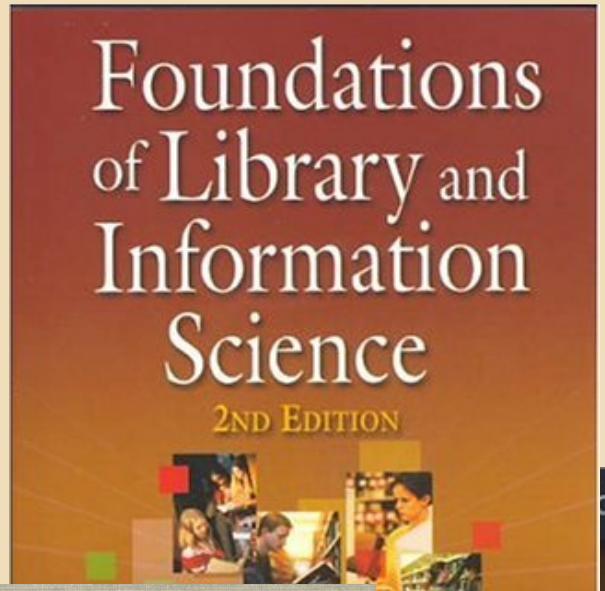
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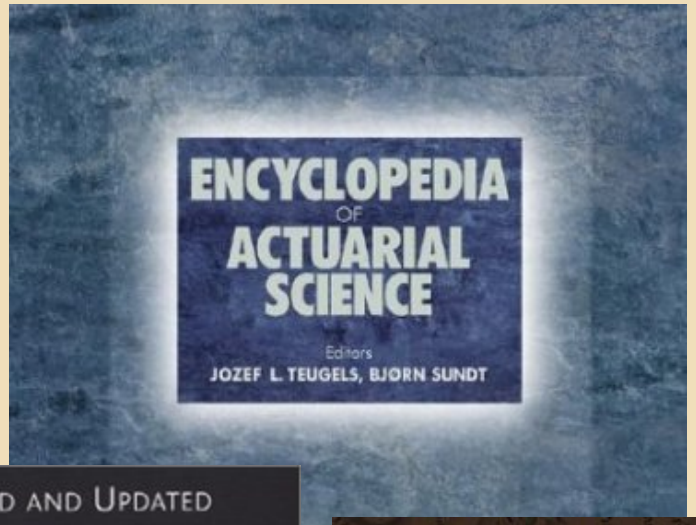
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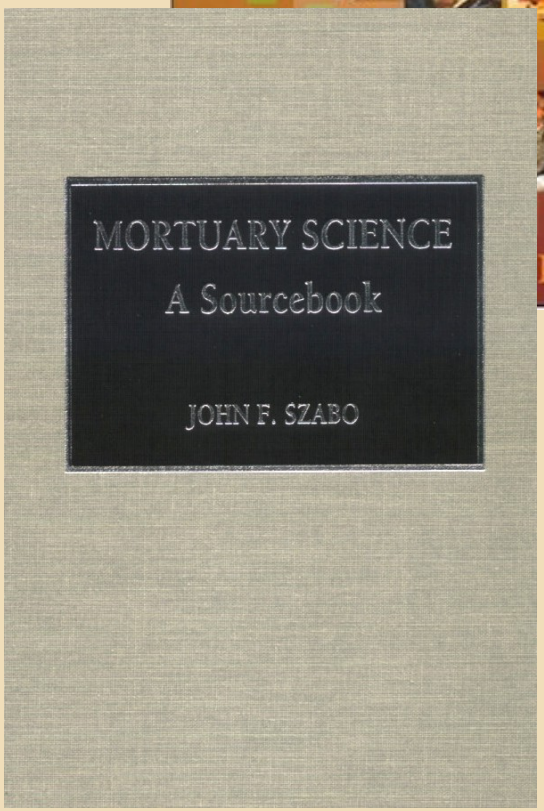
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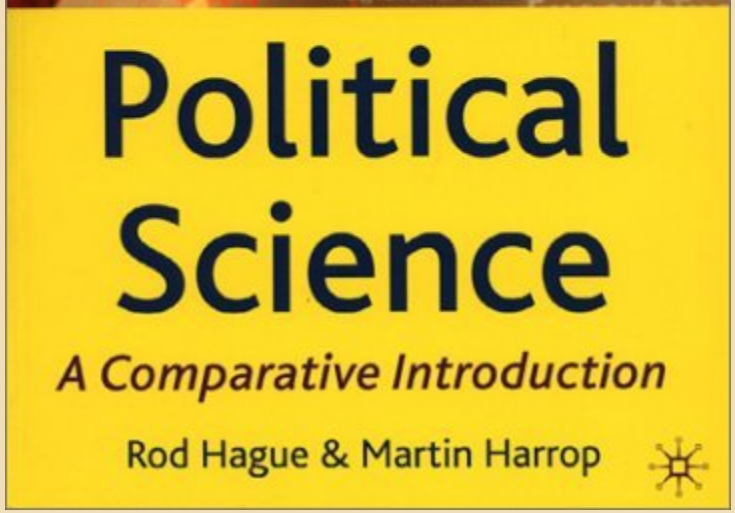
Government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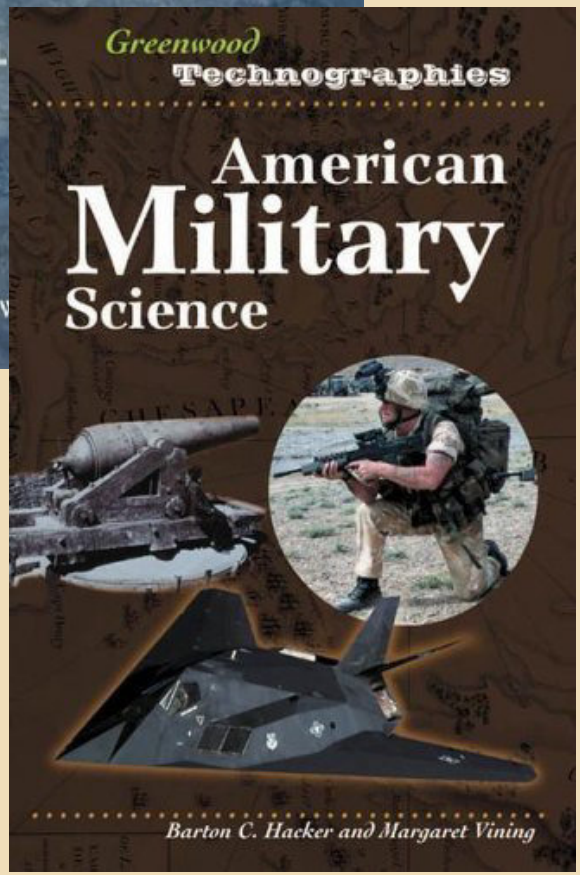
A Comparative Introduction
Rod Hague & Martin Harrop


Greenwood Technographies
American Military Science
Barton C. Hacker and Margaret Vining

“I’m not a scientist.”

“But . . .”

What is Science?

"I shall not today attempt further to define the kinds of material I understand to be embraced within that shorthand description; and perhaps I could never succeed in intelligibly doing so. **But I know it when I see it.**"

– Justice Potter Stewart
From Jacobellis v. Ohio (1964)
In reference to "hard-core pornography"

Scientific Method

1. Systematic, controlled, objective observation or experiment, leads to:

2. Formation of hypothesis, followed by:

3. Further observations or experiments that confirm or invalidate the hypothesis.

4. Repeat steps 1–3 to accumulate reliable knowledge.

Principia Mathematica

WHITEHEAD &
RUSSELL

VOLUME I

***5·15.** $\vdash : p \equiv q \,.\, \vee \,.\, p \equiv \sim q$

Dem.

$\vdash .\, *4{\cdot}61 \,.\, \supset \vdash : \sim(p \supset q) \,.\, \supset \,.\, p \,.\, \sim q \,.$
$[*5{\cdot}1] \qquad \supset \,.\, p \equiv \sim q :$
$[*2{\cdot}54] \quad \supset \vdash : p \supset q \,.\, \vee \,.\, p \equiv \sim q \qquad (1)$
$\vdash .\, *4{\cdot}61 \,.\, \supset \vdash : \sim(q \supset p) \,.\, \supset \,.\, q \,.\, \sim p \,.$
$[*5{\cdot}1] \qquad \supset \,.\, q \equiv \sim p \,.$
$[*4{\cdot}12] \qquad \supset \,.\, p \equiv \sim q :$
$[*2{\cdot}54] \quad \supset \vdash : q \supset p \,.\, \vee \,.\, p \equiv \sim q \qquad (2)$
$\vdash .\, (1) \,.\, (2) \,.\, *4{\cdot}41 \,.\, \supset \vdash .$ Prop

***5·16.** $\vdash . \sim(p \equiv q \,.\, p \equiv \sim q)$

Dem.

$\vdash .\, *3{\cdot}26 \,.\, \supset \vdash : p \equiv q \,.\, p \supset \sim q \,.\, \supset \,.\, p \supset q \,.\, p \supset \sim q \,.$
$[*4{\cdot}82] \qquad \supset \,.\, \sim p \qquad (1)$
$\vdash .\, *3{\cdot}27 \,.\, \supset \vdash : p \equiv q \,.\, p \supset \sim q \,.\, \supset \,.\, q \supset p \,.\, p \supset \sim q \,.$
$[\text{Syll}] \qquad \supset \,.\, q \supset \sim q \,.$
$[\text{Abs}] \qquad \supset \,.\, \sim q \qquad (2)$
$\vdash .\, (1) \,.\, (2) \,.\, \text{Comp} \,.\, \supset \vdash : p \equiv q \,.\, p \supset \sim q \,.\, \supset \,.\, \sim p \,.\, \sim q \,.$
$\left[*4{\cdot}65 \frac{q,\ p}{p,\ q}\right] \qquad \supset \,.\, \sim(\sim q \supset p) \qquad (3)$
$\vdash .\, (3) \,.\, \text{Exp} \,.\, \supset \vdash :. p \equiv q \,.\, \supset : p \supset \sim q \,.\, \supset \,.\, \sim(\sim q \supset p) :$
$[\text{Id.}(*1{\cdot}01)] \qquad \supset : \sim(p \supset \sim q) \,.\, \vee \,.\, \sim(\sim q \supset p) :$
$[*4{\cdot}51.(*4{\cdot}01)] \qquad \supset : \sim(p \equiv \sim q) :. \supset \vdash .$ Prop

***5·17.** $\vdash : p \vee q \,.\, \sim(p \,.\, q) \,.\, \equiv \,.\, p \equiv \sim q$

Dem.

$\vdash .\, *4{\cdot}64{\cdot}21 \,. \qquad \supset \vdash : p \vee q \,.\, \equiv \,.\, \sim q \supset p \qquad (1)$
$\vdash .\, *4{\cdot}63 \,.\, \text{Transp} \,. \quad \supset \vdash : \sim(p \,.\, q) \,.\, \equiv \,.\, p \supset \sim q \qquad (2)$
$\vdash .\, (1) \,.\, (2) \,.\, *4{\cdot}38{\cdot}21 \,.\, \supset \vdash .$ Prop

***5·18.** $\vdash : p \equiv q \,.\, \equiv \,.\, \sim(p \equiv \sim q)$ $\left[*5{\cdot}15{\cdot}16 \,.\, *5{\cdot}17 \frac{p \equiv q,\ p \equiv \sim q}{p,\qquad q}\right]$

***5·19.** $\vdash . \sim(p \equiv \sim p)$ $\left[*5{\cdot}18 \frac{p}{q} \,.\, *4{\cdot}2\right]$

***5·21.** $\vdash : \sim p \,.\, \sim q \,.\, \supset \,.\, p \equiv q$ $[*5{\cdot}1 \,.\, *4{\cdot}11]$

***5·22.** $\vdash :. \sim(p \equiv q) \,.\, \equiv : p \,.\, \sim q \,.\, \vee \,.\, q \,.\, \sim p$ $[*4{\cdot}61{\cdot}51{\cdot}39]$

***5·23.** $\vdash :. p \equiv q \,.\, \equiv : p \,.\, q \,.\, \vee \,.\, \sim p \,.\, \sim q$ $\left[*5{\cdot}18 \,.\, *5{\cdot}22 \frac{\sim q}{q} \,.\, *4{\cdot}13{\cdot}36\right]$

***5·24.** $\vdash :. \sim(p \,.\, q \,.\, \vee \,.\, \sim p \,.\, \sim q) \,.\, \equiv : p \,.\, \sim q \,.\, \vee \,.\, q \,.\, \sim p$ $[*5{\cdot}22{\cdot}23]$

***5·25.** $\vdash :. p \vee q \,.\, \equiv : p \supset q \,.\, \supset \,.\, q$ $[*2{\cdot}62{\cdot}68]$

On page 379:

$*54{\cdot}43.\quad \vdash :. \alpha, \beta \in 1 . \supset : \alpha \cap \beta = \Lambda . \equiv . \alpha \cup \beta \in 2$

Dem.

$\vdash . *54{\cdot}26 . \supset \vdash :. \alpha = \iota`x . \beta = \iota`y . \supset : \alpha \cup \beta \in 2 . \equiv . x \neq y .$

[*51·231] $\equiv . \iota`x \cap \iota`y = \Lambda .$

[*13·12] $\equiv . \alpha \cap \beta = \Lambda \qquad (1)$

$\vdash . (1) . *11{\cdot}11{\cdot}35 . \supset$

$\vdash :. (\exists x, y) . \alpha = \iota`x . \beta = \iota`y . \supset : \alpha \cup \beta \in 2 . \equiv . \alpha \cap \beta = \Lambda \qquad (2)$

$\vdash . (2) . *11{\cdot}54 . *52{\cdot}1 . \supset \vdash .$ Prop

From this proposition it will follow, when arithmetical addition has been defined, that $1 + 1 = 2$.

Deduction

$A \supset B$, $A \therefore B$.

If A, then B ; A, therefore B.

If this bird is a duck, then it can swim.
This bird is a duck. Therefore, it can swim.

(1) All ducks can swim.	[Theory]
(2) This bird is a duck.	[Observation]
(3) This bird can swim.	[Deduction]

Deduction leads to certain knowledge.

Induction

The process by which a scientific theory is established.

Knowledge from induction is based on observation.

Bird A is a duck, and it can swim.
Bird B is a duck, and it can swim.
Bird C is a duck, and it can swim.
Bird D is a duck, and it can swim.
Bird E is a duck, and it can swim.
⋮

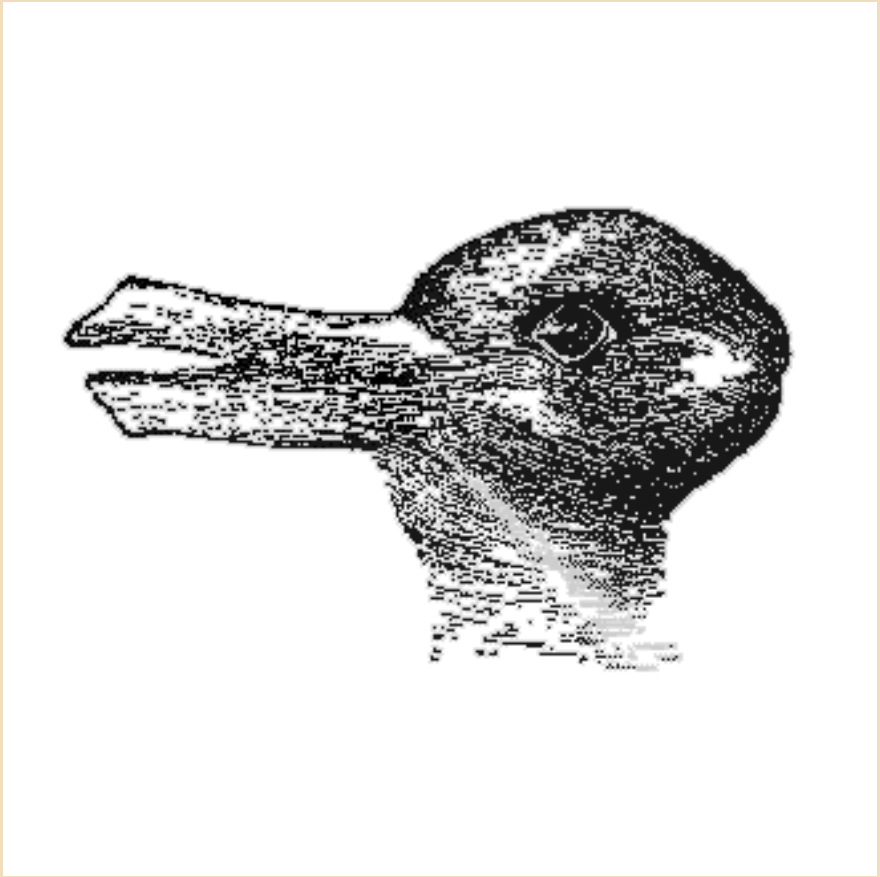
Therefore, all ducks can swim.

Problem 1 for Scientific Method:

Induction does not lead to certain knowledge.

Problem 2 for Scientific Method:
Observation is not completely objective.

All observations are prejudiced.

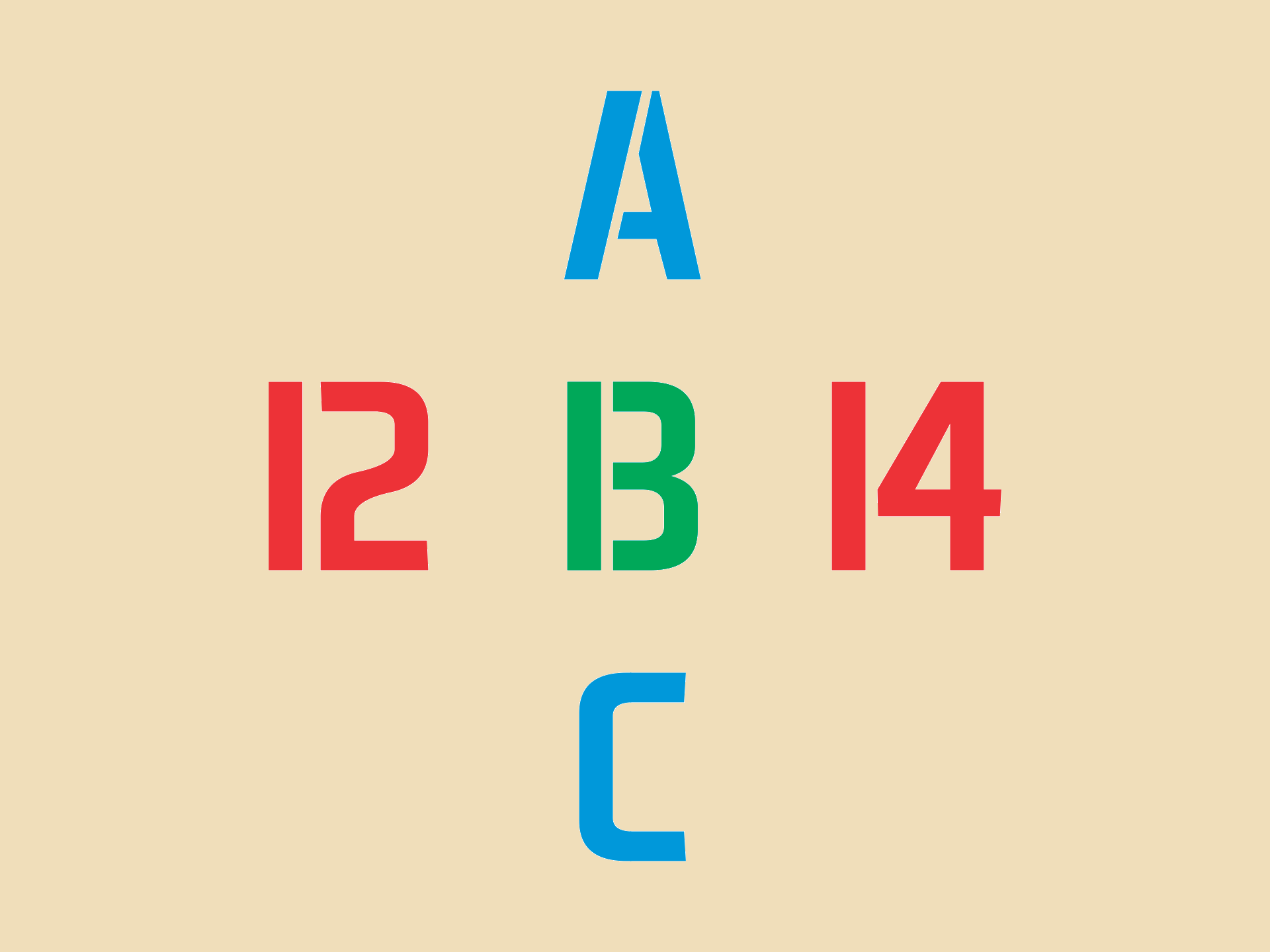


A

B

C

12 13 14


A
12
13
14
C

“It is also a good rule not to put overmuch confidence in the observational results that are put forward until they have been confirmed by theory.”

–Arthur Eddington

Falsification

Karl Popper:

For a statement to be scientific, it must be falsifiable.

Falsification

Falsifiable:

"It never rains on Monday."
"Heavy objects fall faster than light objects."
"All objects fall at the same rate."

Not Falsifiable:

"Either it's raining or it's not."
"All bachelors are unmarried."
"You may find a $5 bill today."

Falsification

The logic of falsification:

A falsifiable statement: “All X are Y.”

No number of observations of Xs that are Ys can **prove** the statement correct.

However, **one** instance of an X that is **not** a Y can prove the statement wrong (that is, falsify it).

Falsification

Popper's recommendations for advancing science based on falsification:

Scientific statements should be as clear as possible to make falsification easier.

To foster progress, scientific statements should be highly speculative, because these are most easily falsified.

Falsification

Strengths & Weaknesses

Repairs the inductive method's logic problem.

Does not deal with the problem that observations depend on theory.

Does not indicate how to deal with a falsified theory.

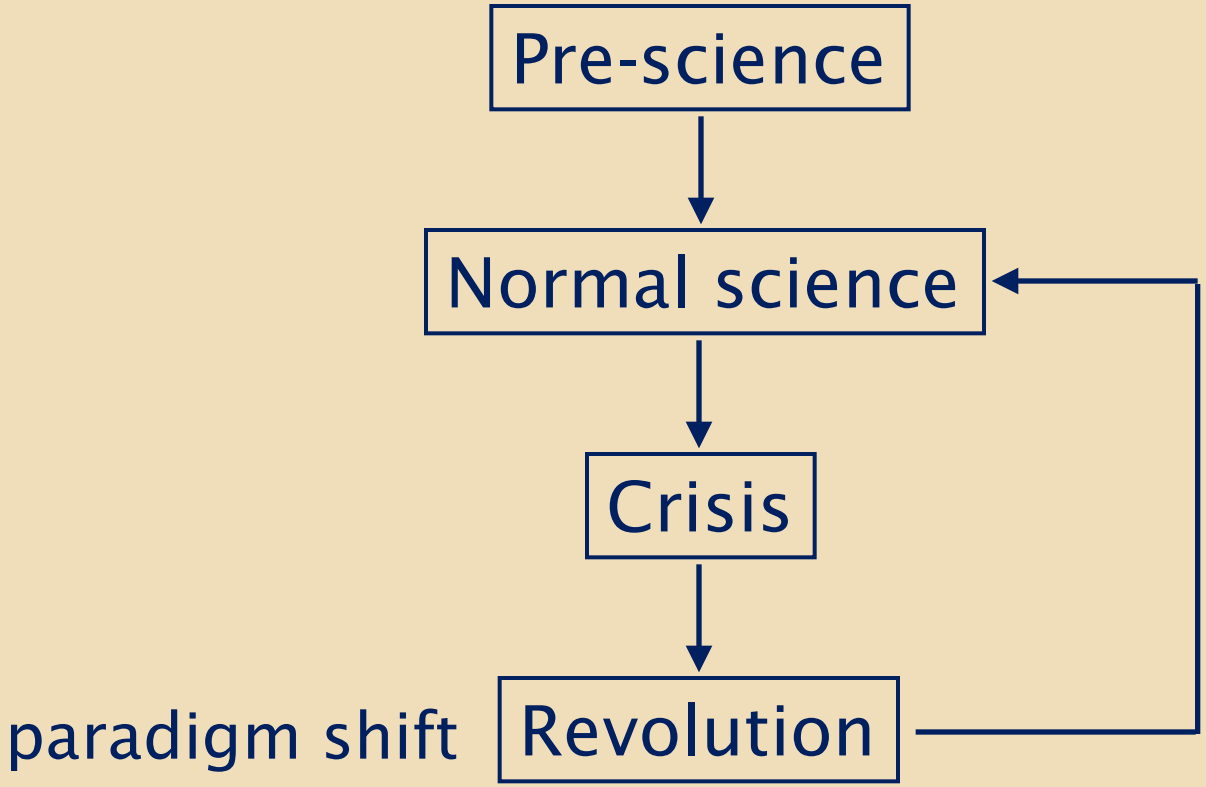
Was the observation wrong?

What part of the theory is wrong?

Is this how science actually advances?

Structure of Scientific Process

Kuhn's description of science
based on its historical development



Structure of Scientific Process

Kuhn's description of science

Recognizes that there is a social aspect to science. Scientific progress requires cooperation.

But, there is no standard for the validity of a scientific theory, beyond the agreement of the community of scientists.

Structure of Scientific Process

Feyerabend's anarchy

Because there is no prior standard for the validity of scientific theory, scientists are free to choose whatever they want.

Anything goes!

Paul Feyerabend:

"A mature citizen is a person who . . . has *decided* in favor of what he thinks suits him best. . . . To prepare himself for his choice, . . . he will study it [science] together with other fairy tales such as myths of 'primitive' societies . . ."

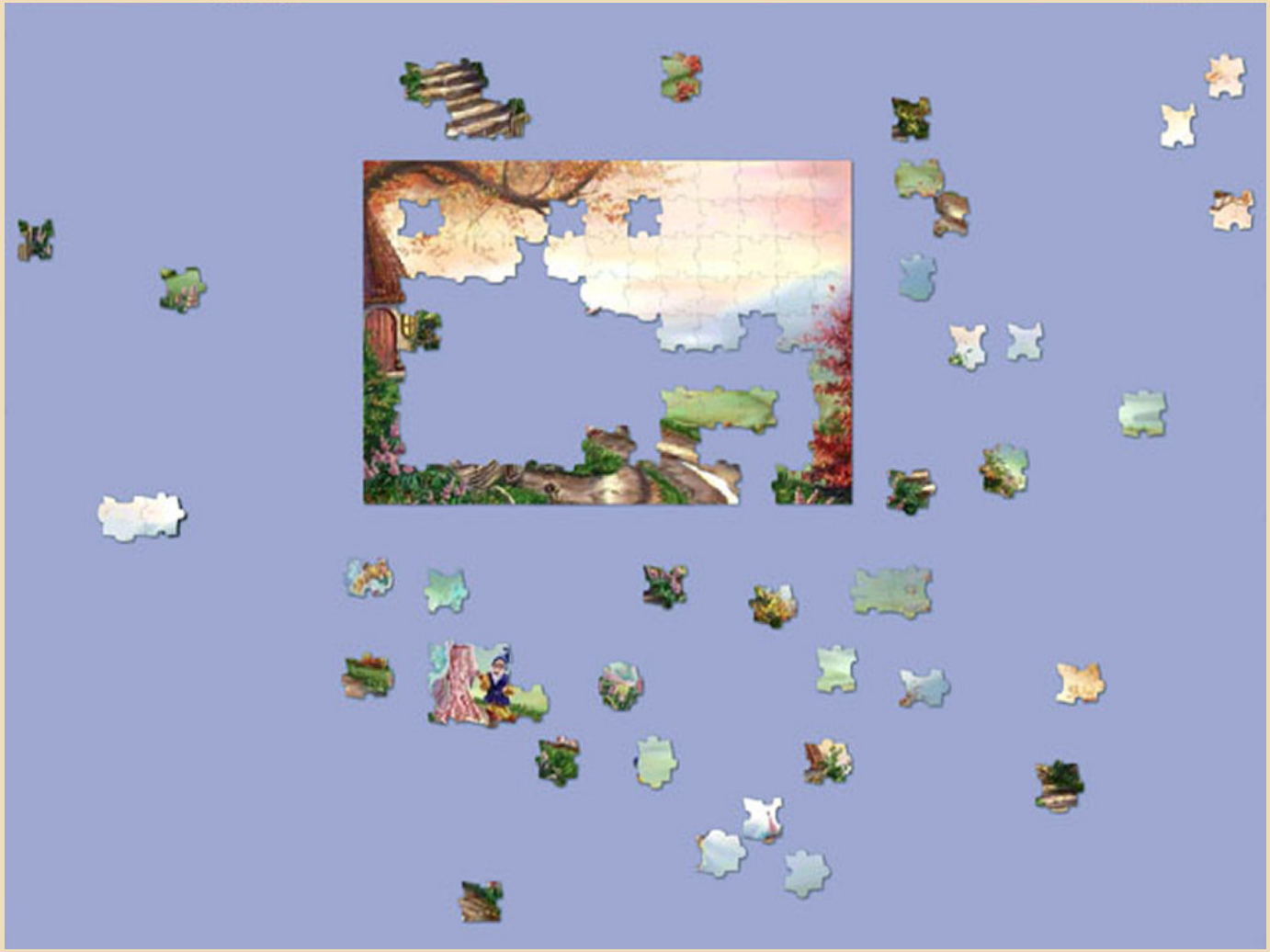
"Let us free society from the strangling hold of an ideologically petrified science just as our ancestors freed *us* from the strangling hold of the One True Religion."

Paul Feyerabend:

"The idea that science can, and should, be run according to fixed universal truths, is both unrealistic and pernicious."

Turn away from looking for universal rules for scientific activity, and look to find more realistic descriptions.

Process of Doing Science
Michael Polanyi: Puzzle Solving



Structure of Scientific Theory

Philip Kitcher: A Map

Scientific Explanations

Some types of explanation:

- deductive
- statistical
- mathematical
- analogical
- causal
- functional
- mechanistic

Scientific Explanations

Deductive

Why are snakes cold-blooded?

Because they are reptiles.

All reptiles are cold-blooded.

Snakes are reptiles.

Therefore, snakes are cold-blooded.

Scientific Explanations

Statistical

How did John get lung cancer?

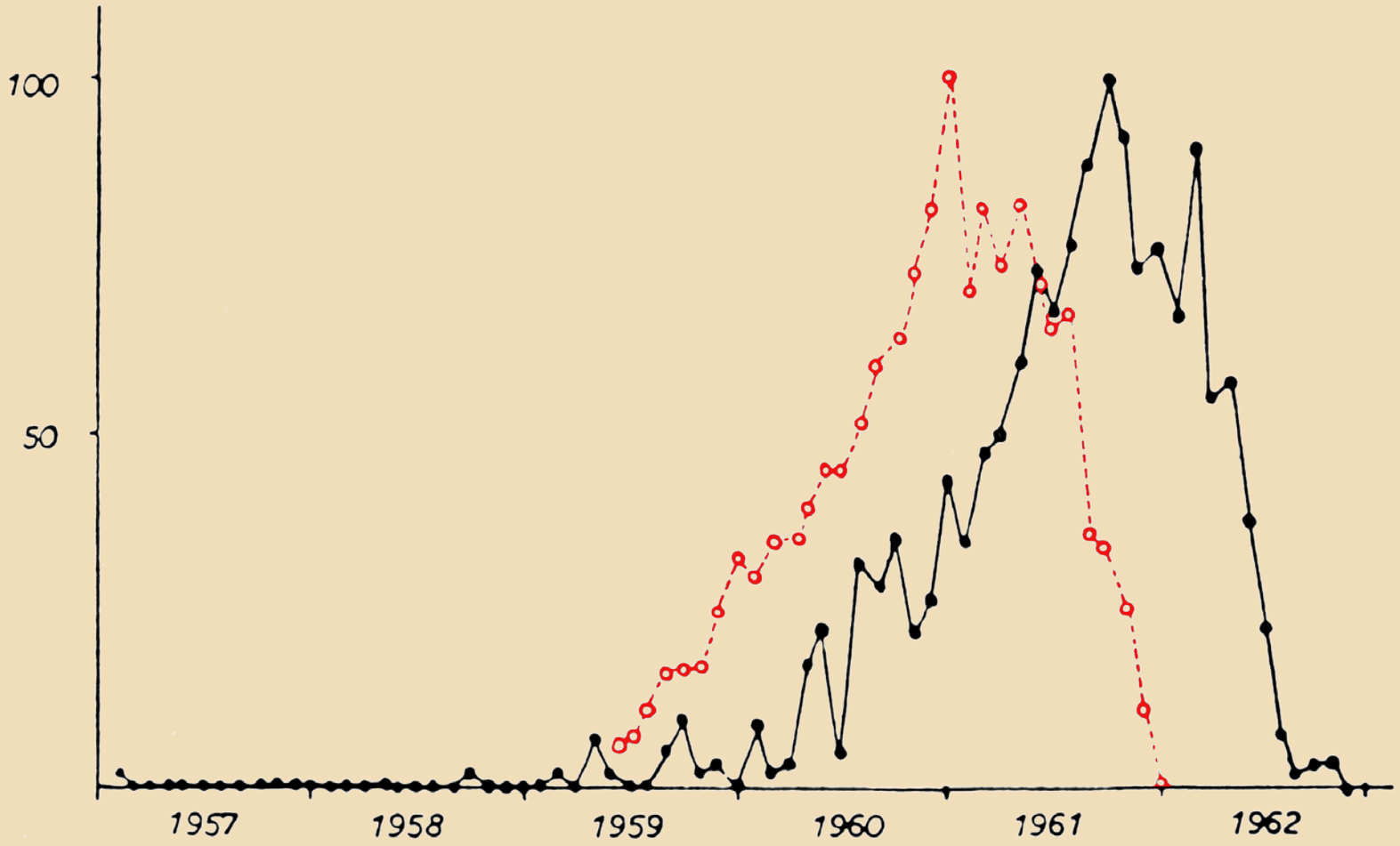
John smoked cigarettes.

Most people who smoke develop lung cancer.

John smoked.

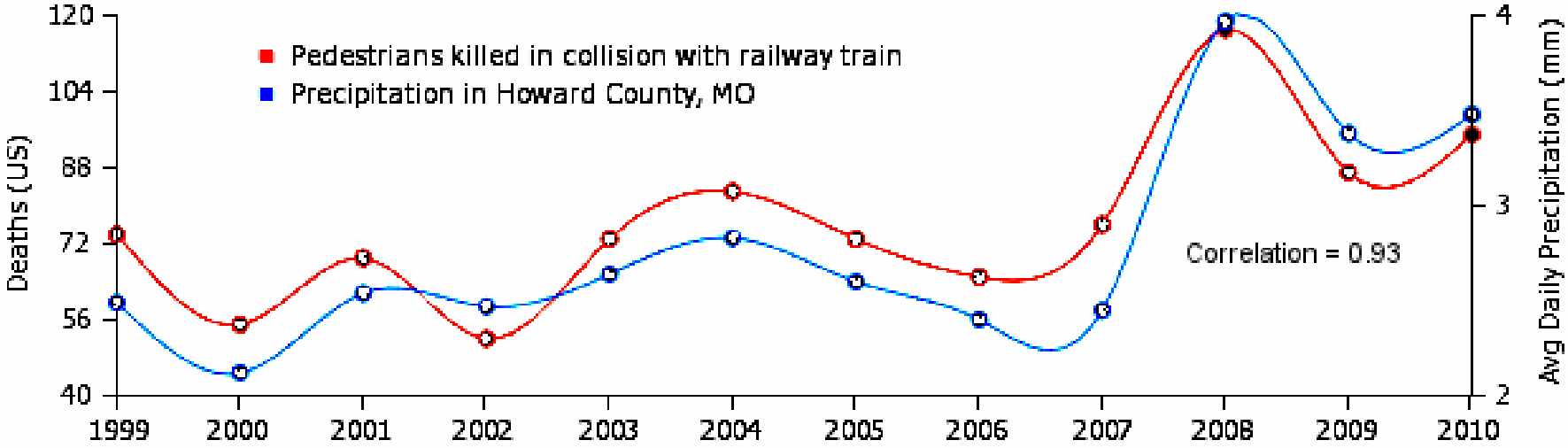
Therefore, John developed lung cancer.

Statistical Explanation



Occurrence of phocomelia birth defects

Sales of thalidomide


Pedestrians killed in collision with railway train
Precipitation in Howard County, MO
Correlation = 0.93
Deaths (US)
Avg Daily Precipitation (mm)
120
104
88
72
56
40
4
3
2
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010

Scientific Explanations

Mathematical

Why does a gas expand when heated?

Because PV = nRT.

If n and R and P are constant, then an increase in T requires an increase in V.

Scientific Explanations

Analogical

How does a plant cell function?

A plant cell is like a factory. It takes in carbon dioxide as a raw material and converts it into products, such as sugar.

Scientific Explanations

Causal

What makes the rooster crow?

The rising sun causes the rooster to crow.

Scientific Explanations

Functional

What is the function of the external ear?

The external ear directs sound waves into the ear canal.

Scientific Explanations

Mechanistic

What caused the vase fall off the shelf?

The cat walked along the shelf
and pushed the vase off.

Scientific Explanations

Mechanism: a system of interrelated parts that interact to produce functional behaviors

Mechanistic explanations use analogies to real-world mechanisms.

Ancient: wheels, levers
18th Century: steam engines, foundries
19th Century: trains, electric motors
20th Century: automobiles, airplanes, televisions, computers

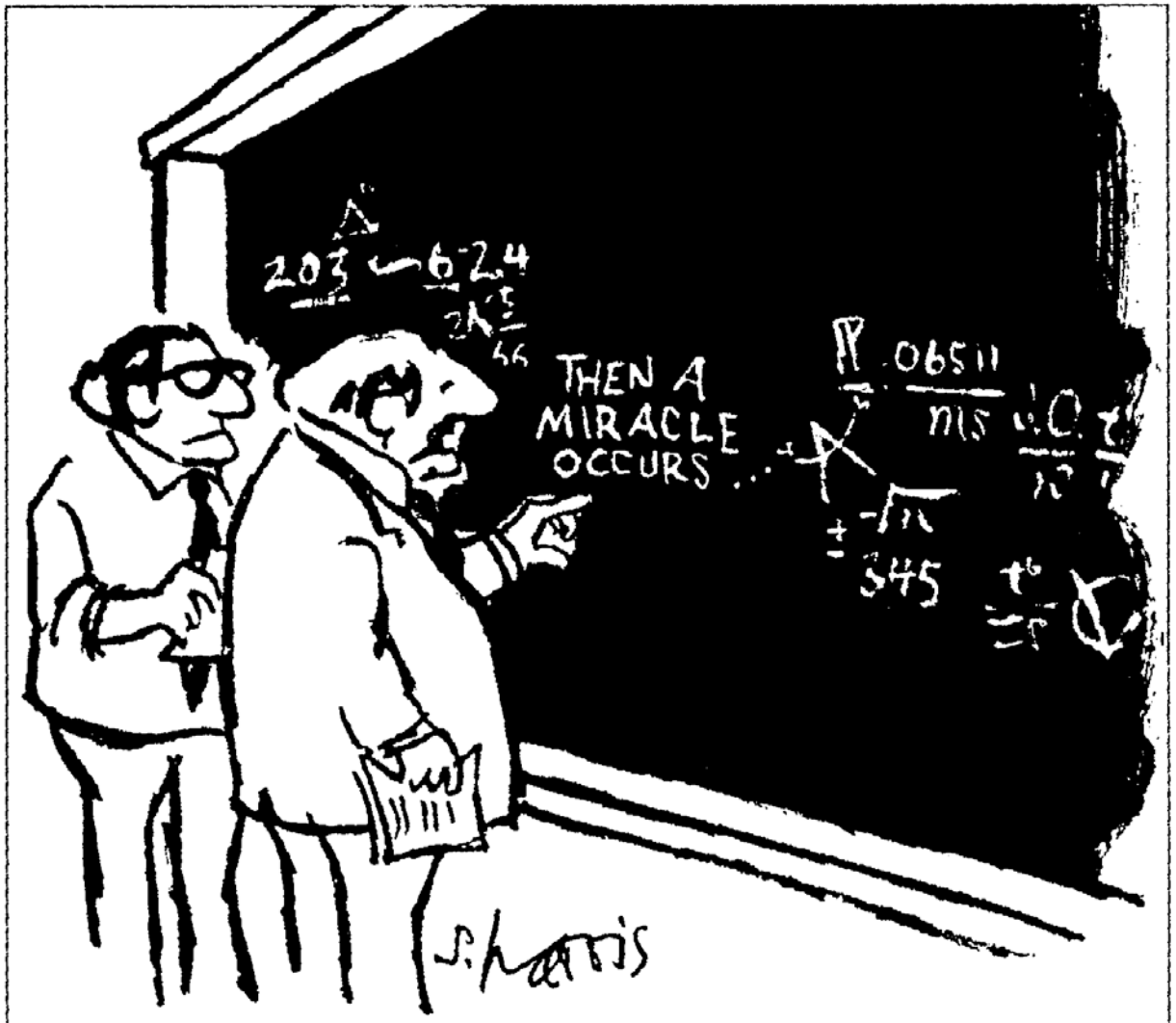
Scientific Explanations

In scientific explanations, intention, purpose, and will are not allowed.

"Why?" is not a scientific question.

Steven Weinberg:
"No purpose is revealed in the laws of nature."

Corollary:
Scientific explanations
do not permit
supernatural features.



"I THINK YOU SHOULD BE MORE EXPLICIT HERE IN STEP TWO."

"There's probably some perfectly simple religious explanation for it . . ."

So,
exactly what is science?