Title: Giulio @ 13:30

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Abstract:

The pure and reversible pictures of Quantum Mechanics

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Perimeter Institute for Theoretical Physics

Workshop "Conceptual Gems of Theoretical Physics",
Friday October 14 2011, Perimeter Institute

Plan of the talk

* Prologue: the new view of Quantum Mechanics
* Physical processes and information flow: the language of pictures
* The causality principle
* The pure and reversible pictures of Quantum Mechanics

What did QM give to our culture so far?

- **Complementarity (Bohr, mid '20s)**
  Some experiments are incompatible:
  observing one feature prevents us
  from observing the other

- **Uncertainty (Heisenberg, 1927)**
  We cannot know with arbitrary precision
  the position and the velocity of a particle

- **Indeterminism (Born, 1926)**
  We cannot predict with certainty the outcome of an experiment,
  no matter how well we know the measured system

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Old view of QM: a theory of limits

THE NEGATIVE VIEW OF QUANTUM MECHANICS:
theory of limits to knowledge, indetermination, imprecision, uncertainty, randomness, fuzziness, ...

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Nostalgia
of determinism:

Quantum Information

- Secure communication (Bennett Brassard '84, Ekert '92)
  The laws of QM guarantee that we can communicate privately

- Fast computer algorithms (Shor 1997, Grover 1992)
  In the quantum world we can solve problems in less steps
  than in the classical one

- State teleportation ('93)
  A finite amount of communication is enough
  to transfer from one location to another
  the information contained in a system
  with an infinite number of possible states

(top, left) Richard Jozsa, William K. Wootters, Charles H. Bennett. (bottom, left) Gilles Brassard, Claude Crépeau, Asher Peres. Photo: André Berthiaume.

New view of QM: a physical theory of Information

A POSITIVE VIEW OF QUANTUM MECHANICS:

theory of new unexpected possibilities for communication, computation, and processing of information.

QM describes not only our
limits in the knowledge of the physical world,
but also, and perhaps most importantly,
our possibilities as information processing agents
interacting with it!

The game of the lab 1

Imagine you are in a laboratory

There you find many devices: each device transforms an input system in an output system

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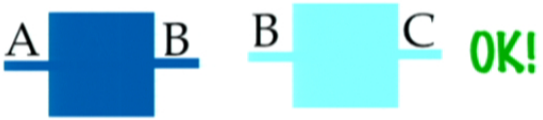
You can connect two devices as long as the input of the second matches the output of the first



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OK!

The game of the lab 2

You find that some devices have no input:
they "create" a system in some state

The game of the lab 2

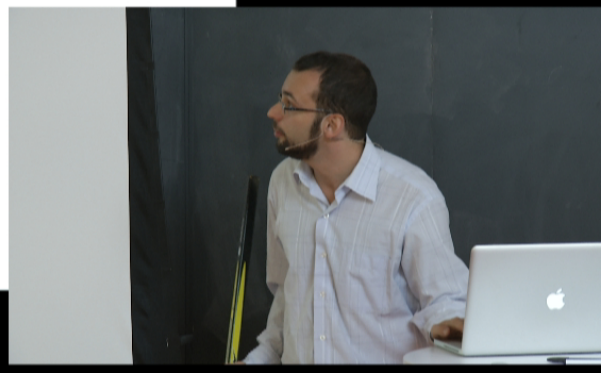
You find that some devices have no input:
they "create" a system in some state

Some other devices have no output:
they perform measurements that "destroy" the measured system, leaving only an outcome,
with some probability

Let's play the game

You can now start making experiments:

- prepare a system in some input state



Let's play the game

You can now start making experiments:

- prepare a system in some input state
- transform it, obtaining an output state
- measure the output and see what outcome you get

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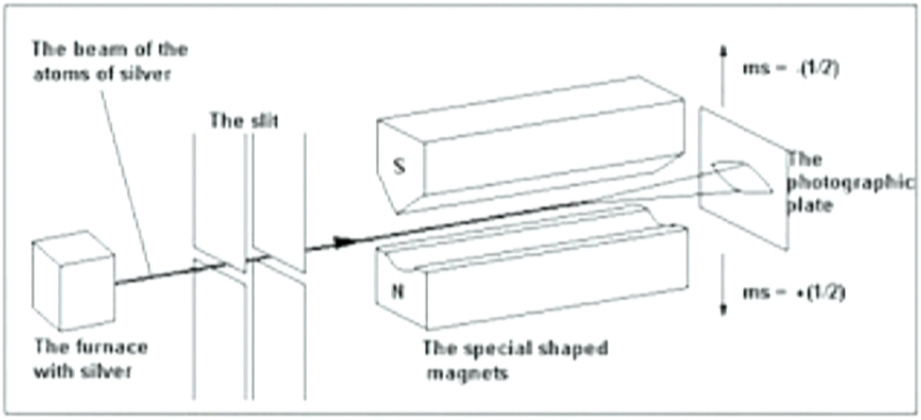
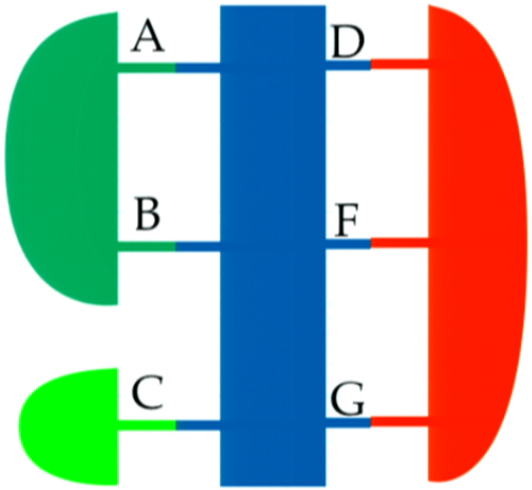
Your information about the system is contained in its state and propagates from input to output

Example: the Stern-Gerlach experiment



The Stern-Gerlach experiment. On the photographic plate are two clear tracks.

And you can make more complicated experiments...



- prepare A and B together
- prepare C
- transform A, B and C into D, E ,and F
- measure everything together

Non-physics examples

THE LANGUAGE OF PICTURES
CAN DESCRIBE MANY SITUATIONS,
NOT ONLY THAT OF A PHYSICIST IN A LAB!

Non-physics examples

We make to ourselves pictures of facts

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Pictures in the bank!

Pictures in the kitchen!

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Reversible processes

A process 

is reversible

if there is another process 

such that 

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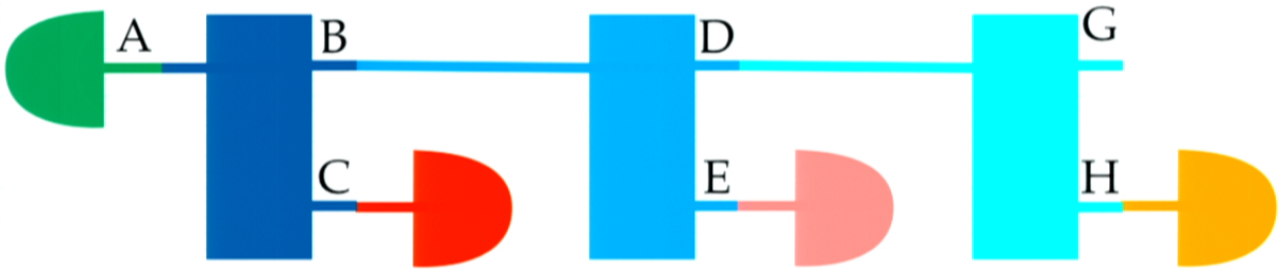
and 

for every possible states 

The causality principle

Causality

Imagine a sequence of measurements, like



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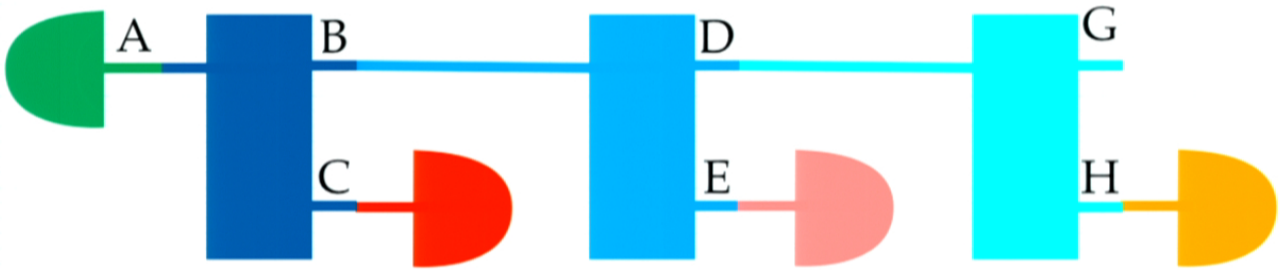

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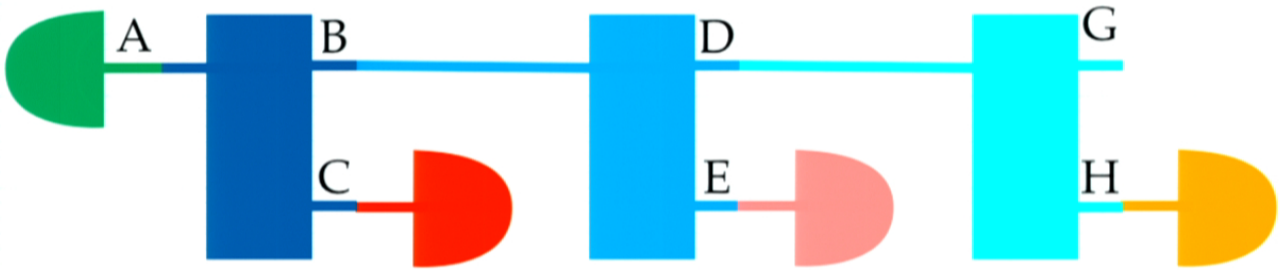

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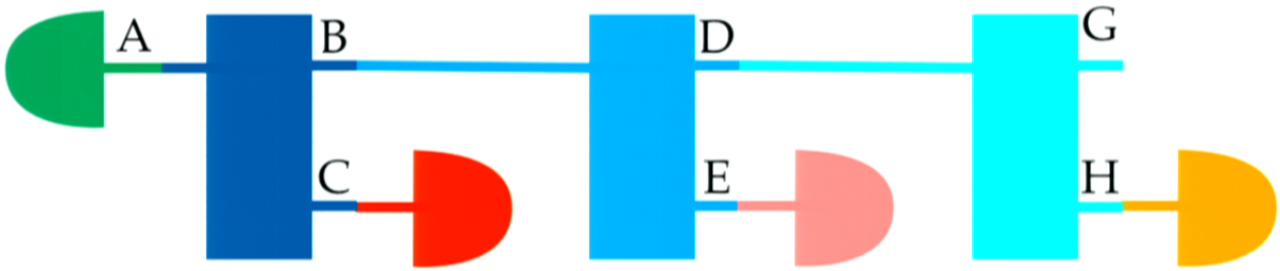

The causality principle states that the outcome of a measurement at a certain time ("red measurement", here) does not depend on the choice of measurements performed later ("salmon" and "tangerine", here)

Painting causality

To "discard a system" means to perform a measurement on it and to ignore the outcome.

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The system A has been "destroyed" without leaving any information

Keeping one, discarding the other

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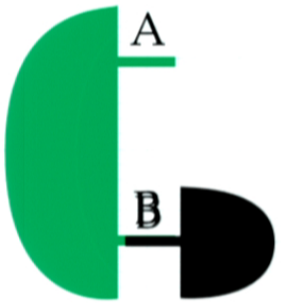
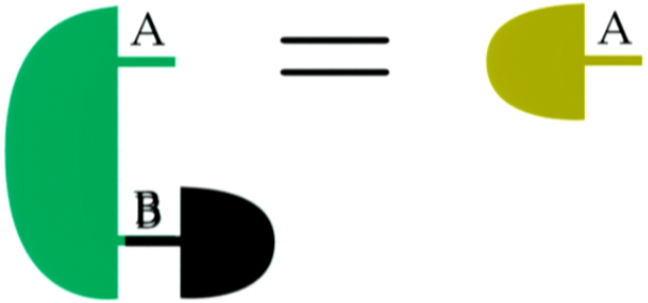
- Take a state of A and B together
- Discard B



Keeping one, discarding the other

- Take a state of A and B together
- Discard B
- What remains is a state of A alone



The pure and reversible pictures of Quantum Mechanics

Pure states

The state describes our information about the system

Two possibilities:

1) our information is maximal:
there is no way to know the system better.

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"Pure states"

example: polarized light
(we know exactly
the polarization)

Mixed states

2) our information is not-maximal:
the system could be in many different pure states,
but why don't know which

"Mixed states"

example: sunlight
(the polarization
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Purification 1

Quantum Mechanics has an amazing property:

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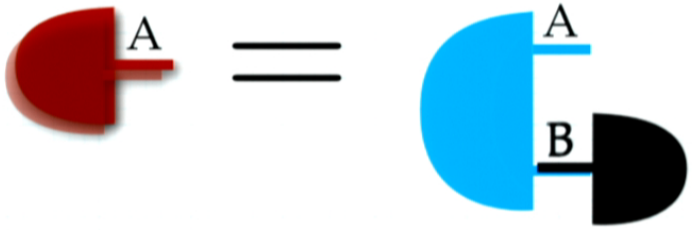
Every mixed state 

can be obtained from a pure state
of two systems together 

by discarding one system



Purification 2

In other words, whenever we are ignorant about a system we can always imagine that our ignorance is due to the fact that there is some other system that missed to consider, a system that completes our information

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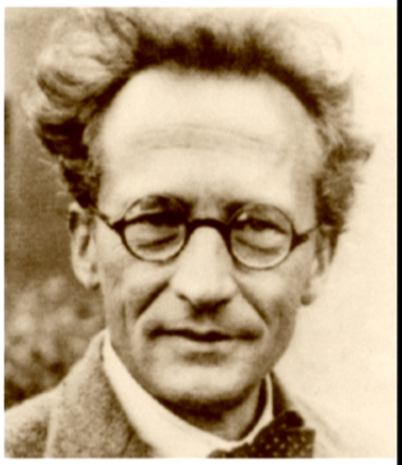
example: sunlight
each photon is generated by a reaction in the photosphere.
Its polarization is random, but if we include the electrons and hydrogen atoms that participate in the reaction, these systems together are in a pure state

Entanglement

"The best possible knowledge of a whole does not necessarily include the best possible knowledge of all its parts"

"I would not call that one but rather the characteristic trait of quantum mechanics, the one that enforces its entire departure from classical lines of thought."

Schrödinger, 1935



Purification 3

Purification implies another surprising property:

Every irreversible process 

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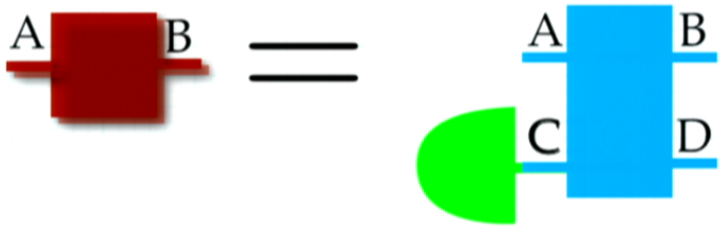
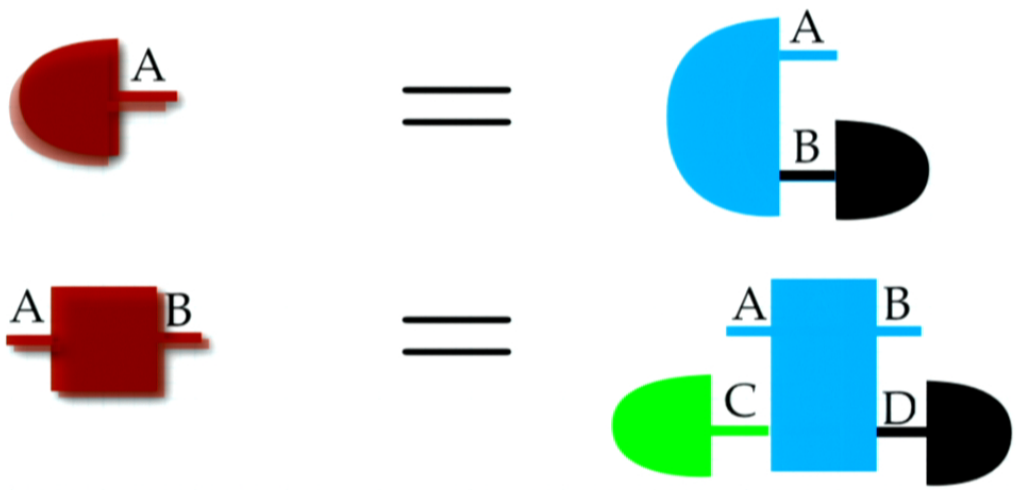
as follows:



In summary

Our actual experience: ignorance and irreversibility

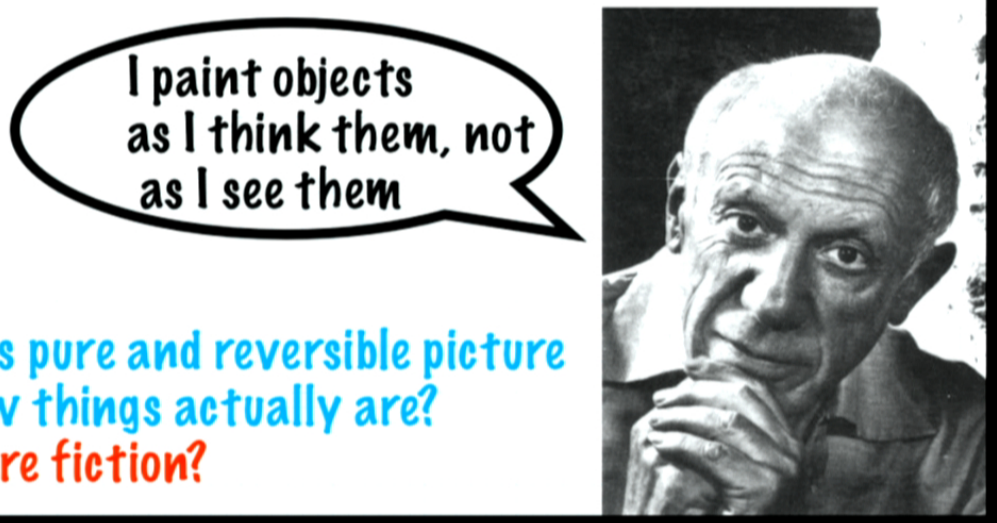
Pure and reversible picture: maximal information and reversibility



In summary

Quantum mechanics is a physical theory of information:

it reconciles our experience of information-processing agents with a pure and reversible picture of the world



But does this pure and reversible picture describe how things actually are?
Or is it a mere fiction?

Two metaphors and a conclusion

Completing the picture

To construct a pure and reversible picture we generally have to imagine virtual systems that are are not observing.

This process recalls some optical illusions, where our brain completes a picture by imagining shapes that are not in the picture itself:

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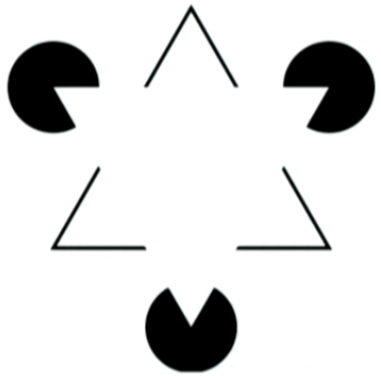

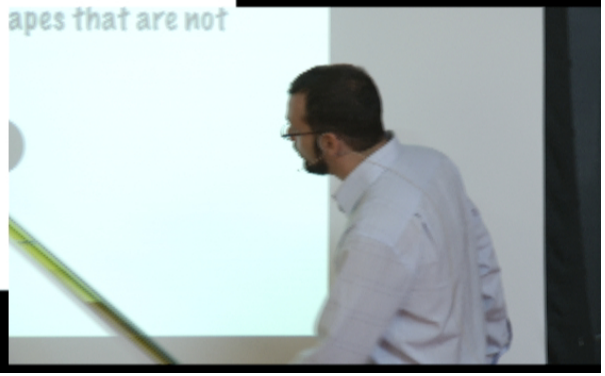

Twin systems in narrative

The idea that two systems can be in a pure state together
but separately appear in mixed states
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Weronika observes the world
through a transparent ball,
while the train window
reflects the image,
alluding to her far apart double,
Veronique.

Scene from
The double life of Véronique
(1991)

Conclusion

Quantum Mechanics is much more than just a theory of limits:

It is the physical theory that combines
our limited experience of information-processing agents
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Whether this picture is fact or fiction,
perhaps it is not so important:

The cultural richness of Quantum Mechanics is exactly
in the possibility to construct new pictures about the world
and of our interaction with it.

Short bibliography

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