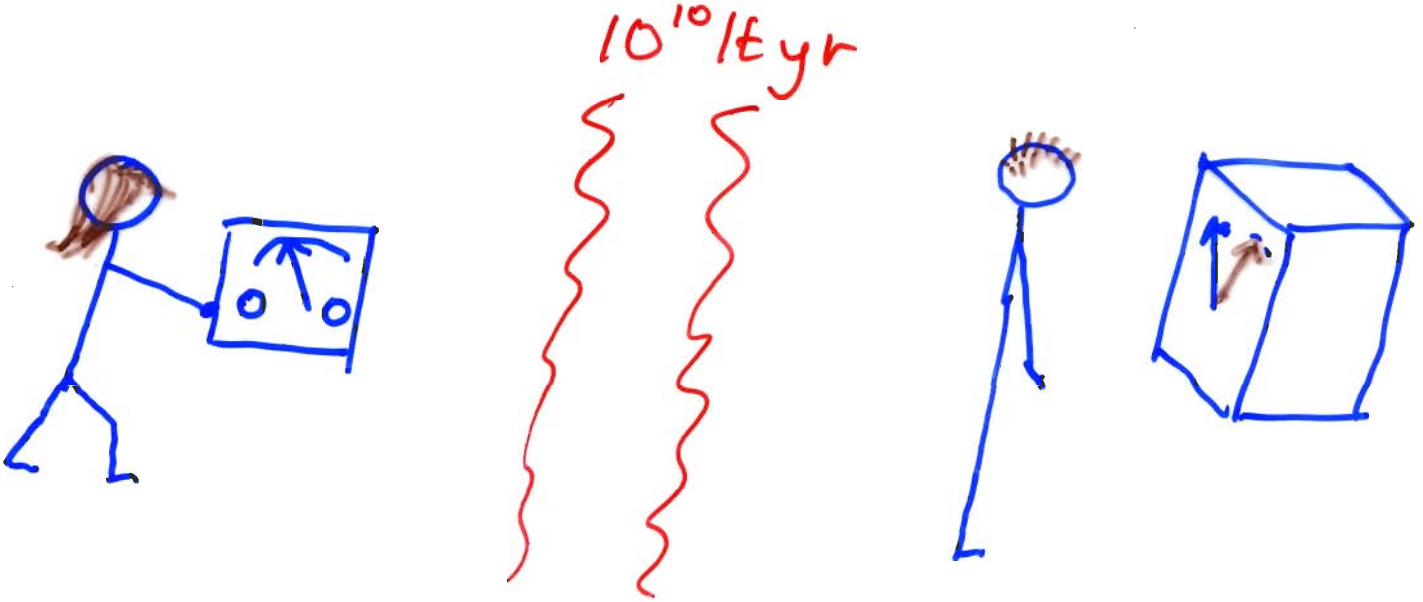
Is Quantum Mechanics Non-Local?

- On Is Face - Silly.
(Unable to send Signals Faster Than Light).



Non Local - Alice - Performs Manipulation $\Longrightarrow$ Bob - sees effect. (arb. prep. instr.)

MANY PEOPLE (POPES!)

- QUANTUM EFFECTS ARE NON-LOCAL

" WEIRD ACTION AT A DISTANCE " (EINSTEIN)

QUANTUM "SUPERPOSN."

STATES $|\psi\rangle$, $|\phi\rangle$

POSSIBE "States" of

PHYSICAL WORLD

a) There exists "a"

$\cos\theta\,|\psi\rangle + \sin\theta e^{i\mu}\,|\phi\rangle$

prob. phase

(i) Prob of $|\psi\rangle \Rightarrow \cos^2\theta$

$|\phi\rangle \Rightarrow \sin^2\theta$

ii) There exists some attribute of system. whose prob of value = 1 for this State.

Spin 1/2 electron.

$|\uparrow\rangle, |\downarrow\rangle$

$\frac{1}{\sqrt{2}}(|\uparrow\rangle + |\downarrow\rangle) = |\rightarrow\rangle$

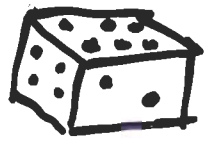
$\frac{1}{\sqrt{2}}(|\downarrow\rangle - |\uparrow\rangle) = |\leftarrow\rangle$

$(|\uparrow\rangle + i|\downarrow\rangle) = |\bullet\rangle$

$(|\uparrow\rangle - i|\downarrow\rangle) = |\circ\rangle$

($|\uparrow\rangle$ - probability of finding spin pointing in up direction is 1).

"Classical"



$\Rightarrow \quad |6\rangle$

TOTAL Prob of 1

$\Rightarrow \frac{1}{6}|1\rangle + \frac{1}{6}|2\rangle + \cdots + \frac{1}{6}|6\rangle$

There exists No attribute for which this leads to prob = 1 for some value.

(other than trivial $\Rightarrow$ eg dice exists)

Non Commuting Attributes.

"States of One Corresponding to certainty for value $\Rightarrow$ Prob. Distr for Other. (Uncertainty).

Paradigm: Position, Momentum (Heisenberg, Born Jordan 1925)

$$\Delta x \quad \Delta p \geq \frac{\hbar}{2}$$

System can never have certainty in position & momentum

EINSTEIN PODOLSKY ROSEN

EINSTEIN: PROBABILITIES COME THROUGH IGNORANCE.

- DIE 1/6 coming up 6
  ⟹ we are ignorant of actual state of die. ⇒ Throw it
  Die knows which way it will come up.

[Metaphor - die knows nothing → ontological fact about world.
→ fact about counterfactual situation where we study die very carefully.]

If we can know value of an attribute with certainty without affecting the system, Then that attribute belongs to an element of reality.

To be complete, every element of reality must have an expression in the theory

Same mass.

$$X_1 + X_2 = 0$$

$$P_1 - P_2 = 0$$

Measure P_2 arb accuracy

Measure X_1 arb accuracy

Value $P_2 \Longrightarrow$ value P_1

$\Downarrow$

Know P_1, X_1 arb accuracy. (at least just before meas. of X_1)
(Meas. X_1 disturbs P_1

No Wave Function

Can Represent condition

of Particle 1

Q. M. Is Incomplete.

(Or it is non-local)

One could object to this conclusion on the grounds that our criterion of reality is not sufficiently restrictive. Indeed, one would not arrive at our conclusion if one insisted that two or more physical quantities can be regarded as simultaneous elements of reality *only when they can be simultaneously measured or predicted*. On this point of view, since either one or the other, but not both simultaneously, of the quantities P and Q can be predicted, they are not simultaneously real. This makes the reality of P and Q depend upon the process of measurement carried out on the first system, which does not disturb the second system in any way. No reasonable definition of reality could be expected to permit this.

While we have thus shown that the wave function does not provide a complete description of the physical reality, we left open the question of whether or not such a description exists. We believe, however, that such a theory is possible.

E. P. R.

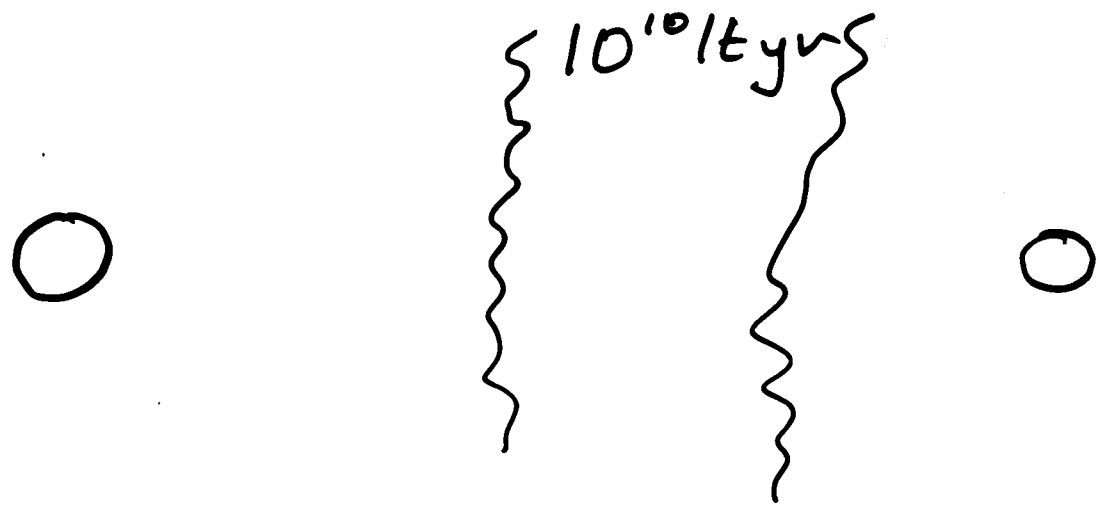
$$\frac{1}{\sqrt{2}}\left(|\uparrow\rangle|\uparrow\rangle + |\downarrow\rangle|\downarrow\rangle\right)$$

$$= \frac{1}{\sqrt{2}}\left(|\nearrow\rangle|\nearrow\rangle + |\swarrow\rangle|\swarrow\rangle\right)$$

At any angle in

in  xy plane

particle spin directions are absolutely correlated.



Particles in "entangled" state

Measure $\longleftrightarrow$ for blue

$\Downarrow$

$\longleftrightarrow$ for black.

Measure $\updownarrow$ for black

$\Longrightarrow$ Know both $\updownarrow$ $\alpha\longleftrightarrow$

BOHR

Largely incoherent or beside the point, But goes for option EPR reject.

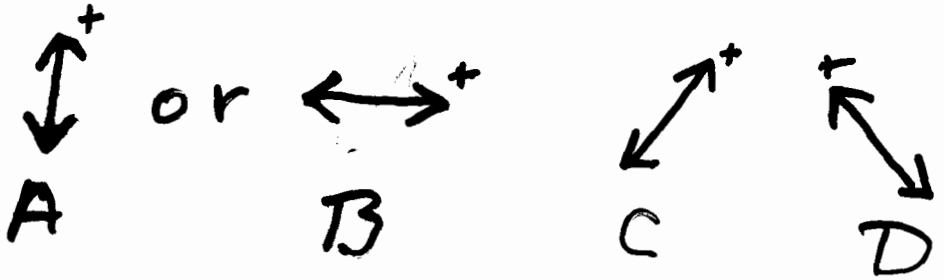
BELL

CAN CLASSICAL MECH MIMIC QUANTUM MECHANICS?

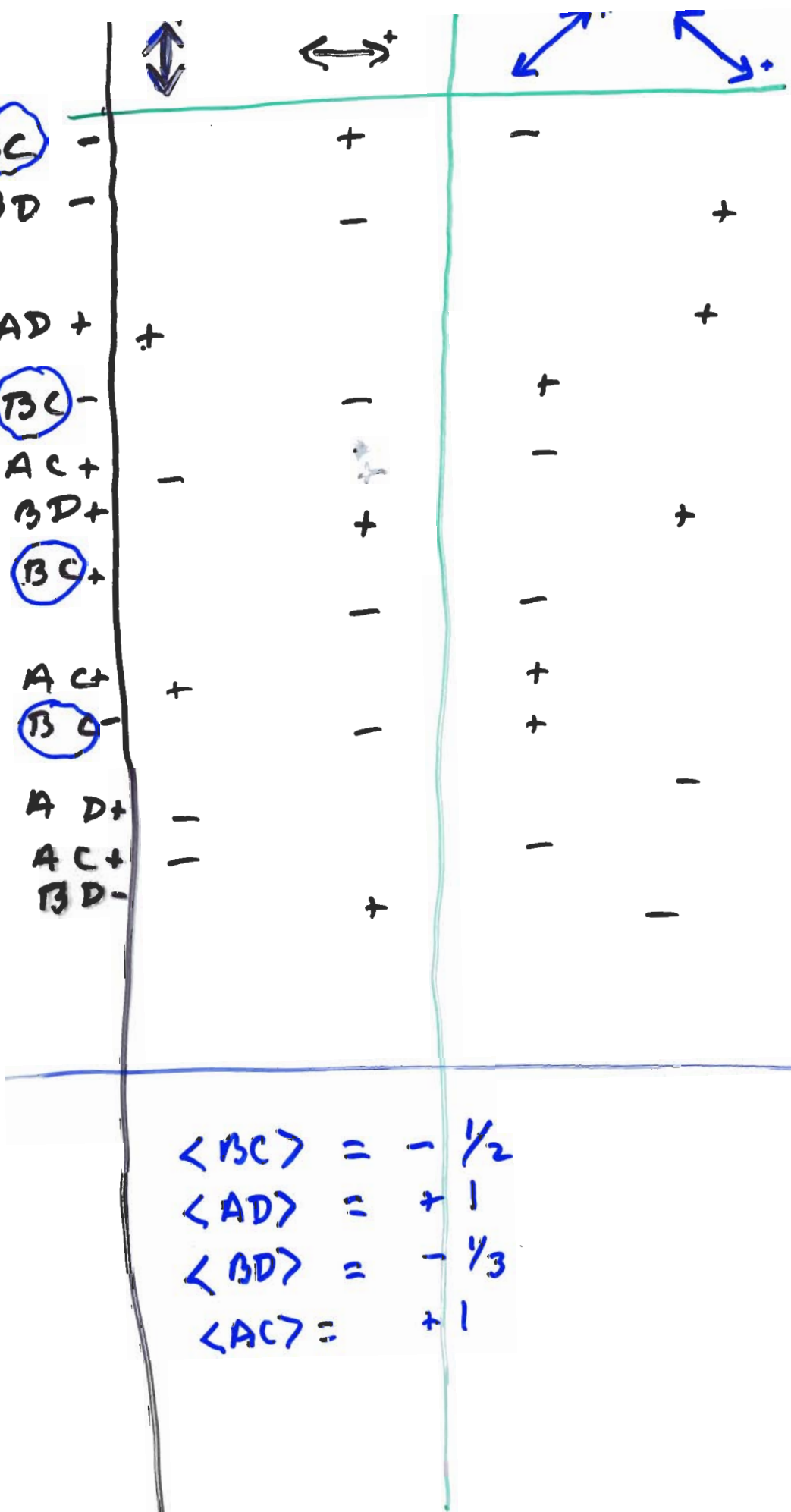
Are classical correlations As Good As QUANTUM Correlations ?

$$\frac{1}{\sqrt{2}}\left(|\uparrow\rangle|\uparrow\rangle + |\downarrow\rangle|\downarrow\rangle\right)$$

$(+1)(+1)$ $(-1)(-1)$



$$\langle AC\rangle + \langle AD\rangle + \langle BC\rangle + \langle BD\rangle$$



$\langle BC \rangle = -\frac{1}{2}$

$\langle AD \rangle = +1$

$\langle BD \rangle = -\frac{1}{3}$

$\langle AC \rangle = +1$

CRITICAL ARGUMENT.

Measure correlations

$\langle AC \rangle , \langle AD \rangle , \langle BC \rangle , \langle BD \rangle$

In separate experiments

$\langle AC + BC - AD + BD \rangle$

In single experiments.

$\langle (A+B)C + (B-A)D \rangle$

Since $A, B \pm 1$, Therefor

i) $A+B = \pm 2, 0$

ii) $A-B = \pm 2, 0$

Perfectly anti corr.

$A+B = \pm 2 \iff A-B = 0$

$A+B = 0 \iff A+B = 0.$

$$\langle \underbrace{(A+B)C}_{\pm 2} + \underbrace{(-A+B)D}_{0} \rangle$$

$$\text{or} \quad 0 \qquad \pm 2$$

Average must lie between ± 2

QUANTUM $= 2\sqrt{2}$

IS

$$\langle AC \rangle - \langle AD \rangle + \langle BC \rangle + \langle BD \rangle \overset{?}{=} \langle AC + BC - AD + BD \rangle$$

LOCALITY.

SINCE No way system 1 can know which of C, D measured at 2, Values cannot depend

Ie - EQUIVALENCE VALID FOR CLASSICAL SYSTEM.

EQUIVALENCE - TRUE IN Q. MECH.

Q. Mech MUST BE

LOCAL

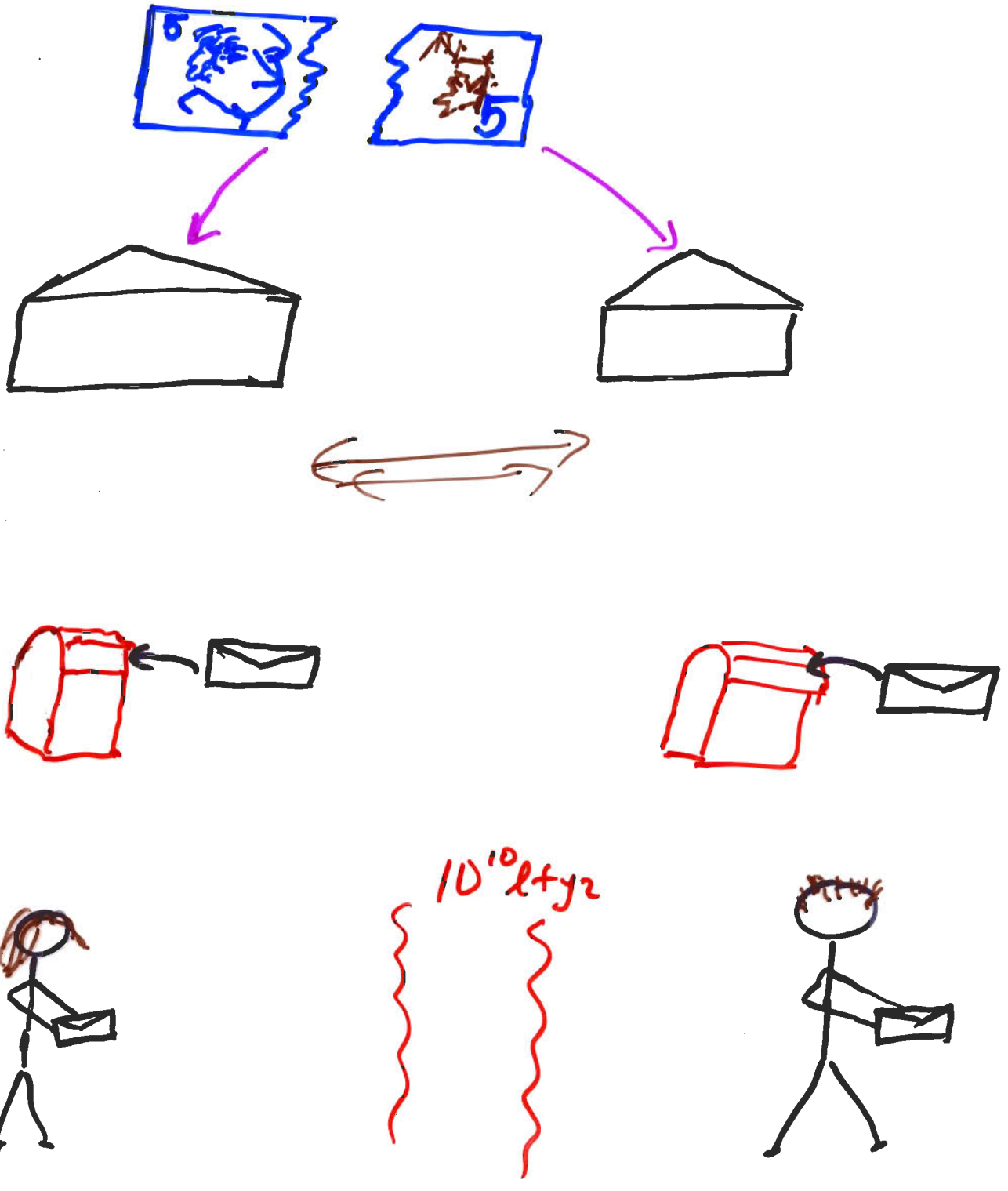
WHAT NOT

$(|\uparrow\uparrow\rangle + |\downarrow\downarrow\rangle)$

How Does Blue Particle
Know That Its Spin
Should line up?
whenever $|\uparrow\rangle$ then $|\uparrow\rangle$

Non Local Influence
From ↕ to ↕

NUTS



When Alice opens + finds Dig 5, Bob mysteriously finds Head.

Correlations SET

UP INITIALLY DETERMINE

FUTURE Correlations

Quantum Mech Obeys "Commutativity"

- Take averages + add or add + take averages.

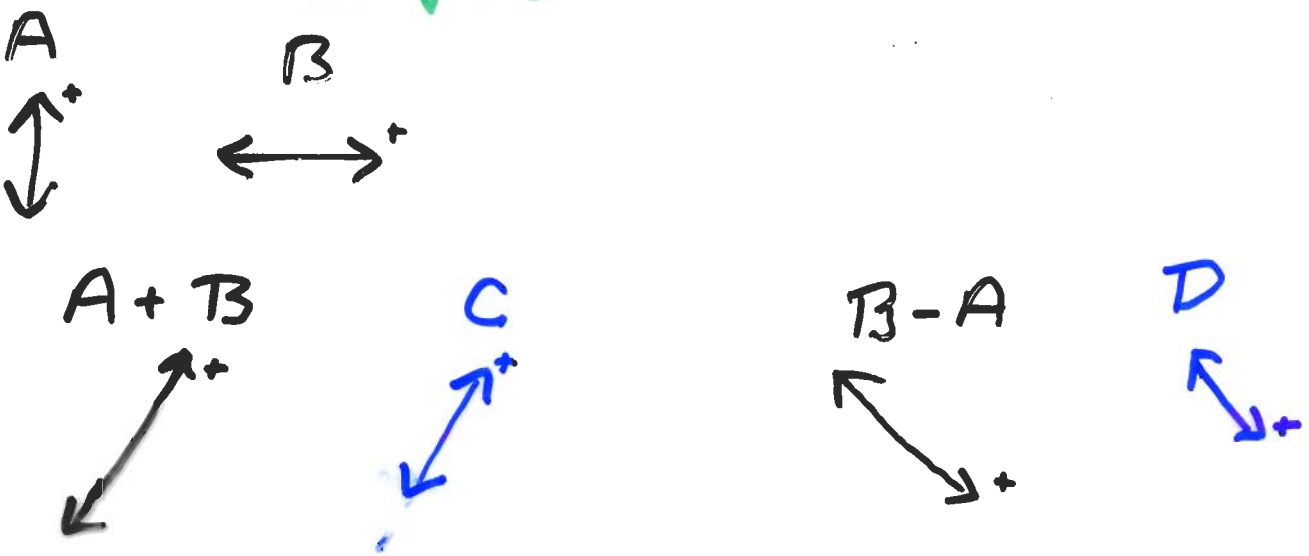
$$\langle \underbrace{(A+B)}\, C + \underbrace{(-A+B)}\, D \rangle$$

operator (attribute)

Ditto.

Not $\pm 2, 0$

But $\pm\sqrt{2}$



(a) $\left.\begin{matrix} A+B \\ \text{or } A-B \end{matrix}\right\} \neq \pm 2, 0$

(b) $\left.\begin{matrix} A+B \\ A-B \end{matrix}\right\}$ Not perfectly anti correlate.

Fundamental assumption about SINGLE particle wrong in Bell's anal.

LOCALITY Is Irrelevant.

STAPP

Henry Stapp, L.B.L.
particle phys.

QUANTUM MECHANICS
IS NON LOCAL.

L. Hardy.

2 particles.

L R

A, B C, D

Joint state

If A=1 then C=1

If C=1 then (always) B=1

If B=1 then D=1

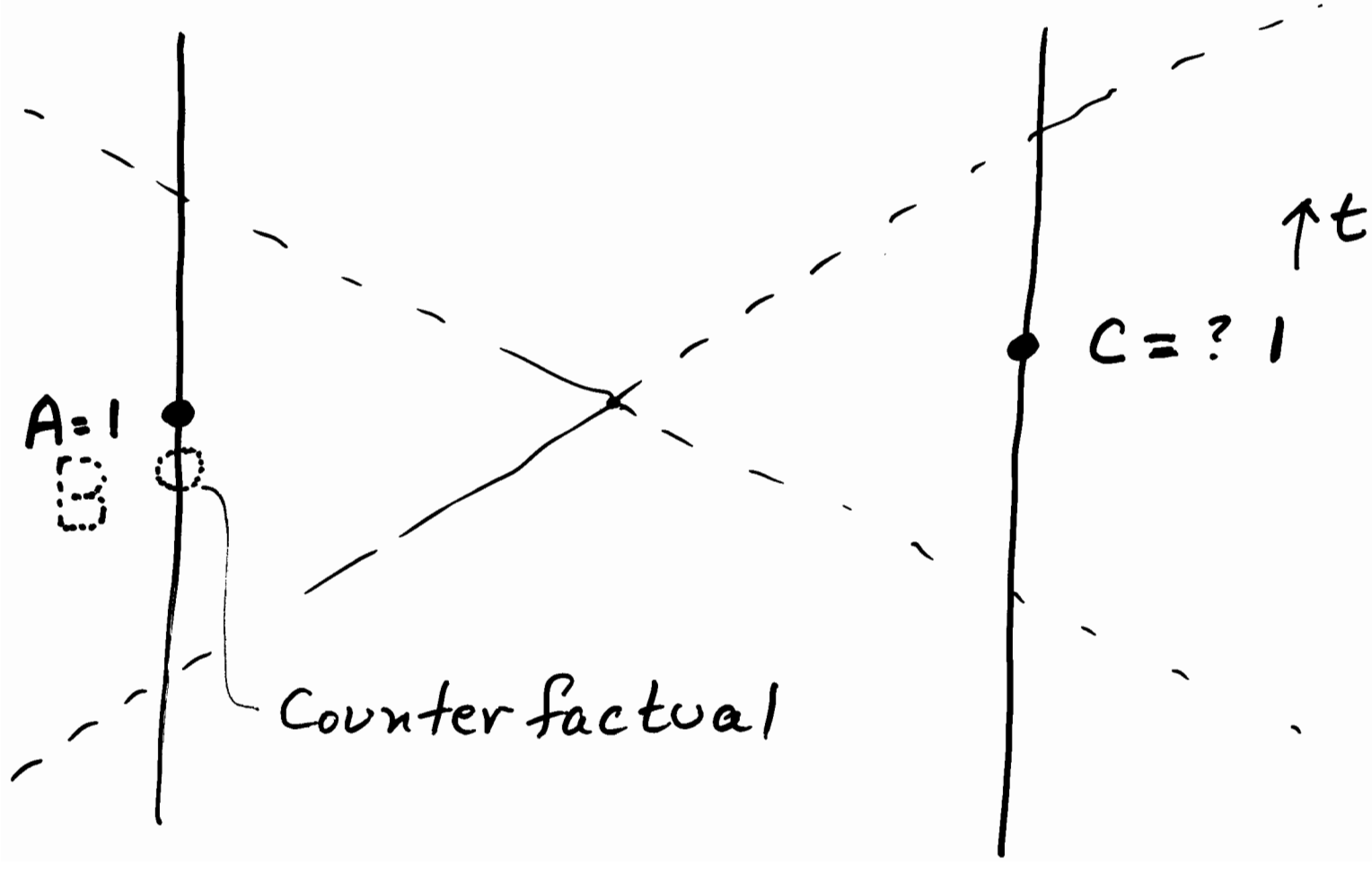
If A=1 then D=?

Quantum Mech

Prob (D=1 given A=1)
as small as desired

[P(A=1) becomes small]

Non Locacity.



A measured and found to be 1

C measured MUST BE 1

In that same situation what if we had Measured B instead?

Must be 1

[counter factual]

But what if D had been measured instead of C $\Longrightarrow$ Because

$B = 1$, $D = 1$.

But $D \simeq -1$

Counterfactual Reasoning

If, instead of S, T were true instead.

Can one draw conclusions

Perez's MOTHER.

What if my father and mother had both married different people. Whose child would I be?

Counterfactuals are crap

Theory

i) Transmigration of souls - matrilinear

ii) Essense of person is soul.

⇓

MOTHER!

I have blue eyes. My Father has blue eyes, my mother has brown. If they had married different peoples, whose child would have blue eyes?

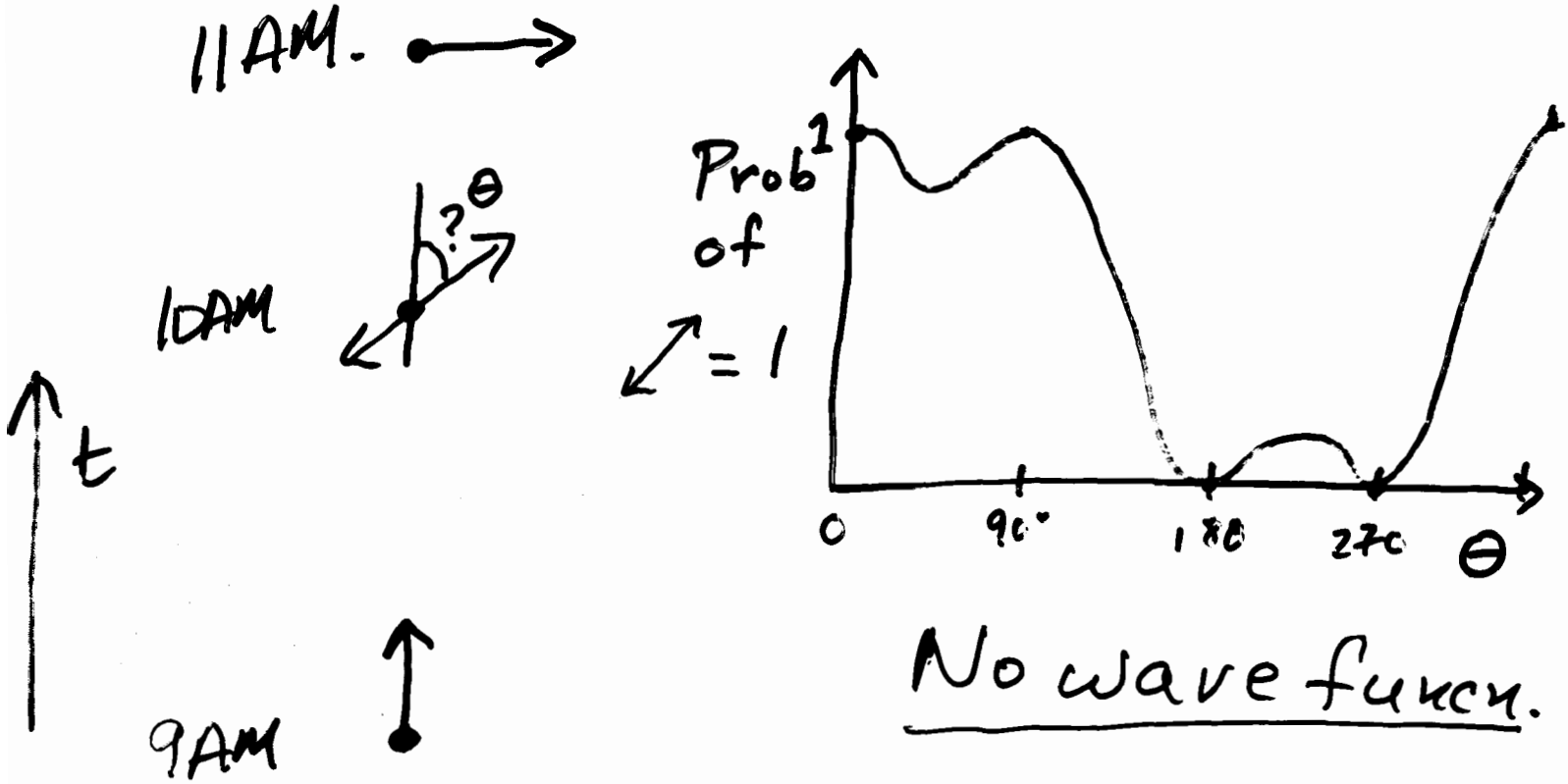
COUNTER FACTUAL ARG. ARE THEORY BASED

"In same situation" not defined in Q. Mech.

⇓

Stapp's arg. fails

Inadequacy of Wave function



No wave funct.

EINSTEIN RIGHT - No Wavefunc. can describe this experiment.

BUT Q. MECH. COMPLETE (It was used to calculate above graph).

Aharonov, Vaidman, Hardy

9AM. $\frac{1}{\sqrt{3}}\left(|A\rangle|b\rangle + |B\rangle|a\rangle + |B\rangle|b\rangle\right)$

10 AM → Randomly look in A and a.

(Sometimes only one, Sometimes both).

11AM → Each keeps only if $\frac{1}{\sqrt{2}}(|A\rangle - |B\rangle)$ and $\frac{1}{\sqrt{2}}(|A\rangle - |B\rangle)$ true afterwards.

If either looks in $|A\rangle$ or $|a\rangle$ - always finds particle there.

If both look, never find both particles both in Box.

How Do particles know to flee box only when other person looking.

Non-locality?

Initial State
- ensures both never find particles in box A, a.

Final Condition - correlation always throws out states where other person did not find particle in a, A <u>if</u> only one looks.

NOT NON LOCAL