Phil. 4400
Notes #1: The problem of induction

I. Basic concepts:

The problem of induction:
- Philosophical problem concerning the justification of induction.
- Due to David Hume (1748).

Induction: A form of reasoning in which
a) the premises say something about a certain group of objects (typically, observed objects)
b) the conclusion generalizes from the premises: says the same thing about a wider class of objects, or about further objects of the same kind (typically, the unobserved objects of the same kind).
- *Examples:*

All observed ravens so far have been black.	The sun has risen every day for the last 300 years.
So (probably) all ravens are black.	So (probably) the sun will rise tomorrow.

Non-demonstrative (non-deductive) reasoning:
- Reasoning that is not deductive.
- A form of reasoning in which the premises are supposed to render the conclusion more probable (but not to entail the conclusion).

***Cogent* vs. *Valid* & *Confirm* vs. *Entail*:**
'Cogent' arguments have premises that *confirm* (render probable) their conclusions.
'Valid' arguments have premises that *entail* their conclusions.

The importance of induction:
- All scientific knowledge, and almost all knowledge depends on induction.
- The problem had a great influence on Popper and other philosophers of science.

Inductive skepticism:
Philosophical thesis that induction provides no justification for (*no reason* to believe) its conclusions.

II. An argument for inductive skepticism

1. There are (at most) 3 kinds of knowledge/justified belief:
   a. Observations
   b. A priori knowledge
   c. Conclusions based on induction
2. All inductive reasoning presupposes the "Inductive Principle" (a.k.a. the "uniformity principle"): "The course of nature is uniform", "The future will resemble the past", "Unobserved objects will probably be similar to observed objects"
3. So inductive conclusions are justified only if the IP is justified. (From 2.)
4. The IP cannot be justified:
   a. The IP cannot be directly observed.

b. The IP cannot be known a priori. (Contingency argument)
c. The IP cannot be justified by induction. (Circularity argument)
d. So the IP cannot be known/justified. (From 1, 4a, 4b, 4c.)

5. Therefore, no inductive conclusion is justified. (From 3, 4.)

Comments:

- (5) is *inductive skepticism*.
- Notice how radical (5) is. Conclusion is *not* merely: "Inductive conclusions are never 100% certain."

III. Preview of some responses

- Some reject (2). Claim that (2) begs the question / presupposes deductivism.
- Some reject (4b). (Russell)
- J.S. Mill rejects (4c).
- Some reject (1), claim that some other kind of inference has been overlooked. (Foster, Stove)
- Many have embraced the conclusion (5):
  - Hume
  - Popper

Phil. 4400
Notes #2: Popper & Falsificationism

Elements of Popper's theory:

I. Inductive skepticism

• Accepts Hume's argument for inductive skepticism (see previous lecture).
  - Principle of Induction is not analytic.
  - Principle of Induction not known by experience. Infinite regress problem.
  - No synthetic, a priori knowledge.
• Probabilism no help.
  - Just requires another principle of induction, e.g., "The future will *probably* resemble the past."
  - This faces the same difficulties.
• Hence, we must rely on *deductivism:* The view that all legitimate reasoning is deductive.

II. The deductive approach to science: Falsificationism

• A scientific theory is formulated. No logic of this. Distinguish: Logic vs. psychology
• Predictions are *deduced* from the theory.
• Predictions compared w/ observation:
  - If true, the theory is "corroborated."
  - If false, the theory is *falsified*.
• But corroborated theories *are not thereby supported*.
  "Nothing resembling inductive logic appears in the procedure here outlined. I never assume that we can argue from the truth of singular statements to the truth of theories. I never assume that by force of 'verified' conclusions, theories can be established as 'true', or even as merely 'probable'." (33)

III. The criterion of demarcation

• The problem of demarcation: How to distinguish scientific (empirical) theories from non-scientific theories.
• Answer: Scientific theories are *falsifiable*.
• Key point: The *asymmetry* between verification and falsification: A universal generalization can be falsified, but never verified.
• Examples:
  astrology, Marxism, sociobiology, psychoanalysis

IV. Objections

A. The Duhem-Quine Thesis:

An individual scientific theory entails no empirical predictions in isolation; auxiliary assumptions are always required.

• Corollary: A scientific theory can (consistently) be maintained come what may, provided one is willing to make sufficient adjustments elsewhere in one's system.
• Hence, the asymmetry Popper sees between falsification & verification is illusory.
• *Example:* How to refute the law of gravity?

B. Kuhn's Anomalies:

• There are *always* anomalies.
• A theory is rejected when *enough* anomalies accumulate, & there is a *better* theory. It is not "falsified".

C. The case of probabilistic theories:

• Probabilistic theories cannot be falsified.
• But some are scientific. E.g., quantum mechanics.
• Popper: introduces a "methodological rule" permitting them to be "regarded as" falsified.
• Stove's objection:
  - This approach would enable anyone to defend any logical claim (including inductivism).
  - More to the point: Popper can't change the facts of logic by fiat.
    1. Popper says only falsifiable theories are scientific.
    2. Popper also embraces deductivism.
    3. No probabilistic theory can be deductively falsified.
    4. So, on Popper's theory, no probabilistic theory is scientific.

  No "methodological rule" can change any of these facts.

D. The problem of pointlessness:

• On Popper's theory, there is *no reason* for believing any scientific theory. So what's the point?

Phil. 4400
Notes #3: Inference to the best explanation

Main idea:

- Induction depends upon inference to the best explanation. An inductive inference actually requires two steps:
  - *First*: An inference from observations to a hypothesis that provides the best explanation for those observations.
  - *Second*: An inference from that hypothesis to further predictions. (This step is deductive.)
  - Examples:

	Observation: This coin has come up heads 100 times in a row.
(inference to the best explanation)	
	Hypothesis: This coin has heads on both sides.
(deduction)	
	Prediction: This coin will continue to come up heads in the future.

	Observation: Bodies have always behaved gravitationally.
(inference to the best explanation)	
	Hypothesis: It is a law of nature that bodies behave gravitationally.
(deduction)	
	Prediction: Bodies will behave gravitationally in the future.

- The *hypothesis* is justified because,
  a) unless there were some explanation, the *observation* would be highly improbable, and
  b) the hypothesis provides the best explanation.
- *Induction is not a primitive form of inference*:
  Imagine that we somehow knew there were no laws of nature. Then would we be justified in thinking bodies will continue to behave gravitationally?

Skeptical objections:

- *Objection*: The observed regularity really doesn't require any explanation, because it is just as likely as every other possible sequence of events. (Example: Coin toss outcomes.)
  Reply: What matters is comparison of the probability of the observed regularity *on the alternative hypotheses* (not its probability compared to that of other possible observations).
- *Objections from alternative hypotheses:*

a) There is no relevant law; past regularity is purely due to chance.
  Problem:
  - This hypothesis is extremely improbable.

b) It is a law of nature that: (up until 2100 A.D., bodies behave gravitationally).
Problems:
- This creates a further mystery: What is so special about the year 2100?
- Actually, this hypothesis seems to be metaphysically impossible: the current time cannot be a causally relevant factor. (my point)

c) There is a law of nature that (bodies behave gravitationally), but the law ceases to exist in the year 2100 A.D.
Problems:
- This creates a further mystery: What is so special about the year 2100?
- Actually, this hypothesis seems to be metaphysically impossible: Laws of nature cannot stop existing. (my point)

d) It is a law that (in ϕ-circumstances, bodies behave gravitationally).
Where we define "ϕ-circumstances" in such a way that it applies to all the times when we have actually been observing bodies, but is unlikely to apply to other times.
Problem:
- This hypothesis gives a different explanation for different cases of gravitational behavior.
- Our explanation gives a *unified* explanation.
- Unified (and hence, simpler) explanations are more likely to be true.
  - It is improbable that you just happen to have always been observing during one of the ϕ-circumstances. I.e., if there were 5 million different causally relevant factors, it is improbable that you would happen to have been looking during exactly the times when one of the relevant circumstances held, unless those circumstances hold almost all the time.

Phil. 4400
Notes #4: Bayesianism

I. The pure mathematics of probability:

A. Measure theory:

- A measure on a set, S, is a function, M, which assigns positive real numbers to subsets of S, such that $M(\varnothing) = 0$, and such that, when A and B are disjoint subsets of S, $M(A \cup B) = M(A) + M(B)$. (Disjoint sets are sets that have no members in common.)
- Note how this captures the bare bones of the intuitive idea of 'measuring' the sizes of sets.

B. Probability theory as a branch of measure theory:

- A *probability measure* is a specific kind of measure: viz., a measure in which the measure of the total set is 1. In other words, a probability measure is a function, P, satisfying these axioms:

1. $P(T) = 1$	where T is the total set.
2. $P(A) \geq 0$	where A is any subset of T.
3. $P(A \cup B) = P(A) + P(B)$	whenever A and B are disjoint subsets of T.

In addition, an expression "|" can be defined in this way:

4. $P(A|B) = \dfrac{P(A \cap B)}{P(B)}$ (this will become useful later)

• A probability of x (in the *pure mathematics* sense) is just a number that is assigned to x by a probability measure.

II. Interpretations of probability:

- Probabilities are applied either to *events* or to *propositions*. Applied to propositions, there are 4 axioms:

1. $P(T) = 1$	where T is any tautology
2. $P(A) \geq 0$	where A is any proposition
3. $P(A \vee B) = P(A) + P(B)$	whenever A and B are mutually exclusive
4. $P(A \,\&\, B) = P(A) \times P(B|A)$	where "$P(B|A)$" is the probability of B given A

• Interpretations of probability:

I. Frequency interpretation (objective, physical)
II. Probabilities as objective, single-case propensities, or degrees of causal influence (objective, physical)
III. Rational degrees of belief. (subjective)
Related idea: fair betting odds. (Related: Dutch book arguments)
IV. A logical relation (like degrees of entailment). (Similar to III. Objective, non-physical.)
Related idea: probability of x as the measure of the set of possible worlds in which x is true.

• For our purposes (investigating the justification of induction), interpretations III and IV are the important ones.

III. Interesting results of probability theory:

- Probabilities of logically equivalent hypotheses are equal.
- If $A \equiv B$, then whatever confirms A confirms B, and vice versa.

  Bayesian definition of "confirmation":

  A confirms B iff P(B|A) > P(B).
- Bayes' theorem: Suppose H is a hypothesis, and E is a piece of evidence relevant to H. Then

5. $P(E \& H) = P(H \& E)$	obvious; logically equivalent prop's
6. $P(E) \times P(H\|E) = P(H) \times P(E\|H)$	applying axiom 4 to step 5
7. $P(H\|E) = \dfrac{P(H) \times P(E\|H)}{P(E)}$	6, division by P(E)

(7) is Bayes' Theorem. Another form of the theorem:

8. $$P(H|E) = \frac{P(H) \times P(E|H)}{P(E|H)\times P(H) + P(E|{\sim}H)\times P({\sim}H)}.$$

- Exercise for the student: prove (8).
- Note how Bayes' theorem explains aspects of scientific practice:
  a) A theory is confirmed by *predicted* observations. (P(E|H) is high.)
  b) A theory is better-confirmed by the less initially probable observations (or: observations that are less probable on the alternative hypotheses).
  c) Obviously, the higher the initial probability of H, the higher the probability of H in the light of observations.

- Fun aside: probability densities:
  - Suppose X is a random variable with real-number values between 2 and 3. What is the probability that $X = 2.3$ (exactly)? Answer: 0.
  - More useful concept: the probability density function, ρ:

$$\rho(x) \;=\; \lim_{e\to 0} \frac{P(x-e \;<\; X \;<\; x+e)}{2e}$$

  - Or: A probability density is a function that, when you integrate it over an interval, gives you the probability of the variable falling in that interval.
  - Note that the probability density is normally greater than 0 (and could be greater than 1).
  - Analogy: compare density of matter.

IV. The problem of induction: the Bayesian approach

- The Bayesian approach to the problem of induction: non-demonstrative reasoning is reasoning in accordance w/ the probability calculus. When learning *e*, one should alter one's degree of belief in *h* by "conditionalization".
  - *Conditionalization:* Upon learning new evidence *e*, you set your new degree of belief in *h* equal to what you previously estimated as the probability of *h* given *e*, i.e.: $P_{new}(h) = P_{old}(h|e)$.
- e *confirms* h iff $P(h|e) > P(h)$.
- Recall Bayes' Theorem:

$$P(h|e) = \frac{P(h) \times P(e|h)}{P(e)}.$$

- Apply this to Foster's proposal of inference to the best explanation. *h* is the hypothesis of natural necessity. *e* is the existence of some regularity. $P(e)$ is low; $P(e|h)$ is high. Thus, *e* confirms *h*.

V. A problem for Bayesianism:

What determines the *initial* probabilities?

- "Subjective" Bayesians: Many different sets of initial probabilities are equally good.
- "Objective" Bayesians: The probability calculus must be supplemented, to allow only one value for each initial probability. How?
  - A proposal: *the Principle of Indifference*: When there is no evidence relevant to which possibility is the case, assign each possibility the same probability.
  - A puzzle for the principle of indifference:

    Problem: You know that Sue has traveled 100 miles, and it took her somewhere between 1 hour and 2 hours. That's all you know. What is the probability that her trip lasted between 1½ and 2 hours?

    First answer: Applying the principle of indifference: 1 ½ - 2 hours is 50% of the total range of possible *durations*. Therefore, give it a 50% probability. Answer: ½.

    Second answer: We know that Sue's average velocity during the trip was between 50 mph and 100 mph. Sue's trip lasted between 1½ and 2 hours iff her speed was between 50 mph and 67 mph. This is 1/3 of the total range of possible *velocities*. Answer: ⅓.

- A general statement of the problem:
  - Different *partitions* of (ways of dividing up) a given set of possibilities are possible.
  - Applying the Pr. of Indifference across different partitions yields inconsistent results.
  - Hence, the Pr. of Indiff. either is inconsistent, or requires a specification of a privileged way of partitioning.

Phil. 4400
Notes #5: David Stove's argument

I. Important concepts:

- *Inductive inference :* Two kinds:
  a) Inference from the frequency of a trait in a certain sample drawn from a larger population, to the frequency of that trait in the whole population.
  b) Inference from the premises of (a) to a prediction about the presence or absence of that trait in a particular unobserved individual.
- *Probabilistic independence :* A is probabilistically independent of B iff $P(A|B) = P(A)$ (equivalently: $P(B|A) = P(B)$).
- *The skeptical thesis :* Two interpretations of it:
  a) Inductive inference has no cogency. $P(H|E) = P(H)$, whenever E is inductive evidence, and H is an inductive conclusion.
  b) Alternatively: Separate observations are always probabilistically independent.

  Note: Thesis (a) is obviously probabilistically incoherent; (b), however, is not.
- *Proportional syllogism :* Everyone agrees that the following kind of inference is cogent:
  1. 99% of all A's are B.
  2. x is an A.
  3. $\therefore x$ is B.
- *The law of large numbers :* This is a well-known theorem of probability:
  If the probability of an event E at each trial is x, then in a large number of trials, the frequency with which E occurs will almost certainly be close to x. (With increasing certainty as the number of trials increases.)
- *General strategy :* To show that an inductive inference can be reconstructed with proportional syllogisms & the law of large numbers; thereby showing that inductive inference is cogent.

II. The problem:

Assume the following:

- Pop is a population of 1 million ravens.
- S is a sample, from Pop, of 3000 ravens.
- 95% of the ravens in S are black.

To prove: It is highly probable that:

- Approximately 95% of the ravens in Pop are black.
- The next raven observed will be black.

General argument:

1. Almost all the 3000-fold samples of Pop are representative (no matter what the proportion of black ravens in Pop). (Arithmetical form of law of large numbers.)
2. Therefore, S is almost certainly representative. (From 1; proportional syllogism.)
3. The proportion of black ravens in S is 95%. (Given.)

4. Therefore, almost certainly, the proportion of black ravens in Pop is close to 95%. (From 2,3; deduction.)
5. Therefore (probably), the next observed raven from Pop will be black. (From 4; proportional syllogism.)

Further elaboration:
(1) Almost all the 3000-fold samples of Pop are representative:

- Best case: Suppose the proportion of black ravens in Pop = 100%. Then all samples are representative.
- Other best case: Suppose the proportion of black ravens in Pop = 0%. Then all samples are representative.
- Worst case: Suppose the proportion of black ravens in Pop = 50%. Even so, the vast majority of samples are representative:
  In general:

$$C(m,n) = \frac{m!}{n!(m-n)!}$$

  # of 3000-fold samples in Pop:

$$C(3000,\ 1\ million) = \frac{1{,}000{,}000!}{(3000!)(997{,}000!)} \approx 10^{8867.9}$$

  # of "representative" samples: We call a sample "representative" if it matches within 3% the frequency of black ravens in Pop. Hence, S will be representative iff it contains between 1410 and 1590 black ravens (and between 1590 and 1410 non-black ones). The number of samples containing 1410 black ravens and 1590 non-black ones is:

$$C(1410{,}500000) \times C(1590{,}500000) = \frac{500{,}000!}{(1410!)(498590!)} \times \frac{500{,}000!}{(1590!)(498410!)}$$

  This is not enough: We need the # of samples containing 1410 black ravens, + the # containing 1411 black ravens, + ... + the # containing 1590 black ravens. In other words:

$$\sum_{n=1410}^{1590} \frac{(500{,}000!)^2}{n!\,(500{,}000-n)!\,(3000-n)!\,(497{,}000+n)!} \approx 10^{8867.9-.00087}$$

  The proportion of representative samples, therefore, is:

$$\frac{10^{8867.9-.00087}}{10^{8867.9}} = 10^{-.00087} \approx 99.8\%$$

- Further important points:
  - The qualitative result holds for any population size, and for any sample size ≥ 3000; i.e., the sample will almost certainly be representative. (Statisticians figure out stuff like this.)
  - How does this relate to inference to the best explanation? In the "general argument" above:
    - (3) as the observation
    - (4) as the hypothesis
    - (5) as the prediction

Phil. 4400
Review of unit 1

<u>Know what these things are:</u>
Principle of induction
Kinds of inference:
- Demonstrative
- Non-demonstrative, incl.:
  - Induction
  - Inference to the best explanation
  - Proportional syllogism

Confirmation & cogent inferences
Inductive skepticism
Deductivism
Duhem-Quine thesis
Probability
- Axioms of probability (all 4)

Bayesianism
- Their interpretation of probability
- Definition of confirmation
- Bayes' Theorem & its epistemological significance
- How to update beliefs

Law of large numbers
Principle of Indifference
Problem of demarcation
- Popper's view of it

<u>Know what these people thought about non-deductive inference:</u>
Hume
Popper
Foster
Stove

<u>Know these arguments:</u>
Arg. for inductive skepticism
- Where (if anywhere) the above people would disagree with it.
- The 3 kinds of knowledge recognized by the arg.

Stove's objection to Popper
The Duhem-Quine objection to Popper
Foster's justification of induction
- The steps involved in justifying induction
- His criticism of alternative explanations

Stove's vindication of induction--
- The main steps in his argument & how they are justified

Main objection to Pr. of Indifference

Phil. 4400
Notes #6: Thomas Kuhn

Kuhn trivia

- Author of *The Structure of Scientific Revolutions*
- Most cited 20th-century work in *Arts & Humanities Index*, 1976-1983 <http://home.comcast.net/~antaylor1/fiftymostcited.html>
- Originator of new sense of "paradigm", "paradigm shift"

Paradigms

- Exemplars of what a science is supposed to be like. Ex.: Newton's *Principia Mathematica*
- More broadly: The accepted general theoretical framework in a given scientific field. Ex.:

Aristotelian physics	Geocentric astronomy
Newtonian physics	Heliocentric astronomy
General relativity	Theory of the 4 elements
Theory of the 4 humors	Atomic theory
Germ theory of disease	Evolution
	Continental drift/plate techtonics

Two kinds of science

- Normal science: Puzzle-solving within the paradigm
  • Anomalies exist, but ignored. ***Anomalies**:* cases where nature defies paradigm-induced expectations
  • Resistance to any questioning of the paradigm.
  • Normal science is most science.
  • Normal science is valuable & useful.
  • Paradigms essential for science.
- Scientific revolutions:
  • *Anomalies* build up/gain attention.
  Note: Precise paradigms make awareness of anomaly possible.
  • New paradigm promises solutions.
  Note: No revolution without a better paradigm.
  • New paradigm supplants old.
    - Note: new paradigm is *incompatible* w/ old paradigm. Progress not cumulative.
    - Paradigms are "***incommensurable***": no neutral methods for resolving debate, b/c paradigms differ on the criteria of theory assessment
    - People who don't accept new paradigm become increasingly ignored (astrology example, 19)
    - Max Planck exaggerates in saying:

    > A new scientific truth does not triumph by convincing its opponents and making them see the light, but rather because its opponents eventually die, and a new generation grow up that is familiar with it. (*Scientific Autobiography & Other Papers*, 33-4)

- Postrevolutionary textbooks hide the process.
  - Written from perspective of new paradigm.
  - Omit much history, things important to earlier paradigms.
  - Falsely portray science as cumulative.

Scientific progress, truth, &c.

- Paradigm shifts not cumulative progress
- Paradigm shift requires faith & non-empirical criteria (what questions are *important*, value of "simplicity", "elegance", etc.)
- A few holdouts remain,

> And even they, we cannot say, are wrong. ... [T]he historian ... will not find a point at which resistance becomes illogical or unscientific. At most he may wish to say that the man who continues to resist after his whole profession has been converted has *ipso facto* ceased to be a scientist. (159)

Phil. 4400
Notes #7: Scientific Irrationalism (Stove)

I. Some irrationalist quotations:

Popper:

"We must regard all laws and theories as guesses." (*Objective Knowledge*, 9)

"There *are* no such things as good positive reasons." (*The Philosophy of Karl Popper*, 1043)

"Belief, of course, is never rational: it is rational to *suspend* belief." (*PKP*, 69)

"I never assume that by force of 'verified' conclusions, theories can be established as 'true', or even as merely 'probable'." (*Logic of Scientific Discovery* [1968], 33)

"[O]f two hypotheses, the one that is logically stronger, or more informative, or better testable, and thus the one which can be *better corroborated*, is always *less probable*—on any given evidence—than the other." (*LSD*, 363)

"[*I*]*n an infinite universe* [...] *the probability of any (non-tautological) universal law will be zero.*" (*LSD*, 363)

Kuhn:

"One often hears that successive theories grow ever closer to, or approximate more and more closely to, the truth. [...] There is, I think, no theory-independent way to reconstruct phrases like 'really there'; the notion of a match between the ontology of a theory and its 'real' counterpart in nature now seems to me illusive in principle. Besides, as a historian, I am impressed with the implausability [*sic*] of the view." (*Structure of Scientific Revolutions*, 3rd ed., 206)

Feyerabend:

"[S]cience is much closer to myth than a scientific philosophy is prepared to admit. It is one of the many forms of thought that have been developed by man, and not necessarily the best. It is conspicuous, noisy, and impudent, but it is inherently superior only for those who have already decided in favour of a certain ideology, or who have accepted it without ever having examined its advantages and its limits." (*Against Method*, 295)

"One of my motives for writing *Against Method* was to free people from the tyranny of philosophical obfuscators and abstract concepts such as 'truth', 'reality', or 'objectivity', which narrow people's vision and ways of being in the world." (*Killing Time*, 179)

Stove:

"We should for a moment try, though it is almost impossible, to take in the full grotesqueness of the contemporary situation in the philosophy of science. We have already encountered Popper, a grown man and a professor, implying that it is a guess—that is, *something like a cricket captain's call of 'heads'*—that the sun does not go round the earth every day. But here is Kuhn, perhaps the most learned and certainly the most influential of living historians of science, writing in such a way as to imply that, like a great many people in 1580 and a few uncommonly ignorant ones even now, he *does not know that it is false* that the sun goes round the earth every day!" (*Anything Goes*, 47)

Main points:

Popper: - There's no reason to believe anything.
- Every scientific law is 100% certain to be false (and that's cool).

Kuhn: - There is no reality.

Feyerabend: - Science is myth.
- We should abandon 'truth', 'reality', and 'objectivity'.

II. The historical root

Scientific developments:

1687: Publication of *Philosophiæ Naturalis Principia Mathematica* by Isaac Newton. ("Mathematical Principles of Natural Philosophy")

17th - early 20th century:
- Newtonian physics (esp.: N's laws of motion + N's theory of gravity) is held in extremely high regard.

20th century: Three developments overthrow classical physics:
- Special relativity
- Quantum mechanics
- General relativity

The philosophical reaction:

Horrors! We must ensure that this *never, ever* happens again . . . by believing nothing!

***Bonus speculations** (mine):*

- Political correctness, intellectual egalitarianism
- 19th-century idealism
- Cultural relativism

III. The philosophical root

Deductivism: The thesis that only deductively valid inferences can provide a reason for believing anything.

• Note: Not the same as inductive skepticism. Premise from which inductive skepticism is inferred.
• Stove's basis for identifying this:

(I) All observed bachelors have been slobs.
Therefore (probably), all bachelors are slobs.

• Hume says this "presupposes" something like: "The unobserved things will resemble the observed things."
• Note that this is *the validator* of (I).
Validator: The premise that must be added to an argument to make it deductively valid.
• Assuming that an inference must presuppose its validator is tantamount to assuming deductivism.

Phil. 4400
Notes #8: (Il)logical Postivism

I. Basic concepts

- *Empiricism :* There is no synthetic, a priori knowledge. (Hume, Berkeley, perhaps Aristotle)
- *Verificationism :* The (cognitive) meaning of a statement is given by the conditions under which it would be verified or refuted. Corollary: If it cannot, in principle, be known whether S is true or false, then S is "meaningless".
- *logical positivism* : empiricism + verificationism ⇒ There are 2 kinds of meaningful sentences:
  a) Analytic (or contradictory) sentences: These are true (or false) in virtue of the meanings of words; "verified" by all (or no) possible experience.
  b) Contingent & empirically testable sentences.

Comments:

- Practical vs. in-principle verifiability
- Strong & weak sense of "verifiable".
- The meaning of "meaningless". Fails to assert a proposition, not truth-apt.
  - Cognitive meaning vs. 'emotive meaning'.

II. The implications of positivism

1. Mathematics: Analytic. Says nothing about reality. Leads to formalist philosophy of mathematics.
2. Logic: Like mathematics.
3. Ethics: meaningless. Leads to non-cognitivism.
4. Religion: meaningless.
5. Metaphysics: meaningless.
6. Philosophy: Only legitimate function is to clarify language usage.

III. Arguments for positivism

IV. Objections

1. How is the verification criterion known?
2. Positivists confuse metaphysics with epistemology, truth with justification. There can be facts we can't know. Why can't there be statements that we can't know whether they are true?
3. Sentence meanings are compositional. The meaning of a sentence is determined by whether the individual words are meaningful & combined in an appropriate way. There is no guarantee that such combinations will always turn out to be verifiable. (Example.)
4. Examples of unknowable things:
   - What happened before the Big Bang.
   - How many hairs were on Aristotle's head on his 35th birthday.
   - Religious claims.

5. There are many examples of synthetic, a priori knowledge.
   • Mathematics.
   • Ethics.
   • Metaphysics.
   • Miscellaneous other a priori knowledge, often neglected by philosophers:
     "Nothing can be both completely red and completely blue."
     "If a person wants to do A, knows that he can do A, and has no reasons to refrain from A, then he will do A."
     "If A is inside B, and B is inside C, then A is inside C."
6. Circularity: How do you know whether S is "verified" by an observation or not? Must understand the meaning to know what verifies/fails to verify it.

V. The History of Positivism:

1. Motivations for positivism:
   - Scientism: worship of science & mathematics; disparagement of other intellectual endeavors.
   - Positivists seek a blanket way to dismiss all work in metaphysics. Hence the verification criterion.
   - It is fun to sound "hard-headed".
   - Heavily influenced by Hume.
2. Verificationism becomes early 20^{th}-century dogma, almost universal in analytic philosophy. They did not feel the need of arguments for it.
3. Leads to acceptance of all the implications under (II) above.
4. Scientists are brought into this credo, esp. hard scientists.
5. Scientists & mathematicians develop positivist-inspired theories (relativity, quantum mechanics).
6. Most philosophers later reject the verification criterion (while holding on to empiricism). Scientists, however, still maintain it.
7. The implications of positivism, under (3) and (5), however, remain accepted orthodoxy.
8. The orthodox theories are now used to argue for empiricism ("science has shown that positivism is true").

Lessons:
• Philosophical fashions come and go. Cases in point: (a) scholasticism, (b) 19^{th} century idealism, (c) illogical positivism.

Phil. 4400
Notes #9: A Priori Knowledge

I. Important distinctions

Analytic/Synthetic:

Analytic: A sentence S is analytic iff the negation of S can be transformed into a formal contradiction by substitution of synonymous expressions and formally valid inferences. (Or: iff S can be transformed into a logical truth by substitution of synonymous expressions and formally valid inferences.)

Synthetic: S is synthetic iff S is (meaningful but) not analytic.

Empirical/A priori:

Empirical: S knows that P empirically = S knows that P, and S's justification for P essentially contains/involves observation.
- *Observation:* sensory perception or introspection. On my view: a thing whose justification consists in the fact that one has a sensory or introspective appearance.
- *"Essentially":* Means that an observation is a necessary part of the justification; if the observation is removed, then the belief is no longer justified.

A priori: S knows a priori that P = S knows that P, not empirically.
• *Possible kinds of a priori kn.:*
1. Innate knowledge
2. Knowledge acquired through reason/intuition

Necessary/Contingent:

Necessary: Could not have been otherwise.

Contingent: Could have been the case, and also could have not been the case.

Empiricism/Rationalism:

Empiricism:
1. General idea: All knowledge of objective reality is empirical.
2. Modern interpretation: No synthetic a priori knowledge.
3. Role of reason: operates on information provided by observation.

Rationalism:
1. There is a priori knowledge of objective reality.
2. There is synthetic a priori knowledge.
3. Role of reason: (a) operates on information provided by observation, and (b) provides some information of its own.

II. Examples of A Priori Knowledge

A. Logic

Examples:

"Anything implied by a true proposition is true."
Law of Identity: "Whatever is, is."
Law of Non-Contradiction: "Nothing can both be and not be."

Law of Excluded Middle: “Everything must either be or not be.”
Principle of induction

Argument:

1. Some principles of logic are known.
2. No principle of logic is known by observation.
3. All inference presupposes the truth of one or more principles of logic.
4. Therefore, principles of logic cannot in general be known by inference. (From 3.)
5. Any thing known empirically is known by observation or by inference.
6. So principles of logic cannot in general be known empirically. (From 2, 4, 5.)
7. So some principles of logic are known non-empirically. (From 1, 6.)

B. Ethics

Examples:

“Happiness is intrinsically better than misery.”
“If A is better than B and B is better than C, then A is better than C.”

Argument:

- Similar to above.
- No ethical truth is known by observation.
- No ethical truth can be known by inference from wholly non-evaluative premises.

C. Mathematics

Examples:

“2 + 2 = 4”
“Two points determine a line.”
“P(A or B), when A and B are mutually exclusive, = P(A) + P(B).”
“If there exist objects *a* and *b*, then there is a set containing them, {*a*, *b*}.”

Arguments: Why these are not just like empirical generalizations (e.g., “All men are mortal”):

1) One instance suffices for knowing a mathematical generalization. Further instances do not increase probability.
2) They can be certain.
3) They are *necessary*. We can’t entertain a hypothetical in which they are false.

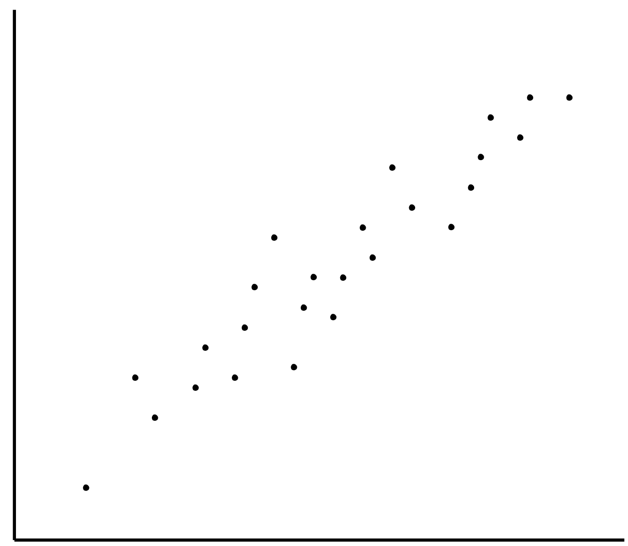
Phil. 4400
Notes #10: Simplicity

I. The problem of simplicity

- Simplicity widely appealed to in science & other empirical reasoning
  - Scientific ex.: Ptolemaic vs. Copernican astronomy
  - Ordinary ex.: the appliance failures; the detective
- Kinds of simplicity: kinds, tokens, & principles
  - Kinds matter: chemistry, elementary particle theory
  - Tokens also matter:
    - The neutrino case
    - Neptune
  - Simplicity of principles:
    - Law of gravity ex.: Which of these is simpler?

$$F_G = \frac{Gm_1m_2}{r^2} \qquad F_G = \frac{Gm_1m_2}{r^{2.0001}}$$

    - The curve-fitting problem: How would you fit a curve to these data points?



- Questions:
  1. Why is simplicity a virtue?
  2. What is simplicity?

II. Some failed accounts

A. The pragmatic account

- Simpler theories aesthetically pleasing
- Easier to work with
- *Problem:* Pragmatic value of avoiding error swamps the above pragmatic values.

B. The efficient convergence account

- Occam's Razor is (a) guaranteed to reach the truth eventually, if the truth is attainable, and (b) minimizes the number of changes of opinion one may be forced into (among methods satisfying (a)).
- Consider 3 methods:
  (1) Assume A's exist, unless proven otherwise. Problem: violates (a)
  (2) Assume A's exist, until 1 million unsuccessful attempts to detect A's. Problem: violates (b)

(3) Assume A's exist, until 1st A is detected. Most efficient method.

- *Problems:*
  - Why care about efficiency?
  - Doesn't guarantee truth, doesn't guarantee probability of truth
  - Doesn't even minimize *expected* # of changes of opinion

C. The empiricist account

- *First version:*
  1. In the past, simpler theories have generally proven better than complex theories.
  2. Therefore, simpler theories will probably continue to be better than complex theories. (induction)
  3. Therefore, we should continue to rely on the criterion of simplicity.

- *Second version:*
  1. Science has been very successful.
  2. The best explanation of this is that scientific methodology is truth-conducive.
  3. So, probably scientific methodology is truth-conducive. (From 1, 2)
  4. Simplicity is central to scientific methodology.
  5. So, probably simplicity is a mark of truth. (From 3, 4)

- *Problem:*
  - Neither version explains why simplicity is a mark of truth.
  - First version may be circular: induction relies on a form of simplicity
  - Second version circular: Inference to the best explanation relies on simplicity criterion

D. The axiomatic account

- Axiom: Simplicity is evidence of truth.
- Argument for this: a) We intuitively favor simpler theories.
  b) Other accounts of virtue of simplicity fail.
- *Problems:*
  - It doesn't seem self-evident.
  - Other accounts don't fail.

III. Some probabilistic theories

A. The boundary asymmetry account

- A boundary asymmetry: degree of complexity is unbounded in 1 direction:
  - There is a lower bound to degree of complexity
  - No upper bound
- Probability distributions must be *normalizable*: probabilities must sum to 1.
- How is this possible with an infinite set? Answer:
  - Countably infinite: convergent series, decreasing probabilities.
  - Decreasing probability density, integrates to 1.
- Hence, more complex hypotheses must have lower probabilities.

B. The numerousness account

- There are more complex than simple theories
  - Consider parameters in equations
  - Relate to ontological parsimony
- Indifference to degree of complexity ➞ lower Pr. for complex theories

C. The likelihood account

- *Important concepts:*

  Likelihood of H (relative to E): P(E|H).
  Model: theory with values of some parameters left unspecified.
  Specific theory: theory with values of all parameters specified.

1. Compare two theories, Simple and Complex, with the same evidence E:

$$P(S|E) = \frac{P(S) \times P(E|S)}{P(E)} \qquad P(C|E) = \frac{P(C) \times P(E|C)}{P(E)}$$

Hence, $$\frac{P(S|E)}{P(C|E)} = \frac{P(S) \times P(E|S)}{P(C) \times P(E|C)} = \frac{P(S)}{P(C)} \times \frac{P(E|S)}{P(E|C)}.$$

This is the ratio of the *priors* of S and C times the ratio of the *likelihoods* of S and C.

2. The likelihood theory: S has the higher *likelihood*, P(E|S).
   a. Simpler models accommodate narrower ranges of data.
      - More adjustable parameters ➞ wider range of data
      - Ex.: Quadratic vs. linear equations
   b. Total likelihood is 1.
   c. Hence, simpler model has higher likelihood *within the range* of possible data it accommodates.

3. Hence, S is better supported by E, if S accommodates E.

An illustration of the likelihood account:

- The appliance-failure case. Lamp & computer fail

  H1 Power failure.
  H2 Light bulb burned out & computer crashed.

  - H1 clearly simpler, better
  - Adjustable parameters:

  H1: time of power failure
  H2: time of light bulb failure, time of computer crash

- The appliance-failure, Hawaii version.
  - H1 still simpler
  - H2 clearly better.
  - Reason: H2 has higher likelihood.

  H1: parameter must be set to a relatively narrow range (a few hours)
  H2: both parameters can be set independently, wide range (6 months)

Phil. 4400
Review of Unit 2

Know something about these people's views:
Kuhn
Popper
Feyerabend
Ayer
Passmore
Russell
Huemer

Know these concepts:
paradigm
normal science
anomaly
scientific revolution
deductivism
analytic/synthetic
a priori/empirical
boundary asymmetry
likelihood
model
adjustable parameter

Know these theses:
The historical root of irrationalism, acc. to Stove
The philosophical root of irrationalism, acc. to Stove
Incommensurability of paradigms
Empiricism
Verificationism
Logical positivism
Rationalism
Pragmatic account of simplicity
Axiomatic account
Boundary asymmetry account
Numerousness account
Likelihood account

Be familiar with these arguments:
Why arg. for inductive skepticism presupposes deductivism
Objections to positivism:
- Self-undermining of verification criterion
- Compositionality objection
- Circularity problem

Why logic is a priori
Why ethics is a priori
Why mathematics is a priori
- Necessity argument
- Certainty
- Effect of further instances

Why simpler theory accommodates narrower range of data,
+ why it has higher likelihood
+ why this is good
Objection to pragmatic view of simplicity
Appliance-failure (+ Hawaii) examples—how they support likelihood account

Phil. 4400
Notes #11: Absolute Space

I. The traditional dispute: Two conceptions of space + time

- *The Relational Conception of Space:* All that exists are spatial relations between bodies.
- *The Substantival Conception of Space:* Space exists independently of bodies. Bodies merely 'occupy' space.
- *The Relational Conception of Time:* There are only temporal relations between events.
- *The Substantival Conception of Time:* Time exists independently of events. Events merely 'occupy' time.
- "bodies": Material objects.
- "substance": Something that 'exists independently'; everything else that exists depends on substances. Also: ultimate subjects of predicates; not predicated of anything. Hence the term "substantival conception of space."
- *Note:* Please do not confuse "the relational theory of space" with the theory of relativity, which will be discussed in a later class.

II. Related concepts

- ***Location:***
  - For absolutists: The part of space a body occupies. A statement of location has the form *x*O*y*, where *x* is a body and *y* is a part (a region or point) of space.
  - For relationists: A body's spatial relation to other bodies. A statement of location has the form *x*R*y*, where *x* and *y* are both bodies. R is a spatial relation, e.g. "inside", "next to", etc.
  - Similar points apply to 'location' in time.

- ***Duration of an event:***
  - For absolutists: The measure of the region of time the event occupies.
  - For relationists: A relationship between the beginning of the event (which is itself a small event) and the end of the event. Or, alternately: the number of cycles of a clock that pass during the event (hence, a relationship between the event and some other process).

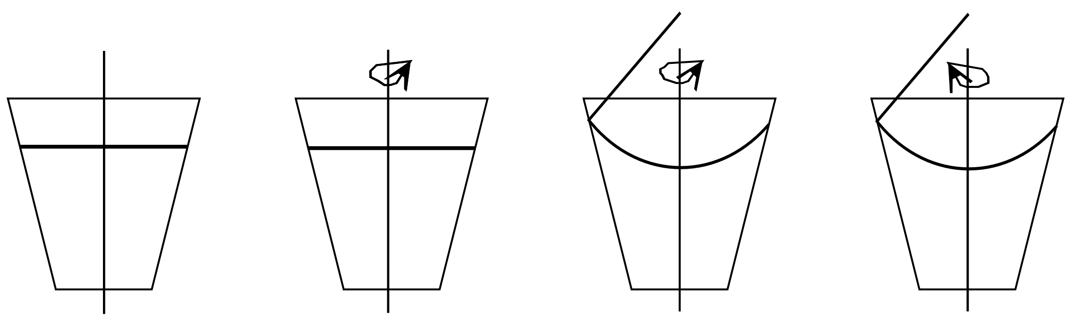
- ***Motion:***
  - *Absolute motion:* change in the part of space a body occupies, over time.
  - *Relative motion:* change in the spatial relations between bodies. *Or:* the difference in the absolute motions of two bodies.
  - Note: Substantivalists believed in absolute motion; relationists believed in only relative motion, for obvious reasons. Thus, traditional substantivalists were also *absolutists*.
  - Example: Suppose you walk at 5 mph on the deck of a ship. The ship is moving at 20 mph in the ocean. Finally, the earth is moving at 1000 mph *in space*. All these motions are in the same direction. Then your *absolute motion* is 1025 mph (the sum of these motions).
  - *Question:* Is absolute motion "motion relative to absolute space"? No; that tries to define absolute motion in terms of relative motion. Relative motion is "difference in absolute motions."

III. Measurement

- We measure the *size* of a body by comparing it with another, *rigid* body (a body that doesn't change its own size).
  - For absolutists: This means it does not change the amount of space it takes up.
  - For relationists: It retains the same "bigger than"/"smaller than" relations to a lot of other bodies.
- Similarly, we measure the *duration* of an event by comparing it with a *uniform* motion/process (a process that continues at a constant speed).
  - For absolutists: It does not change the amount of absolute time that each cycle takes up.
  - For relationists: It keeps a constant relationship (keeps synchronized) with lots of other processes.

IV. Newton's Bucket

- A bucket of water is suspended from a rope. The bucket is turned around several times, twisting the rope up.



Stage		Relative motion of water w/ respect to bucket	Surface of water
1.	Before releasing bucket.	0	Flat
2.	Bucket is released, starts spinning as rope unwinds.	←	Flat
3.	Water picks up motion of the bucket, starts 'spinning with the bucket.'	0	Concave
4.	Rope has twisted up in the other direction, starts unwinding again. Bucket spins in the opposite direction from stage 2.	→	Concave

- *Newtonian account of the events:*
  - *Newton's First Law:* Bodies at (absolute) rest tend to remain at rest, and bodies in (absolute) motion tend to remain in motion in a straight line, unless compelled to change their state by forces impressed on them.
  - 'Centrifugal forces' appear for rotating bodies: The 'force' pushing towards the outside of the

circle is really just the tendency to continue in a straight line.
  - Centrifugal force exists in stage 3, 4, because the water is rotating absolutely.

- *Relationist cannot explain this.*
  - Newton's first law is malformed, according to them: there is no such thing as absolute motion in a straight line.
  - Suppose you substitute "relative motion": "Bodies in relative motion tend to remain in relative motion in a straight line unless compelled to change their state by forces impressed on them." *Problem:* This is false.
  - The relative motions in stages 1 and 3 are the same (0), but there is centrifugal force in stage 3, not in stage 1. Why?
  - The relative motions in 2 and 4 are the same (in opposite directions, but that shouldn't matter), but there is centrifugal force in 2 but not in 4. Why?
  - The centrifugal force is completely unrelated to the *relative* motions. It can only be explained by the absolute motion of the water.

Phil. 4400
Notes #12: Positivism & Relativity

Claim:

Whether 2 events are simultaneous is relative to a reference frame.
• Contemplate how radical this claim is.

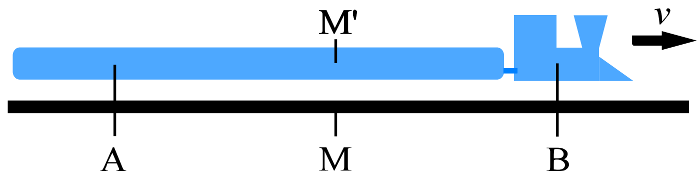
Outline of the Argument

1. ***Def. of simultaneity:*** *x* is simultaneous with *y* iff: An observer placed at the midpoint between *x* and *y* would see *x* and *y* at the same time.
2. Observers in different states of motion (but both at the same point in space) could differ on whether they saw *x* and *y* at the same time.
3. Therefore, *x* and *y* could be simultaneous *for* one observer (or one reference-frame) and not for another.

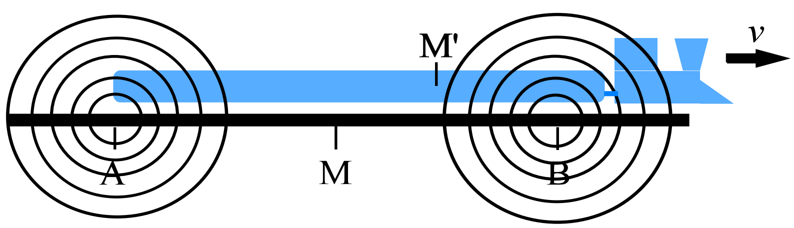
Defense of the Definition

• Verificationism: The meaning of a statement is determined by its method of verification.
  - Corollary: the meaning of a predicate is determined by the method of determining whether it applies to a thing.
  - Corollary: the meaning of a predicate must specify the method of verifying its application *in every case* in which it can be applied.
    (Implicit rationale: This is the only way to avoid unverifiable statements, given compositionality of meaning?)
• The suggested def. satisfies this criterion.
• *Objection*: The def. assumes that the light travels at the same speed from *x* to the observer, as it does from *y* to the observer.
  - *Reply*: This isn't an assumption, but a "stipulation which I can make of my own freewill."
    [How can he think this? Understand how this results from verificationism.]
• What's wrong with this definition: *x* is simultaneous with *y* iff *x* and *y* happen at the same time.
  - Answer: No obvious method of verification for distant events.

Why this Leads to Relativity of Simultaneity



- We have:
  - A train moving with velocity *v* with respect to a railway embankment.
  - Events A and B happen at the railway embankment (and right next to people who are on the train as it passes).
  - Point M on the embankment is halfway between the points *on the embankment* where A and B happened.
  - Point M' on the train is halfway between the points *on the train* adjacent to where A and B happened.
- The train moves to the right as the light from A and B travels towards observers at M and M':



  - Light rays emanate from A and B.
  - M receives the light from A and B simultaneously
  - M' must receive the light from B before the light from A.
  - Hence, *for M*, A and B are simultaneous; *for M'*, B is before A.

Criticism

- An alternative def. of simultaneity:

  x and *y* are simultaneous iff they happen at the same time.

  - Einstein could not object to the expression “at the same time,” since it appears in *his own* definition.
  - This def. lets “simultaneous” keep the same meaning for events with different spatial relations to each other.
  - It also avoids the counter-intuitive result of relativity of simultaneity.

- Verificationism has previously been criticized.

Phil. 4400
Notes #13: Special Relativity

Spacetime:

- Two concepts of a space:
  - *Physical space:* the space you are moving around in.
  - *Mathematical space:* a set of things (‘points’) that have certain mathematical properties. Basically, they have relations to each other that enable them to be arranged along one or more dimensions. *Ex.:* logical space, the color space, the IQ-height space, various spaces in statistics. Physical space is also a mathematical space.
- Another *mathematical* space:
  Spacetime: the 4-dimensional ‘space’ in which the points are ordered quadruples giving (physical) spatial and temporal coordinates. Spacetime is a mathematical space; it includes physical space.
- Learn to enjoy spacetime diagrams.

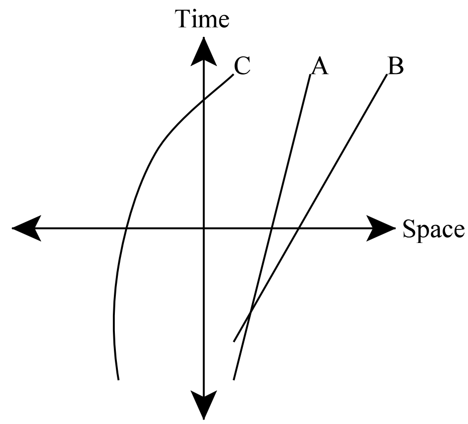


Figure 1. Spacetime. We suppress two spatial dimensions to make it possible to draw on a flat piece of paper. Vertical axis is time; horizontal axis is space. Line A represents an object moving to the right. B is an object moving *faster* to the right. C is an object *accelerating*.

What is the Special Theory of Relativity (STR)?

- It is a theory of the structure of spacetime.

Newtonian spacetime:

- Shortest path between 2 points is a straight line. Distance between points:
  $$D^2 = \triangle t^2 + \triangle x^2 + \triangle y^2 + \triangle z^2$$
- Distinguishes:
  Straight lines / curved lines
  Vertical lines / slanted lines
- Spatial & temporal coordinates are separable. Spatial and temporal distances both objective.
- No speed limit.
- See figure 1.

Minkowski spacetime:

- Shortest path *not* a straight line (but the path of a light ray). The invariant spacetime interval:
  $$I^2 = (c\triangle t)^2 - \triangle x^2 - \triangle y^2 - \triangle z^2$$
  Note the minus signs!
- Distinguishes:
  Straight lines / curved lines

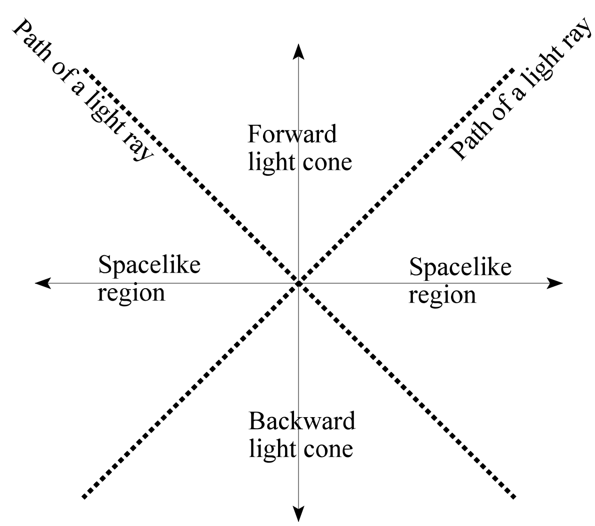


Figure 2. Minkowski spacetime. For any given spacetime point, there is a set of points that would be connected to it by a light pulse sent out in all directions: this set of points is the *forward light cone*. Similarly, there’s a backward light cone. Outside the light cones are the points at ‘spacelike separation.’

- Space & time are inseparable. Spacetime intervals are objective, but how they divide into spatial and temporal components is not.
  - There are multiple equally acceptable specifications of the time axis.
  - Hence, no absolute simultaneity.
- Has an objective 'light cone structure' (any given point has a forward & backward light cone). Which s-t points are in the light cone is invariant.
- See figure 2.

Famous features of STR:

- All inertial reference frames are equally good.
- The speed of light (*c*) is constant; i.e., every r.f. must agree on whether a thing is traveling at *c*.
- All of the following are 'relative':
  - Velocity of an object (if below *c*)
  - Length of an object
  - Time-order of two (spacelike) events
  - Shape of an object
  - Mass of an object
  - Duration of an event
- Nothing can travel faster than *c*. Why:
  - The putative 'stages' of the spacteime worm of such an object would be *spacelike* related to each other.
  - There is no objective time order to spacelike separated events.
  - Also, it would require infinite energy.

About relative vs. absolute quantities:

- 'Relative' quantities are those which differ between reference frames. They are not in objective reality; they are convention-dependent.
- 'Absolute' quantities are *invariant* ones: i.e., all rf's agree on them. They are in objective reality.

Common misunderstandings:

- STR is not the relational theory of space.
- STR does *not* say "objects shrink (gain mass, etc.) when they go faster." (Understand why that's wrong!) What do these equations mean:

$$L = L_0\sqrt{1 - \frac{v^2}{c^2}} \qquad T = \frac{T_0}{\sqrt{1 - \frac{v^2}{c^2}}} \qquad m = \frac{m_0}{\sqrt{1 - \frac{v^2}{c^2}}}$$

Phil. 4400
Notes #14: Alternative to Special Relativity

I. The Lorentz Ether Theory

- LET uses the same equations, with different interpretation:

$$L = L_0\sqrt{1-\frac{v^2}{c^2}} \qquad T = \frac{T_0}{\sqrt{1-\frac{v^2}{c^2}}}$$

- Interpretation: These are *real, dynamical effects* of motion through the ether (or absolute space), unlike in relativity.
  - Absolute motion (or motion relative to the ether) causes objects to shrink (really!).
  - Absolute motion causes internal movement & other processes to slow down.
  - Absolute motion causes things to gain mass.
  - Marklin favors ether; Tooley favors absolute space
- This theory is empirically equivalent to STR.
  - See why length contraction, time dilation are not measurable
  - LET & STR just place different interpretations on the same equations.
  - Why light ray will appear to have a *round-trip* velocity *c*, for any observer: see Appendix.
- Trivia: The LET is the original source of these equations, which is why they're called "the Lorentz transformations."

II. Objections to LET

A. The Argument from Authority

1. Physicists say STR is true.
2. Physicists are smart.
3. Therefore, STR is true.

B. The Positivist Argument

1. If LET, then there are undetectable facts, unmeasurable quantities (which could be named).
2. This is impossible.
3. So LET is false.

C. The Simplicity Argument

1. LET has more spacetime structure than STR.
2. So LET is more complex than STR.
3. Ceteris paribus, simpler theories are more likely to be true.
4. So, ceteris paribus, STR is more likely than LET.

D. The "We got here first" Argument

1. New theories must have novel predictions to be justified.
2. LET has no novel predictions.
3. So LET is unjustified.

E. LET is Ad Hoc, Physically Weird

- Why would objects shrink in the direction of motion through the ether?
- Partial answer: The forces that determine the distances between particles are electromagnetic. The ether is what transmits electromagnetic effects.

F. The Conspiracy of Silence Objection

1. It is impossible to detect absolute motion.
2. On LET, this is an improbable "conspiracy of silence."
3. So this is evidence against LET.

Tooley's Response to the Conspiracy of Silence:

a. (1) is true only if (and only because): It is impossible to measure the 1-way velocity of light.
b. If it is impossible to measure the 1-way velocity of light, then this is an improbable "conspiracy of silence" *regardless* of whether LET or STR holds.
c. So the same conspiracy of silence holds on either theory.
d. So this isn't a reason to prefer STR over LET.

Why (a) is true:

- Suppose O is moving at absolute velocity v. O sends a light ray in the direction of his movement.
  Absolute speed of light: c
  Speed relative to O: $c - v$
  Apparent speed, after Lorentz transformation: $c^2 / (c + v)$. *Calculations:*
    - Given the length contraction, a distance D will *appear* as $[D / (1\text{-}v^2/c^2)^{1/2}]$.
    - Given time dilation, a time T will *appear* as $T(1\text{-}v^2/c^2)^{1/2}$.
    - So a velocity $V{=}D/T$ will appear as

$$\frac{(D/\sqrt{1-v^2/c^2})}{(T\sqrt{1-v^2/c^2})} = \frac{D}{T(1-v^2/c^2)} = \frac{V}{(1-v^2/c^2)} = \frac{Vc^2}{c^2-v^2}$$

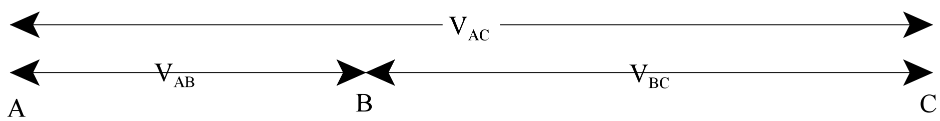
    - So the relative velocity of the light ray, $(c - v)$, will appear as

$$\frac{(c-v)c^2}{c^2-v^2} = \frac{(c-v)c^2}{(c+v)(c-v)} = \frac{c^2}{(c+v)}$$

- Now suppose O sends a light ray in the opposite direction:
  Absolute speed of light: c
  Speed relative to O: $c + v$
  Apparent speed, after Lorentz transformation: $c^2 / (c - v)$
    - Calculation here exactly parallel to that above.

III. Advantages of LET

1. The following propositions seem intuitively obvious:
   - Waves require a medium. (There can't be a wave with nothing that waves.)
   - The size, shape, and mass of objects are objective properties of those objects (not convention-dependent, and not relationships to other objects. An object has only one length (shape, mass) at any given time.
   - The Galilean Law of the Addition of Velocities: If A, B, and C are all moving along a single dimension, the velocity of A with respect to B is V_{AB}, the velocity of B with respect to C is V_{BC}, and the velocity of A with respect to C is V_{AC}, then $V_{AB} + V_{BC} = V_{AC}$.



   - Time is distinct from space. Time is not just like another spatial dimension.
   - Events have an objective time-order.
   - There's such a thing as "everything that exists (or is taking place) *now*" (and it's not convention-dependent). Something can be happening now, even if it's not here.
   - Space (the same space) continues to exist through time.

2. STR is incompatible with all the propositions in (1). LET is compatible with all of them.

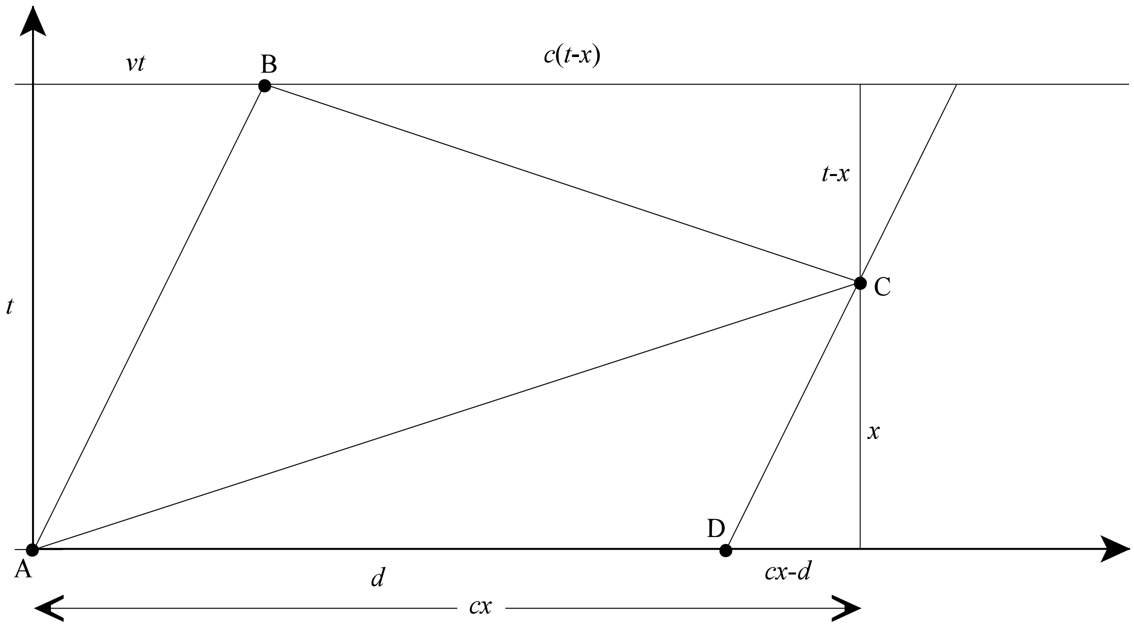
3. STR provides no *reason* for denying these propositions.
   a. The empirical evidence is equally compatible with LET.
   b. There are no other arguments against them either. Scientists who adopted STR never even considered them.

4. So, LET is better than STR.

Appendix: Why the round-trip velocity of light appears to be *c*

Scenario: An observer at A is moving to the right with (absolute) velocity v. He sends a light ray to bounce off a mirror at point C and come back to him. The round trip takes a time t. (See diagram.)

Question: What will this observer take the round-trip velocity of light to be?



Observations:

- The true velocity of the light is c. The light will take some amount of time (call it "x") to get to the mirror. It will take a smaller amount of time ($t - x$) to get back to the observer, since he's moving to the right.
- The real distance traveled by the light to get from A to C is cx (velocity times time = distance).
- Similarly, the real distance traveled by the light to get from C to B is $c(t - x)$.
- Let d be the length of the path that the observer *thinks* the light is traveling between A and C. Since he thinks he's stationary, he thinks point D on the diagram is directly below point C, so he thinks AD is the distance traveled. And he thinks the return trip is the same length.

Plan:

- First we'll find the actual length d of the segment AD.
- Then we apply the Lorentz length-contraction formula to figure out how long AD will *appear* to the observer.
- Then we'll apply the Lorentz time-dilation formula to figure out how long the time interval t will *appear* to the observer.
- Then we'll divide what the observer takes the total distance to be (that's twice what he takes the length of AD to be) by what he takes the total time to be. The desired result is c, that is, that the observer will measure the round-trip speed of the light to be c, its real speed (despite all the deceptions he's subject to).

Solution:

$$\frac{cx-d}{x} = \frac{vt}{t} \qquad (similar\ \ triangles) \qquad \text{(Equation 1)}$$

$$cx = vt + c(t-x) \qquad \text{(Equation 2)}$$

$$x = \frac{vt+ct}{2c} \qquad (rearranging\ \ equation\ \ 2) \qquad \text{(Equation 3)}$$

$$d = x(c-v) \qquad (rearranging\ \ equation\ \ 1) \qquad \text{(Equation 4)}$$

$$d = \frac{vt+ct}{2c}(c-v) = \frac{t}{2c}(c^2-v^2) \qquad (substituting\ \ Eq.\ 3\ \ into\ \ Eq.\ 4\ +\ simplifying) \qquad \text{(Eq .5)}$$

Since we want the round trip, we're actually considering 2d, so:

$$2d = \frac{t}{c}(c^2-v^2) \qquad \text{(Eq. 6)}$$

Applying the Lorentz length contraction, this distance will *appear* as:

$$Apparent\ \ distance = \frac{t}{c}(c^2-v^2)\times\frac{1}{\sqrt{1-v^2/c^2}} \qquad \text{(Eq. 7)}$$

Applying the Lorentz time dilation, the time will appear as:

$$Apparent\ \ time = t\sqrt{1-v^2/c^2} \qquad \text{(Eq. 8)}$$

Finally, dividing Eq. 7 by Eq. 8, we get the apparent velocity of the light ray:

$$Apparent\ \ velocity = \frac{\frac{t}{c}(c^2-v^2)\times\frac{1}{\sqrt{1-v^2/c^2}}}{t\sqrt{1-v^2/c^2}} = \frac{1}{c}(c^2-v^2)\times\frac{1}{1-v^2/c^2}$$

$$= \frac{1}{c}(c^2-v^2)\times\frac{c^2}{(c^2-v^2)} = c$$

Phil. 4400
Notes #15: Non-Euclidean Geometry & General Relativity

I. About Pure Geometry

- Three kinds of geometry:
  (“Parallel” lines: Lines that do not cross.)
  a) *Elliptical geometry* : through a given point outside a given line, there are no parallel lines.
  b) *Hyperbolic geometry* : through a given point outside a given line, there are infinitely many parallel lines.
  c) *Euclidean geometry* : through a given point outside a given line, there is exactly one parallel line. (This is the “axiom of parallels.”)
- Two kinds of geometry:
  Pure geometry is a word game with made up, stipulative definitions and rules. No connection to reality needed.
  Applied geometry is the application of a geometrical system to some thing in the world.

a) A model of elliptical geometry: The “plane” is the surface of a sphere. The “straight lines” are great circles.

- Features of this geometry:
  1) No parallel lines.
  2) The interior angles of a triangle will be more than 180°.
  3) C/d of a circle < π.
- Note: Again, “line”, “triangle”, etc. are *not* used in the ordinary English sense of the words.
- This surface has “positive curvature”.
- This proves: Elliptical geometry is consistent.
- Why is it called “elliptical”: it can be modeled on the surface of an “ellipsoid”.

b) A model of hyperbolic geometry: The “plane” is a saddle surface (surface of a hyperboloid). “Straight lines” are geodesics.

- Features of this geometry:
  1) Many parallel lines.
  2) The interior angles of a triangle will be less than 180°.
  3) C/d of a circle > π.
- This surface has “negative curvature”.
- This proves: Hyperbolic geometry is consistent.

- *Note* : Two senses of “curvature”: a) Physical curvature
  b) Mathematical “curvature”

II. About general relativity

- Spacetime as a mathematical space. (Note: Lots of things are “spaces” in the mathematical sense, although they have nothing special to do with physical space.)
- Points as ordered quadruples. (event locations)
- Newton’s spacetime: Euclidean.
- Einstein’s theory:
  1. Concentrations of mass/energy alter the geometry of spacetime, “curving” spacetime. Note:

a) *Spacetime*, not *space*
b) It is not *physically* curved. It is curved in the mathematical sense.

2. Objects travel straight lines through spacetime when not acted on by forces. Gravitational 'force' is replaced by spacetime curvature.
3. Light always traces straight lines through spacetime.

• Empirical evidence:
a) the bending of light around the sun
b) gravitational red shift
c) advance of the perihelion of Mercury

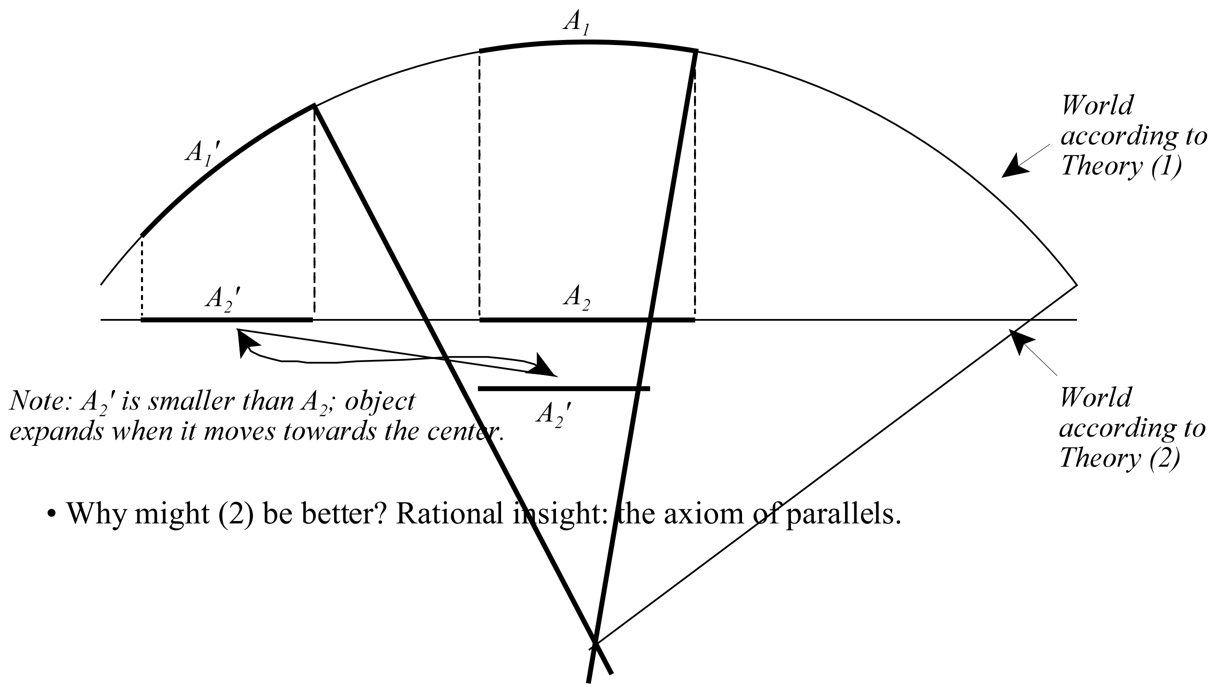
III. Two alternative interpretations (Carnap's example)

• You have two people occupying a 2-dimensional world (see diagram below).
Theory 1 : You have rigid (fixed size & shape) rods moving on a curved surface.
Theory 2 : Rods affected by universal forces, on a flat surface.

- 'Universal forces': Forces that distort everything in the same way and cannot be shielded against.
- A heuristic for seeing the relation between the theories: Imagine the theory-1-world above the theory-2-world, and a light shining directly down from above. In (2), objects expand or contract to be the size of the 'shadow' of the objects in theory (1).

• Note that they get the same empirical predictions. (See why.)
  • You cannot directly measure distortions made by universal forces.
  • They have *effects* indiscernible (by observation) to those of the noneuclidean geometry.

• Which theory is better?
  • Einstein: (1) is better.
  • Carnap: (1) and (2) are the same theory.
  • BonJour: (2) is better.



• Why might (2) be better? Rational insight: the axiom of parallels.

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Notes #16: Simultaneous Causation

Two views of causation:

Sequential: Causes immediately precede their direct effects.
Simultaneous: Causes occur at the same time as their direct effects.

Common sense examples of simultaneous causation

- Lifting a pencil.
- A ball on a cushion.
- *Objection:* at the micro-physical level, there is a slight time delay.

Simultaneous causation in physics

- Two examples:
  Newton's Second Law: $\mathbf{F} = m\mathbf{a}$
  The Lorentz equation: $\mathbf{F} = q\mathbf{E} + q\mathbf{v}\times\mathbf{B}$
- The basic causal laws of physics are *differential equations*. Understanding this:
  - The effect is typically a *rate of change*.
  - The rate of change exists at exactly the time of the cause.
  - Differential equations do *not* require instantaneous events or "infinitesimal" changes. The temporally-extended change event (effect) occurs during the same *interval* as its temporally-extended cause.

The problem of temporally extended causal processes

Hume's objection:

1. If all direct causation is simultaneous, there are no temporally extended causal processes.
2. There are temporally extended causal processes.
3. So not all direct causation is simultaneous. At least some is sequential.

Hume's view of the structure of time:

- The discrete conception:
  a) Time is made up out of indivisible parts.
  b) For each such part (moment), there is a next moment following it.
- Hume accepts the principle of *no action at a temporal distance*.
- Conclusion: To have extended causal processes, effects must occur at *the next* instant in time. (This is valid.)

In the continuous structure of time:

- There is no smallest (non-zero) temporal interval.
- There's no next point in time after any other point. (Time is "dense".)
- How temporally extended causal processes result:
  - Laws specify a relation between the *current configuration* of a system and the *rate of change* of one or more aspects of its configuration.
  - Integrate rate of change over finite interval → finite change.

- Note: extended change is a logical consequence of the view.

The Principle of Reciprocity

Objection:

1. Example: two balls collide, ball A causes ball B to gain momentum.
2. If cause & effect are simultaneous, then momentum conservation is violated.
3. This is impossible.
4. So cause & effect are non-simultaneous.

Reply:

- Change in momentum is a continuous process, not a discrete event.
- The rates of change are simultaneous.
- Actually, the *sequential* view violates momentum conservation: if the effect is latter than the cause, then there is a time when total momentum is lower than at the beginning.

Objection:

1. Example:
   A ball is lowered onto a cushion. Ball exerts force F, causing compression of cushion, which causes an upward force on the ball, which causes a reaction force R from the ball.
2. If causes & effects are simultaneous, then when the ball exerts force F, it exerts force F+R.
3. This is impossible.
4. So the causes & effects are not simultaneous.

Reply:

- Compression of cushion is not instantaneous. (Instantaneous force has 0 effect.)
- Compression is a continuous process.
- The force-exerting and cushion-compressing events occur over the same time interval.
- Rate of change of the ball's downward force = the rate of change of the cushion's upward force due to compression.

Distinguishing causes & effects

Why we believe forces cause accelerations, not vice versa:

1. Intuitive notion of 'force'.
2. Asymmetry of determination:
   Laws determine function: configuration → forces → acceleration
   Do not determine function: acceleration → forces → configuration

Phil. 4400
Review, Unit 3

Know these concepts:

Relational theory of space
Substantival conception of space
- interpretation of position, absolute motion, & relative motion.

Newton's 1st Law
Centrifugal force
Simultaneity, Einstein's def.
spacelike separation
forward light cone
backward light cone
Galilean law of the addition of velocities
Euclidean geometry, incl.
- Axiom of parallels

Elliptical geometry, including
- Its axiom of parallels
- How to model it
- Effect on angles of a triangle
- Its curvature

Hyperbolic geometry, incl.
- Its axiom of parallels
- How to model it
- Effect on angles of a triangle
- Its curvature

Curvature of a surface

Know these theories:

Special Relativity, including:
- The invariant interval
- What is relative, what is absolute
- The speed limit
- Interpretation of Lorentz equations
- View of simultaneity

Lorentz Ether Theory, including:
- Interpretation of Lorentz equations
- Its view of spacetime & what is absolute
- Why Lorentz contractions are unobservable
- Why our absolute speed is undetectable

General relativity, basic principles of it
Universal forces theory (alternative to GR)
- What the universal forces do
- The geometry of the theory
- Carnap's view of it
- BonJour's view of it

Simultaneous conception of causation, incl.:
- Its view of time
- What the immediate effects are
- Why there are temporally extended causal processes
- Correct understanding of derivatives

Sequential conception of causation, incl.:
- Its view of time
- When direct effects occur

Know these arguments:

Einstein's argument against absolute simultaneity
Conspiracy of silence objection
- Incl., what's the "conspiracy"

Tooley's response to Conspiracy-of-Silence
- Incl., the other "conspiracy" T discusses

Some reasons for preferring LET over STR
Argument for simultaneous causation, incl.,
- No action at a temporal distance

Know these examples:

Newton's bucket & what it shows
Some examples of simultaneous causation

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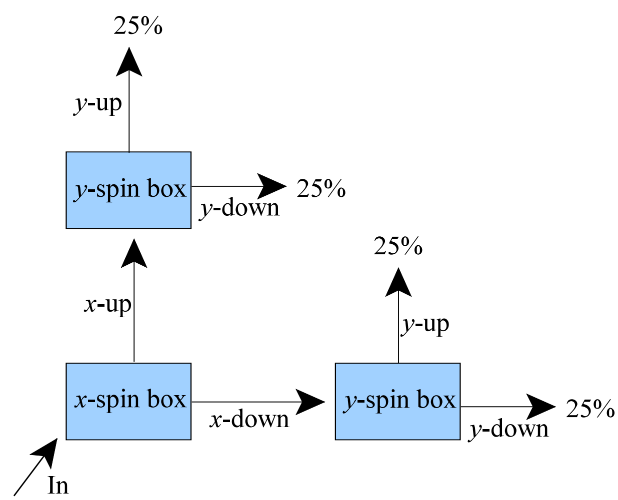
Notes #17: Quantum Mysteries

I. Electron Spin Mysteries

- Electrons have a property called "spin". About spin:
  - An electron has spin in any given direction, e.g., "spin in the *x* direction", "spin in the *y* direction", "spin in the *z* direction". These are distinct.
  - The spin in a given direction can take one of two values: "spin up" (spin +½) and "spin down" (spin -½).
  - Spin affects behavior in a magnetic field. Spin-up electrons are deflected up by a certain amount in a nonuniform magnetic field. Spin down electrons are deflected down by the same amount.
  - Spin in orthogonal directions is completely uncorrelated.

- Measurement:
  - An "x-spin box" is a device that measures x-spin (spin in the x direction), and sends spin up electrons out in one direction, and spin down electrons out in another direction.
  - Similarly for a "y-spin box".
  - Successive measurements of x-spin are 100% correlated. Similarly for y-spin.
  - But measuring x-spin completely *randomizes* y-spin, and vice versa (see picture at right).

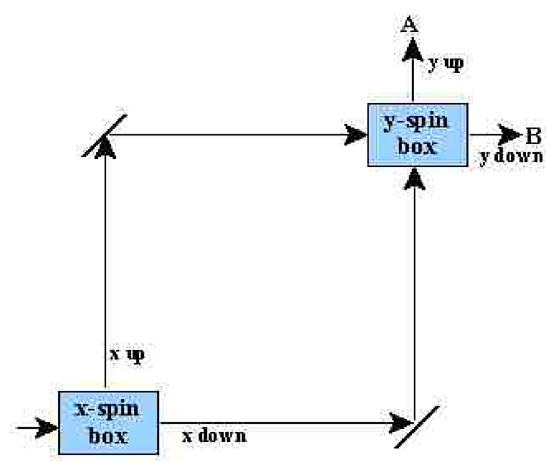


- A mystery: We feed electrons with various properties into the device at right. Here's what we would expect:

What goes in	What should come out
x-spin up	50% at A, 50% at B
x-spin down	50% at A, 50% at B
y-spin up	50% at A, 50% at B
y-spin down	50% at A, 50% at B

- Here's what actually happens:

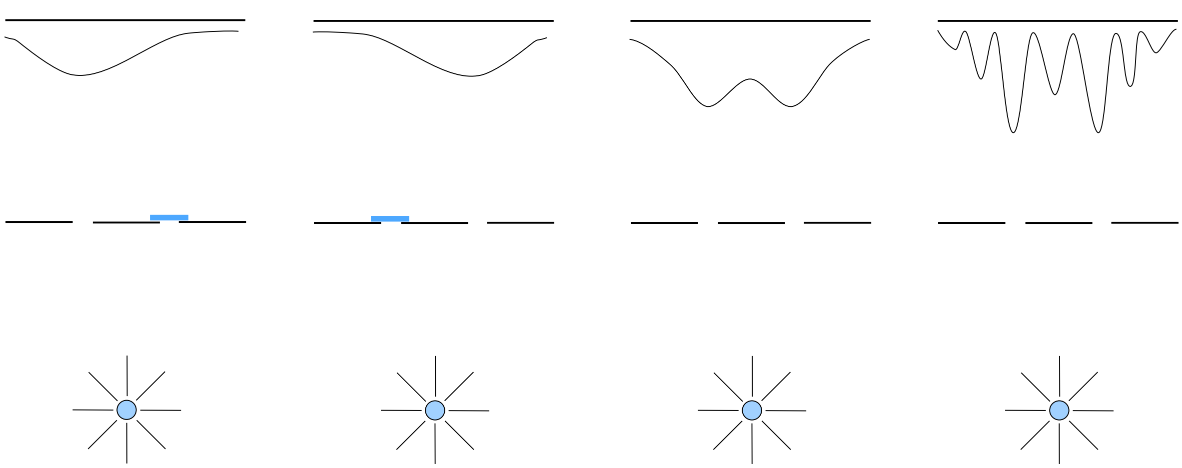
What goes in	What comes out
x-spin up	50% at A, 50% at B
x-spin down	50% at A, 50% at B
y-spin up	100% at A
y-spin down	100% at B



- Superposition (Albert): Say we feed a y-up electron into the device. It comes out at A.
  (1) The electron doesn't (simply) take the upper path.
    - If the lower path is blocked, all the electrons coming through are x-spin up, and have a 50% chance of coming out at B.
    - Similarly if an electron detector is placed on either path to find out where the electron is.
  (2) The electron doesn't take the lower path.
    - Ditto.
  (3) It doesn't take both paths.
    - If electron detectors are placed, an electron is always found along one path or the other.
  (4) It didn't take neither path.
    - Ditto.
    - If both paths are blocked, nothing gets through.
  (5) We say the electron is in a *superposition* of both paths, and a superposition of *x*-up and *x*-down.

II. The Double Slit Experiment

- We shoot particles at a wall with 2 slits in it. Behind this wall is a fluorescent screen. We can see where the particles hit the screen.
- If just one slit is open, we get the distribution in (a).
- If the other slit is open, we get the distribution in (b).
- If both slits are open, we *expect* the distribution in (c).
- Instead, what we get is (d).
  - This is an *interference pattern*, explained by wave mechanics.
  - This occurs even if the particles are sent through one at a time.
- If any sort of detectors are placed to determine which slit the particle goes through, the distribution turns into (c).



(a) (b) (c) (d)

- Which slit does the particle go through?
  - When measured, the wave/particle acts like a particle, and goes through one slit or the other. No interference pattern.
  - When not measured (with respect to which slit it goes through), it acts like a wave. Parts of the wave from both slits interfere with each other. The “particle” is in a “superposition” of going through the left slit and going through the right slit.

Phil. 4400
Notes #18: Quantum Formalism

I. Vector mathematics

What are vectors?

- Vectors have: (a) magnitude/length, (b) direction.
- Can be represented as an arrow in a space (or, given an origin, as a point [see why that's the same]).
- Can also be represented by an array of numbers. (coordinates)

Some mathematical operations on vectors

- Vector × number ⇒ vector

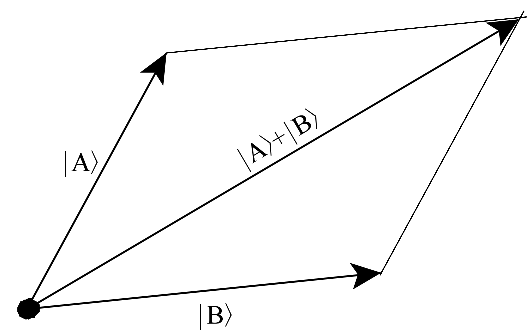
  Multiply length by number. Same direction.

  $$c\begin{bmatrix}a_1\\a_2\end{bmatrix}=\begin{bmatrix}ca_1\\ca_2\end{bmatrix}$$

- Vector + vector ⇒ vector

  $$\begin{bmatrix}a_1\\a_2\end{bmatrix}+\begin{bmatrix}b_1\\b_2\end{bmatrix}=\begin{bmatrix}a_1+b_1\\a_2+b_2\end{bmatrix}$$

  Parallelogram law for addition of vectors: see figure at right.



- Vector • vector ⇒ number
  - ⟨A|B⟩ = length of |A⟩ × length of |B⟩ × cosine (angle between |A⟩ and |B⟩).
    (This is the "dot product" or "inner product" or "scalar product".)
  - Product of perpendicular vectors = 0 (Cosine 90°=0).
  - Product of a vector with itself, ⟨A|A⟩, = square of the length of |A⟩. (Cosine 0°=1.)
  - This is equivalent to:

    $$\begin{bmatrix}a_1\\a_2\end{bmatrix}\bullet\begin{bmatrix}b_1\\b_2\end{bmatrix}=a_1b_1+a_2b_2$$

Vector spaces

A vector space is a collection of vectors, such that, if |A⟩ and |B⟩ are vectors in the space, and *c* is any constant,

c|A⟩ is in the space
|A⟩ + |B⟩ is in the space

Operators

- An operator is a function that takes vectors in a vector space as inputs and returns vectors in that same space as outputs. (It is a mapping from a vector space into itself.)
- Examples:
  "Take any vector and multiply it by 5."
  "Take a vector and rotate it 45°."
  "Take any vector, and return the vector [5 -3]."

Linear operators

- A linear operator is a special kind of operator. It's an operator that satisfies (a) and (b):
  a) $cO|A\rangle = Oc|A\rangle$ (where c is any constant. That is, it doesn't matter if you operate on a vector first, then multiply by a number, or multiply first then operate.)
  b) $O(|A\rangle + |B\rangle) = O|A\rangle + O|B\rangle$ (It doesn't matter if you operate on two vectors first, then add them together, or add the vectors first and then operate.)
- Any linear operator (in a 2-dimensional space) is equivalent to multiplying by a 2×2 matrix. I.e., O can be represented by a matrix, $\begin{bmatrix} O_{11} & O_{12} \\ O_{21} & O_{22} \end{bmatrix}$, such that for any vector $|A\rangle$,

$$O\,|\,A\rangle = \begin{bmatrix} O_{11} & O_{12} \\ O_{21} & O_{22} \end{bmatrix} \times \begin{bmatrix} a_1 \\ a_2 \end{bmatrix} = \begin{bmatrix} O_{11}a_1 + O_{12}a_2 \\ O_{21}a_1 + O_{22}a_2 \end{bmatrix}.$$

  Note that the result on the right hand side of the above equation is a 2×1 matrix.

Eigenvectors

- Sometimes an operator has a special relation to a particular vector: when applied to that vector it doesn't change the direction (but it may change the length). In that case, that vector is an *eigenvector of* that operator. I.e., if

  $O|A\rangle = e|A\rangle$

  (for some constant *e*) then A is an "eigenvector of O".
- Also, *e* is called the "eigenvalue" for that eigenvector.
- For most operators, most vectors are not eigenvectors. Only a few special ones are.
- Some examples:
  - What are the eigenvectors & eigenvalues for the unit operator ("multiply every vector by 1")?
  - What about "multiply every vector by 5"?
  - What about "rotate any vector 75° about the vector $|C\rangle$"?
  - What about the operator $\begin{bmatrix} 3 & 0 \\ 0 & 3 \end{bmatrix}$?

II. The Quantum Mechanical Algorithm

A. Physical states:

Represented by vectors of length 1. These are called *state vectors*.
Note: "states" vs. "properties":
- Properties can take on any of multiple values. (Ex.: "position", "spin in the x-direction")
- States are specific values of those properties (or collections of such values, for a system). (Ex.: "Boulder, Colo.", "spin up in the x direction")

B. Observables (measurable properties):

Represented by linear operators. The operators must relate to the state vectors as follows:
a) If O represents an observable property, then the state vectors that correspond to definite values of that property are the *eigenvectors* of O.

b) When a physical object's state vector is an eigenvector of O with eigenvalue a, then a is the value of the property.

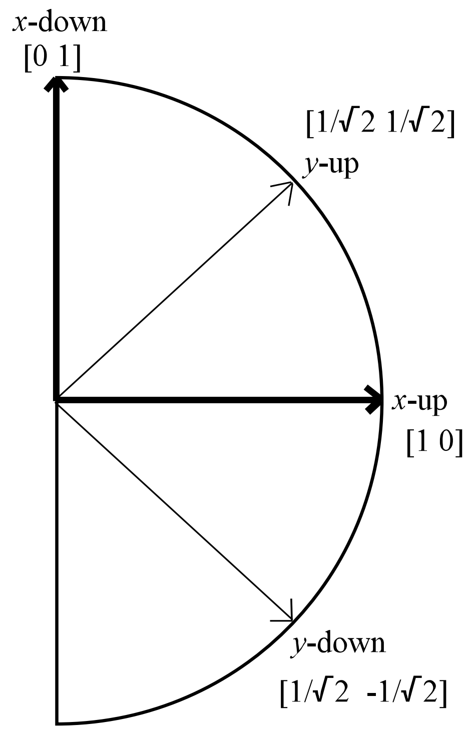
Examples:

$$x\text{-spin} = \begin{bmatrix} 1 & 0 \\ 0 & -1 \end{bmatrix}. \quad |\text{x-up}\rangle = \begin{bmatrix} 1 \\ 0 \end{bmatrix}. \quad |\text{x-down}\rangle = \begin{bmatrix} 0 \\ 1 \end{bmatrix}.$$

$$y\text{-spin} = \begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix}. \quad |\text{y-up}\rangle = \begin{bmatrix} 1/\sqrt{2} \\ 1/\sqrt{2} \end{bmatrix}. \quad |\text{y-down}\rangle = \begin{bmatrix} 1/\sqrt{2} \\ -1/\sqrt{2} \end{bmatrix}.$$

You can verify that these definitions satisfy (a) and (b).

Picture below shows the spin space. (*Do not confuse with physical space!*)



Also notice that:

$$\left|x-up\right\rangle \;\;= \frac{1}{\sqrt{2}}\left|y-up\right\rangle + \frac{1}{\sqrt{2}}\left|y-down\right\rangle$$

$$\left|x-down\right\rangle = \frac{1}{\sqrt{2}}\left|y-up\right\rangle - \frac{1}{\sqrt{2}}\left|y-down\right\rangle$$

$$\left|y-up\right\rangle \;\;= \frac{1}{\sqrt{2}}\left|x-up\right\rangle + \frac{1}{\sqrt{2}}\left|x-down\right\rangle$$

$$\left|y-down\right\rangle = \frac{1}{\sqrt{2}}\left|x-up\right\rangle - \frac{1}{\sqrt{2}}\left|x-down\right\rangle$$

reflecting the fact that $|x\text{-up}\rangle$ is a superposition of $|y\text{-up}\rangle$ and $|y\text{-down}\rangle$, etc.

C. Dynamics of the state vector (unobserved):

When not observed: evolves according to Schrödinger Equation.

- This equation is deterministic.
- It is also linear: If

  $|A\rangle$ evolves into $|A'\rangle$, and
  $|B\rangle$ evolves into $|B'\rangle$

  then

  $a|A\rangle + b|B\rangle$ evolves into $a|A'\rangle + b|B'\rangle$.

D. Results of measurements:

Suppose a system is in a state (represented by) $|A\rangle$, and you measure some observable (represented by) O. Then:

- If $|A\rangle$ is an eigenvector of O, then you will, with certainty, find the system to be in the state corresponding to that eigenvector. The state is not disturbed by the measurement.
- If $|A\rangle$ is *not* an eigenvector of O, then two things will happen:
  1) The system will immediately *jump to* a randomly selected eigenvector of O. The probability of its jumping to any given eigenvector $|E\rangle$ is given by $|\langle A|E\rangle|^2$.
  2) You will thereupon observe the system to be in that state.

- Step (1) above is where chance enters QM.
  - Called “State vector collapse” / “wave function collapse”
  - The claim that wave-function collapses occur is “the collapse postulate”.

III. The Copenhagen Interpretation

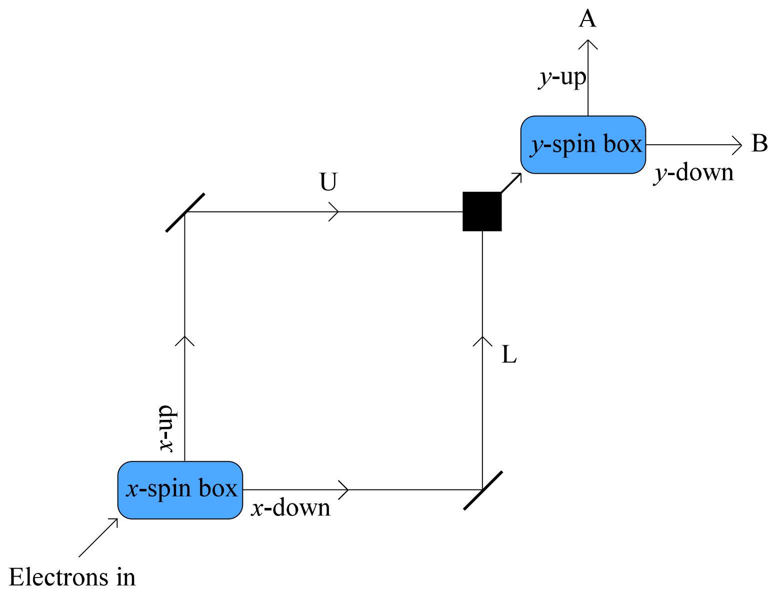
- When an object is in a superposition of two states, it has no definite state. This is not a matter of ignorance.
- Observers (or “measurements”) cause things to go into definite states.
  - Corollary: Observers (or measuring devices) are governed by different laws from the rest of the universe.
- What constitutes a measurement/observation?
  - When there is a conscious being?
  - When there is an interaction with a “macroscopic” object? How large?
- Gives rise to the Shrodinger’s Cat example. Is the cat enough to collapse the wave function?

IV. 'Explanation' of the Quantum Mysteries

In the device at right, we feed in electrons with $|y\text{-up}\rangle$, say.

U and L are points on the upper and lower paths, respectively.

E is the point where the electrons end up when the two paths recombine.



What will happen?

(1) $|y-up\rangle = \frac{1}{\sqrt{2}}|x-up\rangle + \frac{1}{\sqrt{2}}|x-down\rangle$ (as discussed earlier).

(2) An electron with $|x\text{-up}\rangle$ would evolve into $|x\text{-up}\rangle|E\rangle$. (That's the state where it still has spin up in the x direction, and it's located at point E.)

(3) Similarly, an electron with $|x\text{-down}\rangle$ would evolve into $|x\text{-down}\rangle|E\rangle$.

(4) Therefore (due to linearity), an electron with $\frac{1}{\sqrt{2}}|x-up\rangle + \frac{1}{\sqrt{2}}|x-down\rangle$ would evolve into $\frac{1}{\sqrt{2}}|x-up\rangle|E\rangle + \frac{1}{\sqrt{2}}|x-down\rangle|E\rangle$. (From 2, 3.)

(5) This state is equal to:

$$|E\rangle\left(\frac{1}{\sqrt{2}}|x-up\rangle + \frac{1}{\sqrt{2}}|x-down\rangle\right) = |E\rangle\left(\frac{1}{\sqrt{2}}\begin{bmatrix}1\\0\end{bmatrix} + \frac{1}{\sqrt{2}}\begin{bmatrix}0\\1\end{bmatrix}\right) = |E\rangle\begin{bmatrix}1/\sqrt{2}\\1/\sqrt{2}\end{bmatrix} = |E\rangle|y-up\rangle.$$

Hence, the electron will emerge as a y-spin up electron.

The strange effect of measurement:

- If route L is blocked, then step (3) fails.
- If a measuring device is placed to determine which route the electron takes, then
  - wave function collapses into *either* $|x-up\rangle|U\rangle$ *or* $|x-down\rangle|L\rangle$ (each 50% likely).
  - If the first happens, then the electron winds up at $|x-up\rangle|E\rangle$ and subsequently has a 50% chance of coming out at A and a 50% chance of coming out at B.
  - If the second happens, then the electron winds up at $|x-down\rangle|E\rangle$ and subsequently has a 50% chance of coming out at A and a 50% chance of coming out at B.

Phil. 4400
Notes #19: Quantum Nonlocality

I. The EPR Argument

This is due to Einstein, Podolsky, and Rosen (EPR).

• Consider a pair of electrons in the state $|A\rangle$,

$$|A\rangle = \frac{1}{\sqrt{2}}|\text{x-up}\rangle_1|\text{x-down}\rangle_2 - \frac{1}{\sqrt{2}}|\text{x-down}\rangle_1|\text{x-up}\rangle_2$$
$$= \frac{1}{\sqrt{2}}|\text{y-up}\rangle_1|\text{y-down}\rangle_2 - \frac{1}{\sqrt{2}}|\text{y-down}\rangle_1|\text{y-up}\rangle_2$$

In this state, neither electron has a definite spin, *but* they have opposite spin.

• Imagine the two electrons sent far apart, and then spin of electron 1 is measured. Spin of electron 2 subsequently guaranteed to be opposite.

1. If it is possible to predict, with certainty, the outcome of a measurement on an object without disturbing the object, then there exists an element of reality corresponding to that outcome (i.e., the object already has that property).
2. It's possible to measure the x-spin of electron 1, when the system is in state $|A\rangle$, without disturbing electron 2.
   Key Assumption: **Locality:** Events at spacelike separation cannot affect each other.
3. If this is done, the x-spin of electron 2 can be predicted with certainty.
4. So, when the pair is in state $|A\rangle$, electron 2 already has a definite x-spin. (From 1-3)
5. By similar reasoning, electron 2 has a definite y-spin. (*Note:* Same reasoning applies to spin in *any* direction.)
6. So objects can have definite values of "incompatible" properties simultaneously. (From 4,5)
7. State $|A\rangle$ does not represent the x-spin of electron 2.
8. So qm is incomplete. (From 4, 7)

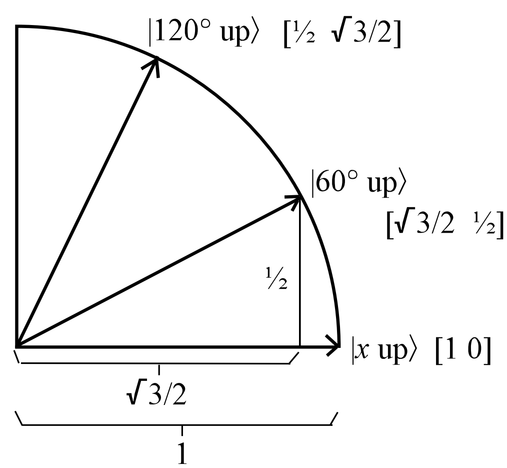
II. Bell's Theorem

• EPR propose that the particles have a determinate value for spin in each direction.
Suppose we measure spin in one of the following 3 directions:

0° (the x direction), 60° (in the x-y plane), or 120° (in the x-y plane)

for each particle. (So there are 9 combinations of measurements.)

• Suppose we measure 60°-spin on electron 1, and x-spin on electron 2.
- Result of 1st measurement: P(spin up) = .5
  P(spin down) = .5



- Result of 2nd measurement:

  |Spin up in the 60° direction⟩ = |60° up⟩ = $\begin{bmatrix} \sqrt{3}/2 \\ 1/2 \end{bmatrix}$

  If 1st measurement was x-spin up, then for 2nd measurement:

  P(spin up, 60°) = |⟨60°up|x up⟩|² = $\left(\begin{bmatrix} \sqrt{3}/2 \\ 1/2 \end{bmatrix} \cdot \begin{bmatrix} 1 \\ 0 \end{bmatrix}\right)^2 = \left[\left(\frac{\sqrt{3}}{2}\right)(1) + \left(\frac{1}{2}\right)(0)\right]^2 = \left(\frac{\sqrt{3}}{2}\right)^2 = \frac{3}{4}$

  P(spin down, 60°) = $1 - P(spin - up) = 1 - \frac{3}{4} = \frac{1}{4}$.
- So, probability of *agreement* (both results come out "spin up" or both come out "spin down") = 3/4. Probability of *disagreement* = 1/4.

• Similarly, we can calculate the probabilities for all the results of each of the nine possible combinations of measurements. Results shown below.

QM predicts:

Spin Property Measured Electron 1	 Electron 2	Probability of *dis*agreement
0°	0°	1
0°	60°	¼
0°	120°	¼
60°	0°	¼
60°	60°	1
60°	120°	¼
120°	0°	¼
120°	60°	¼
120°	120°	1

Question:

Is it *mathematically possible* to achieve these statistical results, by assigning definite values to spin in each of the three directions, for each electron?

• Suppose a large number of electron pairs in state |A⟩ are produced.
  - Each pair is sent in opposite directions, then measurements of spin in the 0°, 60°, or 120° direction is measured on each.
  - We do each of the 9 possible combinations of spin measurements many times, to verify the statistics.
  - Which spin measurements are done each time is *random* (so the electrons can't "know" what spin measurements they're going to encounter).
  - On each occasion, the electrons must have one of the following 8 sets of properties:

    (*Example*: In profile (a1), the first particle is spin up in the 0° direction, spin up in the 60° direction, and spin up in the 120° direction. The second particle is the opposite on all three.)

Possible sets of spin properties for the 2 EPR electrons

	Profile (a1)		Profile (b1)		Profile (c1)		Profile (d1)	
	Elect. 1	Elect. 2	Elect. 1	Elect. 2	Elect. 1	Elect. 2	Elect. 1	Elect. 2
0° spin	↑	⇨	↑	⇨	↑	⇨	⇨	↑
60° spin	↑	⇨	↑	⇨	⇨	↑	↑	⇨
120° spin	↑	⇨	⇨	↑	↑	⇨	↑	⇨

	Profile (a2)		Profile (b2)		Profile (c2)		Profile (d2)	
	Elect. 1	Elect. 2	Elect. 1	Elect. 2	Elect. 1	Elect. 2	Elect. 1	Elect. 2
0° spin	⇨	↑	⇨	↑	⇨	↑	↑	⇨
60° spin	⇨	↑	⇨	↑	↑	⇨	⇨	↑
120° spin	⇨	↑	↑	⇨	⇨	↑	⇨	↑

- *Observations:*
  - In each profile, Electron 2 has the opposite spin properties from Electron 1. This is because, when the *same* spin property is measured on Electron 1 and Electron 2, the probability of disagreement is 100%.
  - Profile (a1) is equivalent to (a2) except that the roles of Electron 1 and 2 have been interchanged. So they're equivalent as far as disagreement goes.
  - Similarly for (b1) and (b2), for (c1) and (c2), and for (d1) and (d2).
  - These 8 profiles are exhaustive.

- *Terminology:*

  a = the frequency with which (profile (a1) or profile (a2)) occurs.
  b = the frequency with which (profile (b1) or profile (b2)) occurs.
  c = the frequency with which (profile (c1) or profile (c2)) occurs.
  d = the frequency with which (profile (d1) or profile (d2)) occurs.

- *Equations:*

$a+b+c+d = 1$ **(1)** Because the 8 alternatives are logically exhaustive.

$a+b = \frac{1}{4}$ **(2)** Because when 0 and 60 are measured, P(disagreement) = ¼.

$a+c = \frac{1}{4}$ **(3)** Because when 0 and 120 are measured, P(disagreement) = ¼.

$a+d = \frac{1}{4}$ **(4)** Because when 60 and 120 are measured, P(disagreement) = ¼.

- *The Impossibility:*
  Adding equations **(2)**, **(3)**, and **(4)**:

$$3a+b+c+d = \frac{3}{4} \qquad \textbf{(5)}$$

  Now, subtracting equation **(1)** from equation **(5)**:

$$2a = -\frac{1}{4} \rightarrow a = -\frac{1}{8} \qquad \textbf{(6)}$$

  Note: This is not possible. Profile (a1) or (a2) cannot occur -1/8 of the time.

- The predictions of QM have been experimentally verified. (Alain Aspect's experiment)

Conclusion

- EPR's theory is wrong.
- In fact, *Locality* is false.
  - There is superluminal action. (Influences between events outside each other's light cones.)
  - This may be incompatible with Special Relativity.
  - This is independent of one's interpretation of QM, or even the QM algorithm: The *experimental results* are incompatible with Locality.

Phil. 4400
Notes #20: Bohm's Interpretation of QM

I. Basic postulates

(a) A physical system consists of particles *and* a pilot wave.
(b) The wave always evolves in accordance with the Schrödinger Equation. No collapse.

$$i\hbar\frac{\partial\Psi}{\partial t}=-\frac{\hbar^2}{2m}\nabla^2\Psi+V\Psi$$

(c) Particle has a determinate but unknown initial position. The (epistemic) probability of its being at a location is proportional to the square of the amplitude of the wave function at that location. $\rho=|\Psi|^2$
(d) The wave causes the particle to move in a specific way. The particle gets carried along with the flow of the amplitude of the wave function, according to the equation below. (It moves in the direction of the gradient of the wave function.) The equation of motion:

$$\frac{dQ_k}{dt}=\frac{\hbar}{m_k}\mathrm{Im}\frac{\Psi^*\nabla_k\Psi}{\Psi^*\Psi}(Q_1,\cdots,Q_N)$$

(e) For a system of many particles, there is a *single* wave, occupying a many-dimensional *configuration space*. The equation in (d) determines the change in the position of the system in configuration space.

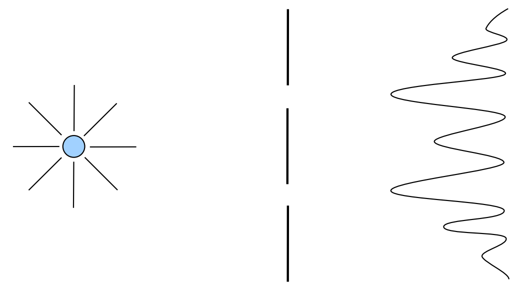
Configuration space:
- A mathematical "space" that a system occupies, with three dimensions for each particle.
- The system occupies a point in that space. The location of the system in the configuration space reflects the locations of all the particles in physical space.
- Example: Consider two particles, A [located at (1, 3, -4)] and B [located at (-1, 2, 0)]. The 2-particle system occupies the point (1, 3, -4, -1, 2, 0) in the 6-dimensional configuration space.

II. Interesting features

- Postulates (c) and (d) entail that the probability distribution for particle positions at any *later* time will *also* be proportional to Ψ^2. (The equation of motion is specifically cooked up to achieve this result.)
- The theory is deterministic. But indeterministic variants can be developed. (As suggested by Bohm & Hiley in *The Undivided Universe*.)
- The theory gives the standard empirical predictions of quantum mechanics.
  - One exception: If a sufficiently precise collapse theory is given, it is possible in theory (but extremely difficult) to test for wave function collapses. Bohm predicts that no such collapse will be found.
- The theory is nonlocal. Instantaneous action at a distance is possible. Bohm says everything is interconnected.
- All properties other than position are "contextual".
  Contextual properties: Properties that depend on a relationship of the object to its environment (esp. the experimental apparatus used for "measuring" them).
  - Ex.: Outcome of a spin measurement depends on orientation of the measuring device.

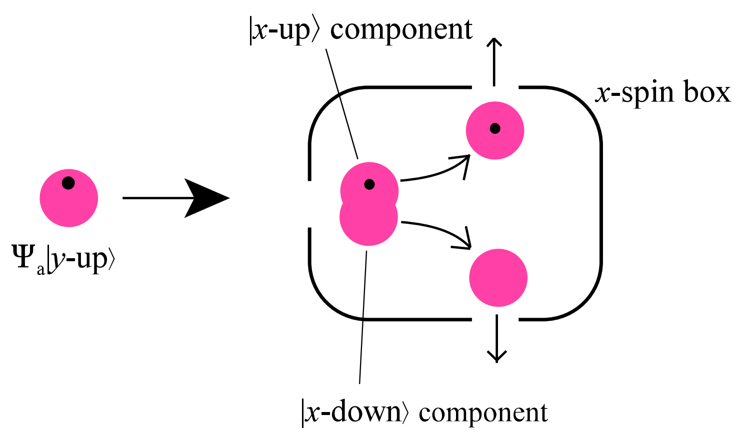
III. How does the theory deliver QM phenomena?

A) The double slit experiment



- Pilot wave goes through both slits, producing interference.
- Particle goes through one slit or the other, depending on its initial position.
- The equation of motion [(d) above] implies that the particle will be carried away from areas where the amplitude of the wave is lowest. Hence the observed interference pattern.
- If one slit is blocked, the pilot wave only goes through the other. No interference.

B) A spin measurement

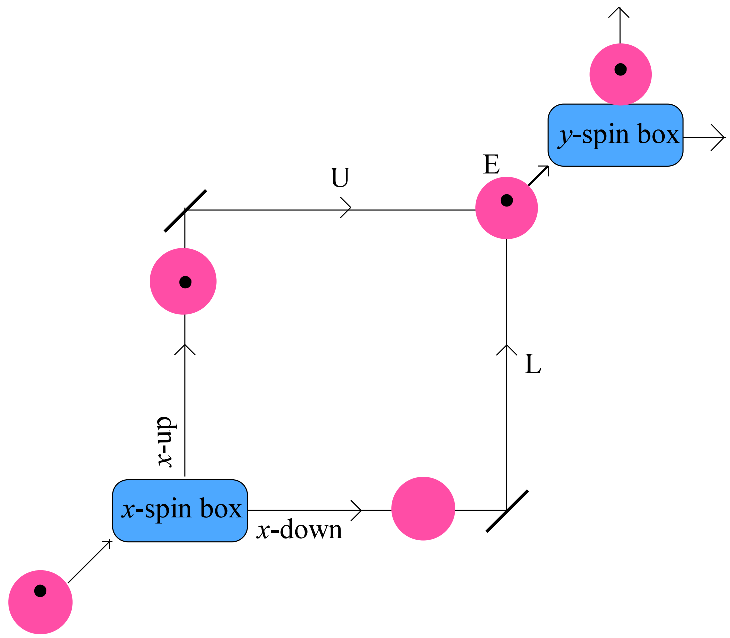


- Electron starts out with |y-up⟩ wave function, is fed into x-spin box.
- The wave function evolves: The |x-up⟩ component of the wave function moves towards the aperture indicating "spin up", while the |x-down⟩ component moves the opposite way.
- Electron carried along with the wave function. Suppose electron starts in upper half of the wave. Then it will move up.
  - As the "x-up" and "x-down" components move apart, the electron winds up in a region where the "x-down" component is absent *first*.
  - It is subsequently carried along by the "x-up" part of the wave function.
- *Note:* No collapse. The |x-down⟩ part of the wave function still exists.
- Why will electron subsequently be measured as *x*-up, with 100% probability?
  - |x-down⟩ component is no longer in the region where the electron is located.
  - Electron's motion determined by the wave function at its current location.
  - This explains the *apparent* collapse.
- But if the x-down component is somehow brought back to where the electron is, it can then affect the electron's behavior.

C) The mysterious two-path experiment

- Electron takes one path or the other.
- The wave splits in two and takes both paths.
  - The |x-up⟩ component takes the U path.
  - The |x-down⟩ component takes the L path.

- The wave components recombine at point E, creating a |y-up⟩ wave function once again. (See diagram.)



D) "Effective" collapses

- Measurement brings about "effective collapse": the wave function does not actually collapse, but system acts as if it did.
  - Components of the wave function corresponding to different possible measurement outcomes (outcomes that would have occurred had the initial position been different) still exist.
  - But these components separate into different places in configuration space.
  - Only the wave function components in the vicinity of *the system's current position* affect its motion.
- The non-existence of collapses is *in principle* detectable. After a measurement:
  - Different components of the wave function (corresponding to different possible measurement outcomes) must be recombined in configuration space.
  - An 'interference effect' (as in the double slit experiment, or the 2-path experiment above) would occur, according to Bohm.
  - Collapse theories predict no interference effect.
- This is *in practice* unfeasible. Why:
  - Recombination of wave function components implies:

    The system is at a place in configuration space, such that it would have been at that same place, if one of the other measurement outcomes had occurred.

  - That means: *Every particle* in the system is where it would have been (in physical space), had another measurement outcome occurred.
  - That means: Every trace of the measurement outcome, in the position of any particle, has been erased.

IV. Advantages of Bohm

1. Uniform dynamics:
   - Wave function always evolves in the same way. (The collapse postulate is bogus.)
   - Measuring devices/observers governed by same laws as the rest of physical reality.
2. Logical coherence:
   - Cats are either alive or dead, not in a 'superposition' of alive and dead.
3. Precision: Copenhagen interpretation requires a vague concept of "measurement," or "macroscopic" objects.
4. Determinism, if you consider that an advantage.

V. Objections to Bohm

1. Conflicts with Special Relativity.
   - Bohm's theory is *blatantly* nonlocal:
     - In the EPR experiment, outcome can depend on order in which measurements are done.
     - Anyway, because motion of system depends on the wave function at the system's location in configuration space, the location of particle 1 can affect the motion of particle 2 (even if particles 1 and 2 are far apart).
   - That means: it requires a preferred reference frame.
     - But we can *not* use the nonlocality to send signals.
     - We also cannot *identify* the preferred reference frame.
2. A positivist objection: Bohm's theory entails the existence of undetectable facts (as just noted).
3. Copenhagen got here first. Bohm's theory lacks novel predictions.
4. Another conspiracy of silence objection: Isn't it bizarre how the world conspires to prevent us from detecting (a) the preferred reference frame, (b) the truth of determinism, (c) the lack of collapses? I.e., things are set up exactly to make it look like orthodox QM is true?
5. The probabilistic postulate, $\rho = |\Psi|^2$, is ad hoc. Why should the epistemic probability be that?
6. *Technical objection:* Difficult to come up with a Bohmian version of relativistic quantum field theory.

Phil. 4400
Review of Unit 4

Know these concepts:
vector, state vector
superpositions
  Including, how they're different from mere ignorance
wave interference effects
operator
linearity (incl.: linear dynamics)
eigenvector
observables
wave function collapse
  & why it's supposedly needed
locality / non-locality
configuration space
effective collapse

Know these examples, & what happens in them:
Double slit experiment
Ordinary spin measurements
  & Copenhagen account of them
  & Bohmian account
The two-path experiment
  & how Copenhagen Interp. explains it
  & how Bohm explains it
EPR example
  & what it was intended to show

Know these principles:
Evolution of wave function (unobserved)
Bell's theorem & what it shows
In Bohm's interpretation:
  His view of wave-particle duality
  His view of collapse, "measurement", and such
  The motion of particles
  Determinism
  Non-locality
  'Effective' collapses: when they happen
Copenhagen Interpretation, including:
  Collapse postulate
  what's determinate / indeterminate
  views of 'measurement'

Know these arguments:
Objections to Copenhagen Interp:
  Logical incoherence
  Special role for observers
Objections to Bohm:
  How it conflicts w/ Relativity
  The conspiracy of silence