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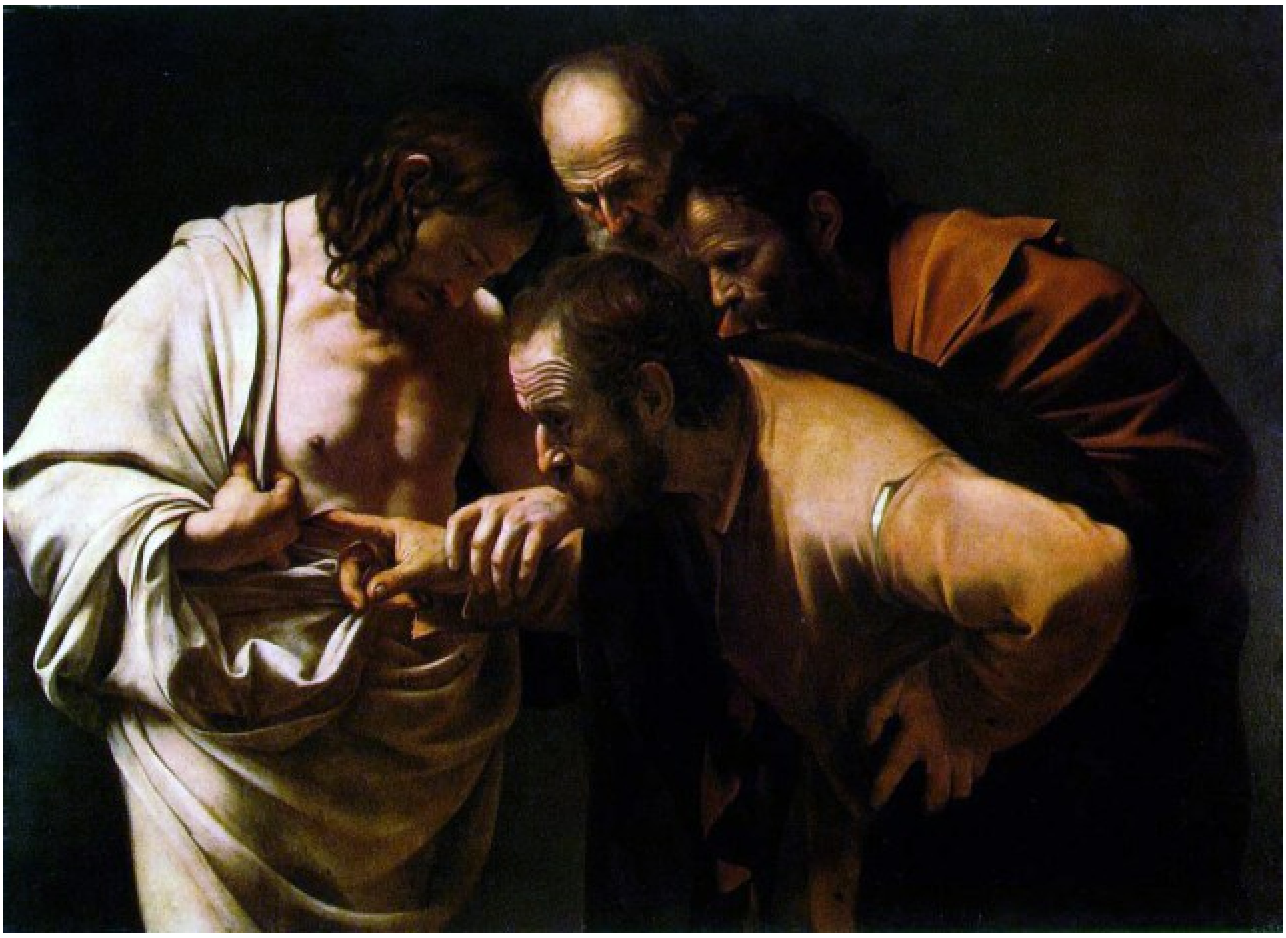
SECTION 1: Faith and Revelation



Doubting Thomas, Caraveggio
from Wikimedia Commons

“Faith is to believe what you do not see; the reward of this faith is to see what you believe.”
—St. Augustine

“Faith is the substance of things hoped for; the evidence of things not seen.”

—Hebrews 11:1

"Faith and reason are like two wings on which the human spirit rises to the contemplation of truth; and God has placed in the human heart a desire to know the truth"
—Pope St. John Paul II, Fides et Ratio

1.1 HOW AND WHY WE BELIEVE

Let's talk about belief first, that you think something is true. Clearly there is a difference between the statements "*I believe in one God…*" (the Credo) and "I believe it's going to rain tomorrow." An obvious difference is what one is willing to do or to pay to act on one's belief. The Christian martyrs were willing to suffer and to die for their beliefs'; ' you might be willing to bet five dollars that it will rain tomorrow, but not your life, no matter what the weather forecast is.

Accordingly, there are degrees of belief, which in fact can be quantified using various techniques in subjective probability and decision theory (see "Probability and the Art of Judgment" and "Subjective Probability–The Real Thing" by Richard Jeffrey). To explore these methods in detail would require another book, but those interested can go to the Stanford Encyclopedia of Philosophy articles .

1.2 PASCAL'S WAGER

Possibly the most famous example of quantifying belief and using outcome probabilities as a guide to action is Pascal's Wager, in which Pascal argues that belief in God is the prudent choice, given the existence of an afterlife (even though the probability of that existence might be infinitesimally small). Objections, most of which are substantial to Pascal's arguments, have been raised and countered (see Pascal's Wager Revisited–The Pearl of

Great Price)

Blaise Pascal
from Wikimedia Commons

Nevertheless, we don't always act rationally based on our beliefs. We will bet on the lottery, even if the odds–expectation value for a likely gain–are not in our favor. We will take on insurance, even if it is likely to be a losing proposition in the long run. As Pascal himself argued (Pensees, #233), it is not always easy to believe based on prudence and rationality:

"I am so made that I cannot believe. What, then, would you have me do?"

Pascal replies:

> *"Endeavor then to convince yourself, not by increase of proofs of God, but by the abatement of your passions. You would like to attain faith and do not know the way; you would like to cure yourself of unbelief, and ask the remedy for it…There are people…who are cured of an ill of which you would be cured. Follow the way by which they began: acting as if they believed, taking the holy water, having masses said, etc."*

Now can one "*fake it until you make it*" as Pascal suggests? Or will the sacraments be ineffective, because the motive of the recipient is mercenary? Which of the Catechism dicta below are appropriate?

> (1131)"*The sacraments are efficacious signs of grace….They bear fruit in those who*

receive them with the required dispositions.”
—Catholic Catechism

(1128) *“The sacrament is not wrought by the righteousness of either the celebrant or the recipient, but by the power of God.”*
—*ibid*

The second suggests that if one prays for faith, then the “topdown” approach will work, starting from the head and eventually through to the heart, or, as Pascal suggests:

“…at each step you take on this road you will see so great certainty of gain, so much nothingness in what you risk, that you will at last recognize that you have wagered for something certain and infinite, for which you have given nothing.”
—Blaise Pascal, *Pensees*, art. 233

1.3 FAITH AND REASON

So we can see that belief, as manifested in faith, is not an absolute, a two-valued yes or no, but a quality that is measured on a continuous scale, and that can be implemented by other than strictly rational means.

“Faith is to believe what you do not see; the reward of this faith is to see what you believe”
—St. Augustine of Hippo, Sermones 4.1.1

As the quote from St. Augustine puts it, faith is belief in that which is not confirmed by direct evidence from the senses. On the other hand, what about revelation, such as the vision St.

Paul had on the road to Damascus? That is surely a personal experience, not experienced directly by others. Revelation—the direct word from God or His messengers, the Angels—is not confirmable. It happens once, and even if it happens to more than one person (as in the descent of the Holy Spirit at Pentecost), one still has to believe the word of those to whom it occurred.

St. Teresa Benedicta of the Cross (Edith Stein) explored the relationship between philosophy and theology, or equivalently, between faith and reason. In her work, Finite and Eternal Being, she proposed a hierarchy, that faith went beyond rational knowledge:

> *"Since the ultimate ground of all existence* [alles Seienden] *is unfathomable, everything which is seen in this ultimate perspective moves into that 'dark light' of faith, and everything intelligible is placed in a setting with an incomprehensible background."*
> –St. Teresa Benedicta, "Finite and Eternal Being," p.25

I'll put this another way: the fundamental question we ask is "Why are we here?" Science might be able to say **how** our physical bodies came to be here, but science can't answer the question: "**Why** did we come to be. Science would respond: "that question is meaningless, can't be answered by scientific methods." Only faith can give a satisfactory answer to that why question.

In the next section, "Rational Inquiry," we'll explore the different methods by which come to believe by reason: logic to determine what kinds of statements are true; factual exploration to determine what is real. We'll also see what limits there might be to such methods.

SECTION 2: Rational Inquiry

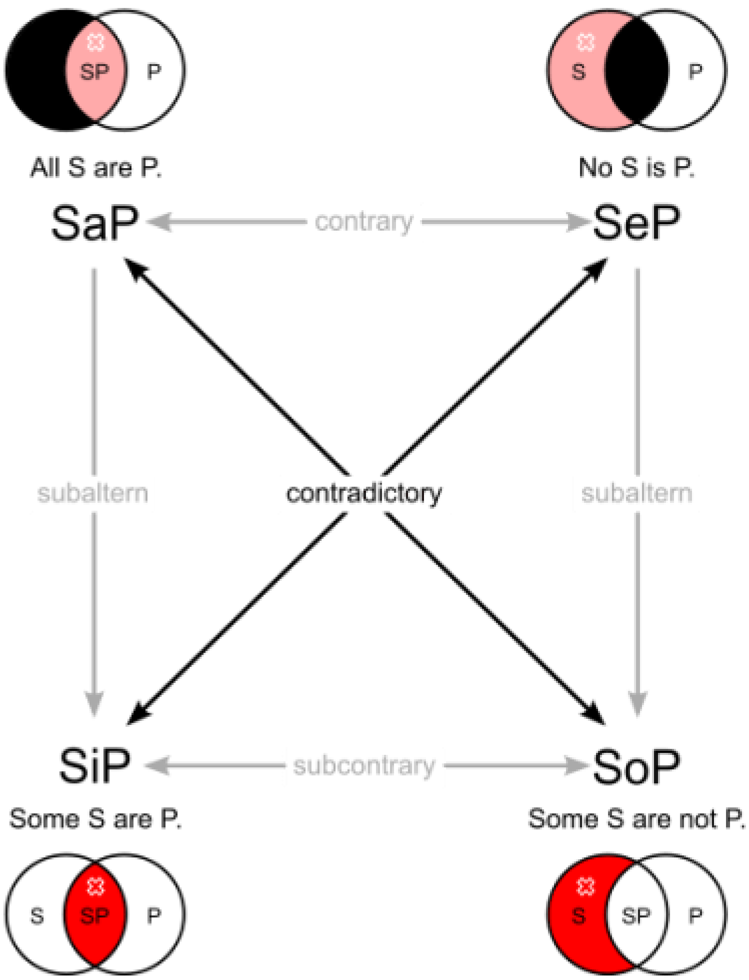
2.1 DEDUCTIVE LOGIC

> *"'Contrariwise,' continued Tweedledee, 'if it was so, it might be; and if it were so, it would be; but as it isn't, it ain't. That's logic.'"*
> —Lewis Carroll, "Through the Looking-Glass"

Syllogisms and Venn Diagrams

One way of knowing other than by faith/revelation is by deduction, drawing conclusions from propositions we believe to be true ("premises"), using logical procedures first set up by Aristotle–going from the general to the specific. Here's an example (with apologies to Gelett Burgess), a "syllogism":

> Major Premise: All cows are purple.
> Minor Premise: This animal is a cow.
> Conclusion: This animal is purple.



Venn Diagrams to Understand Logic: The Rule of Opposition. **Black Areas**: area is empty; **Red Areas**: at least one element in area (**Faded Red** applies only in

If you know the premises to be true, then the conclusion is true. If the premises aren't generally true (as in this example), then the conclusion may or may not be true. For example, you could paint a cow purple, or it could be a mutation.

classical logic, i.e. for non-empty areas.)
From Wikimedia Commons

Note the difference between the syllogism above and the one below:

Major Premise: All cows are purple.
Minor Premise: This animal is purple.
Conclusion: This animal is a cow.

There are animals that are not cows that are purple, for example, purple frogs; therefore the conclusion is false. Note: if the Major Premise was stated as "Only cows are purple," then the conclusion would be true.   This kind of logical fallacy is called "affirming the consequent."

Venn diagrams can help us understand logic problems, as shown in the diagram above, where several types of logical propositions are classified according to the corresponding Venn diagram.

To make this example concrete, let "S stand for "cows" and "P" for "purple animals." Accordingly, the "SaP" proposition is "All cows are purple (animals);" the white space means some purple animals are not cows and the black space means there aren't any cows that aren't purple.   The "SeP" proposition is "No cow is purple;" the black space where the two circles overlap shows that there aren't any animals that are both purple and a cow. The "SiP" proposition is "Some cows are purple;" there are cows that are not purple (white space in the "S" circle) and cows that are purple (red space where the S and P circles overlap) and purple animals that are not cows (white space in the P circle). The SoP proposition is "Some cows are not purple (animals);" the red space of the S circle. You can see (I hope) that the major premise of both syllogisms corresponds to SaP, and since there is a white space in the P circle (purple animals), there are some purple animals that aren't cows, so the second syllogism can't be true.

"Complicated" Deductive Logic, "Sorites"

Charles Dodgson (better known as Lewis Carroll, author of the Alice books), an Oxford academic, gave us many amusing and complicated puzzles that mixed his love of nonsense and logic. (These "polysyllogisms" are termed "sorites.")   Some of Carroll's logical puzzles were exceedingly complicated, involving many statements and logical variables. Here's a relatively simple one:

1. All babies are illogical.
2. Nobody is despised who can manage a crocodile.
3. Illogical persons are despised.

We combine 1 and 3 to give

4. All babies are despised.

Then 4 and the contrapositive[1] of 2 can be combined to yield

5. No baby can manage a crocodile.

Here's another example by Alex Bellos, given in the Guardian, with its solution:

"The only people in the cereal cafe are from Stoke.

Every person would make a great Uber driver, if he or she is not allergic to gluten.

When I love someone, I avoid them.

No one is a werewolf, unless they have orange skin and blond hair.

No one from Stoke fails to Instagram their breakfast.

No one ever asks me whether I prefer Wills to Harry, except the people in the cereal cafe.

People from Thanet wouldn't make great Uber drivers.

None but werewolves Instagram their breakfast.

The people I love are the ones who do not ask me whether I prefer Wills to Harry.

People with orange skin and blond hair are not allergic to gluten."

Such complicated problems often may require computer methods for their solution. Some of the statements (premises) may be redundant and some may be contradictory.   The type of analysis required to make sure that none of the statements are contradictory, so that no paradoxes will occur, is a sub-discipline in mathematical logic, "satisfiability theory".

Certainly the deductive method should yield propositions which are either true or false. Not so! There are uncertainties, paradoxes, in logical deduction, which is the topic we'll look at next

Some Logical Paradoxes

"A paradox, a paradox, a most ingenious paradox!"

–Gilbert & Sullivan, The Pirates of Penzance

Can deductive logic always yield an unambiguous true or false set of propositions?   In his very fine book, Labyrinths of Reason, William Poundstone gives examples of logical paradoxes for which it is difficult to make a truth judgment. Perhaps the most famous of these is the Cretan Liar paradox (see Star Trek, Fooling the Androids Episode):

> "Epimenides the Cretan says, 'All Cretans are liars.'"

Question: Is this statement true or false? If it is true, then Epimenides is a liar, but if Epimenides is a liar, how can his statement be true?

There is also the barber paradox,

> "The barber is a man in town who shaves all those, and only those, men in town who do not shave themselves."

Question: Who shaves the barber? If the barber doesn't shave himself, according to the statement he does shave himself…

Both paradoxes invoke self-reference, whence the paradox.   Bertrand Russell attempted to deal with the problem of self-reference by his "Theory of Types," which sets up a hierarchy of statements, i.e. statements about statements, statements about (statements about statements), etc.

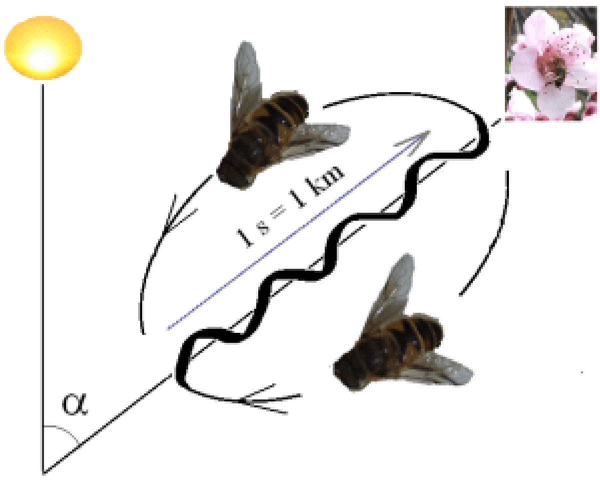
Let's look next at another rational path, induction or inductive reasoning. The results aren't as sure, but it still is a basic route to judgment in law, science and everyday life.

2.2 INDUCTIVE REASONING

“The deductive method is the mode of using knowledge, and the inductive method the mode of acquiring it.”
—Henry Mayhew, nineteenth century British Journalist,

Induction is generally regarded as proceeding from particular instances or events to a general conclusion. (I’m not referring in this context to the mathematical method of proof.) Here’s an example.

> A naturalist notices that bees move their rear end back and forth in a special way—”dance”–after they have been gathering nectar from a certain group of flowers. The dance is the same for a given group of flowers. The naturalist concludes that this bee-dancing is a communication to other bees about the location of the flowers and receives a Nobel Prize. (We’ll see below that science is generally more than collecting data and making inferences.)
>
> Here’s a neat video of bees doing the waggle dance.



BEE WAGGLE DANCE:
DISTANCE—How long the waggles occur gives the distance of the flowers;
DIRECTION—Where the bee points shows the direction;
from Wikimedia Commons

There are methods of assessing inductive reasoning propositions by means of probability statements, strength of belief quantification, and by Bayesian probability analysis.

2.3.ABDUCTIVE REASONING—INFERENCE TO THE BEST EXPLANATION (IBE)

> *"When you have eliminated the impossible, whatever remains, however improbable, must be the truth."*
> –Sherlock Holmes, The Sign of the Four, Chapter 6.

One of the best known examples of abductive reasoning is given in the quotation above and indicated by its commonly used name, "**Inference to the Best Explanation"** or "**IBE**." IBE uses given data to infer the most likely explanation of a past event that could have caused the data. It is commonly used in the so-called "historical sciences" (geology, paleontology, cosmology) for which laboratory experiments aren't in order.

Here's an everyday example adapted from one given in Stephen Meyer's book about Intelligent Design, The Signature in the Cell:

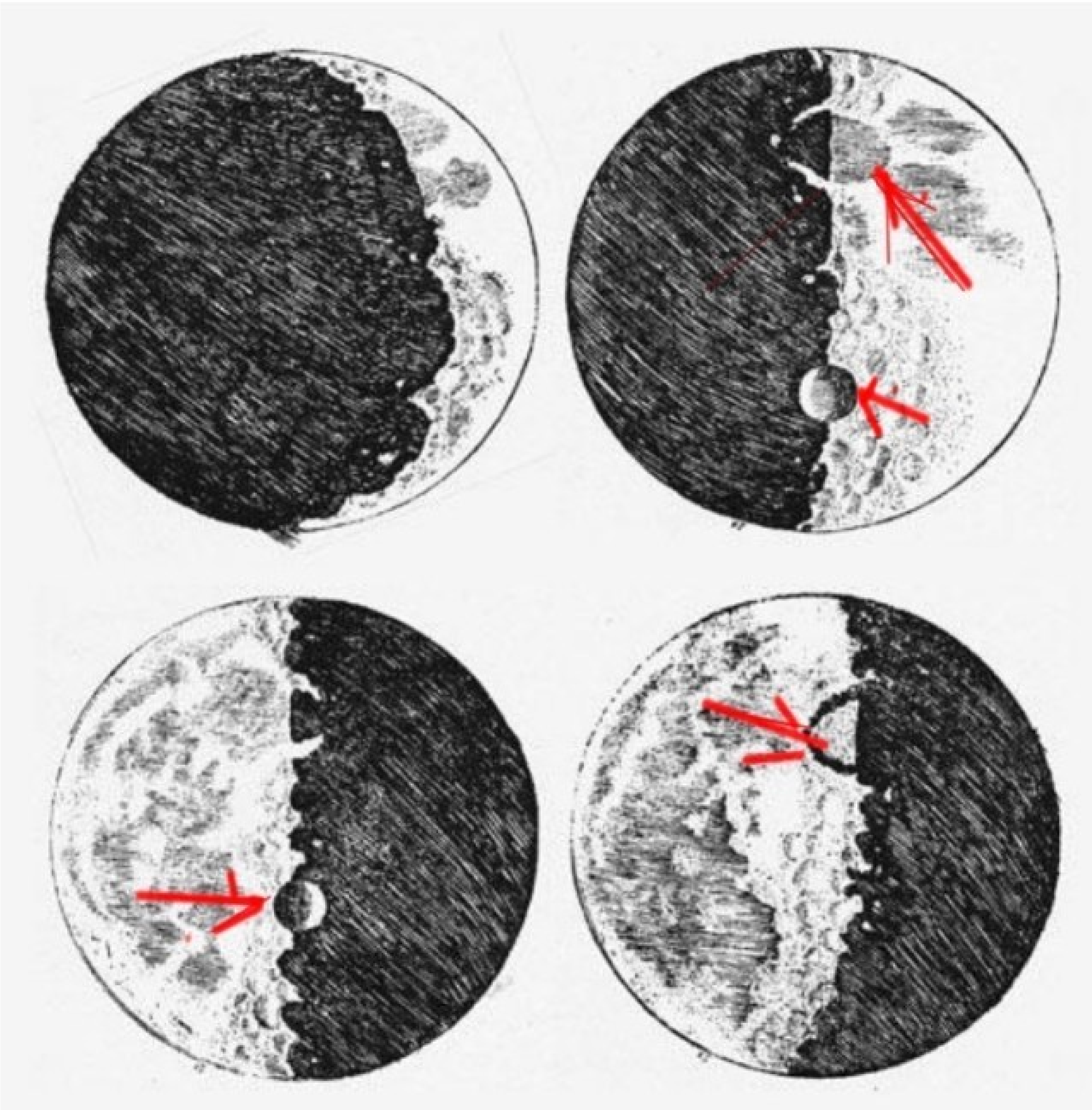
> You look out your window and note that your driveway is wet; three possible explanations occur to you: it has rained, the sprinkler has been set so that it also wets the driveway, your car has been washed. You notice that neither the street nor your lawn are wet, so you conclude that the third explanation—your car has been washed—is the correct one. A pail of water beside your car is confirmatory evidence for that conclusion.

Some philosophers of science put down IBE as lacking certainty and leading to false conclusions. In the past theories proposed as best explanations have turned out to be duds: phlogiston as caloric fluid for heat, ether as a medium for electromagnetic waves. However, it should be kept in mind that these theories were disproved by additional empirical evidence: caloric theory of heat, by Count Rumford's cannon-boring experiments, the ether as a medium for electromagnetic waves, by the Michelson-Morley experiments. See "Science Background—Elements of Thermodynamics," for a more detailed account of how science works to prove IBE type theories.

2.4 RETRODUCTIVE REASONING

> *"In a retroduction, the scientist proposes a model whose properties allow it to account for the phenomena singled out for explanation. Appraisal of the model is a complex affair, involving criteria such as coherence and fertility, as well as adequacy in accounting for the data. The theoretical constructs employed in the model may be of a kind already familiar (such as "mountain" and "sea" in Galileo's moon model) or they may be created by the scientist specifically for the case at hand (such as "galaxy," "gene," or "molecule")."*
> –Ernan McMullin, "A Case for Scientific Realism"

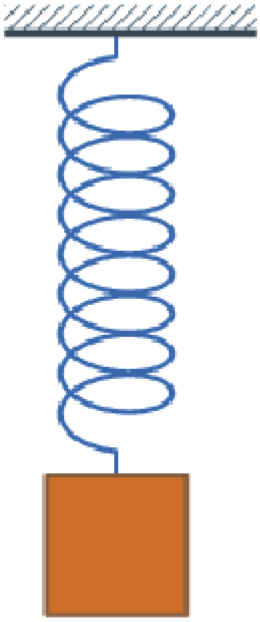
Retroductive reasoning is commonly used by scientists to explain phenomena by a familiar model. A very early example is that in which Galileo proposed that the moon had seas and mountains on it just as does the earth, in order to explain the differing patterns of light and dark on the moon at different orientations with respect to the sun.

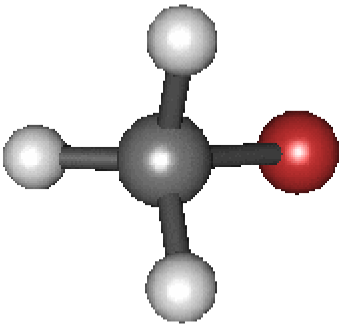


“Galileo’s Moon Sketches; red arrows show different shadows and light, depending on the direction of sunlight; these light and shadow patterns suggest the presence of mountains and craters.

Modified from Wikimedia Commons

An example from contemporary molecular physics is the model used to describe molecular vibrations (nuclei in a molecule vibrating back and forth): a weight attached to a spring, vibrating back and forth, the so-called “harmonic oscillator.”





Vibrating Molecule:
red ball represents bromine,
white balls, hyrdogen;
black ball, carbon
from [Wikimedia commons]

Model for vibrating molecules: a harmonic oscillator, a weight attached to a spring.
From [Wikimedia Commons]

2.5 Notes

[1]The **contrapositive** of a logical statement just switches the hypothesis (premise) and conclusion of the statement and negates both. We can write the statement symbolically as A>B, (meaning “if the hypothesis A is true, then the conclusion B is true,”); then the

contrapositive of that statement would be written symbolically as NotB>NotA, (meaning that if the negation of B is true, then the negation of A is true).   For example, going to the first syllogism above,

A; this animal is a cow (minor premise);

B: this animal is purple (conclusion);

, would correspond to

“If this animal is a cow, then this animal is purple” (true if the major premise of the syllogism, “all cows are purple,” were true).

The contrapositive would be

NotB: this animal is not purple (contrapositive premise);

NotA: this animal is not a cow (contrapositive conclusion),

which corresponds to

“If this animal is not purple, then this animal is not a cow.”

SECTION 3: What Science is All About

The Laboratory of Dr. Frankenstein or “Science Gone Wrong”
from Wikimedia Commons

3.1 INTRODUCTION

> *“To answer the question ‘To be or not to be?’ we cannot turn to a science textbook.”*
> —Fr. Stanley Jaki, The Limits of a Limitless Science.

The quote from Fr. Jaki says it all—there are questions that science cannot answer, by the very nature of how science works:

Why should science explain?
Why should the laws of nature "*be written by God in the hand of mathematics*" (Galileo)?
Where does "*The unreasonable effectiveness of mathematics in the natural sciences*" (Eugene Wigner) come from?

I'll discuss possible answers to those questions in this Section (or why there might be no answers).

3.2 PHILOSOPHICAL BACKGROUND

As a onetime practicing physicist, I never bothered about why science works. It was only after retiring that I began to wonder about the philosophical ground on which science rests. Delving into texts, I found there were two main camps of philosophers of science: realist and antirealist. A summary of my blog post about the realists and antirealists, Tipping the Sacred Cow of Science—Confessions of a Science Agnostic, is given below.

The Realists.

> "*Scientific realism … is a quite limited claim that purports to explain why certain ways of proceeding in science have worked out as well as they (contingently) have*."
> —Ernan McMullin, A Case for Scientific Realism"

Scientists and philosophers who are "scientific realists" believe there is an underlying reality corresponding to a scientific description. Thus, they believe that the so-called "God particle", the Higgs boson, is real, even though its existence is inferred from theory and high energy particle scattering data.

It should not be surprising that most scientists are scientific realists. Why would a molecular biologist spend his life exploring the mysteries of the human genome unless he/she believed that this was a "true" explanation of how molecular chemistry expresses itself in heredity and our biology? Why would I (when I was an MRI physicist) have spent too many hours per day wondering how the state of biological tissue affected the environment of water protons, unless I believed that protons existed and that their magnetic properties depended on physical interactions with their tissue environment? To most of us scientists it's more than a game; it's a passionate desire to know how nature operates, and for those of us who believe in God, to understand His wisdom in Creation.

The Anti-Realists

> *"The fundamental laws of physics do not describe true facts about reality. Rendered as descriptions of facts, they are false; amended to be true, they lose…explanatory force."*
> —Nancy Cartwright, "How the Laws of Physics Lie"

Antirealist philosophers deny the fundamental reality of scientific theories/laws/entities and claim that science is validated only empirically, by the truth or falsity of the predictions derived from scientific theories. For these "antirealists" there are no scientific laws, and the reality of theoretical entities–quarks, gluons, etc–is problematic. According to them, scientific theories do not mirror reality, veiled or unveiled. Their philosophical positions are illustrated by Nancy Cartwright's How the Laws of Physics Lie, and Bas van Fraassen's The Scientific Image, discussed below.

Nancy Cartwright does not believe that fundamental, theoretical scientific equations are true (e.g. Maxwell's equations, the Schrodinger equation), although she does believe that theoretical entities are real (e.g. the electron, quarks), and that phenomenological equations are true (relations empirically rather than theoretically derived, such as Poiseuille's Law of viscous flow). Her reason for disbelief, supported by a number of examples, is stated in the quote above. The equations have to be amended, supplemented, supplied with empirical fudge factors, or require conflicting mathematical prescriptions to describe real situations. I won't go over all her examples (Snell's Law of refraction, Crooke's radiometer, quantum damping, the BCS theory of superconductivity) but only say they are well chosen to demonstrate her knowledge of mathematical physics.

Bas van Fraassen believes that a scientific theory can be judged to be true if it is empirically verified, and only by that test. Here I agree with him–to an extent. He believes that theory does not correspond to a real world, discoverable by science–that would be a metaphysical assumption, a truly bad thing for an empiricist philosopher. With this judgment, I might disagree. Van Fraassen also argues that theory cannot be evaluated as a best explanation for phenomena. (The ether is one example of an incorrect but plausible explanation for how electromagnetic waves vibrate.) The function of theory is "to save the phenomena," i.e. to give a concise description of real phenomena that is empirically verified. He also limits that which might be described as truly real, an "observable," to that which can be directly observed (in principle), such as Jupiter's satellites. That which can only be detected by use of instruments—chromosomes, electrons, quarks—would not be an observable and thus not "real."

The antirealists looking at the history of science, see failed theories, theoretical entities disproved by experiment–phlogiston by Count Rumford's cannon-boring experiments, the ether by the Michelson-Morley experiment. On the other hand, one could argue that theory is converging to the truth–the Higgs boson confirmed by the CMS experiments—even though that convergence is an article of faith.
I myself have faith in science as a partial mirror of reality. I believe that the world God created must be an orderly and intelligible world, not the "dappled world" of Nancy Cartwright, with one set of scientific laws here and another there–Bach, not Cage. God gave us intelligence to help us understand his creation; the reality that remains veiled is so because of limits to our intelligence, not because God is irrational. (See Aquinas, Summa

Theologica, Q. 93, Article 1.)

3.3 HOW DOES SCIENCE WORK? BASICS—THE LAKATOS "SCIENTIFIC RESEARCH PROGRAMME"

> *"Man is not born to solve the problem of the universe, but to find out where the problem begins and then restrain himself within the limits of the comprehensible."*
> —J.W. von Goethe, as quoted in The Homiletic Review"

If you do a man-in-the-street survey, asking "How does science work?" you'll get many different answers. Here are some from an adult education class I taught on "Science and the Church" (actually, I supplied the last two answers):

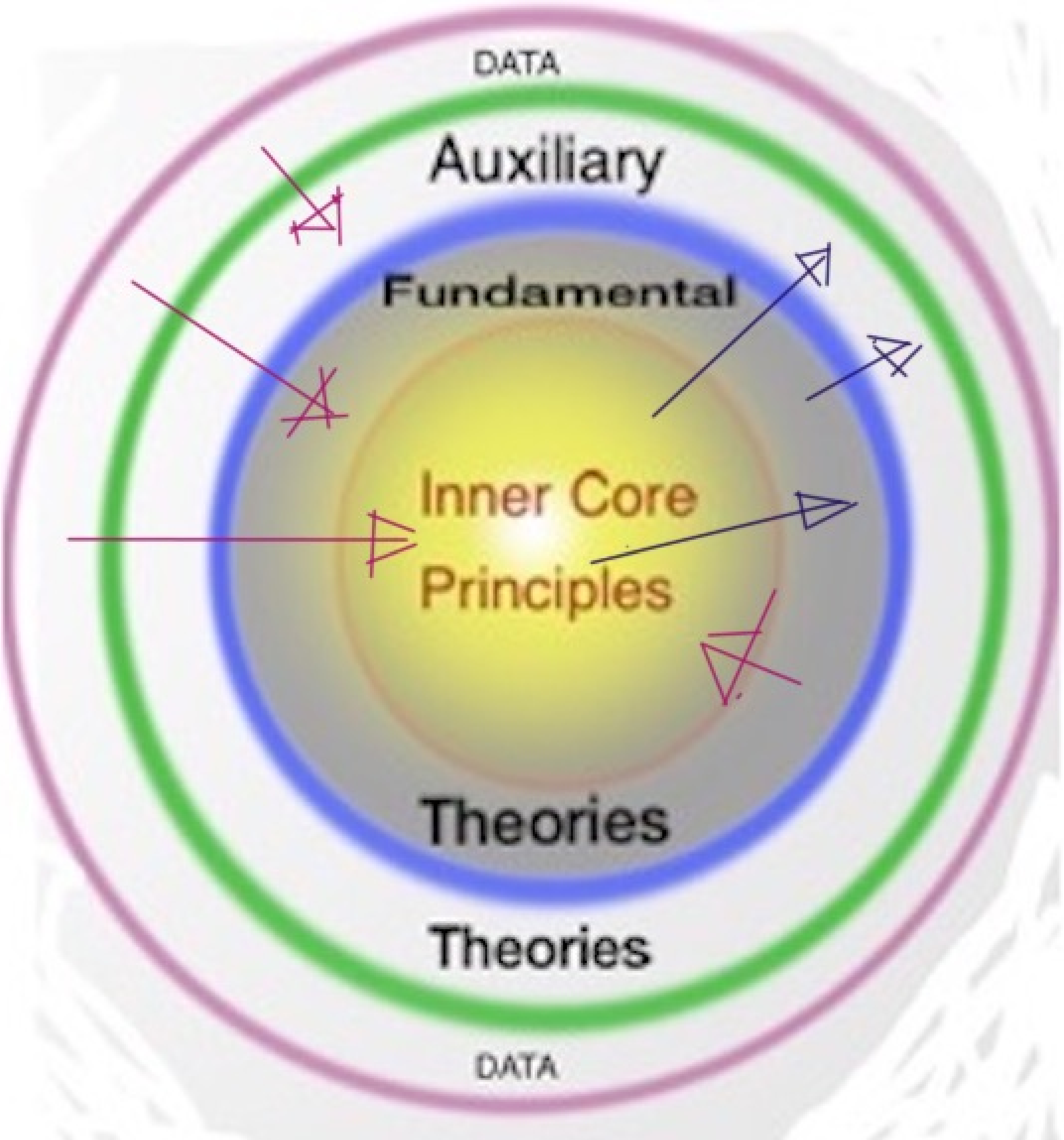
Finding theories to explain everything;
Formulating a hypothesis, testing the hypothesis by experiment;
Finding an unusual experimental result, formulating a theory to explain the result;
Finding a theory that will explain a body of experimental knowledge;
Finding theories that could be proved false by suitable experiments;
Finding which theories are the most elegant and are also consistent with experimental results;
Depends on a scientist's presuppositions and assumptions;
Is "reductionist", i.e. attempts to reduce phenomena and the objects comprising these phenomena to the smallest components and the scientific laws governing the action of these components: for example, intelligence can be reduced to biochemical and electrical events on the molecular level;
Establishes a research program consisting of a network of hypotheses and experimental data: core theory, based on inner core principles, linked to secondary theories and results (Lakatos' scientific research programme—see below).

The correct answer is "all the above," depending on the scientist and his/her research focus.

However, I believe the last answer, the Lakatos Scientific Research Program, gives the best, the most complete description of how science is carried out. This "Scientific Research Programme" can be thought of as a sphere:

An inner core of **fundamental principles--**not theories, but principles to which theories have to adhere; these principles are assumed, because they seem obvious and confirmed generally by our experience: for example, The First and Second Laws of Thermodynamics. But, as we'll see below, there are occasions when these fundamental principles are modified or violated.
A shell of primary or **fundamental theories** surrounds this core of fundamental principles (e.g. thermodynamics, general relativity, quantum mechanics).
Other shells representing **auxiliary theories** surround this shell of fundamental theories; such auxiliary theories are derived from the primary theories and other auxiliary theories; MRI, chemical bonding, heat transfer are examples of such auxiliary theories.
Finally there is an outermost shell of **experimental facts or data**. The interplay between the shells and core that shows how science works is described in the diagram below and illustrated by several examples in **3.4 How Does Science Work? Case Studies.**

In this diagram the inner core principles are linked to fundamental and auxiliary theories, as shown by the black arrows. There is feedback from data to theories, as shown by the red arrows. There is even feedback from data and fundamental theories to inner core principles, as shown by the red arrows.



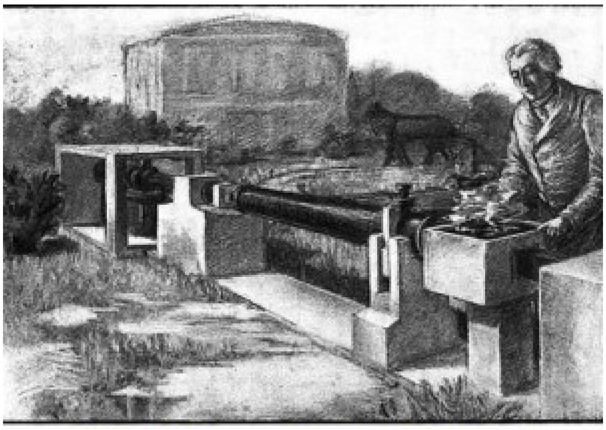
Lakatos "Scientific Research Programme;" arrows indicate feedback direction
(Diagram made by RJK)

Examples of how the Lakatos scheme works are given below.

3.4 HOW DOES SCIENCE WORK? CASE STUDIES

(See Science Background: Section 2, to learn more about thermodynamics, the science of energy.)

History of Thermodynamics: Count Rumford: Cannon Boring —> Heat Not Conserved.



From Elmer Burns' illustrated 1910 book "The Story of the Great Inventions" (See Project Gutenberg .)

Count Rumford's Cannon-Boring Experiment–Making Water Boil

In 1798 Benjamin Thompson, Count Rumford, submitted a paper to the Royal Society about his experiments in which boring a cannon could make water boil, and boring with a blunt instrument produced more heat than with a sharp one (more friction with the blunt). The experiments showed that repeated boring on the same cannon continued to produce heat, so clearly heat was not conserved and therefore could not be a material substance.

This experiment disproved the then prevalent theory of heat, that it was a fluid transmitted from one thing to another, "the caloric." The results validated another theory of heat, the kinetic theory, in which heat was due to the motion of atoms and molecules. However the kinetic theory, despite Rumford's groundbreaking experiment, still did not hold sway until years later, after James Joule showed in 1845 that work could be quantitatively converted into heat.

History of Thermodynamics: James Joule: Work—>Heat

As the weight falls, the potential energy of the weight is converted into work done (a paddle stirs the water in the container against a frictional force due to water viscosity).   The temperature rise corresponding to a given fall of weights (work done) yields the amount of heat rise (in calories) of the known mass of water. Since the temperature rise is very small, the measurements have to be very accurate.

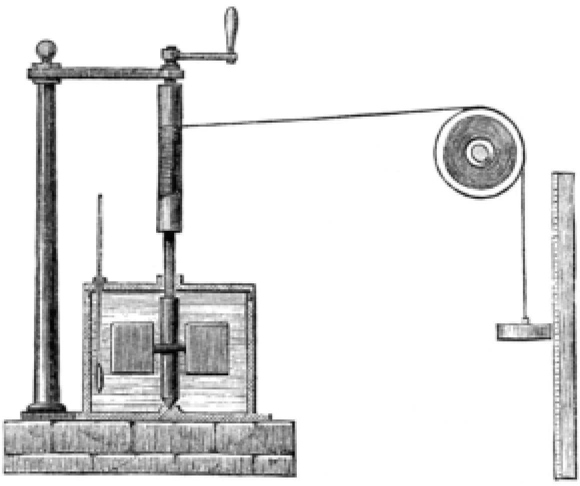


Diagram of Joule's Apparatus for Measuring the Mechanical Equivalent of Heat
from Wikimedia Commons

It took 30 to 50 years after Joule's definitive experiment (and subsequent refinements and repetitions) for the kinetic theory of heat—heat caused by random, irregular motion of atoms and molecules–to be fully accepted by the scientific community.   James Clerk Maxwell published in 1871 a paper, "Theory of Heat". This comprehensive treatise and advances in thermodynamics convinced scientists finally to accept that heat was a form of energy related to the kinetic energy (the energy of motion) of the atoms and molecules in a substance.

Contemporary Science: Experimental Tests of Fundamental Theories

Links are given below to examples of modern experimental tests of ground-breaking primary and secondary theories in various fields of science. (Some are discussed below in more detail and in other Essays.)

Special Relativity
General Relativity
Plate Tectonics
The Genetic Code
The Higgs Field to Endow Particle with Mass See also "God, Symmetry and Beauty in Science: The Standard Model and the Higgs Boson"

3.5 HOW DOES SCIENCE WORK? APPLYING THE LAKATOS SCHEME

Rumford and Joule's Experiments on Heat and Work

The core principle involved in the caloric theory of heat was the conservation of caloric (since it was a substance). Count Rumford's cannon-boring experiments showed that the more the cannon was bored, the more heat was produced; therefore the supply of heat in the cannon was inexhaustible and clearly not conserved. A core principle involved in Joule's experiment is the First Law of Thermodynamics: conservation of energy, with heat and work as forms of energy. Note that this conservation principle is linked to the fundamental theory of thermodynamics developed in the middle of the 19th century and earlier, theories of classical mechanics developed in the 18th century and early 19th century.

Einstein's Special Theory of Relativity and General Theory of Relativity

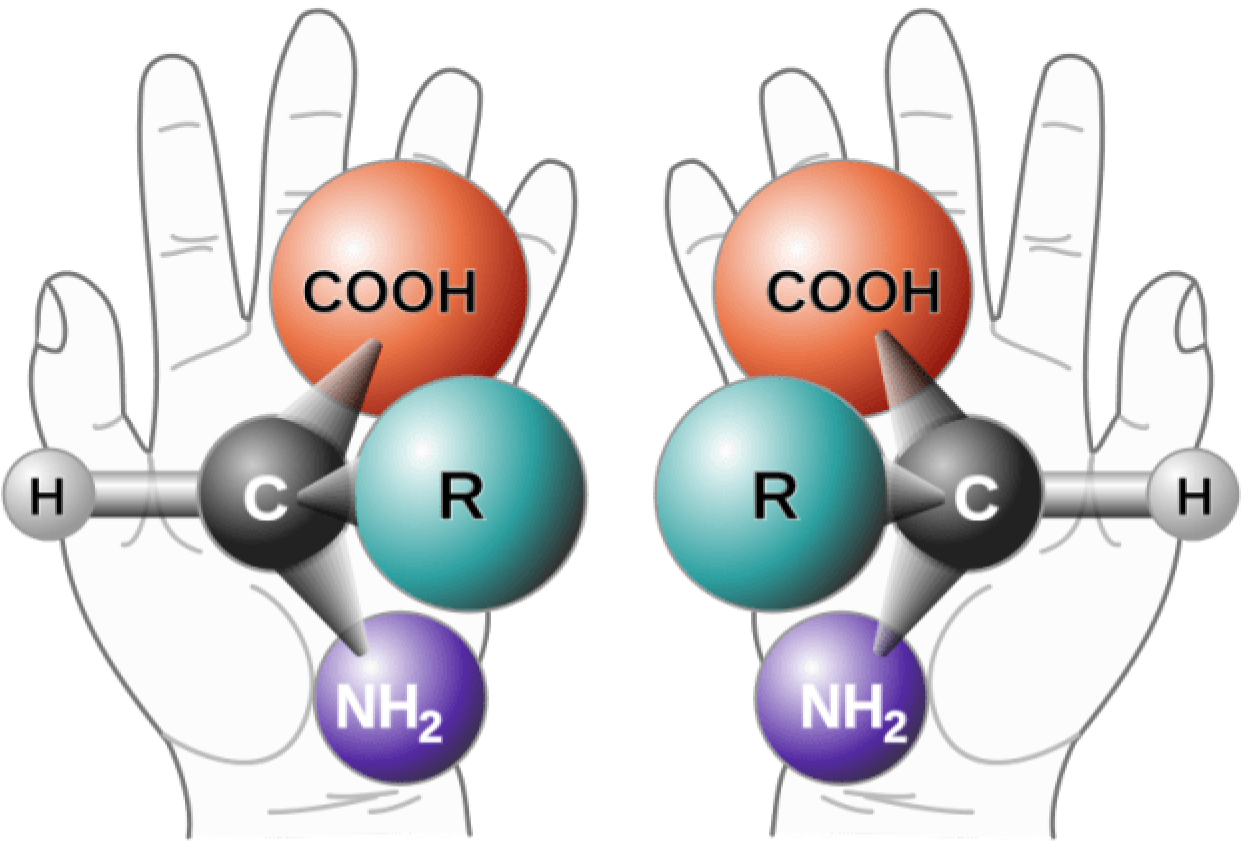
Einstein's two theories of relativity are striking examples of how theory influences fundamental principle (the red arrow), or perhaps more accurately, how fundamental principles are proposed as a basis for general theories. His theory, special relativity, introduced the following new general principles:

the laws of physics are the same for systems ("frames of reference") moving at constant velocity (i.e. "inertial systems");
the speed of light (in vacuum) is constant, regardless of the speed of source or receiver;
neither energy nor mass is conserved but only mass + energy (from $E= mc^2$)

His general relativity theory introduced the "equivalence principle", that inertial and gravitational mass are the same.   In every-day terms, this principle says that a person (mass m) in an elevator accelerating upward experiences a force holding him to the floor due to earth's gravitation, mg, plus a force due to the acceleration of the elevator, ma. This is the same force that the person would experience on a planet where the gravitational acceleration would correspond to g+a, or in a spaceship accelerating at a rate g+a. (See Science Background—Physics of Motion, for more about force and acceleration.)

Recently Einstein's Theory of general relativity has been confirmed again from LIGO measurements of gravity waves. See "Peeling Back the Onion Layers—Gravitational Waves Detected" for a more detailed account.

Is Parity Conserved? Right- and Left-handedness



Left- and right-handed molecules (chiral molecules). These amino acids are mirror images of each other. from Wikimedia Commons

Parity refers to mirror symmetry. For example, many organic molecules are either right- or left-handed (see the illustration below of two amino acids, constituents of proteins: COOH is the organic acid group, NH2 is an amino group, C is the central carbon, R represents a general group attached to the carbon). Now biological molecules can be chiral either as a whole, or with respect to the constituent parts. For example, amino acids found in nature are left-handed; sugars found in nature are right-handed; DNA as a whole has a right-handed spiral (helix).   The question of why only one kind of handedness for biological molecules came about has fascinated chemists and biologists since the time of Pasteur 150 years ago. There are recent theories to explain this, but they are to some extent conjectural

Conservation of parity (handedness) had been a fundamental principle of physics until the late 1950's, when a proposal to test it for nuclear weak force interactions–e,g, beta decay of Co-60 nuclei–showed that it was violated. (See here for an expanded story.)   Since that time a conservation principle, CPT symmetry, linking parity (P) with charge (C) and time reversal (T) has been found to hold.

SECTION 4: The Limits of Science—What Science Can't Do

How do we go from "how science works" to "what science can't do"? The most comprehensive scheme and, to my mind, the one that best matches actual scientific practice is that of Imre Lakatos, described above. Note again these elements of the scheme: a network of hypotheses AND experimental data. The combination of theory and data requires that predictions or explanations made by models and theory must be validated empirically, if the theory or model is to be truly part of science. Measurements must be replicable, which is to say that essentially the same results are required, for whichever team does the measurement or performs the experiment.

Fr. Stanley Jaki has put more stringent requirements on science:

> *"Science…is synonymous with measurements, which are accurate because they can be expressed in numbers. Those numbers relate to tangible or material things, or rather to their spatial extensions or correlations with one another in a given moment or as time goes on."*
> —Fr. Stanley Jaki, The Limits of a Limitless Science," Asbury Theological Journal 54 (1999), p.24

This need for numerical assessment strikes out disciplines which most people would regard as science—biology, geology, paleontology, and such. Here I would have to disagree with Fr. Jaki: abduction and retroduction can be used to assess non-numerical data rigorously. A fine example is the development of the tectonic plate theory. It started in 1915 with the continental drift hypothesis of Alfred Wegener, based on the matching coastline shapes of western Africa and Eastern South America, and the striking similarity of strata and fossils on the two coasts. In the 1960's seismographic data showed that continents and ocean floors rested on vast tectonic plates which were vehicles for continental drift. So, both qualitative and quantitative evidence entered into validation of the theory.

A much more important limit to science has been set by Fr. Jaki:

> *"Hamlet's question, 'to be or not to be,' has a meaning even deeper than whether an*

> *act is moral or immoral. That deeper meaning is not merely whether there is a life after death. The deepest perspective opened up by that question is reflection on existence in general. In raising the question, 'to be or not to be,' one conveys one's ability to ponder existence itself. In fact every bit of knowledge begins with the registering of something that exists.* ***To know is to register existence. But this is precisely what science cannot do, simply because existence as such cannot be measured****.*[emphasis added]*."*
> *—loc. Cit.,* p.30.

What this means is that science can not explain itself. Science can not show why it gives us a partial picture of the world expressed mathematically, or to use the Nobel Laureate Eugene Wigner's apt phrase, science can not explain *"the unreasonable effectiveness of mathematics"* by an underlying scientific theory. The only justification for this success is empirical—it works!

Therefore science can not answer questions about religion. It cannot neither prove nor disprove the existence of a Godhead, nor the existence of the Trinity. Thus, to say that science "proves" the existence of God, is as much an error as saying it disproves that God exists. We can only say that all that we learn about our world from science is in accord with that world which an omniscient and omnipotent God would create.