Phil. 2750
Notes #7: Time Travel

I. Issues/Problems about Time Travel

- Some things that commonly happen in time travel stories:
  - Backward causation: When A causes B, even though A occurs after B.
  - Circular causation: A series of events that loops back on itself; A causes itself (directly or indirectly).
  - Self-defeating causal chains: When A prevents itself (or one of its causes) from occurring.
    - ✏ The Grandfather paradox: I decide to go back in time and shoot my grandfather (before my father is conceived). But this would result in my never having been born, so . . .
  - Changing the past: The time traveler causes something to happen differently from the way it "originally" happened.
    - ✏ This seems to involve two time dimensions
- Time travel stories to discuss:
  - "All You Zombies"
  - *Timeline*

  Are they consistent?
- A basic challenge to concept of time travel: Is time travel contradictory? Does it imply that the time traveler *will* (in the future) be in the *past*?
- Two alternative interpretations of "time travel" stories:
  - *The Time Machine story*: In this story, a person "travels back in time".
  - *The Annihilation Machine story:* A crazy person appears with a bunch of beliefs about the future. Later, a person just like him is born in the normal way, grows up, and gets into a machine that annihilates him.
  - The Time Machine story and the Annihilation Machine story involve "the same things happening at the same times". They are different interpretations of the same events (in a sense).
  - Claim: The Annihilation Machine story is the correct interpretation.
    - ✏ Objection: "The Annihilation story is highly improbable."
    - ✏ See why this is confused.

II. Some Ways to Make Time Travel Coherent?

- The branching timeline theory.
  - The "time machine" sends you to an earlier time in a parallel world.
- On the alleged contradiction & the 2 alternative interpretations of "time travel": Distinguish 'personal time' and 'external time'. (Lewis)
  - Personal time: defined by processes internal to the person (mental & physical).
  - External time: defined by external processes.
  - Time travel stories involve a separation between personal & external time: an event is in the 'future' in personal time, but in the 'past' in external time.
  - Is this concept of "personal time" correct? Is there such a time dimension?
- Fixed points and self-supporting causal sequences.

- Something comes out of the "time machine" at the earlier time that causes that same thing to wind up in the position right in front of the time machine at the later time.
  - ✏ The theory is that *whatever* the environment is like, there will be *something* that could come out of the time machine that has that property.
  - ✏ Whatever it is, it will be what comes out.
  - ✏ This is a "fixed point": A fixed point of a function *f* is a value of x for which *f*(x) = x.
  - ✏ Fixed point theorem: A theorem showing that a given function must have a fixed point. Such theorems exist for many functions.
  - ✏ Generally depend on continuity assumptions: *f* should map a space of possible states continuously *into* itself. (See fig. 1.)
  - ✏ The existence of a fixed point depends on the topology of the state space. (See fig. 2.)
- This eliminates "changing the past" and the Grandfather Paradox. It allows circular causation.
- Unclear whether this solution works.

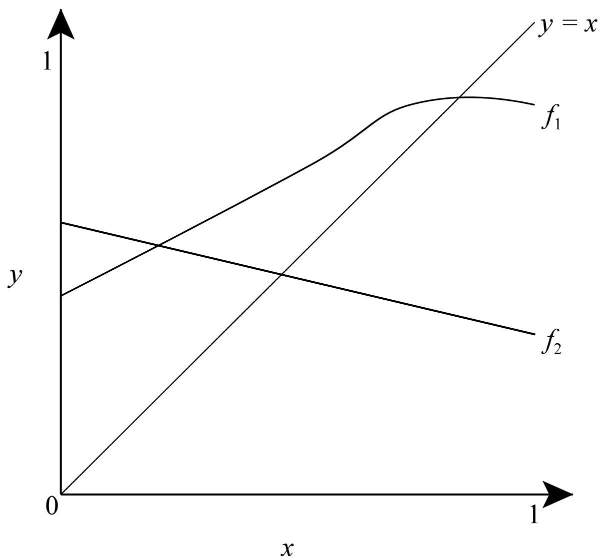


Figure 1. A simple fixed-point theorem: Assume that *f* maps [0,1] continuously into [0,1]. *f* must have a fixed point, for it is impossible to move continuously from x=0 to x=1 without intersecting the x=y line.

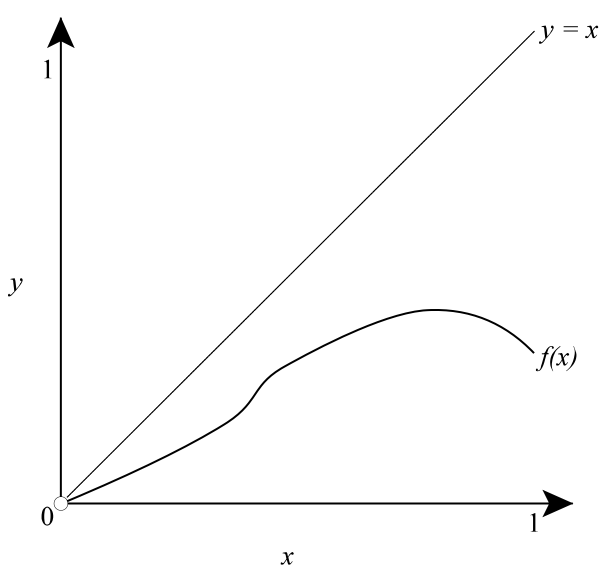


Figure 2. A function with no fixed point: Assume that *f* maps (0,1) continuously into (0,1). *f* may have no fixed point. When the single point x=0 is removed, one can move from the left to the right edge of the graph without touching the x=y line.

Phil 2750
Notes #8: Possible Worlds

I. The Concept of Modality

- Modal concepts: "possible", "necessary", "impossible", "contingent". These are inter-definable:
  P is necessary = ~(Not-P is possible).
  P is impossible = ~(P is possible).
  P is contingent = (P is not necessary & P is not impossible).
- The philosopher's use: possibility = *logical* possibility.
  - Distinguish from: physical possibility, epistemic possibility, feasibility. These are restricted forms of possibility.
- Importance of modality: involved in other concepts:
  - Conditionals ("if A had been the case, B would have been the case")
  - Free will
  - False propositions
  - Meanings of propositions in general
  - Dispositional concepts: Fragility, dangerousness, disgustingness, etc.
- How to understand modal concepts? A standard view:
  - Logically necessary = true in all logically possible worlds.
  - Physically necessary = true in all possible worlds in which the actual laws of nature hold.
  - Epistemically necessary = true in all possible worlds in which our actual knowledge holds.

II. Lewis' Craziness

- There are 'possible worlds.'
- Other possible worlds are worlds, in exactly the same sense that the actual world is one.
- They exist, in exactly the same sense that the actual world exists.
- They each have their own spacetime, disconnected from our spacetime. Like parallel universes, with no way to travel between them & no spatiotemporal relations between worlds.
- 'Actual' just means "pertaining to the world that I'm in."

An argument for the existence of 'possible worlds':

1. Some modal statements are true. (E.g., "I could have had a V8.")
2. Modal statements are best interpreted as assertions about possible worlds, as indicated below:
   "It is possible that p" = "In some possible world, p."
   "It is necessary that p" = "In every possible world, p."
   "It is impossible that p" = "In no possible world does p hold."
3. Therefore, possible worlds exist.

III. Alternative Views

1. Modal expressions are unanalyzable.
   Objection: "This is not an alternative theory at all, but an abstinence from theorizing."
2. 'Possibly, P' = ' "P" is a consistent sentence.'
   Objection: What does "consistent" mean?

    a. "consistent" means "could be true."
       Problem: Then the theory is circular.
    b. "consistent" means "whose denial cannot be derived from some formal system."
       Problem: From Godel's theorem, for any (consistent) formal system, there are truths of arithmetic that cannot be derived from it. The negation of such a sentence is therefore 'consistent' according to (b). But the negation of a truth of arithmetic is not possible.
3. "Ersatz possible worlds": There are 'possible worlds', but they're really just sets of sentences.
   Objection: this will run into the same problem as (2).

IV. Objections to Possible Worlds

1. Only our own world actually exists.
   Reply: True, but "actually" only means "relative to this world".
2. Realism about p.w.'s is unparsimonious: there are too many entities in your theory.
   Reply:
   - Distinguish (a) qualitative simplicity: reduction in the number of *kinds* of things in a theory, (b) quantitative simplicity: reduction in the number of *instances* of a given kind.
   - My (Lewis') theory has qualitative simplicity.
   - Qualitative simplicity is all that matters.
3. Quine says possible objects are hard to individuate. Not so on my (Lewis') theory, since they are exactly the same sorts of objects as the objects in our world, except that they happen to be in other worlds. Each possible object occupies only its own world.
4. (Not really an objection.) Tell us more about p.w.'s. How many are there? Are there multiple qualitatively indistinguishable p.w.'s?
   Reply: I don't know, and I don't know any way to find out.

V. Methodological/epistemological points:

- We start out with pretheoretical 'opinions.'
- Philosophy should seek a *systematic theory* that *respects (or explains the truth of?) those opinions*.
- Also, we seek qualitatively simpler theories, ceteris paribus.

Phil 2750
Notes #9: Mysteries of Quantum Mechanics

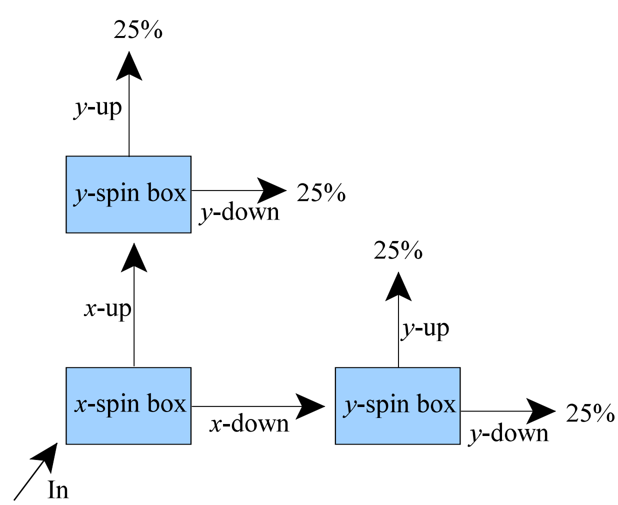
I. Background: Philosophical Interest of Quantum Mechanics

- Some things sometimes said about QM:
  - That it shows that the universe is governed by chance.
  - That it shows that observers create reality.
  - That it converges with Eastern mysticism.
  - That it shows that the Law of Excluded Middle is false, that reality is indeterminate.
    - ✏ LEM: The principle that for any proposition A, either A or ~A.
  - That it shows that all of reality is interconnected.
  - That it shows that maybe there are infinitely many parallel worlds!
- Questions you should ask:
  - Are any of these things true?
  - Why would people say these things?
  - How *could* such things be demonstrated?
- Must understand QM to answer those questions.

II. Electron Spin Mysteries

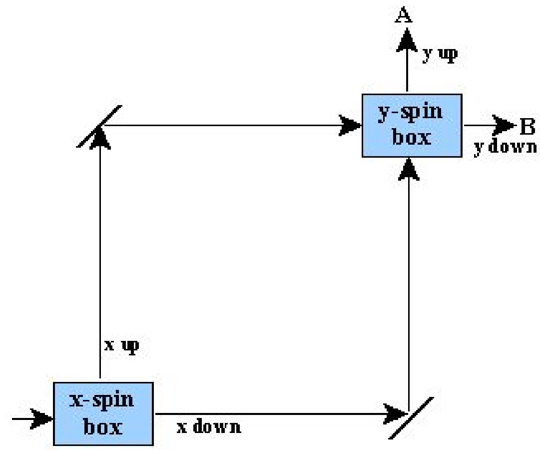
- Electrons have a property called "spin". About spin:
  - An electron has spin in any given direction, e.g., "spin in the *x* direction", "spin in the *y* direction", "spin in the *z* direction". These are distinct.
  - The spin in a given direction can take one of two values: "spin up" (spin +½) and "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:

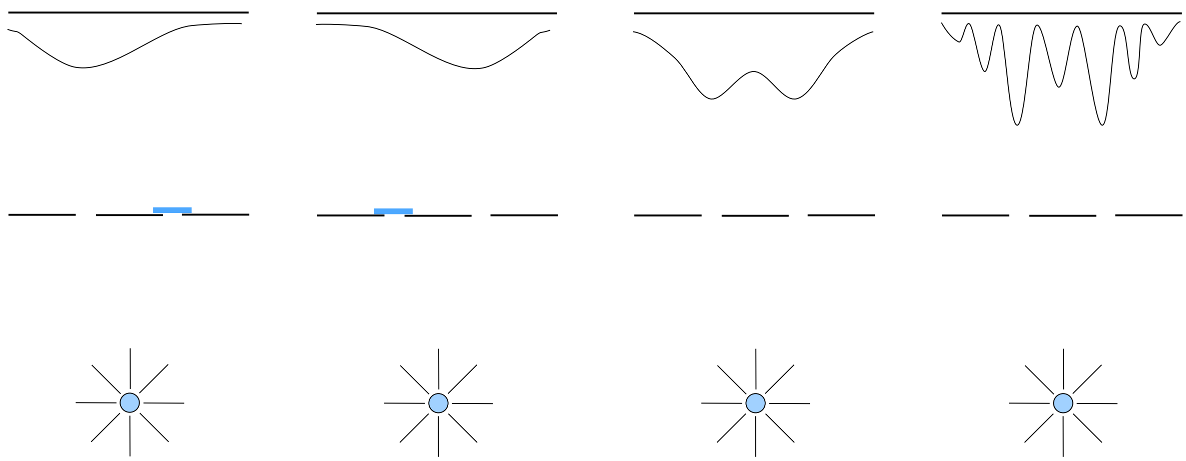
What goes in	What comes out
x-spin up	50% at A, 50% at B
x-spin down	50% at A, 50% at B
y-spin up	100% at A
y-spin down	100% at B

- 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 doesn'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.

III. 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. See diagram below.
- 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).
- 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.



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

Phil. 4400
Notes #10: Quantum Mechanics: The Standard View

I. Background

- QM contains an algorithm for predicting results of measurements.
- The measurement results described above, and many more, are predicted by this algorithm.
- QM is strongly confirmed:
  - These measurement results are very surprising.
  - Classical physics fails to predict them.
  - QM predicts them.
  - This is strong evidence that the algorithm *somehow* reflects the nature of physical reality.
- Q: How should this algorithm be *interpreted*?

II. Basics of the Algorithm

Physical states:
Represented by *state vector*, or *wave function*.

Observables:
These are measurable properties. Represented by *operators* on vectors. Important distinction:

- Properties: This is something that can take on multiple different values (e.g. "position", "charge", "spin").
- States: These are specific values of a property (e.g., "(0,4,5)", "charge of -1", "spin +½").

Determinate states:

- *Eigenvector of an operator:* This is a vector that has a special mathematical relationship (never mind exactly what it is) to the given operator.[1]
  - Most vectors are *not* eigenvectors of a given operator.
  - Each operator has its own, distinct set of eigenvectors.
- When a physical system's state vector is an eigenvector for operator O, then the physical system has a definite value for the property corresponding to O. (We say the system is in an "eigenstate" of that property.)
- Important: When a system is in an eigenstate for a given property, it is generally *not* in an eigenstate for certain other properties.
  - Example: *No* vector is an eigenvector for both *x*-spin and *y*-spin.
  - No vector is an eigenvector for both position and momentum.

What happens when we're not looking:
When physical systems are not being observed/measured, their state vectors evolve in accordance with a *deterministic* law known as the Schrödinger Equation.

What happens when we look:

a) For systems in an eigenstate of O:

---

[1]The mathematical relationship is this: If v_e is an eigenvector of O, then O(v_e) equals a constant times v_e. That is, O fails to change the direction of v_e, and only (at most) changes its length.

- Measurement of O will definitely (100% probability) find the system to be in the corresponding state.
- The state is not disturbed by the measurement.

b) For systems *not* in an eigenstate of O:
- Measurement of O will cause the state vector to jump to an eigenstate of O. The probability of jumping to a given eigenstate is given by a rule known as "the Born rule."[2]
- System will be measured as having the corresponding state.
- Subsequent measurements will have the same result.

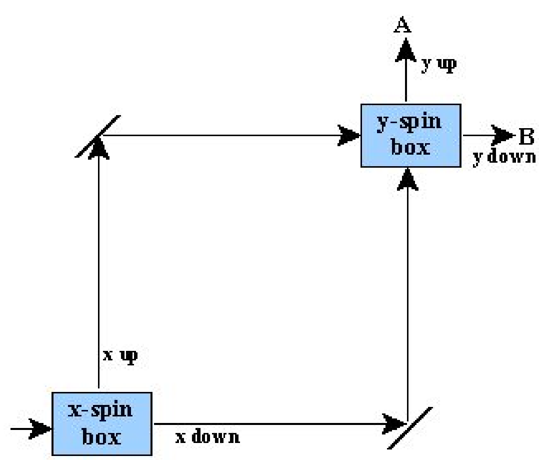
III. The Copenhagen Interpretation

1) The wavefunction is complete: there is nothing in physical reality that the wavefunction doesn't represent.
2) Reality is indeterminate: sometimes objects fail to have, e.g., definite locations. Follows from (1).
   - Example: Heisenberg Uncertainty Principle: No physical object ever has a specific location and a specific momentum at the same time.
   - This is *not* an epistemological claim. It is a metaphysical claim.
   - The QM formalism is incapable of even *representing* an object as having such simultaneous pairs of determinate states!
3) "Observation" or "measurement" induces a *physical change* in the system being observed.
4) The world is *indeterministic*: which state a system jumps to on measurement is fundamentally random.

IV. Explaining the Electron Spin Experiment

Suppose y-up electron goes in at lower left:

- As long as no one *looks at* which way the electron exits the *x*-spin box, or it hasn't interacted with a "macroscopic" object, the *x*-spin hasn't been measured yet.
  - Wave function has not collapsed.
  - Electron in a superposition of *x*-up and *x*-down.
  - The *y*-up vector is *identical* (mathematically equal) to a superposition of *x*-up and *x*-down vectors.



[2]This is the rule: suppose we're measuring a certain property. O is the operator corresponding to that property. Suppose v_e is the eigenvector corresponding to some particular value of the property. And suppose v_s is the current state vector of our physical system. Then the probability of the system jumping to the state corresponding to v_e is $|v_e{\cdot}v_s|$, the absolute value of the inner product of v_s and v_e.

- Also: superposition of upper path and lower path.
- When electron reaches y-spin box, it is still y-up. Hence, measured to be y-up.

Suppose x-up electron goes in:

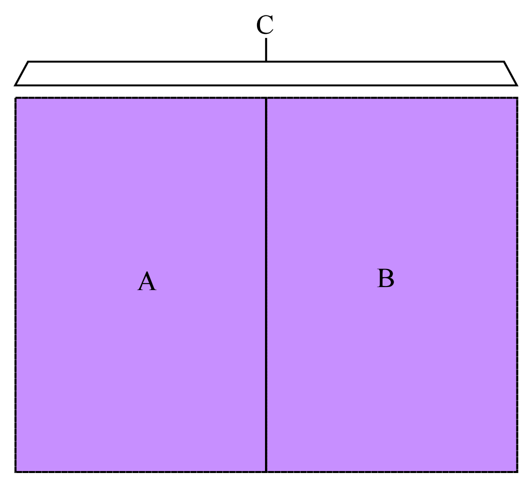
- Takes upper path through device.
- Arrives at y-spin box with x-up.
- Undergoes wavefunction collapse, with 50% probability of becoming y-up, 50% probability of becoming y-down.

Suppose y-up electron goes in, and we observe which path it takes:

- The observation of which path it takes induces a wavefunction collapse, with 50% probability of electron becoming definitely on the upper path, 50% probability of becoming definitely on the lower path.
- Subsequently, the electron is x-up (say) and on the upper path.

V. Criticisms of Copenhagen

- Entails that observers/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?
- The CI is self-contradictory:
  - Assume an electron is definitely in region C, but not in any definite part of it, i.e., it's in a superposition of all different parts of C. (See diagram.)
  - Let A be the left half of C, and B be the right half of C.
  - CI tells us:
    - ☞ Electron is in (A or B).
    - ☞ Electron isn't in A.
    - ☞ Electron isn't in B.
  - That is a contradiction.



Phil. 4400
Notes #11: Many-Worlds Interpretation of QM

I. The Theory

- When measurements happen:
  - World splits into multiple parallel worlds.
  - Each possible result happens in some world.
- How many worlds?
  - How to explain the probabilities of standard QM: ratio of # of worlds in which a given result happens.
  - The probabilities can take on real-# values.
  - Hence, you need *infinitely many* worlds. (Continuum many, in fact.)
- When does the splitting happen? Two versions of the theory:
  a) Whenever a superposition occurs.
  b) Only when a *measurement* of a system in a superposition is carried out.

II. Advantages of this Theory?

- Preserves determinism.
- Consistent with Locality?
- Might avoid the self-contradiction objection, solve Schrödinger's cat problem?
  - Only if you posit world-splitting whenever superpositions exist. See problems with this below.

III. Criticism of the Theory

- Violates Occam's Razor: posits too many things.
- Not testable: Many worlds are not observable.
- Why don't we bump into the other copies of ourselves?
- When do worlds split?
  a) Superposition version: Problems:
    - *Every* quantum state is a superposition of *something*. Determinacy could only be preserved for some, privileged properties. Choice of preferred properties is arbitrary.
    - Do the parallel worlds affect each other?
      - If no: Then no explanation for interference effects, as in double-slit experiment.
      - If yes: Then no explanation for *lack* of interference effects *after* measurement.
  b) Measurement version: Problems:
    - Still assigns special role to "observers" or "measurements".
    - Still allows superpositions for unmeasured systems. Still subject to self-contradiction objection.

Phil. 4400
Notes #12: 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.

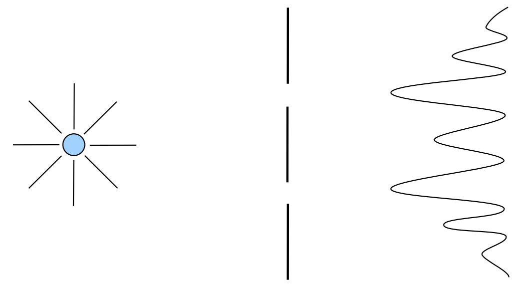
II. Interesting features

- 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.

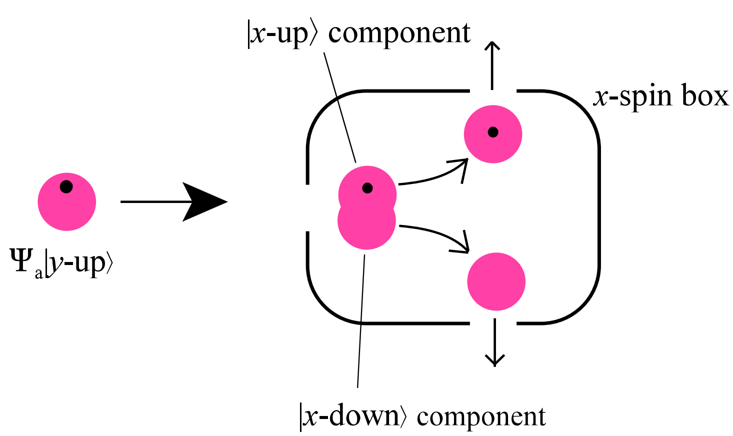
III. How does the theory deliver QM phenomena?

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

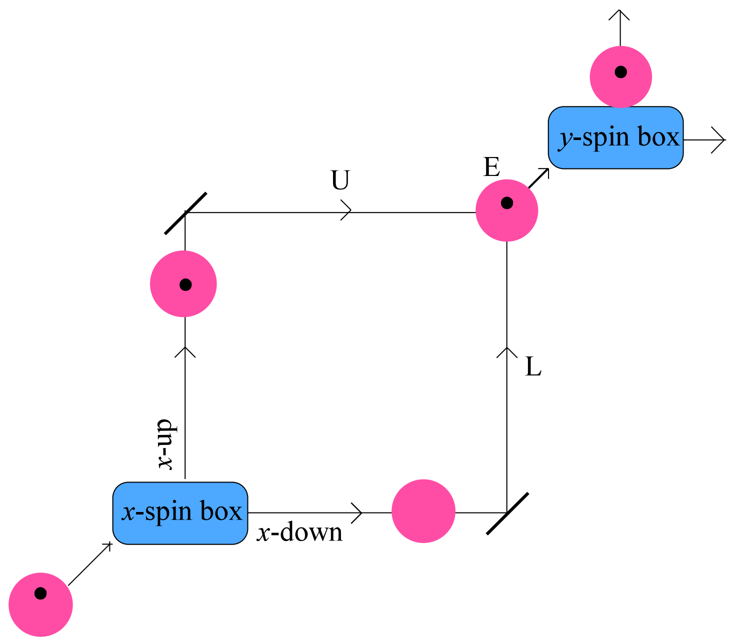


- Electron starts out with |*y*-up⟩ wave function, is fed into *x*-spin box.
- The wave function evolves: The |*x*-up⟩ component of the wave function moves towards the aperture indicating "spin up", while the |*x*-down⟩ component moves the opposite way.
- Electron carried along with the wave function. 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.

Lesson:
None of the things usually said to be supported by QM need be accepted. Except one: Bohm's theory *does* imply that everything is interconnected.

V. Objections to Bohm

1. *Conflicts with Special Relativity.*
   - Bohm's theory is nonlocal: Instantaneous action at a distance is possible.
   - This conflicts with Special Relativity:
     - In SR, the time-order of events outside each other's light cones is relative to a reference frame.
     - Bohm's theory requires such events to have a determinate time order (it matters which event affects which).
     - So Bohm 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. *The 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.