(some reminders)

(1) final HW posted, along with some new links
(2) please fill out the (online) course evaluations by Dec 7
(3) turnitin will be activated shortly for your final essay

In the realm of aesthetic theory, the longstanding duality separating art and reality, or the perceiver and the world, has been exploded by modern discoveries about the nature of perception. Thus the argument I'm making about the effort among contemporary novelists to find a position blending some transformed assumptions from realism and antirealism, to create an art about both reality and artistic process, appears in persuasive theoretical terms in Raymond Williams 's *The Long Revolution*.

> The new facts about perception make it impossible for us to assume that there is any reality experienced by man into which man's own observations and interpretations do not enter. Thus the assumptions of naive realism—seeing the

> things as they really are, quite apart from our reactions to them—become impossible. Yet equally, the facts of perception in no way lead us to a late form of idealism; they do not require us to suppose that there is no kind of reality outside the human mind; they point rather to the insistence that all human experience is an interpretation of the non-human reality. But this, again, is not the duality of subject and object—the assumption on which almost all theories of art are based. We have to think, rather, of human experience as both objective and subjective, in one inseparable pro- cess.[8]

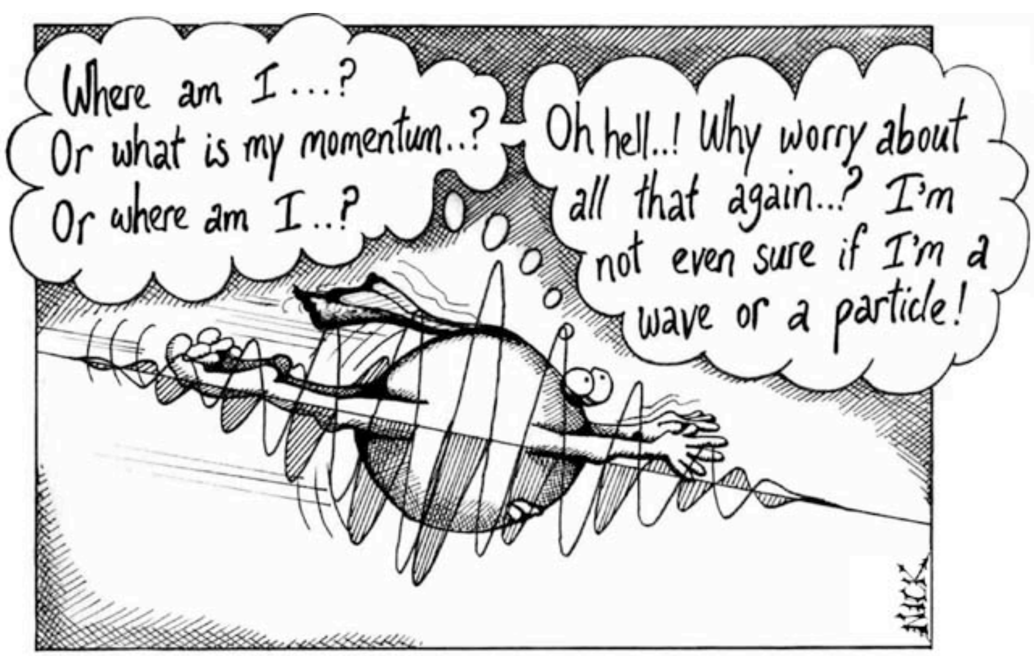
Following Williams's logic, we can understand the group of writers I've identified as radically original: they form a

but cf. Sokal & Bricmont, *Fashionable Nonsense*

Recall our revisited uncertainty principle: you can't predict with certainty what a photon will do at an HV polarizer and at a 45/-45 polarizer...

- Either the particle doesn't actually *"know"* its "HV polarisation" and its "±45 polarisation," or
- if it *does* know both, then measuring one changes the other.

(Either the results of measurements are *not* predictable from the state, or the measurements themselves randomly disturb the state)



Photon self-identity problems.

EPR argument

Q: what do we need to do, to decide whether or not particles "really have" positions, independent of the fact that the quantum state doesn't describe one position?

- **"If, without in any way disturbing a system, we can predict with certainty the value of a physical quantity, then there exists an element of reality corresponding to that quantity."**

- **If two systems are separated by a distance d, nothing I do to one of them can affect the other in a time < d/c.**

If by measuring system 1, I can figure out what system 2's position is *at that instant*, I am learning about system 2 without disturbing it...

Einstein, Podolsky, & Rosen (1935)

Source

Alice **Bob**

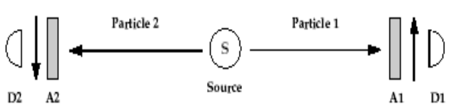


FIG. 1. Bohm's version of the EPR Gedankenexperiment

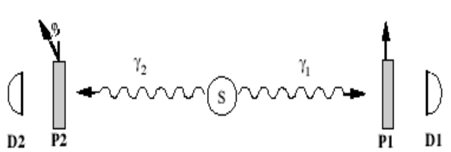


FIG. 2. Optical version of EPR experiment

2 particles emitted together at the same time with opposite speeds.

If Alice measures her particle's position, she knows Bob's. But if she measures her particle's momentum, she knows Bob's.

Did her measurement "affect" Bob's particle instantaneously?
Spooky action at a distance
Or did Bob's particle already have both?
Hidden variables (QM "incomplete")

If particle 1 gets through H, particle 2 never does (only V);

if particle 1 gets through 45, particle 2 never does (only -45);

etc...

Hidden variables?

Einstein seems to have thought the particles "knew" what they were going to do, even if we didn't: QM not wrong but "incomplete".

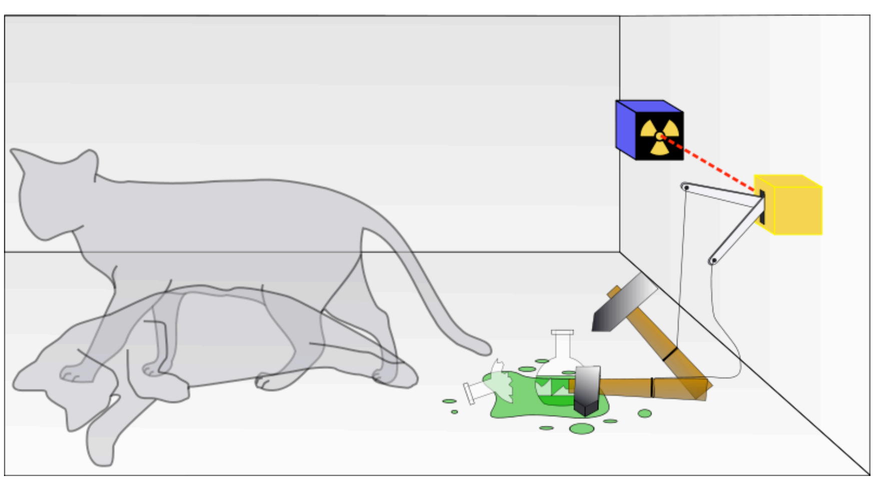
John Bell's example, "Bertlmann's socks":

Schrödinger’s Reply

Schrödinger 1935:
"entanglement"
"Verschränkung"

$$|\psi\rangle = |B\rangle_L |W\rangle_R + |W\rangle_L |B\rangle_R$$

=  + 



"Spontaneous parametric down-conversion"

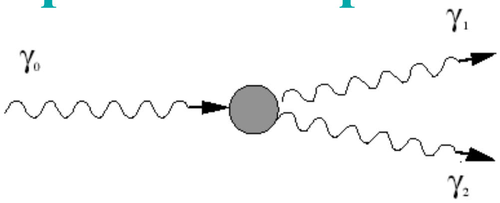
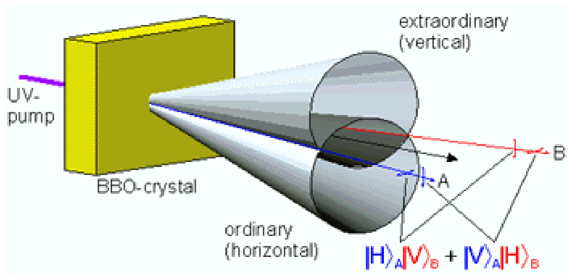
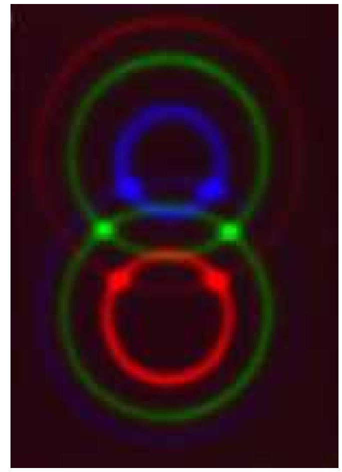


FIG. 3. Two-photon decay from one photon





If you set it up right, the photons are guaranteed to have "opposite" polarisations (0 vs 90, 45 vs -45, 22.5 vs 112.5) no matter what measurement you choose...

Bohr's Reply

(no one really understood him)

The (U.S.?) establishment's reply

The theory still works, right?

Result: from 1935 to roughly 1990 it was frowned upon for physicists to talk about such things.

It took until 1964 for Bell to publish the theorem which I think is among the most significant intellectual results of the 20th century.

This theorem was used in experiments in the early 1970s, more conclusively in 1982, and is now applied in labs all around the world and even used for possible applications.

(I will try to give you a sense of how such a theorem works ...)

Bell's inequality: d'Espagnat's version

Suppose there are three "properties" we can test: A, B, & C.

If you have A but not C, what more can we say?

Well, you either have B or not B.

So you either have (A & not B) or (B & not C).

I know that it's cold but not snowing.
I immediately conclude it's either

- cold *and* raining OR
- not raining *and* not snowing

Probabilities

E.g., if (1 gets through H & 2 gets through 45),

either we have (1 does H & 2 does 22.5)

or (2 doesn't 22.5 and 2 does 45)

same as (1 does H & 2 does 22.5) or (1 does 22.5 and 2 does 45)

P(H,45) < P(H,22.5) + P(22.5,45)

But if 1 does H, 2 has a 50% chance of getting through 45...
And if 1 is H, 2 has a 15% chance of passing 22.5.
If 1 is 22.5, 2 has a 15% chance of passing 45.

But 50% is *not* smaller than 15%+15% !

What should we conclude from Bell's Theorem (Bell's inequality)?

Somehow, QM disagrees with his result.

(1) Either:
QM is wrong
Or the theorem is wrong

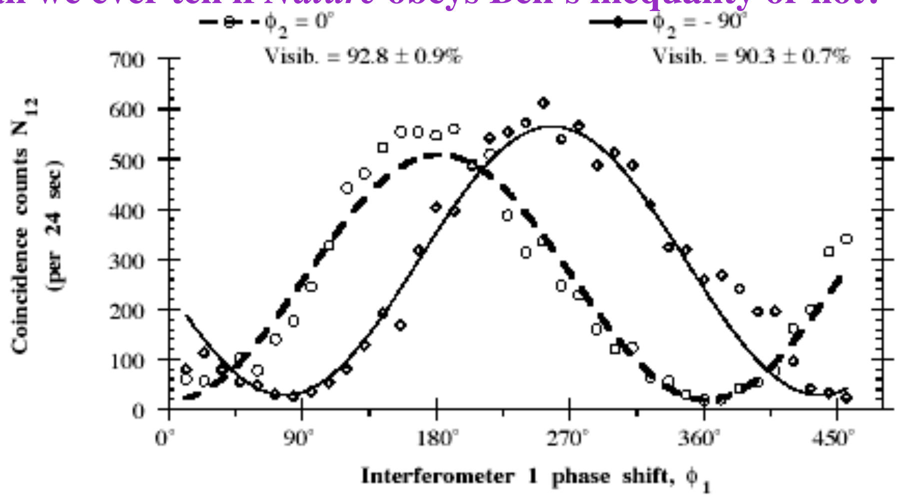
(2) If QM is right...

some assumption of the theorem must be wrong.

What did it assume? That you could ask what particle 1 or particle 2 would do, *and that its "decision" didn't depend on what you chose to measure about the other particle!*

Well, actually, we made other funny assumptions, like "if I know particle 1 would get through H, I am *certain* particle 2 won't get through H"

A central fact about science:
***Nothing* is perfect, nothing is *certain*.**
I can't really say *every* time 2 gets through 45, 1 gets through -45.
So how can we ever tell if *Nature* obeys Bell's inequality or not?



Bell's Theorem, more carefully

Forget Quantum Mechanics. ***(And this time, don't presuppose particular properties like "perfect" correlations...)***

Suppose you've got two particles, and A & B can choose what to measure on each of them – "color" or "dirtiness", for example.
For each measurement, they either get "1" or "0".

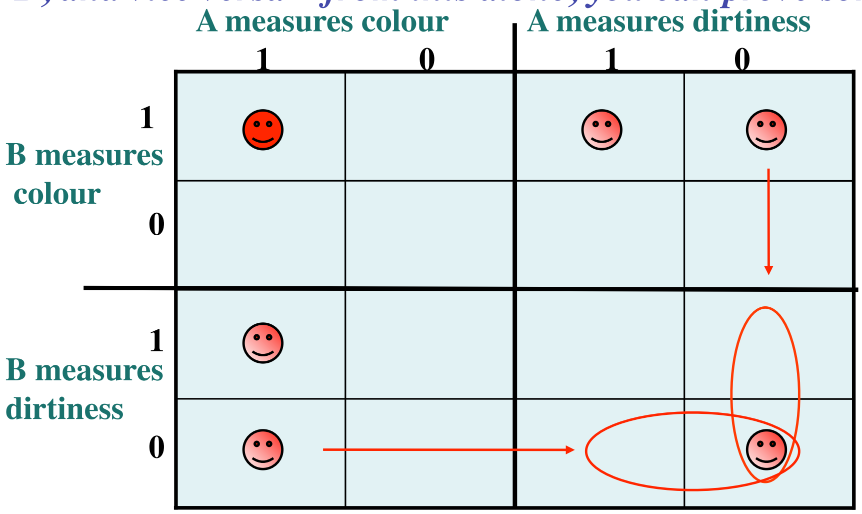
If there are "hidden variables," then A's choice doesn't affect B, and vice versa – *from this alone*, you can prove something.

"Locality" assumption (no action at a distance) --
based on Einstein's reasoning that no influence travels >c.

Bell's Theorem

Suppose you've got two objects, and Alice & Bob can choose what to measure on each of them – "color" or "dirtiness", for example. For each measurement, they either get "1" or "0".

If there are "local hidden variables," then A's choice doesn't affect B, and vice versa – from this alone, you can prove something.



The HVs must tell me what would happen for any choice of measurement: i.e., which box of *each quadrant* the particle is "in."

P(cc ⇒ 11) ≤ P(cd ⇒ 11) + P(dc ⇒ 11) + P(dd ⇒ 00)

For those of you interested in a more mathematical description

"Correlation does not imply causation" **(or does it?)**

Independence: P(A&B) = P(A)•P(B)

Correlation due only to a common cause:
P(A&B | λ) = P(A | λ)•P(B | λ);
note that the full P(A&B) = Σ P(A&B | λ) P(λ) ≠ P(A)•P(B) in general.

Experimental Test of Local Hidden-Variable Theories*

Stuart J. Freedman and John F. Clauser
Department of Physics and Lawrence Berkeley Laboratory, University of California, Berkeley, California 94720
(Received 4 February 1972)

We have measured the linear polarization correlation of the photons emitted in an atomic cascade of calcium. It has been shown by a generalization of Bell's inequality that the existence of local hidden variables imposes restrictions on this correlation in conflict with the predictions of quantum mechanics. Our data, in agreement with quantum mechanics, violate these restrictions to high statistical accuracy, thus providing strong evidence against local hidden-variable theories.

Since quantum mechanics was first developed, there have been repeated suggestions that its statistical features possibly might be described by an underlying deterministic substructure. Such features, then, arise because a quantum state represents a statistical ensemble of "hidden-variable states." Proofs by von Neumann and others, demonstrating the impossibility of a hid-

Experimental Test of Bell's Inequalities Using Time-Varying Analyzers

Alain Aspect, Jean Dalibard,[a] and Gérard Roger
Institut d'Optique Théorique et Appliquée, F-91406 Orsay Cédex, France
(Received 27 September 1982)

Correlations of linear polarizations of pairs of photons have been measured with time-varying analyzers. The analyzer in each leg of the apparatus is an acousto-optical switch followed by two linear polarizers. The switches operate at incommensurate frequencies near 50 MHz. Each analyzer amounts to a polarizer which jumps between two orientations in a time short compared with the photon transit time. The results are in good agreement with quantum mechanical predictions but violate Bell's inequalities by 5 standard deviations.

PACS numbers: 03.65.Bz, 35.80.+s

Bell's inequalities apply to any correlated measurement on two correlated systems. For instance, in the optical version of the Einstein-Podolsky-Rosen-Bohm *Gedankenexperiment*,[1] a source emits pairs of photons (Fig. 1). Measurements of the correlations of linear polarizations are performed on two photons belonging to the same pair. For pairs emitted in suitable states, the correlations are strong. To account for these correlations, Bell[2] considered theories which invoke common properties of both members of the

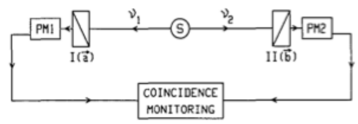
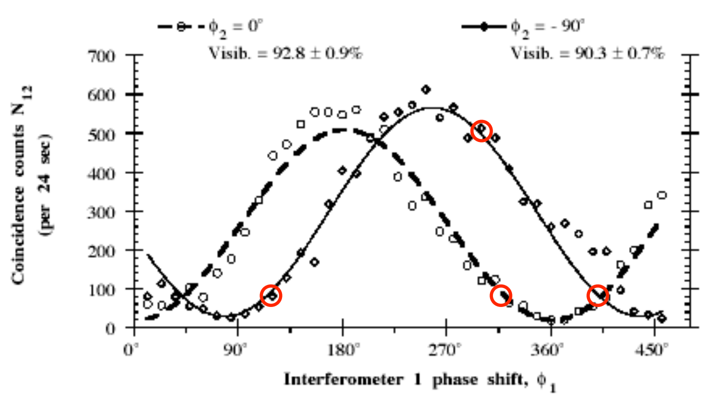


FIG. 1. Optical version of the Einstein-Podolsky-Rosen-Bohm *Gedankenexperiment*. The pair of photons ν_1 and ν_2 is analyzed by linear polarizers I and II (in orientations $\vec{a}$ and $\vec{b}$) and photomultipliers. The coincidence rate is monitored.

The "colour/dirtiness" curve for a photon pair

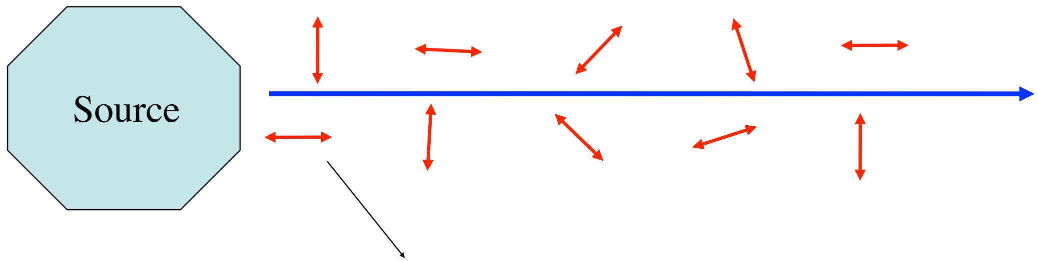


Bell's inequality is violated – in other words, whether or not quantum mechanics is right, this experiment can't be explained by "local hidden variables."

Somehow, we know that the particles don't know what they're doing!

Why can’t we imagine that they do?

Can’t we imagine that each time a pair is emitted, it really comes out with 2 definite polarisations?

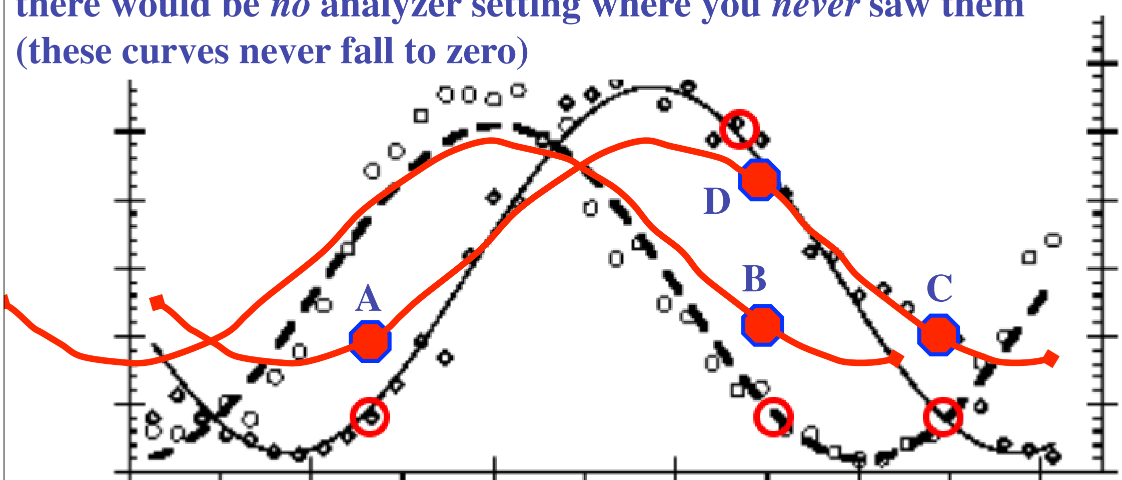


If we measured VH, 1 would be V and 2 would be H.

But **-- if we measured DA, 1 could be either D or A (50/50), and 2 could be either D or A (50/50);**
one half the time, they would be the same (doesn’t happen).

What would we get?

Although it’d be *most likely* to see them for analyzers 90º apart, there would be *no* analyzer setting where you *never* saw them (these curves never fall to zero)



A+B+C > D – exactly as Bell predicted.
And *not* the same as the QM predictions.