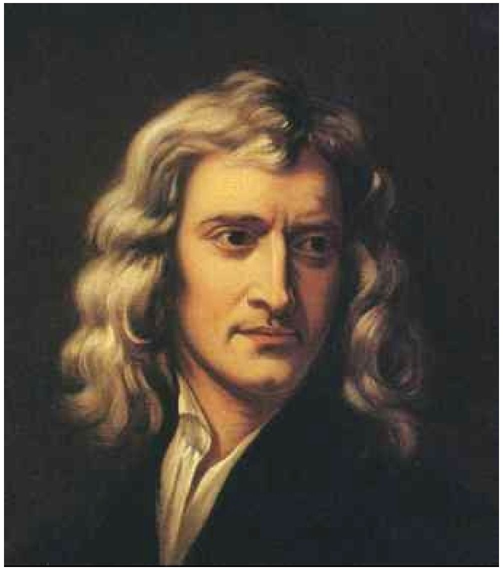
Philosophical Foundations of Science And Quantitative Analysis

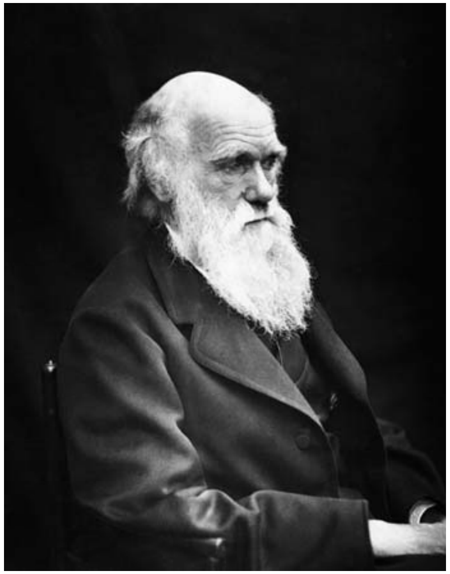
By Dr. Robert Finkelstein

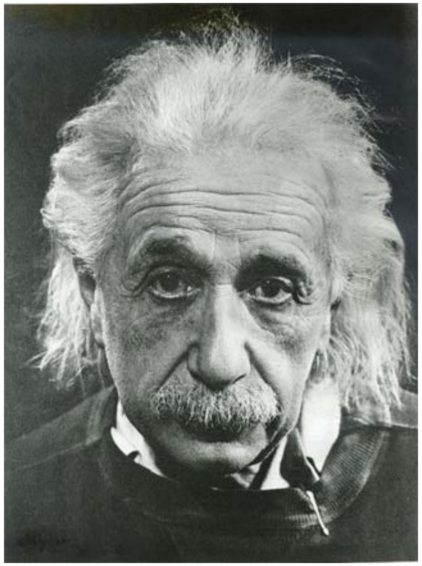
References:

The Structure of Scientific Revolutions, Thomas Kuhn, Third Edition, 1996

Philosophical Foundations Of Physics, Rudolph Carnap, Edited By Martin Gardner, 1966







Section 1: Definitions

Philosophy

- **Theory of the principles underlying conduct, thought, knowledge, and the nature of the universe**
  - Included are such fields as: logic, epistemology, metaphysics, ethics, and aesthetics
- The love of - or search for - wisdom or knowledge
- General principles or laws of a field of knowledge
- **A system of principles for the conduct of life**
  - A study of human morals, character, and behavior

Knowledge

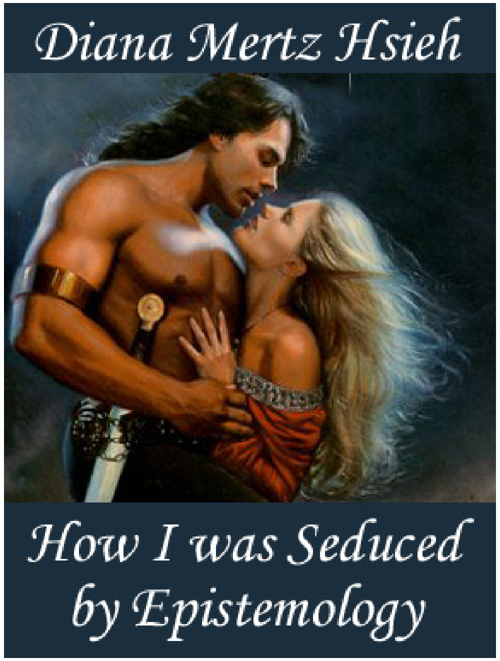
- **The act, fact, or state of knowing**
  - Acquaintance or familiarity with a fact or entity
  - Awareness
  - Understanding
- All that has been grasped or perceived by the mind
  - Learning and enlightenment
- Body of facts, principles, etc. accumulated by mankind
- **A posteriori knowledge (i.e., "knowledge by acquaintance")**
  - Knowledge derived from **experience** (i.e., senses)
- **A priori knowledge (i.e., "knowledge by description")**
  - Knowledge **independent of experience** (e.g., mathematical knowledge) or transmitted from others having sensed experience

Epistemology

- **The study or theory of the nature, sources, and limits of knowledge**
  - What is it to know something?
  - What counts as evidence for or against a particular theory?
  - What is meant by a proof?
  - **Is human knowledge possible at all?**
- **Analytic propositions**
  - The meaning of the predicate term is **contained** in the meaning of the subject term
  - **Example:** “All husbands are married” (“husband” includes in its meaning “being married”)
- **Synthetic propositions**
  - The meaning of the predicate term is **not** contained in the meaning of the subject term
  - **Example:** “All birds are **blue**”

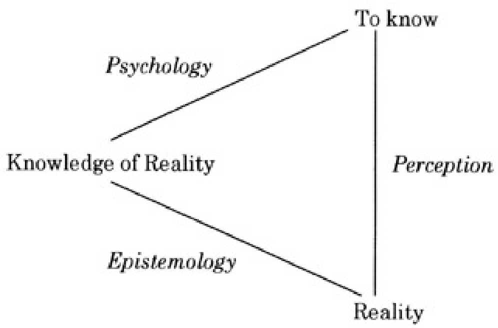
Epistemology

- **Analytic vs. synthetic propositions**
  - Most analytic propositions are a priori
  - Most synthetic propositions are a posteriori
  - **Are a priori synthetic judgments possible?**
    - Question posed by Kant; one of the most important questions in epistemology
- **Tautological propositions**
  - Its constituent terms repeat themselves or they can be reduced to terms that do so
  - The proposition is, fundamentally, of the form a = a
  - **Example:** He is old because he has lived many years, and he has lived many years because he is old
  - No significant propositions can be derived from tautologies
  - **Tautologies** are generally a priori, necessary, and analytic
  - **Significant statements** are generally a posteriori, contingent, and synthetic



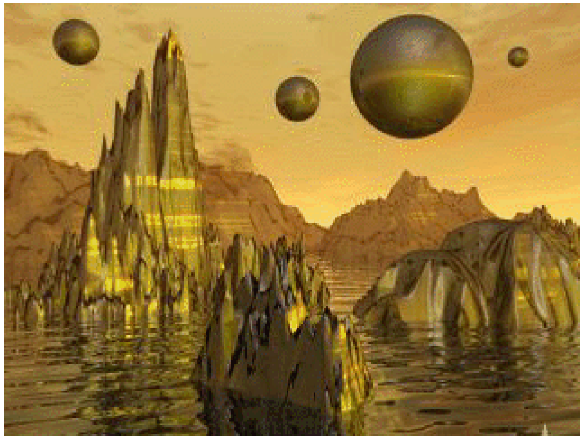
Epistemology

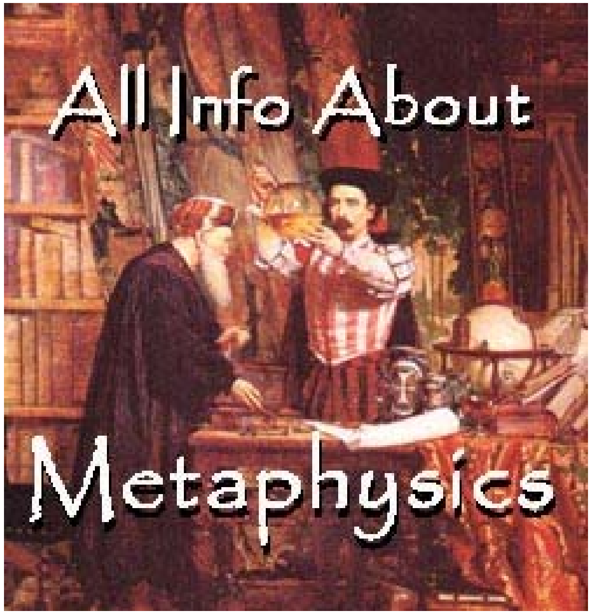
- **An epistemological fact:** our perceptions somehow respond to presented facts so as to satisfy certain general conditions of responsiveness
  - To show **how knowledge is possible**, the philosopher **epistemologist** only **speculates** on the existence of the linkage between perceptions and facts
  - **Scientists** (e.g., perceptual and physiological psychologists**)** explain **why** perceptions respond to facts, describing the **mechanisms** for achieving responsiveness
  - **Scientists** (e.g., evolutionary psychologists) explain **how** the mechanism arose and was selected by Darwinian processes
  - Thus **philosophical and scientific** activities **differ**
    - But the philosopher's existential hypothesis may suggest **experiments and investigations** to the scientist
    - A philosophical speculation may be sufficiently complete as to be amenable to an **immediate empirical test**



Ontology And Metaphysics

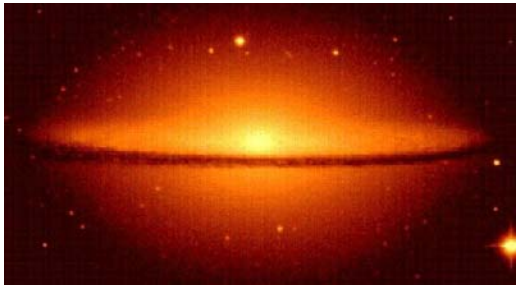
- **Ontology:** the theory of being as such, i.e., the basic characteristics of reality
  - Often taken as synonymous with **metaphysics** (the science of **ultimate reality**)
- What is **ultimately real** versus merely **apparent**?
  - **Examples:** the real size of the moon versus its apparent size in the sky; the real color of an object versus its color viewed in dim light; the real structure of a desk (atoms, quarks, and empty space) versus its apparent structure (e.g., solid wood)
  - **Common sense** is **not** a good guide to reality
  - **Metaphysicians do not agree on the nature of ultimate reality**





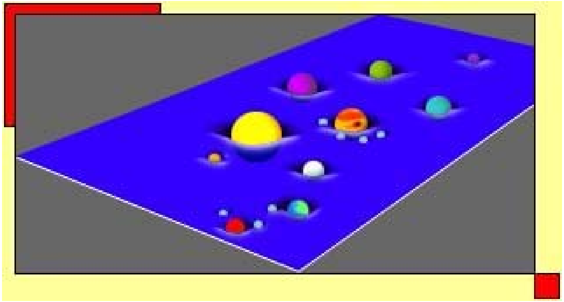
Science

- **Systemized knowledge derived from observation, study, and experimentation**
- A **branch of knowledge** or study, especially one concerned with establishing and **systemizing facts, principles, and methods**, as by experiments and hypotheses
- Any **system of knowledge** that is concerned with the **physical world** and its phenomena and that entails **unbiased observations** and **systematic experimentation**
- A pursuit of knowledge covering **general truths** or the operation of **fundamental laws**
- A skill based on systemized training (e.g., management science)
- **Research:** careful, **systematic**, patient study and investigation in some field of knowledge, undertaken to discover or establish **facts or principles**



Philosophy Of Science

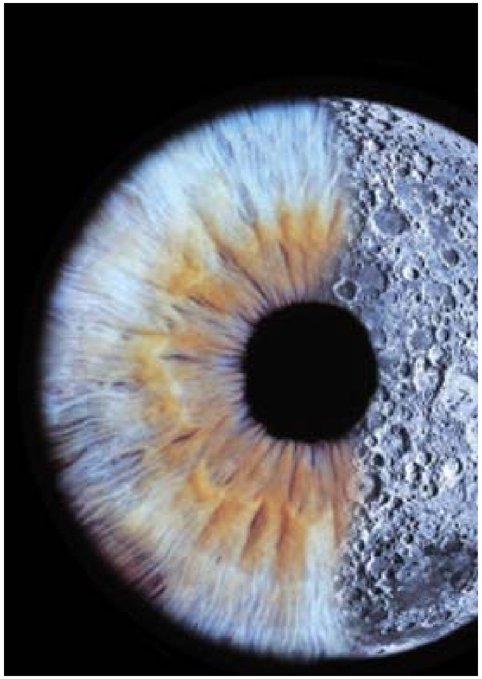
- The study of the **scientific process** or method and its **validity**
- Identifies different **styles of explanation** characteristic of **different sciences** (e.g., psychology versus neurophysiology) or **different stages in a given science** (e.g., Newtonian versus Einsteinian theories of gravity) to determine how **different explanatory styles** reflect the characteristic problems of **different scientific fields and periods**
- **Central philosophical task:** analyze clearly and explicitly
  - **Standards** by which scientists decide whether some **interpretation** is **legitimate**, justified, and conclusively established
  - Considerations that justify **replacing** a currently accepted interpretation (e.g., Newton's theory of gravity) with a **new alternative** (e.g., Einstein's theory of gravity)



From Data To Epiphanies

- **Data:** Unconnected numbers, names, dates, etc.
- **Facts:** Connected data
- **Knowledge:** A particular assemblage of facts which can be taught and compressed; facts in context; actionable facts
- **Experience:** Primarily from self-directed interaction with the real world; internalizes knowledge and takes time to acquire
- **Shared visions:** Philosophical and emotional collective understandings founded on our universality and not individuality; motivating force in organizations and gives purpose needed by leaders
- **Epiphanies:** Level of perception beyond logic and intuition; rare creative brilliance

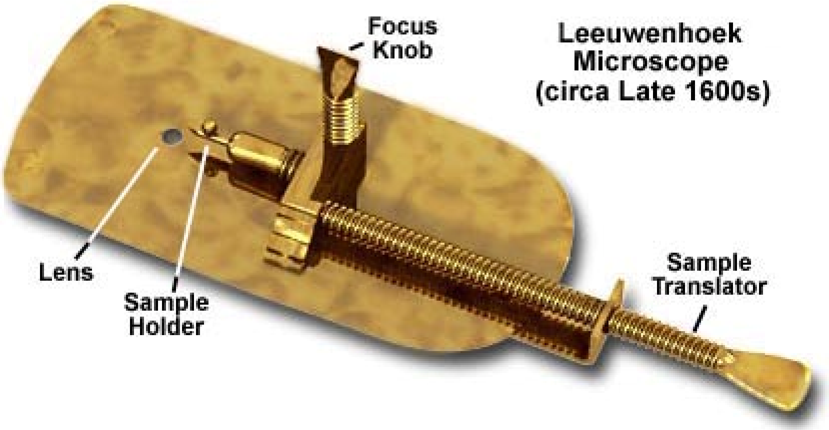
Where is the
WISDOM
We have Lost in
KNOWLEDGE
?



From Data To Epiphanies

- Data * Order = Facts
- Facts * Synthesis = Knowledge
- Knowledge * Perspective = Experience
- Experience * Unifying Principles = Shared Vision
- Shared Visions * Metalogic = Epiphanies

Section 2: Nature Of Normal Science

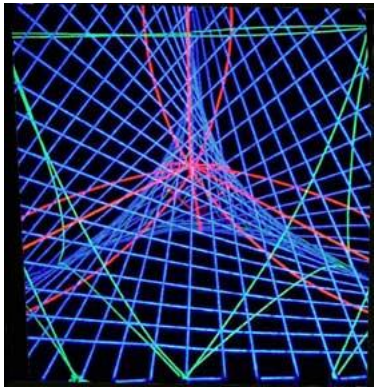


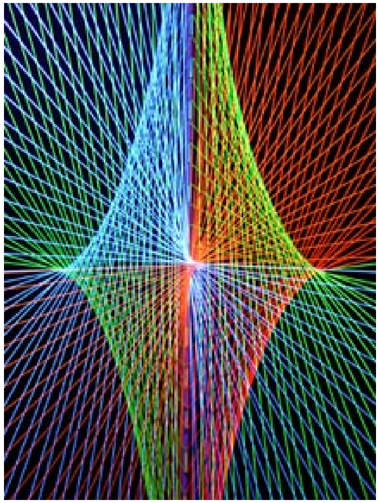
Definitions

- **Normal science**
  - Research based on one or more **past scientific achievements**, achievements that some particular **scientific community** acknowledges for a time as supplying the **foundation** for its further practice (Kuhn)
- **Paradigm**
  - A theory and **body of knowledge** sufficiently unprecedented and compelling as to attract an enduring group of adherents away from competing modes of scientific activity (Kuhn)
  - A coherent **tradition** of scientific research, including **law, theory, application, and instrumentation** (Kuhn)
  - A **pattern, example, or model**; an overall concept accepted by an intellectual community because of its success in **explaining** a complex process, idea, or set of data

Normal Science And Paradigm

- **Paradigms provide the framework for normal science**
  - A common set of **rules and standards** for theory and research
  - Most researchers in a field **share the paradigm – have a research consensus**
  - The existence of a paradigm is a sign of a **mature science**
  - Research without a paradigm (e.g., in a new discipline) is open to new discovery – but **chaotic** so fact-gathering is nearly **random;** phenomena are described and interpreted in many **different** ways

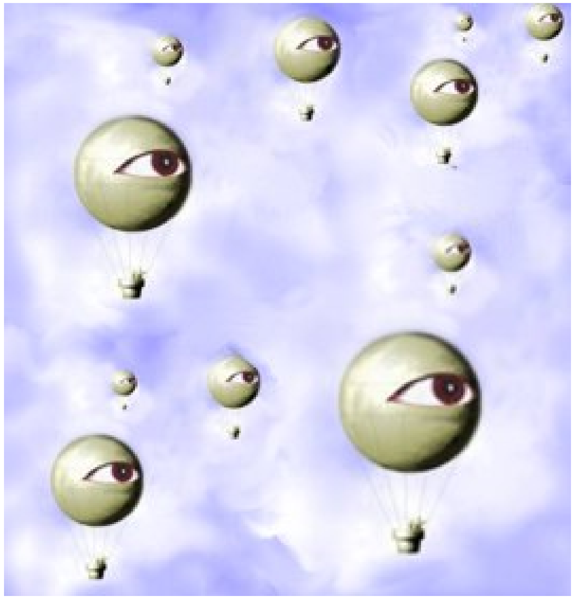




- **The transformation of a paradigm – the transition from one paradigm to another – occurs in a scientific revolution**
  - **Some examples; discovery of:** general relativity; plate tectonics; DNA; quanta and quarks; expansion of the universe; brain biochemicals; intelligent animal behavior; sulfur-based life cycles on sea floor vents; evolution through natural selection
- **Do the social sciences have paradigms yet?**

Paradigm

- **A framework for research and knowledge**
  - **Guides** research
  - Determines **relative importance** of data and facts
  - Serves as an **idea filter**
  - A framework can be **good or bad**
    - **Good:** provides a common basis for discourse and research and the development of research tools; is an **efficient** mechanism for research and advancing knowledge
    - **Bad:** no thinking "outside the box" – **loss of creativity**; facts not within the accepted paradigm are **difficult to perceive** or seen as irrelevant
  - A **theory becomes a paradigm** when it is generally accepted as **superior** to competing theories (i.e., explains and predicts phenomena and facts better)

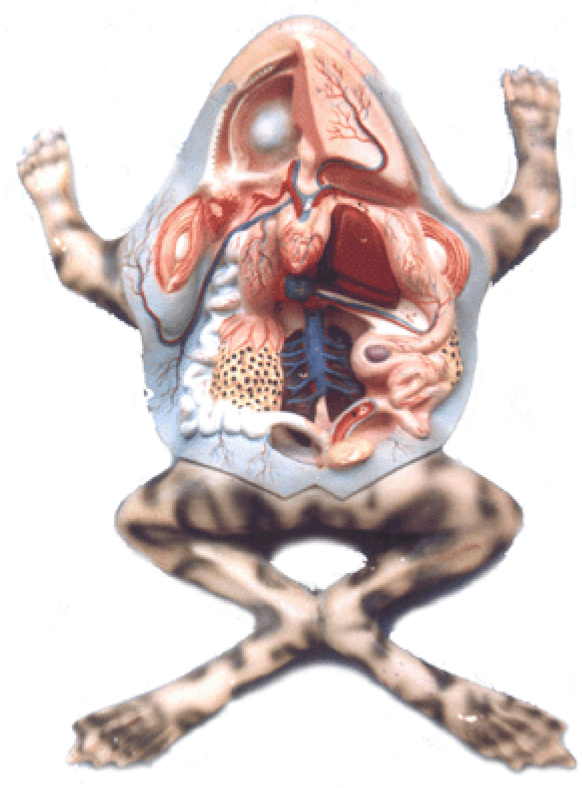


Paradigm

- The accepted paradigm **need not be perfect** and explain all facts and phenomena – just **superior to alternative paradigms**
  - An **imperfect paradigm** can explain phenomena satisfactorily and lead to better instruments, more accurate and precise measurements, and more facts and phenomena
- As facts and phenomena become **unexplainable by the paradigm** and errors accumulate, a **new paradigm emerges**
  - Some researchers cling to the **old paradigm** as a new generation embraces the **new paradigm** – eventually the fogies fade away
- The evolution (or revolution) of paradigms leads to an increasingly **solid basis** for the science
  - Researchers take the paradigm for **granted** and need not explain their research from **first principles**
    - This leads to less and **less comprehension** of the field by those **outside it** (because they are **unfamiliar with the latest paradigm**)

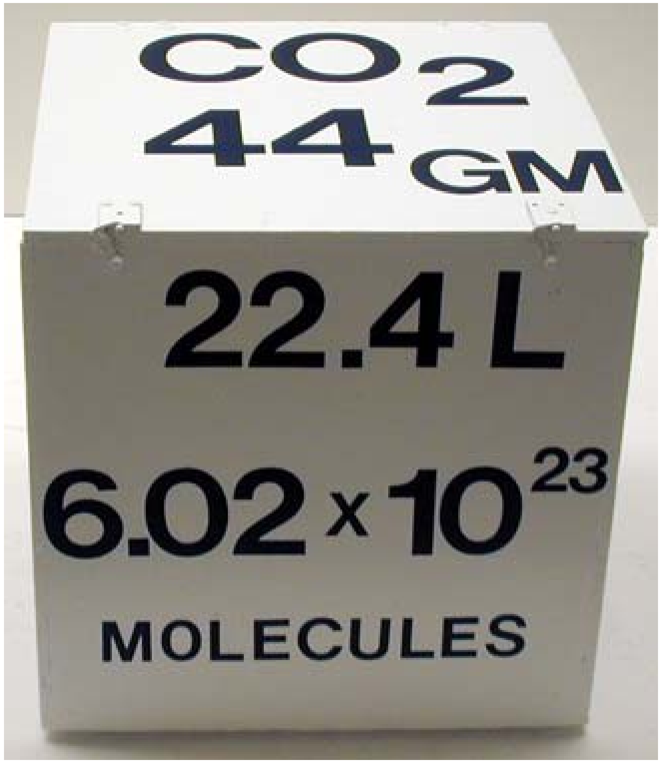
Normal Science

- The **(imperfect) paradigm** requires further articulation and specification under "**new or more stringent** conditions." (Kuhn)
- **Normal science** extends knowledge by increasing the extent of the **match between facts and the paradigm's predictions** and by **further articulating** phenomena, facts, and theories **already explained by the paradigm**
- **Normal science** is a type of **"mopping-up" operation, gathering and refining** facts and phenomena explained and predicted by the paradigm
- **Normal science** is **not** interested in seeking **new phenomena (and, in any event, would not perceive new phenomena outside the paradigm "box")**



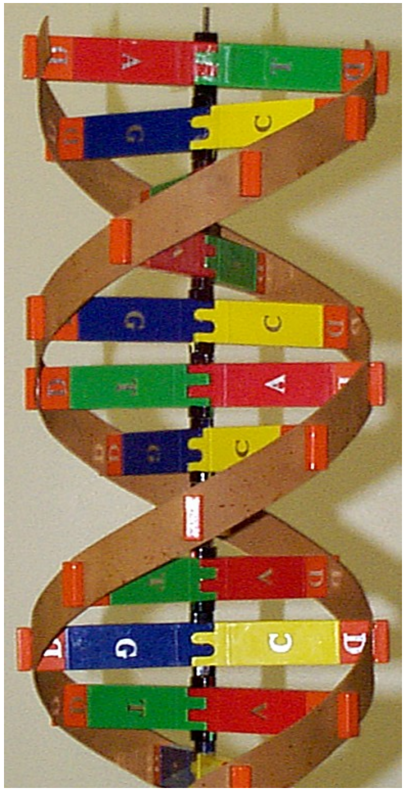
Normal Science

- **Normal sciences focuses on:**
  - **Determining significant data and facts**
    - The paradigm guides the search and perception of data & facts
  - **Matching facts with theory**
    - The paradigm determines problems to be solved (and the instruments needed to solve problems)
  - **Articulating theory**
    - Determination of **physical constants** (e.g., Avogadro's number)
    - Discovery of **laws** (e.g., Boyle's law)
      - **A paradigm may be a prerequisite for discovery of laws**
    - Discovery of **new ways** of applying paradigm to **new areas** of interest

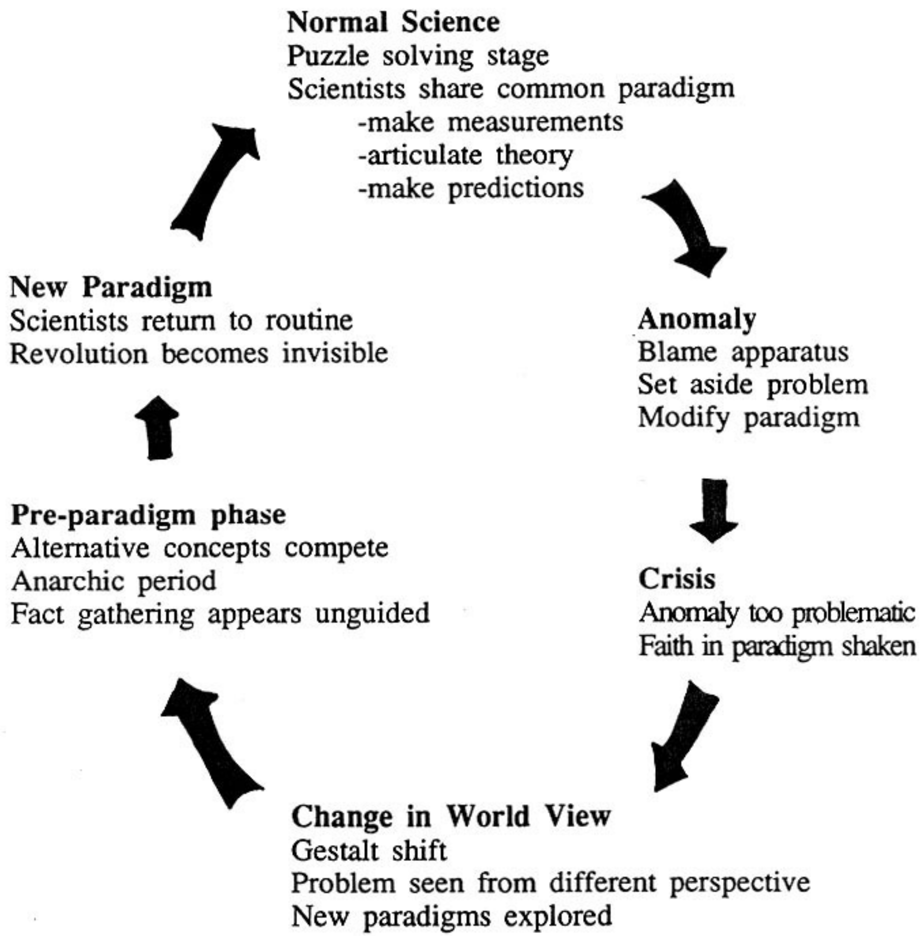


Normal Science

- **Theoretical problems of normal science**
  - Use "existing theory to **predict factual information** of intrinsic value" (Kuhn)
    - **Examples:** astronomical ephemerides; radio propagation curves; composition of human DNA
    - Often relegated by scientists to engineers & technicians
  - **Discover new application** of paradigm or **increase accuracy and precision** of existing application
- **Normal science excludes novel concepts and phenomena**
  - Novel problems are often **rejected** by the research community as **metaphysical**
  - Normal science is highly **constrained and determined**
- **Rules derive from paradigms, but "paradigms can guide research in the absence of rules"** (Kuhn)

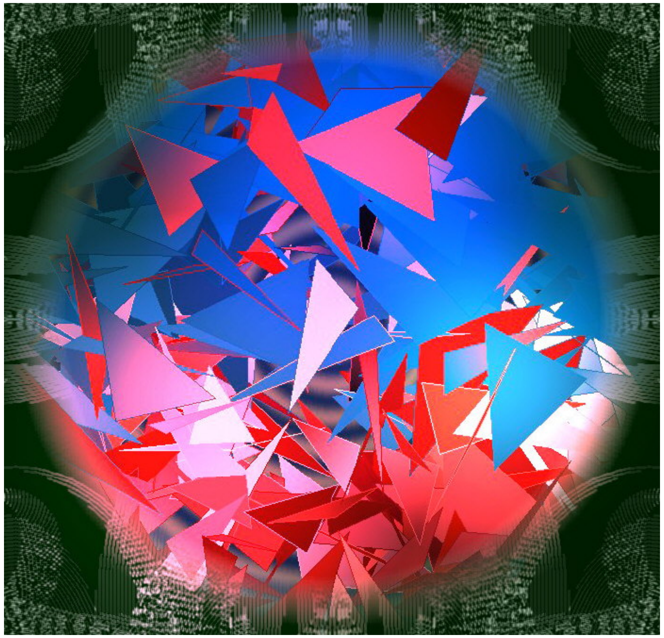


Section 3: Scientific Revolutions



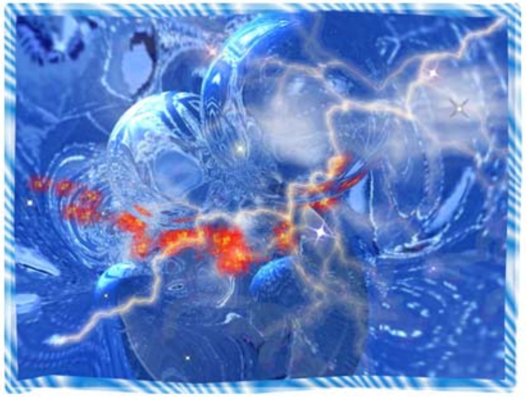
Emergence Of Scientific Discoveries

- **Normal science**
  - Highly **cumulative**; **steady increase** in scope and precision of scientific knowledge
- **Discoveries (new facts) and inventions (new theories)**
  - Lead to **anomalies** in normal science
  - Increasing anomalies lead to crises, which lead to a **paradigm shift** (replacement of an old paradigm with a new one)
- **"Crises are a necessary precondition for the emergence of novel theories"** (Kuhn)
  - Once it has achieved the status of a **paradigm**, a **scientific theory** is declared **invalid** only if an **alternative theory** is available to take its place
  - Crisis **loosens the rules** of normal science "puzzle solving" to allow a **new paradigm to emerge**



Emergence Of Scientific Discoveries

- **Scientists rejecting one paradigm always, simultaneously, accept another**
  - The process of **paradigm rejection and acceptance** involves **comparing both paradigms with nature and each other**
  - A scientist who **rejects an accepted paradigm** - the framework for the (current) normal science - without substituting a **new paradigm**, will be **castigated and ostracized** by his colleagues
- Some **anomalies** are accepted as **imperfections** in **normal science**, while others generate **crises and new paradigms**
  - Some **anomalies** cause crises because of problems in:
    - **Generalizing** the paradigm
    - **Applying** the paradigm to practical applications
    - Further **development of the normal science** which transforms a **trivial anomaly** into a **significant anomaly** (e.g., greater precision, more data, etc.)

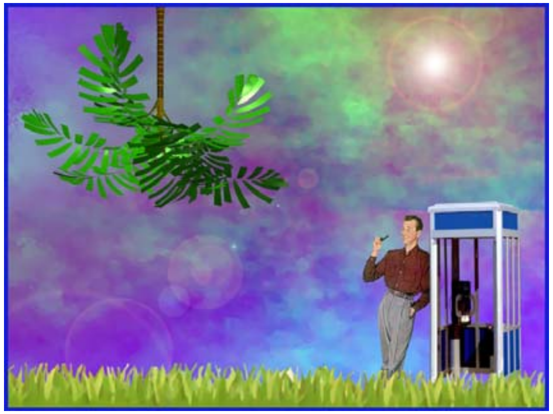


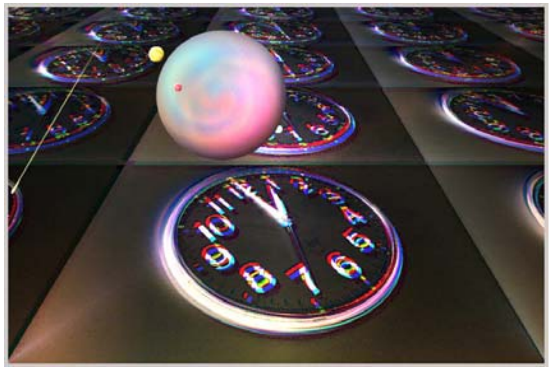
Emergence Of Scientific Discoveries

- **Crises begin with the blurring of a paradigm**
  - **Rules** for normal science research are **loosened**, resembling research during **pre-paradigm period**
- **Transition from paradigm in crisis to new paradigm** (from which a new tradition of normal science emerges):
  - **Not a cumulative process**
  - The field is **reconstructed** from **new fundamentals**
  - Elementary **theoretical generalizations change**, along with methods and applications
  - **Much time** (e.g., one or two generations) can pass before awareness of **breakdown of old paradigm** and **emergence or acceptance** of **new paradigm** (e.g., more than 50 years to accept Newton's laws after publication of *Principia*)
- **Resulting transition to new paradigm is scientific revolution**

Scientific Revolutions

- **What are scientific revolutions and what is their function in scientific development?**
  - Why should a **change in paradigm** be called a ***revolution***?
  - Scientific revolutions "**seem revolutionary** only to those whose paradigms are **affected by them**" (Kuhn). **Outsiders** perceive them as **normal** parts of the developmental process of science.





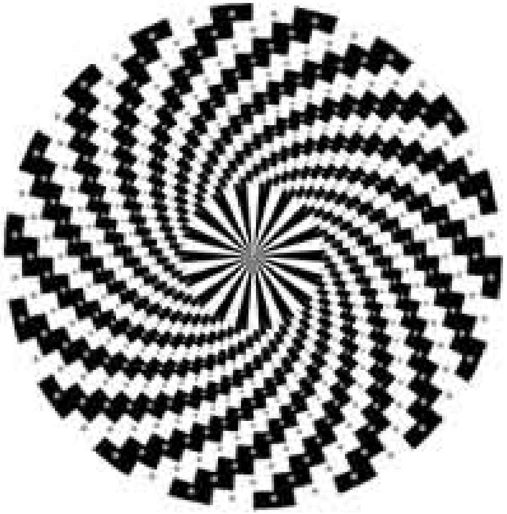
- **Scientific revolution:** "**Non-cumulative** developmental episodes in which an **older paradigm** is **replaced** in **whole or part** by an **incompatible new one**" (Kuhn).
  - **Competing paradigms are incompatible** – scientists must choose one or the other
  - Supporters of a paradigm argue in favor of it **within the context of the paradigm** – leading to circular arguments and tautology

Invention Of New Theories

- **Three types of phenomena about which a new theory may be developed:**
  - Phenomena already well-explained by **existing paradigms**
    - **Rarely leads to new theories**
  - Phenomena whose nature is explained by **existing paradigms** but whose details can be understood only through **further articulation** of the theory
    - **Rarely leads to new theories**
  - Phenomena with **recognized anomalies** which **cannot be assimilated** into existing paradigms
    - **Often leads to new theories**
- Paradigms provide all phenomena – **except anomalies** – with a context in **current theory** and the **scientist's perception**

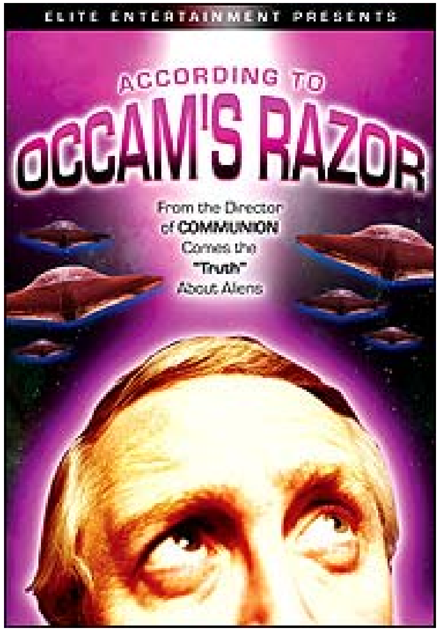
Changes In The World Model

- **Changes in paradigms change the world model**
  - Scientists adopt **new instruments**, look in **new places** for **new phenomena**
  - **Perceptions change** – **familiar entities** are seen in a different light and **unfamiliar entities** become noticeable
  - There is a **change** in the visual (and other senses) **gestalt**
  - **Old scientists** who worked within the **old paradigm** must learn the **new gestalt** (i.e., they need a **perceptual transformation**) – **new scientists** are immediately **receptive and perceptive**
  - With **different world models**, old scientists and new scientists can see **different things** when looking at the **same entities**
  - Many scientists **cannot adapt and do not convert** to the new paradigm (e.g., Kelvin never accepted electromagnetic theory)
    - Continue to believe **older paradigm** will eventually solve all the problems

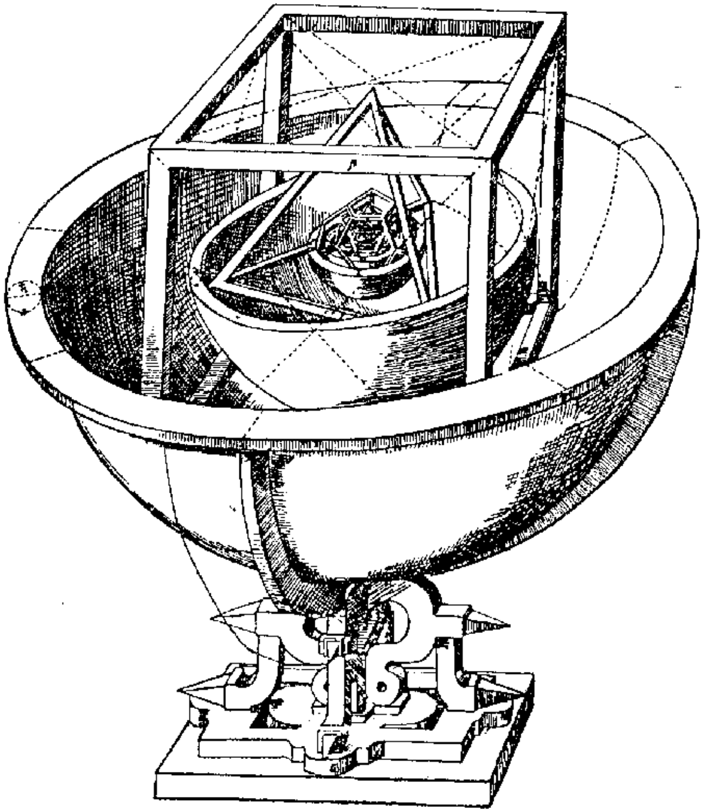


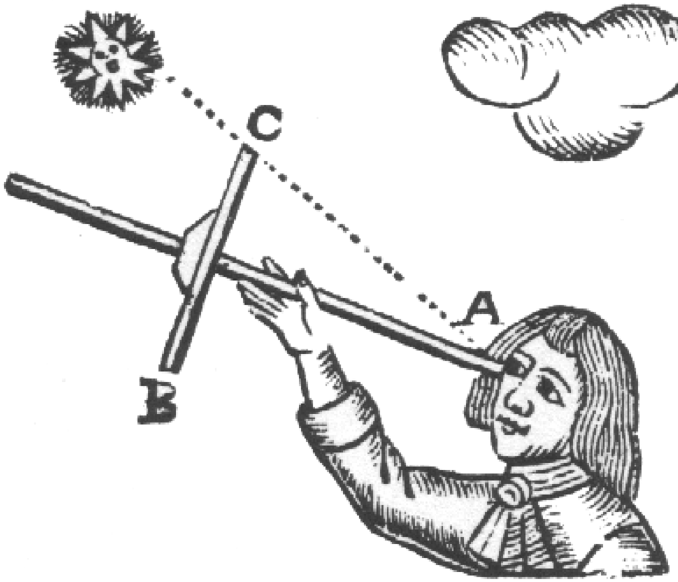
Accepting The New Paradigm

- **Reasons for accepting a new paradigm**
  - **Objective** reason: better ability to **solve problems and make predictions**
  - **Subjective** aesthetic reasons: **simpler** (e.g., Occam's razor), neater, or more suitable explanations
- **Textbooks incorporate new paradigms and ignore the revolutions that produced them**
  - Students take the **pedagogically presented** paradigms for **granted** and do not understand the historical wrenching mental shifts needed to switch from **older to newer paradigms**
  - Scientific progress is presented pedagogically as **linear and cumulative**, rather than as **punctuated equilibrium** (to borrow a term from a theory of evolution)
- **"Does a field make progress because it is a science, or is it a science because it makes progress?"** (Kuhn)



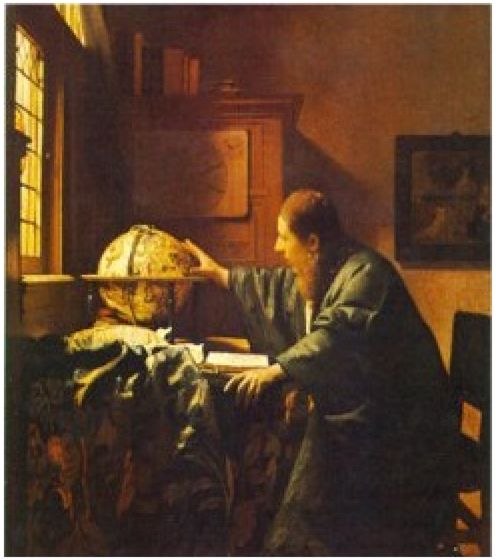
Section 4: Philosophy Of Science





Laws Of Science

- **Laws of science**
  - Statements expressing **observed repetitions or regularities** as precisely as possible
    - **Examples:** fire is hot; ice is cold; a year is 365 days
- **Universal law**
  - A regularity observed at **all times and places**
    - **Examples:** all fire is hot; all ice is cold
- **Statistical law**
  - A regularity occurs only in **some percentage** of cases
    - **Examples:** Ripe apples are red; a man's life expectancy is 73 years
- **Empirical laws**
  - Based on **observable properties** (e.g., color or length)
- **Theoretical laws**
  - Based on **non-observable properties** or concepts (e.g., quanta)



Laws Of Science

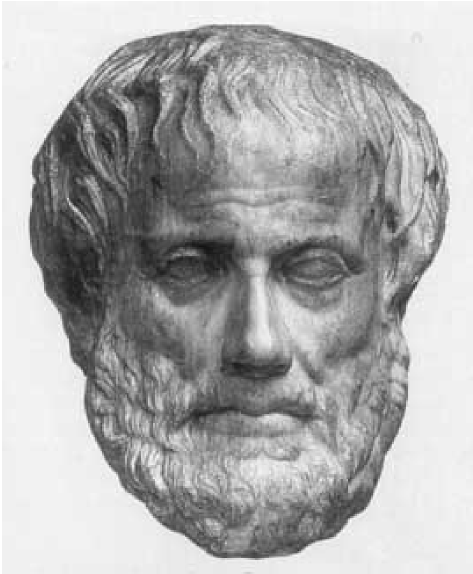
- **Singular statements**
  - A **single fact**; an event in a single time and place
  - **Example:** I saw a brown and white collie at the corner of 5th and Maple Streets
- **Philosophy of science issue**
  - How to go from **singular statements** to assertions of **universal law**
- **Science is based on**
  - Direct observation of **single facts**
  - **Many observations** of single facts to discover **regularities**
  - Expressing the regularities as **laws**
- **Laws**
  - **Explain facts** already known
  - **Predict facts** not yet known

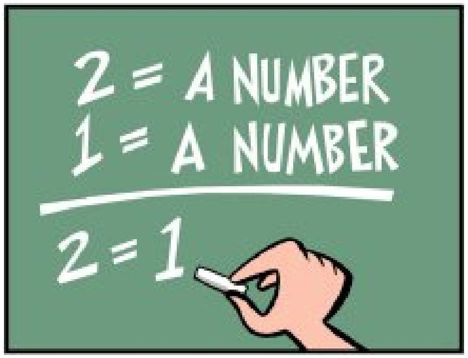
Laws Of Science

- **No explanation** (in science or everyday life) **can be given without referring to at least one law**
  - **Fact explanations are really law explanations** (where laws are tacitly assumed)
  - **Unless facts are connected with other facts by at least one law** (explicitly stated or tacitly understood), **they do not provide explanations**
  - **Example:** Fact: "I am hungry." Why are you hungry? Response: "I have not eaten all day."
    - The **response is an implicit universal law, not merely a fact**: *people who do not eat all day experience the sensation of hunger*
- A universal law may also be **implicit in scientific explanations** (as well as **common sense** explanations)

Laws Of Science

- **Statistical laws**
  - **Because of ignorance** (or, in the case of quantum theory, perhaps underlying reality) a statistical law may be used instead of the stronger universal law
  - **Example:** 5% of the people taking this medication will have an adverse side effect
- **Logic laws**
  - **Laws of logic are universal** but say nothing about the **real world**
  - They state **relationships** that hold between **defined concepts**
  - **Logical statements cannot be contested** (i.e., they are certainly true) because their truth is based on the meanings of the terms involved in the statements
    - **Example:** 1+2=3
  - **Cannot be used as a basis for scientific explanation** because they cannot distinguish the actual universe from any other possible universe



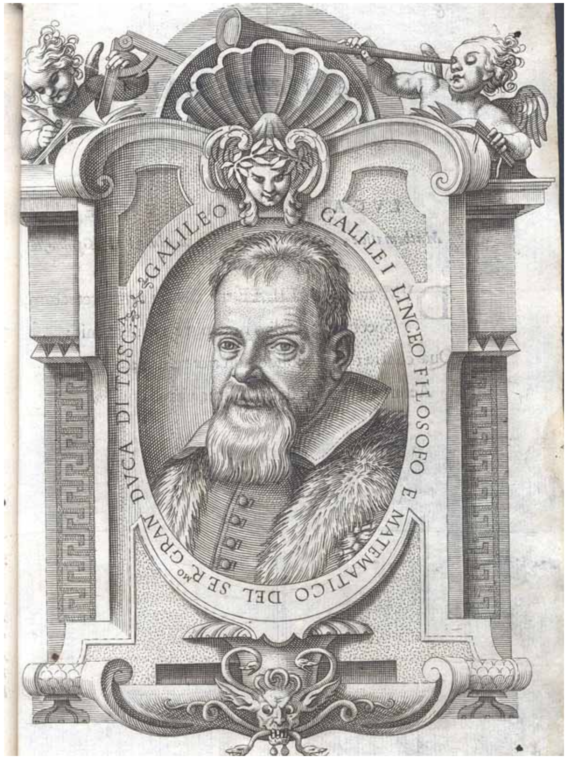


Laws Of Science

- **Empirical laws**
  - Are **not certain** like laws of logic – but they do **reveal truths about our real world**
  - Based on **observed** (through senses or instruments) phenomena
- **How vs. why**
  - In 19th century it was taught that scientists should **only ask "how?" questions and not "why?" questions** – which could only have **metaphysical** answers
  - Now the "why?" question is O.K. – the assumption is that the questioner requests an **explanation in a framework of empirical laws**
- **Explanations without laws are useless and meaningless**
  - **Examples:** explanations for characteristics of life such as *entelechy* or the *soul* or a *life force*

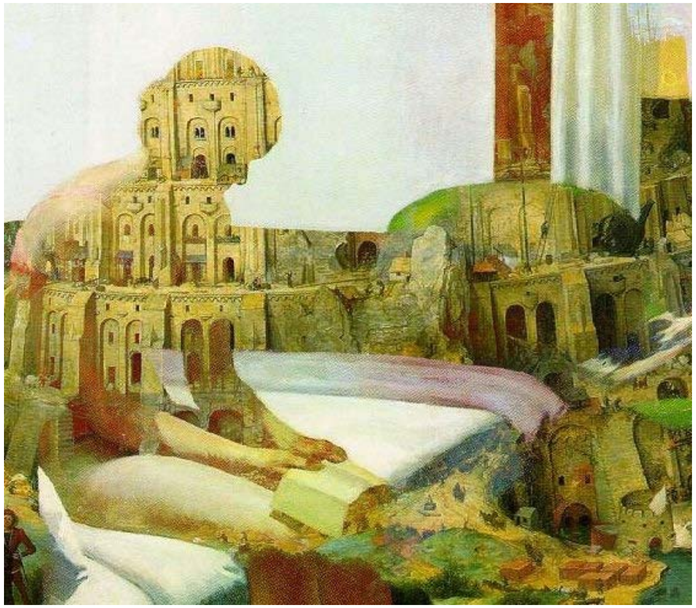
Laws Of Science

- **Laws predict as well as explain phenomena**
  - **Predict new facts not yet observed**
  - The law may be **statistical or universal**
    - **Example**: there is a 75% chance of rain tomorrow
- **People use predictions based on laws in every act of human behavior that involves deliberate choice**
  - **Example:** To stop the car you are driving you step on the brake because you know the **universal law that stepping on the brake will stop the car (**that the car will stop is a **fact not yet observed**)
  - **Example:** You pour milk into the glass because you know the **universal law** that, on the earth, gravity causes the milk to fall downward into the glass (you would not do this while in orbit about the earth)
- A **general theory** is a **system of laws**



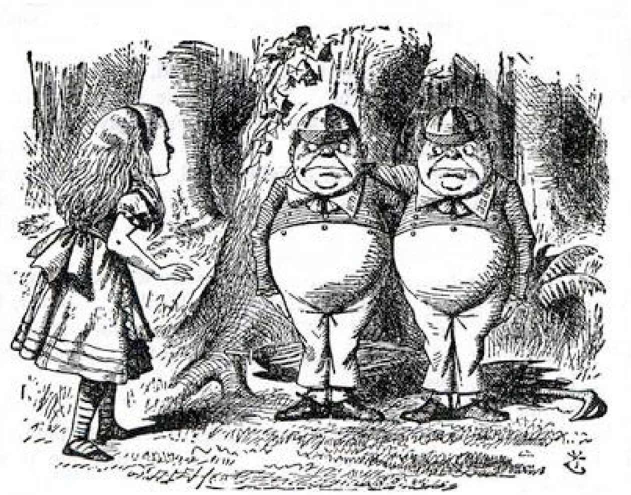
Induction

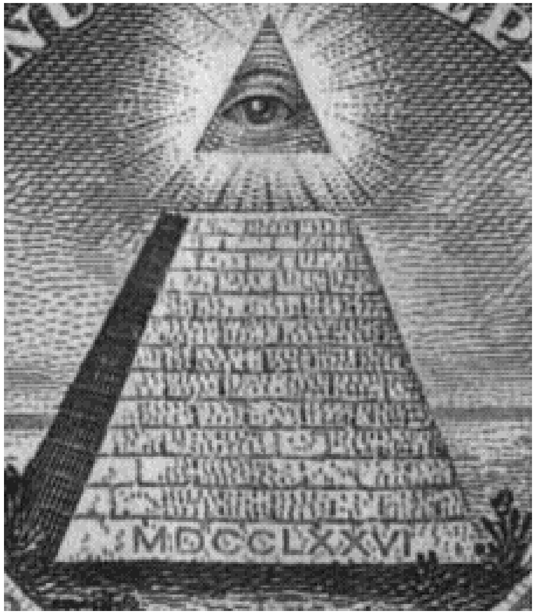
- **How do we determine laws?**
  - Laws constitute **indirect knowledge** – facts constitute **direct knowledge**
  - **On what basis** are we justified in believing that a law holds?
  - What **justifies** going from **directly observed facts** to **generalized statements of law**?
    - Known as ***the problem of induction***
- **Deduction and induction**
  - **Deduction:** goes from the **general to the specific** or singular
  - **Induction:** goes from the **singular to the general**
  - **These definitions are an oversimplification** and may be misleading



Induction

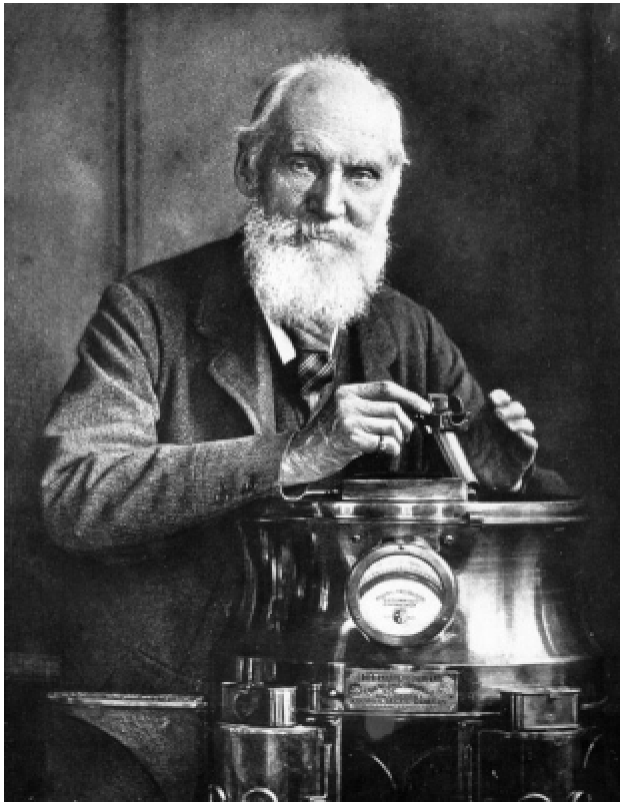
- **Deductive logic**
  - **Inference leads from a set of premises to a conclusion as certain as the premises**
  - **If premises are true, conclusion must be true**
- **Induction**
  - **The truth of an of an inductive conclusion is never certain**
    - Because the **premises cannot be known with certainty**
  - Even if the premises are **assumed to be true** and the inference is a **valid inductive inference**, the **conclusion may be false**
  - With respect to a **given set of premises**, the most you can say is that the **conclusion has a certain degree of probability**
    - **Inductive logic** describes how to calculate the **value of the probability**





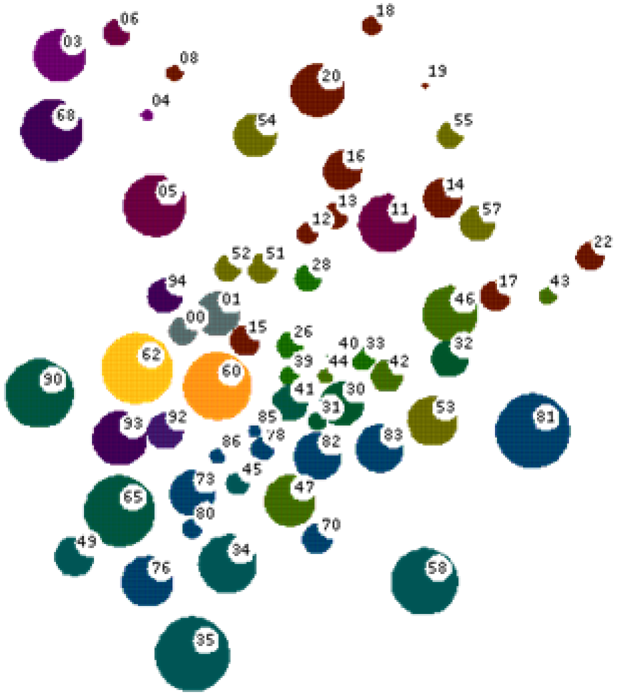
Induction

- **It is impossible to have a complete verification of a law – only a confirmation**
  - Laws are based on a **finite number of observations**
    - Millions of positive observations are **insufficient to verify** a law
  - A law can be **falsified** by a **single negative counter-instance**
    - Although the **negative counter-observation** may **itself be uncertain** (e.g., because of error or deceit)
  - **How many positive observations** are sufficient to confirm a law?
    - It is controversial whether **quantitative values** can be assigned to signify the strength of a **law's confirmation** (e.g., based on many observations)



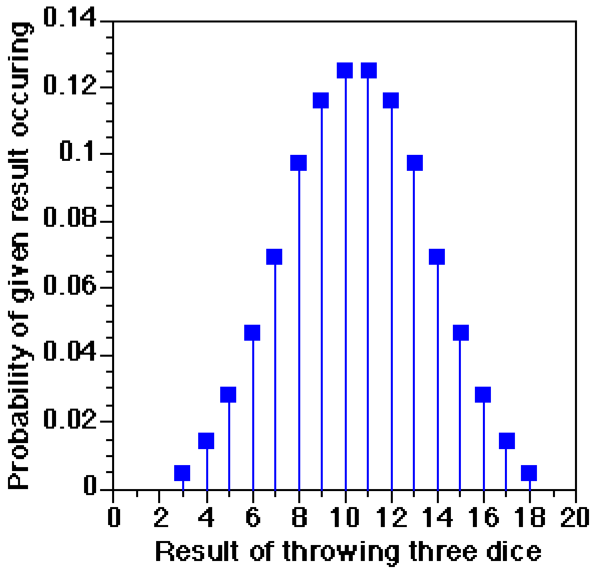
Induction

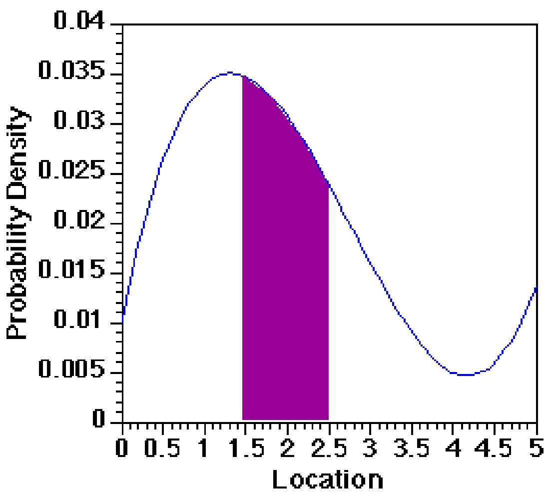
- **Classical definition of probability**
  - The **ratio** of the **number of favorable cases** to the **number of all possible cases**, given that all of the cases are **equally probable**
    - Involves **counting cases**
  - **Example:** the probability of shooting a 2 with a fair die is 1/6 because all of the cases (numbers 1 to 6) are equally probable
  - Criticized as **circular definition** because the word being defined – or a synonym like equipossible – **appears in the definition**
- **Another definition of probability**
  - A measurement of **relative frequency**
    - But **no finite number of tests is sufficient** for determining a probability with certainty



Induction

- **Better definition of probability**
  - The **limit of the relative frequency** in an **infinite series**
    - With a sufficient number of observations, you can at least determine **what the probability probably is**
  - **The probability of the probability** may be calculated
  - **The only concept of probability acceptable in science**
  - Can be applied to **prediction of single cases** (e.g., the probability of rain for tomorrow) because the prediction is **elliptical**
    - **Implicitly** includes **many previous observations** (e.g., of weather conditions leading to observed instances of rain)
- **Another view of probability**
  - A probability statement is **not a statement about the world** but about a **logical relation between two other statements**





Induction

- **Logical probability** (or **inductive probability**)
  - A logical analysis of a stated **hypothesis *h*** and **stated evidence *e*** leads to the conclusion that h is **not logically implied with certainty**, but is **partially implied** to some degree (i.e., it is implied with a **probability**)
  - The **basic concept** involved in all **inductive reasoning**
  - Inductive reasoning focused on **evaluating this probability**
- **Statistical probability** in science
  - **Not purely logical** – based on **observed facts**
  - **A scientific, empirical concept**
    - **Example:** the **probability** of of medicine A curing disease Y is 0.73.
  - **Logical probability** is useful in **meta-scientific** statements
    - **Example:** How **trustworthy** is the above probability prediction? What is the **probability** that the **above probability** is correct?

Induction

- The **degree of certainty** or confidence that our beliefs can have about **future events**
  - Is **logical** probability, **not statistical** probability
- **Logical and statistical probability can be integrated**
  - **First** premise is a **statistical law** (not a universal law)
    - **Example:** the relative frequency of brown shoes is 0.4
  - **Second** premise states that a **certain individual** has a **certain property**
    - **Example:** John owns four pairs of shoes
  - **Third** statement asserts that this certain individual has a **second property** (i.e., this is the **hypothesis based on the two premises**)
    - **Example:** John owns one pair of brown shoes with a probability of 0.4

Induction

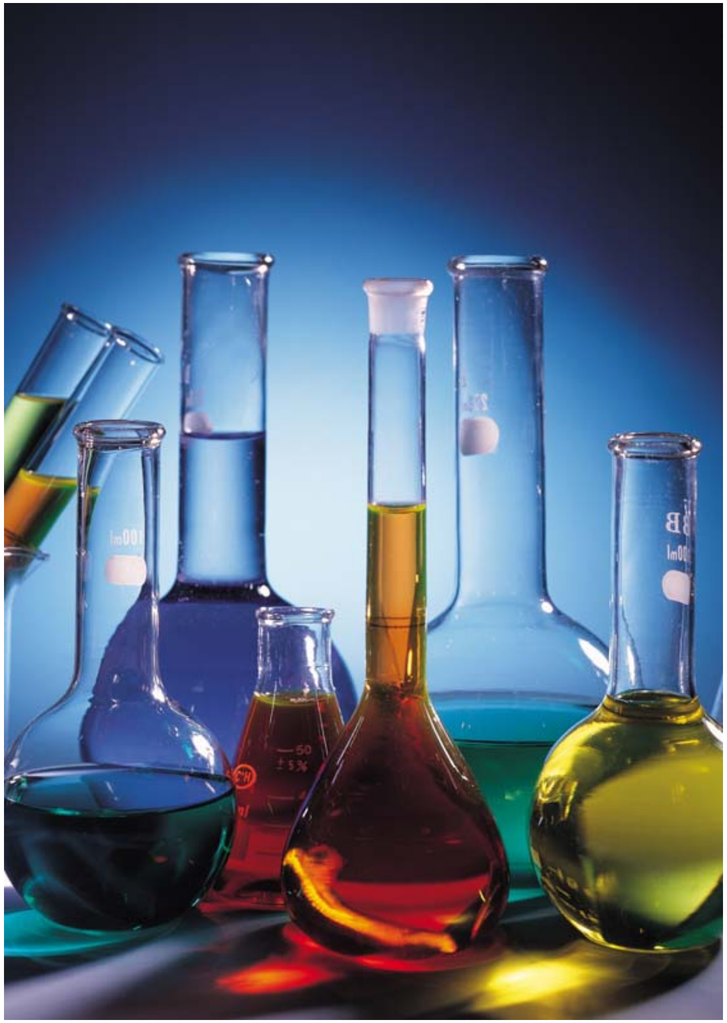
- Both types of probability – **statistical and logical** – may occur in the **same chain of reasoning**
  - **Statistical probability** is part of the object language of science
  - **Logical probability** (part of the meta-language of science) can be applied to statements about statistical probability
- **Indirect inductive inference is made**
  - From a **sample to the population**
  - From a **sample to an unknown future sample**
  - From a **sample to an unknown future instance** (event or observation)
- **Inductive inference is made**
  - From the **population to a sample** or instance

Experimental Method

- **All empirical knowledge depends on observing phenomena**
  - Can **observe passively** (e.g., weather, stars, animals) and **analyze observed phenomena** (e.g., create taxonomies) – or even synthesize observed phenomena into laws
  - Can **perform experiments**
    - Some phenomena **does not permit experiments** (difficult or impossible or expensive or socially unacceptable), e.g., stellar evolution; spreading viruses on a subway
    - Need **quantitative concepts** which can accurately measured
- **Experimental method**
  - Determine the **relevant factors** (variables) involved in the phenomena – **ignore irrelevant factors** (e.g., the weather in Phoenix has no affect on stellar evolution)
    - It can be **difficult to distinguish** relevant and irrelevant factors

Experimental Method

- **Experimental method** (Continued)
  - Keep some of the selected relevant factors **constant** while **varying** the others
    - **Quantify the relationships** among subsets of variables and constants
    - **Example:** For a given gas at a constant temperature, volume is inversely proportional to pressure
  - Determine the relationships among **all of the variables**
    - **Example:** Type of gas; container size and shape; temperature; pressure; volume
- **Quantitative laws are superior to qualitative laws**
  - Some quantitative laws can be derived from **passive** observation
  - Many quantitative laws are derived from **experimentation**



Entity Relationships

- **Three kinds of concepts defining relationships among entities** (physical or conceptual objects): **classification, comparison,** and **quantification**
  - **Classification** (classificatory concept)
    - Placing entities into a class; a **taxonomy**
    - **Examples:** Things that are blue; trees; animals; circles; protons; quarks
    - Can provide **more or less information**, e.g., the class of: animals, dogs, poodles, white poodles, miniature white poodles
    - Provides the **least amount of information** of the three relationship concepts
    - The relationships that we **first learn** as children, the *names* of things (e.g., that is a: house, cat, tree, cloud, paper, pencil, etc., etc.

Entity Relationships

- **Comparison (comparative concept)**
  - **Intermediate in information value** (between classification and quantification)
  - Describes **relationships among entities**
  - **Examples:** A is taller than B; X is warmer than Y; C is heavier than D; P is more expensive than Q; etc.
  - Allow for **rank ordering** (e.g., prioritizing) the entities in a set
  - The **usefulness** of comparisons often **underestimated** or ignored in science
  - Comparisons can become **basis for quantification**
  - Entities in a domain can be arranged into a **hierarchical** structure (i.e., a stratified structure or quasi-serial arrangement) if the **rules of symmetry** (if a*b, then b*a) and **transitivity** (if a*b and b*c, then a*c) **hold**
  - **Comparative concepts** (unlike class concepts) can generate **complex structures** of logical relationships

Entity Relationships

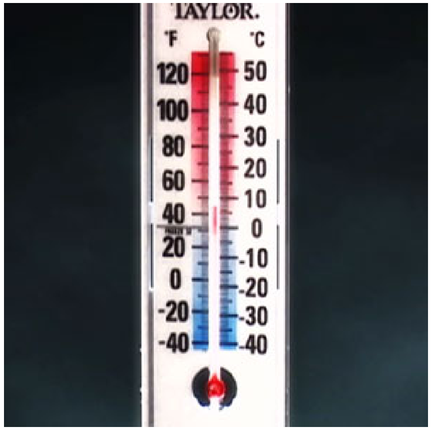
- **Quantification (quantitative concept)**
  - Difference between the **qualitative and quantitative** is **not** a difference in **nature** – it is a **difference in our conceptual system** (i.e., our **language** of discourse)
  - **Qualitative language:** limited to predicates (e.g., the *grass is green*)
  - **Quantitative language:** uses *functo*r symbols (i.e., symbols for functions that have numerical values)
  - **Two types** of quantitative method: **counting** and **measurement**
  - Counting is **more basic** than measuring – it is required for measuring
  - **Counting is actually an isomorphism**, i.e., a one-to-one correlation between the **event of pointing** at (or touching) objects and the **cardinal number** of objects so determined

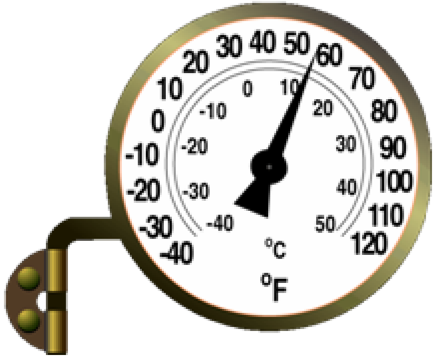
Measurement

- **Procedures** are needed to be able **describe the facts of nature** by **quantitative concepts** (concepts with numerical values)
  - **Counting** gives values expressed in **integers**
  - **Measurement** gives values expressed in **rational numbers** (integers and fractions) and **irrational numbers** – allowing for **mathematical tools** such as calculus which make the scientific method **more powerful**
- Need schema of **rules for the process of measuring** to give **meaning to physical concepts** (e.g., temperature)
  - **Rule 1 (equality):** if $E_M(a,b)$, then $M(a) = M(b)$
  - **Rule 2 (inequality):** if $L_M(a,b)$, then $M(a) < M(b)$
  - **Rule 3 (base state):** assign value (e.g., 0) to easily recognizable and reproducible state (i.e., standard)
  - **Rule 4 (rule of the unit):** assign value to second reproducible state
  - **Rule 5 (difference equality scale):** if $ED_M(a,b,c,d)$, then $M(a) - M(b) = M(c) - M(d)$

Measurement

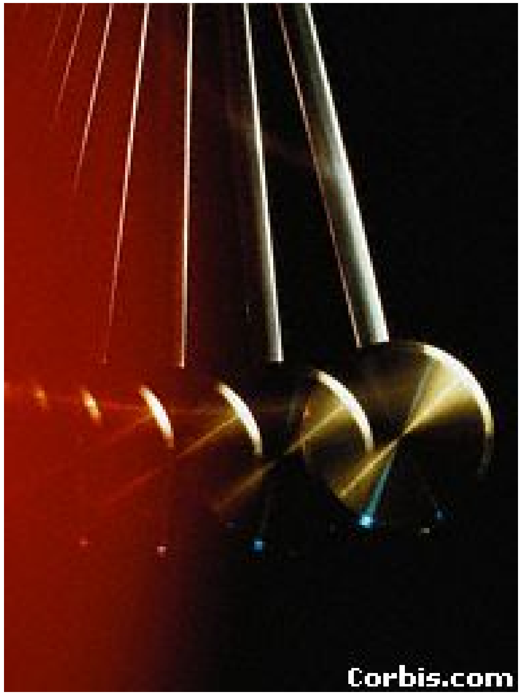
- **The ability to measure often leads to the quantitative concept**
  - **Example:** the invention of the **thermometer** allowed the concept of **temperature** to be given a **precise meaning**
- **Extensive magnitudes**
  - Magnitudes in which two things can be **joined to produce a new thing** that is a **combination of the values** of the two physical or conceptual things (e.g., mass [physical] or time [conceptual])
  - **Examples:** weight, length, volume
  - Can be measured with a **3-rule schema**
    - **Rule 1 (equality):** if $E_M(a,b)$, then M(a) = M(b)
    - **Rule 2 (additivity):** M(a*b) = M(a) + M(b)
    - **Rule 3 (unit rule):** Specify the unit of value for the magnitude
  - **But some extensive magnitudes are not additive** (e.g., relativistic velocity, trigonometric functions [although angles are additive extensive magnitudes])





Measurement

- **Any defined standard (process) is acceptable for measurement**
  - An **arbitrary standard** produces **no logical contradictions** – only **complex or simple descriptions** of the world
  - **Example:** You may use your **pulse as the time standard** (instead of the frequency of the cesium atom or a pendulum)
    - When you exercise and your pulse rate increases, the **earth's rotation** (and everything else in the universe) **slows down**; after you rest, the earth's rotation speeds up
    - Your pulse is **as legitimate a time standard** as a cesium atom – it just leads to a **more complex** description of the universe
  - **Example:** You may use a **rubber ruler** (which changes its length) as a standard of length instead of a **metal ruler**
    - It is a **legitimate standard of length** – it just leads to a **more complex description** of the universe

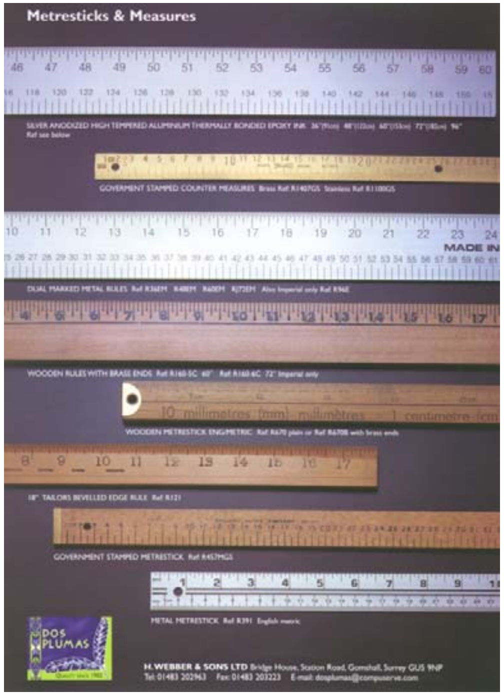


Measurement

- **A process version of Occam's razor** should be used in selecting **measurement standards**
  - **Occam's (or Ockham's) razor:** a philosophical or scientific principle according to which the **best explanation** of an event is the one that is the **simplest**, using the fewest assumptions or hypotheses
- The **simplicity** should reside in the description of the ***phenomena*****,** not necessarily the **measurement *standard***
  - **Example:** It is much **simpler** for me to use my pulse as a time standard than to design and build an atomic clock (or even an ordinary clock) – but the resulting description of phenomena would be extremely complex
  - The **goal is to simplify the physical laws** – even if it means employing **complex measurement standards**

Measurement

- **Derived magnitudes**
  - **Defined** on the basis of **primitive magnitudes** (e.g., length, time, mass)
  - **Examples:** density, velocity, acceleration
- **Are all entities and phenomena measurable?**
  - **People assign numbers to nature** (i.e., entities and phenomena in the universe) – the phenomena only provide observable qualities
  - **All quantities** except the cardinal numbers (which can be correlated to with discrete objects) are introduced by people when devising **procedures for measurement** – **people devise rules on how numbers are to be assigned**
  - Thus **everything,** in principle, **can be measured**
    - Albeit, quantum theory says that you may not be able to measure **two things** simultaneously (e.g., the **position and velocity** of an elementary particle)



Measurement

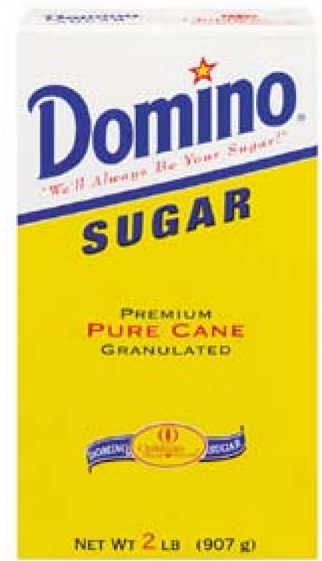
- **Why do people apply numbers to natural phenomena?**
  - **Nature does not quantify** (i.e., it is not *natural*)
  - Quantification increases **efficiency in describing phenomena** (e.g., “it is 110 degrees” instead of “it is very very very very hot”)
    - The **verbal description of colors** is one **exceptional** phenomenon that has many (English) words to describe a multiplicity of states (quantified by electromagnetic frequencies and intensities) – most phenomena (e.g., temperature, mass, length) have very **few verbal descriptors**
  - Quantification permits the formation of **quantitative laws** which can **explain phenomena** and **predict new phenomena**
- Some philosophers claim quantification **does not convey as much of the reality of the phenomena** as does natural language
  - But this is due to **not understanding all of the information** contained in the quantitative formulation (e.g., if you cannot read music, you will **not perceive the music** (in your mind) represented by the notes on a sheet of music)

Synthetic A Priori

- **Is it possible for knowledge to be both synthetic and a priori?**
  - Immanuel Kant asked and **answered the question (yes)**
  - **Contemporary empiricists disagree with Kant (no)**
- **Analytic knowledge**
  - Involves only the **meaning relations** of the terms
  - **Logical** statements
  - **Examples:** “all dogs are animals” or “all fligneys are kwunkles”
- **Synthetic knowledge**
  - Involves **knowledge of the world**
  - **Factual** statements based on observation and experience
  - **Examples:** “all dogs need food and water to live” or “all mammals have hair”

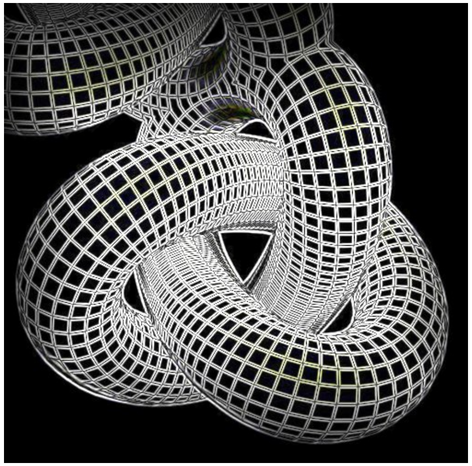
Synthetic A Priori

- **A priori vs. a posteriori**
  - **Epistemological** distinction between **two kinds of knowledge**
- **A priori knowledge (or statements)**
  - **Independent of experience**
  - But **not** necessarily independent of **genetic** (evolutionary) experience and the **cognitive (psychological) manifestation** of genetic experience
  - **All analytic statements are a priori** – it is never necessary to refer to experience as a justification for the truth of an analytic statement
    - **Example:** “all unicorns have a single horn”
- **A posteriori knowledge (or statements)**
  - **Dependent on experience** – empirical knowledge
  - Cannot be justified without **reference to experience**
  - **Examples:** “sugar tastes sweet” or “ice is cold”



Synthetic A Priori

- Kant thought that (Euclidian) **geometry** was an **example of knowledge that was synthetic and *a priori*** (i.e., instinctively correct and yet true about the world)
  - But **non-Euclidian geometry** (which seems to be the geometry of the actual universe) was unknown at the time
  - **Mathematical geometry** is analytical and a priori
    - **Euclidean geometry** says **nothing** about the real world
  - **Physical geometry** is **synthetic and *a posteriori***
  - No geometry is both
- **There is no knowledge of any sort that is both a priori and synthetic** (i.e., there is no example yet)
  - **Theorems about reality are not certain**
  - **Theorems that are certain are not about reality** (i.e., insofar as they are a priori, they are not synthetic)

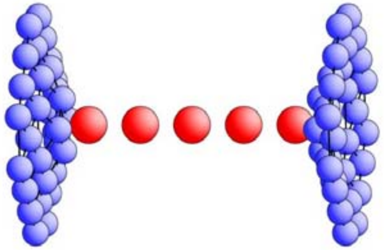


Causality

- What is meant by **"this is the cause of that"**?
  - What does the **cause-and-effect relation** – that one event caused another event - mean?
  - **Example:** I drop a plate on the floor and it shatters. **What caused the plate to break?**
    - **Was it:** Gravity causing the plate to accelerate to the floor? The hard floor disrupting the electrochemical bonds of the plate? The manufacturer (or shipper or retailer) who produced a microscopic fracture in the plate? Me because I released it from my hands? The flower pot that fell on my head causing me to release the plate from my hands? Etc.
- **Things** do not cause events – **processes cause events**
  - The processes may be **static** (e.g., relevant variables or magnitudes are constant over time) or **dynamic**
  - **Example:** a **rock** does not cause a **window** to break; **complex physical processes** between a thrown rock and the struck window cause the window to break

Causality

- **Causal relationships mean predictability**
  - If (in principle) **all relevant facts and laws** are known about a state, then it is **possible to predict**, as a logical consequence, a subsequent state (said to be **caused** by the previous state)
  - **Predictability** may be only a **potential or possibility**, not an **actuality** (e.g., if all the facts are not known at the time of the event)
  - Many events have **complex causes** difficult to discern
  - **Quantum effects** limit knowledge of causal relationships
  - David Hume: causality is just a **temporal succession** of events
- To **investigate causality scientifically**, it is necessary to **isolate critical variables** (i.e., examine one variable while holding all others constant)
  - This is **very difficult to accomplish** – especially with complex systems, such as organisms and social systems
  - **Example:** difficult to determine what causes or cures diseases

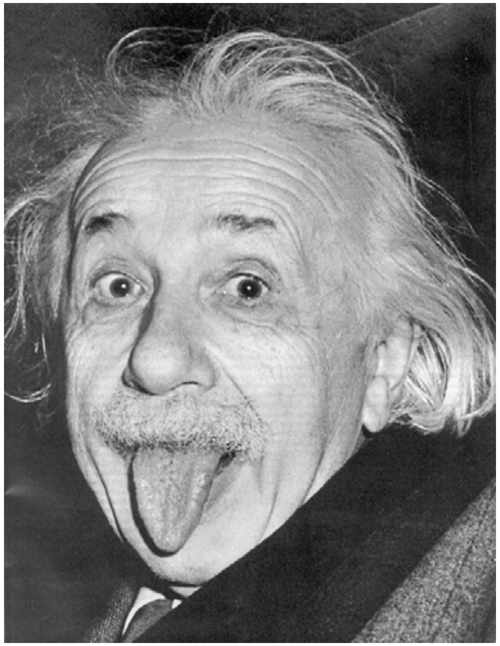


Causality And Necessity

- **Does causality imply necessity?**
  - I.e., at any time or place, if a **system is in a certain state** then another **specific state will follow**
  - A **law implies that the second state must follow**, that there is a **necessary connection** between the two states
    - **Example:** if you increase the pressure on a gas, under constant temperature, it volume will decrease
  - **Laws of logic** hold under all conditions – any **necessity** then also always holds
    - If so defined: "if A, then B" **always** holds
  - But **laws of nature** (science) hold only as a **reflection of reality**
    - A casual statement only describes a **regularity of nature**
  - **Causality cannot be established** on the basis of observing **one case**
    - It must be established on the basis of a **general law** based on **many observations** (e.g., life experiences)

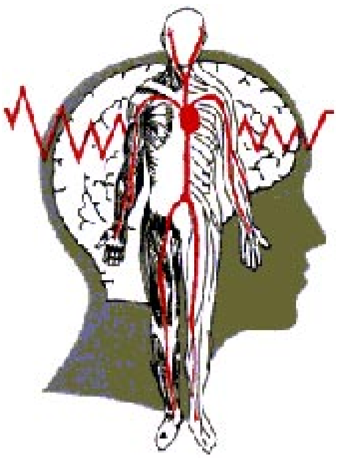
Causality And Necessity

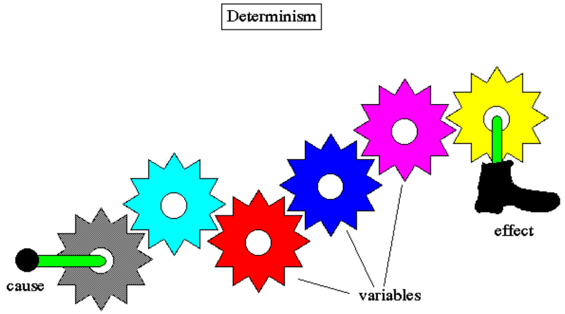
- **Does causality imply necessity?**
  - In the regularities of nature called the ***laws of nature***, **causality does not imply necessity**
  - A **law of nature** asserting that a regularity holds for all time and place, must **always be tentative**
    - A **single counter-observation**, made at any time in the future, may determine the **law to be wrong**
- Must **cause and effect** be of **comparable magnitude** (i.e., must cause equal effect)?
  - A claim used by creationists – the complexities of life (major effect) cannot be due to evolution (minor cause)
  - But **minor causes can always have major effects** (e.g., a single photon can be used to trigger a thousand hydrogen bombs; a single sperm out of millions enters a specific egg and forms a Newton, an Einstein, an Edison, or a Hitler)



Determinism And Free Will

- **Causal laws**
  - Events can be **predicted and explained** on the basis of other events
  - **Totality** of causal laws describes the **causal structure** of the world
- **Determinism**
  - Belief in a **strong causal structure**
  - Given a **complete description** of the state of the universe at one instant and **all relevant laws**, any state (event) in the past or future of the universe can be calculated
  - **Quantum mechanics** has a **causal structure** that is probabilistic, **not deterministic**
- **Do people have free will** (the ability to choose among alternatives) or is the feeling of having **freedom of choice a delusion?**





Determinism And Free Will

- **One view:**
  - Even if determinism were true in the strong sense, **a person would have free will** if a choice (an action) **originates from within the person's character in accordance with the laws of psychology**, i.e., the choice is made **without external compulsion**
  - **Example:** choose to go bowling instead of the opera; choose to drink a glass of water instead of coffee
  - **Causal regularity** (deterministic or probabilistic) is necessary for free will
    - To make a choice, the **consequences of the choice** must be foreseen (at least probabilistically), which is **not possible without causal regularity** (e.g., a glass of water will slake my thirst better at this time than coffee - which judgment I base on previous actions)

Determinism And Free Will

- **Issues** with the view that a **person has free will if a choice** originates from within the person's character in accordance with the laws of psychology**, i.e., the choice is made** without external compulsion
  - **In principle, can you determine a person's psychology and the laws of psychology?**
  - Is my need to work digging in the coal mine, so that I can earn money to get food to eat, an external compulsion or a free choice?
  - If I go to the opera, instead of a football game, to avoid a conflict with my wife – is that external compulsion or free will?
  - If I have a biochemical imbalance due to genetics (e.g., obsessive-compulsive disorder) or a temporary condition due to a psychological disturbance (e.g., road rage), is my choice to wash my hands repeatedly or commit a violent act made with or without compulsion?
  - Does addiction to smoking involve free will or external compulsion?
  - Is it possible to always distinguish between external and internal compulsion – and **why should internal compulsion imply free will?**