Title: PSI 2019/2020 - Quantum Theory (Branczyk/Dupuis)

Speakers: Agata Branczyk

Collection: PSI 2019/2020 - Quantum Theory (Branczyk/Dupuis)

Date: September 03, 2019 - 10:45 AM

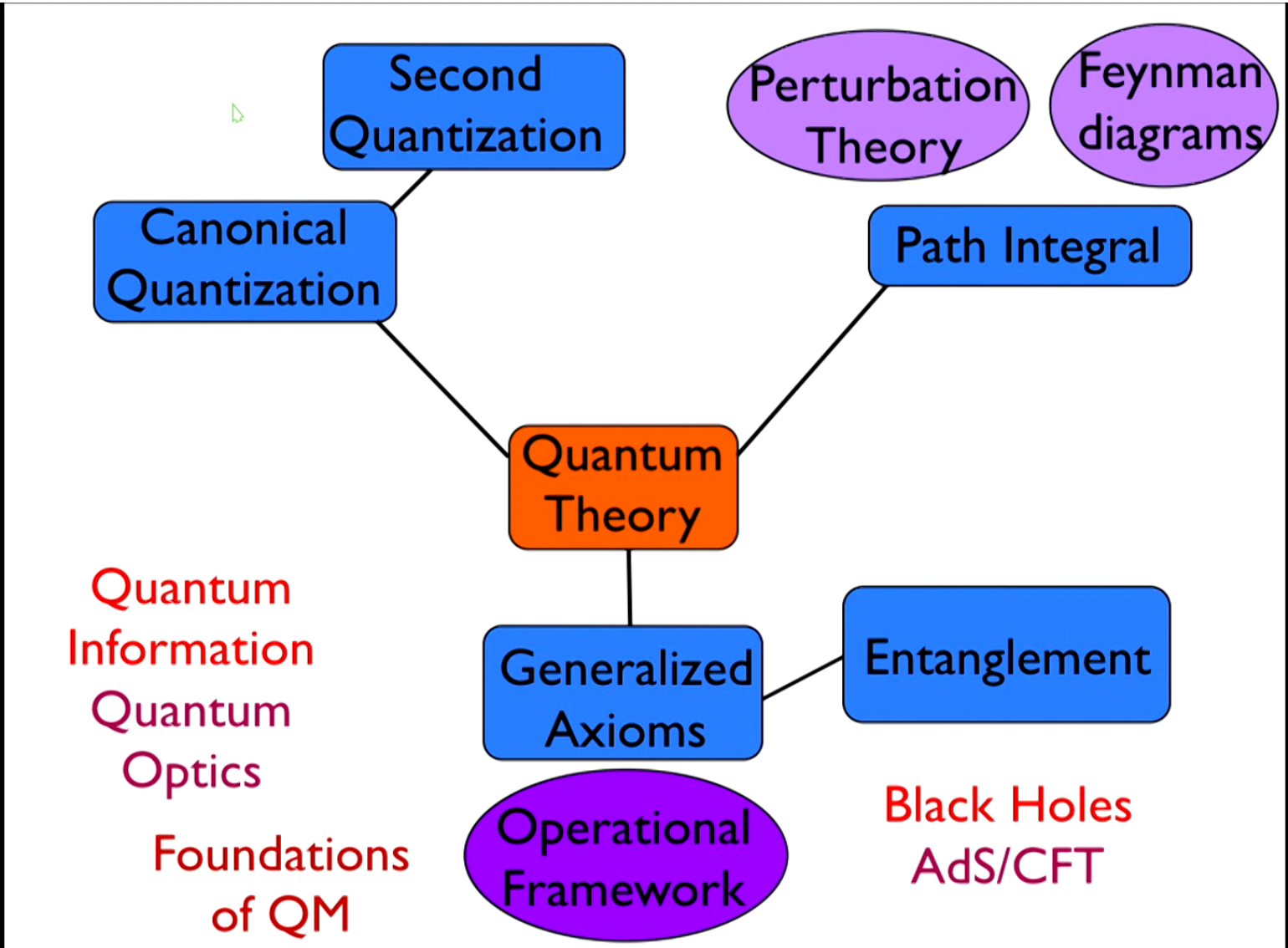
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Quantum Theory Core



September 3rd - 11th: Agata Branczyk
September 12th - 20th: Maïté Dupuis
TA: Tomáš Gonda

PERIMETER SCHOLARS INTERNATIONAL


Second Quantization
Perturbation Theory
Feynman diagrams
Canonical Quantization
Path Integral
Quantum Theory
Quantum Information
Quantum Optics
Generalized Axioms
Entanglement
Operational Framework
Black Holes
AdS/CFT
Foundations of QM

Assessment

- HW1: continuous assessment
- HW2: Problem set
  - out: Mon 9th Sep, in: Mon 16th Sep
- HW3: Problem set
  - out: Mon 16th Sep, in: Mon 23rd Sep
- Interviews: 30th Sep - 4th Oct
  - 30-40 min each
  - You will get example questions in advance and opportunity to practice

About HW1

- based on a continuous assessment,
- Questions every couple of days from recent lectures and/or tutorials.
- Advantages: you work regularly; you get feedback regularly; you make connections between the different lectures/tutorials;...

Tutorials

- Tutorials are mandatory.
- Mostly problem sets

Tutorials

- Tutorials are mandatory.
- Mostly problem sets
- Some tutorials will start with a group activity.
- If you have to miss one: **tell us in advance**

Outline
2 parts



Sept. 3rd - Sept. 11th: Lectures/Tutorials by Aggie.

- Generalized axioms
- Operational Framework
- Entanglement

Sept. 12th - Sept. 20th: Lectures/Tutorials by Maïté.

- The canonical/Dirac quantization
- The Path Integral Quantization
- Feynman diagrams

Two parts to quantum theory.

(i) Identifying the level-structure associated w/ a ph

- $\mathcal{H}$ (Hilbert space); which $|\psi\rangle$?
- Hamiltonian H?
- Which operator A represents measurement?

ntum theory.

l-structure associated w/ a physical systen.

ace) ; which $|\psi\rangle$?

represents measurement?

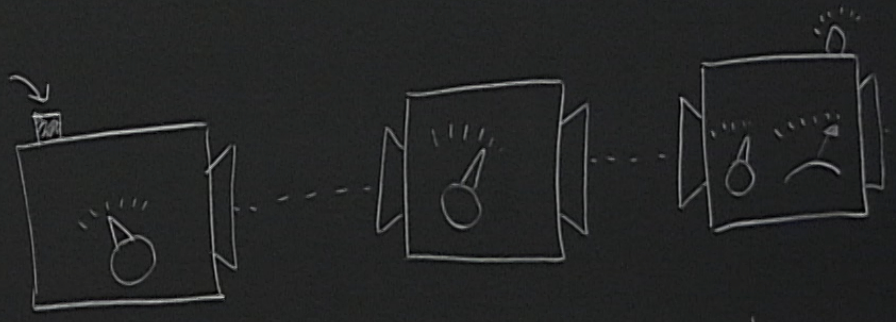
(ii) Predicting the statistics associated with an agent's interactions w/ that system

- given a preparation, and a transformation, what are probs of meas outcomes?

Operational Framework of q. theory

Reduce problem to:

1) Preparations:
2) Transformations:
3) Measurement:

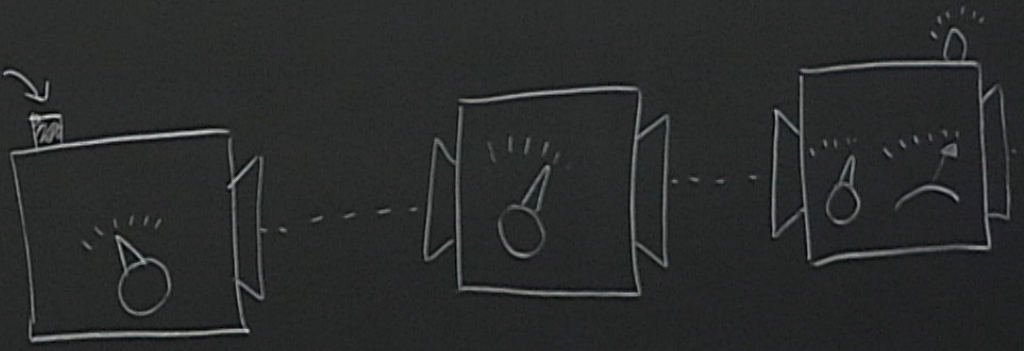


Reduce problem to:

1) Preparations :

2) Transformations:

3) Measurement:



Preparations Transformations Measurements

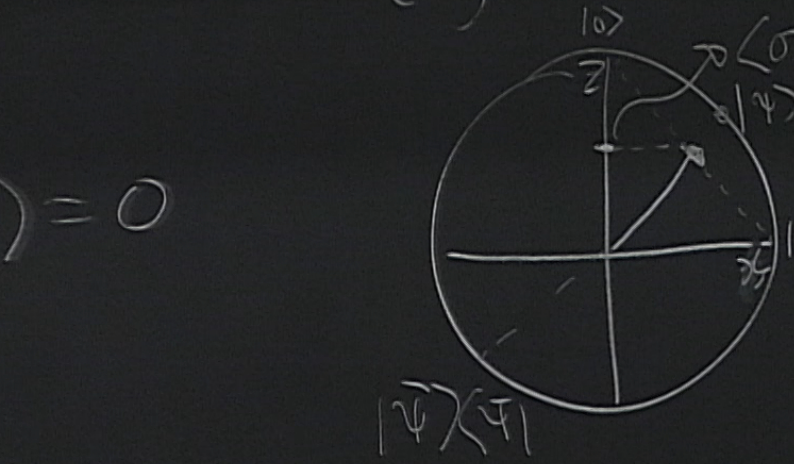
In an operational approach, the theory is charachterized in terms of predictions for macroscopic experiments described using everyday concepts.

Bloch Sphere.

- Opposite states are orthogonal (!) $\langle \psi | \chi \rangle = 0$
- Unitrary transformations → rotations.
- Pure states live on surface
- Mixed states " inside.
- Non-unitary transformations can change length of vector

$|1\rangle$

e.g. Mixed state



$\rho = \frac{1}{2}|0\rangle\langle 0| + \frac{1}{2}|+\rangle\langle +|$

$\Rightarrow Pr(0) - Pr(1)$

$\langle \psi | \chi \rangle = 0$

described using everyday concepts.

	IDEAL		REALISTIC
PREP	PURE STATE $\|\psi\rangle$	$\|\psi\rangle\langle\psi\| = \hat{\rho}$ $\hat{\rho}_A = Tr_B[\|\psi\rangle\langle\psi\|_{AB}]$	DENSITY OPERATORS $\hat{\rho}$
TRANS	UNITARY $\hat{U}$ $\|\psi'\rangle = \hat{U}\|\psi\rangle$	$\hat{U} = \hat{A}_1$ $\mathcal{E}(\rho_A) = Tr_B[U_{AB}\rho_A \otimes \|0\rangle\langle 0\|_B U_{AB}^\dagger]$	CPTP MAPS $\mathcal{E}(\hat{\rho})$ $\hat{\rho}' = \mathcal{E}(\hat{\rho}) = \sum_k A_k \hat{\rho} A_k^\dagger$ (Kraus decomposition)
MEAS	PROJECTORS $\{\hat{P}_m\}$ $Pr(m) = \langle\psi\|\hat{P}_m\|\psi\rangle$ $\|\psi_m\rangle = \frac{\hat{P}_m\|\psi\rangle}{\sqrt{Pr(m)}}$	$\hat{P}_m = \hat{E}_m = M_m^\dagger M_m$ $M_m = \langle m\|_B U_{AB}(\|\psi\rangle_A \otimes \|0\rangle_B)$	POVM $\{E_m\} = \{\hat{M}_m^\dagger \hat{M}_m\}$ $\sum_m \hat{E}_m = \mathbb{1}$ $Pr(m) = Tr[\hat{\rho}\hat{E}_m]$ $\hat{\rho}_m = \frac{\hat{M}_m \rho \hat{M}_m^\dagger}{Pr(m)}$

Two-dim Systems

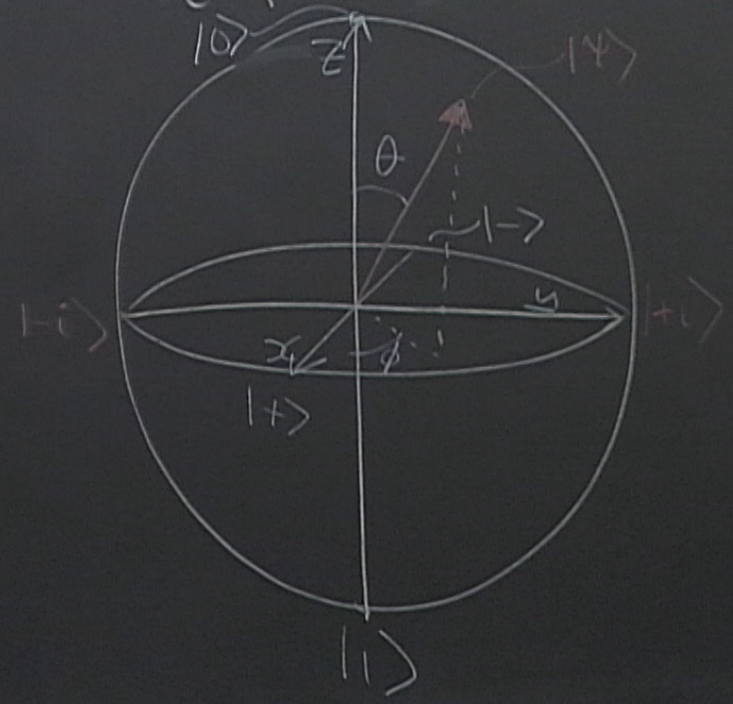
Arbitrary Pure state

$$|\psi\rangle = \cos\frac{\theta}{2}|\uparrow\rangle + e^{i\phi}\sin\frac{\theta}{2}|\downarrow\rangle$$

$$|0\rangle \qquad\qquad |1\rangle$$

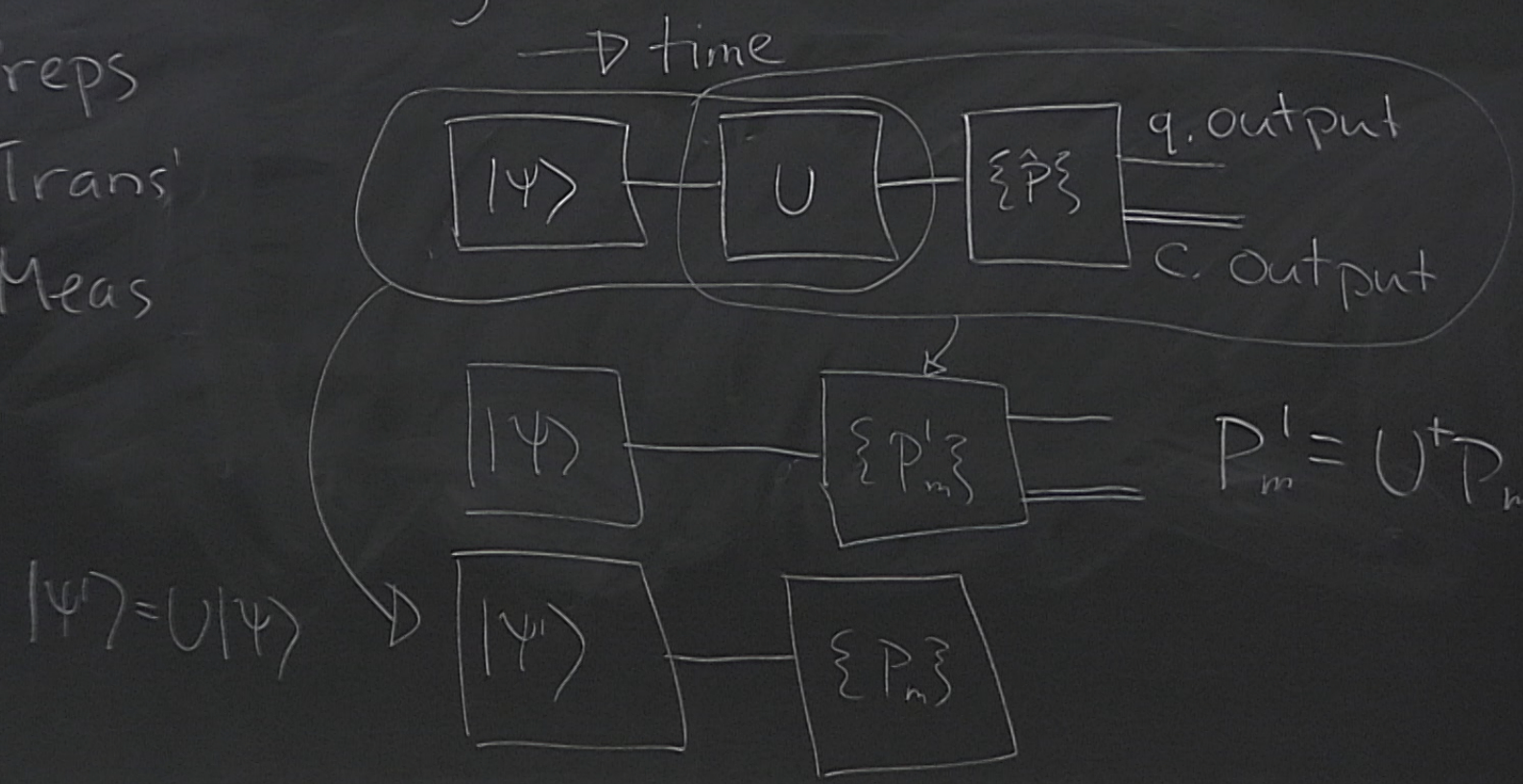
where $|\pm\rangle = \frac{|0\rangle \pm |1\rangle}{\sqrt{2}}$

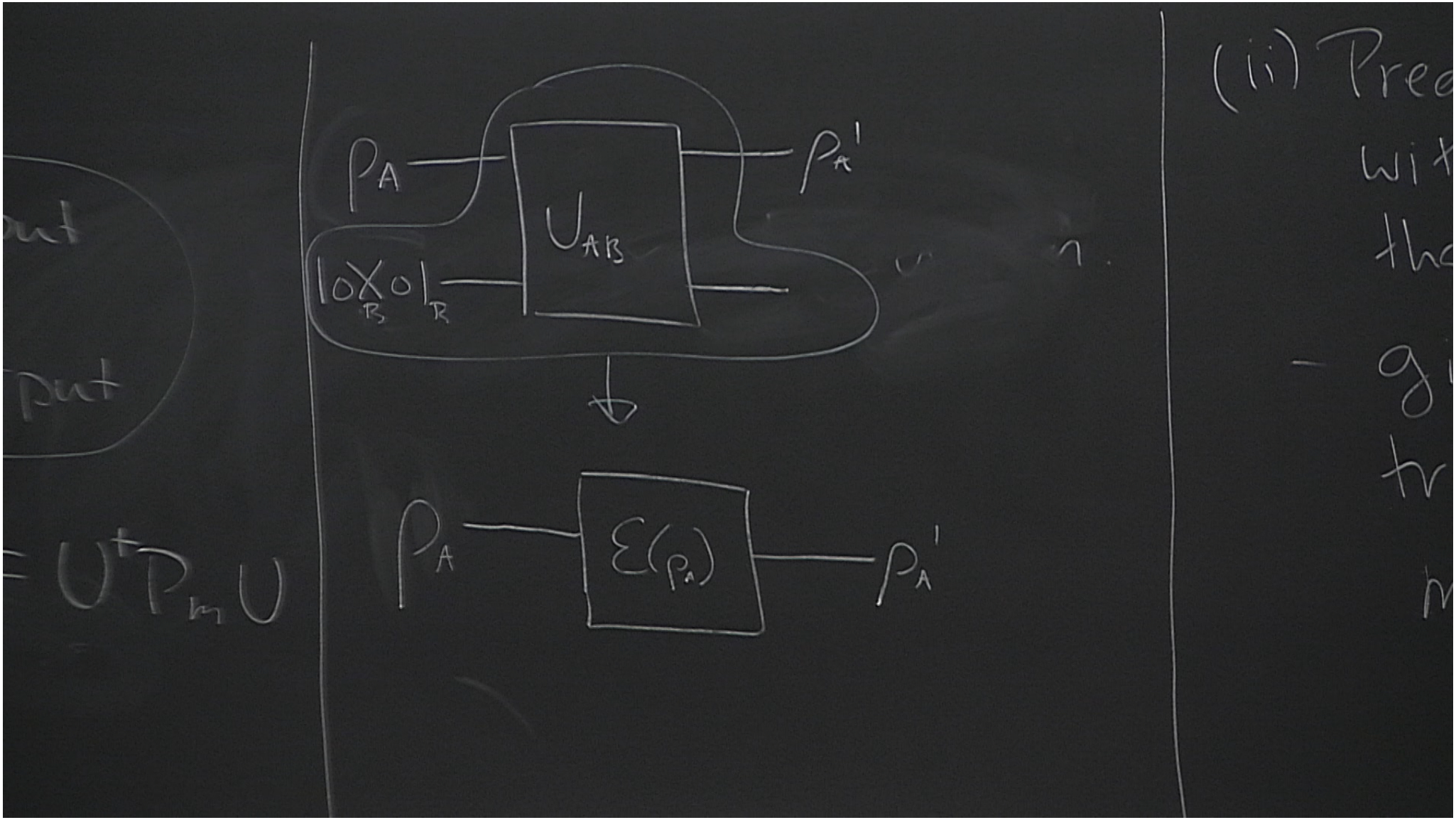
$$|\pm i\rangle = \frac{|0\rangle \pm i|1\rangle}{\sqrt{2}}$$



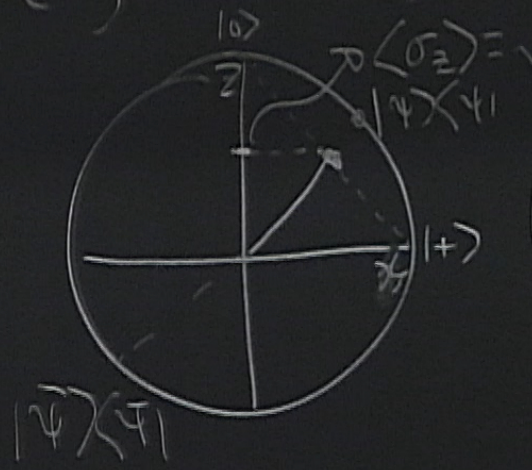
2. "Circuit" diagram

- Preps
- Trans'
- Meas




ρ_A
U_{AB}
ρ_A'
$|0\rangle_B$
$|0\rangle_R$
ρ_A
$\mathcal{E}(\rho_A)$
ρ_A'
(ii)

e.g. Mixed state.



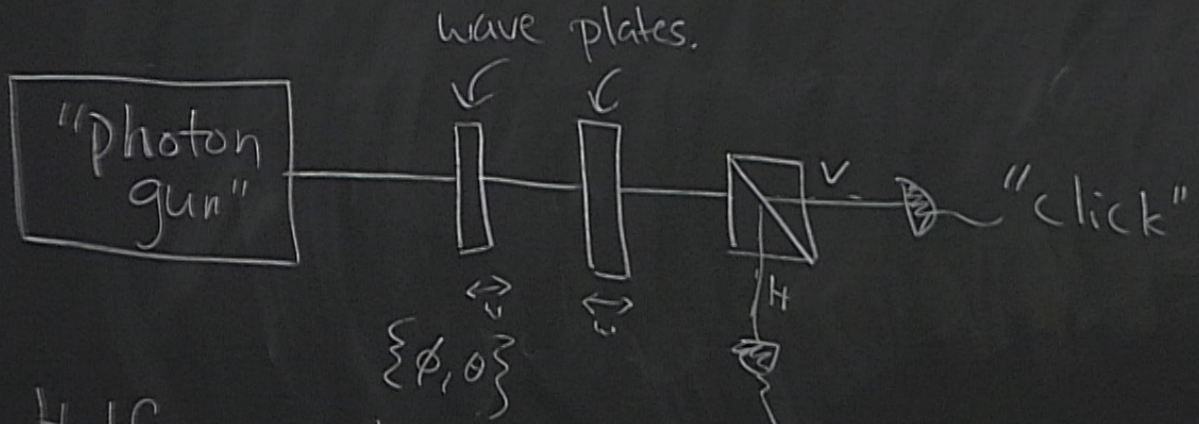
$\rho = \frac{1}{2}|0\rangle\langle 0| + \frac{1}{2}|+\rangle\langle +|$

$|\chi\rangle = 0$

$\Rightarrow Pr(0) - Pr(1)$

Optical experiment.

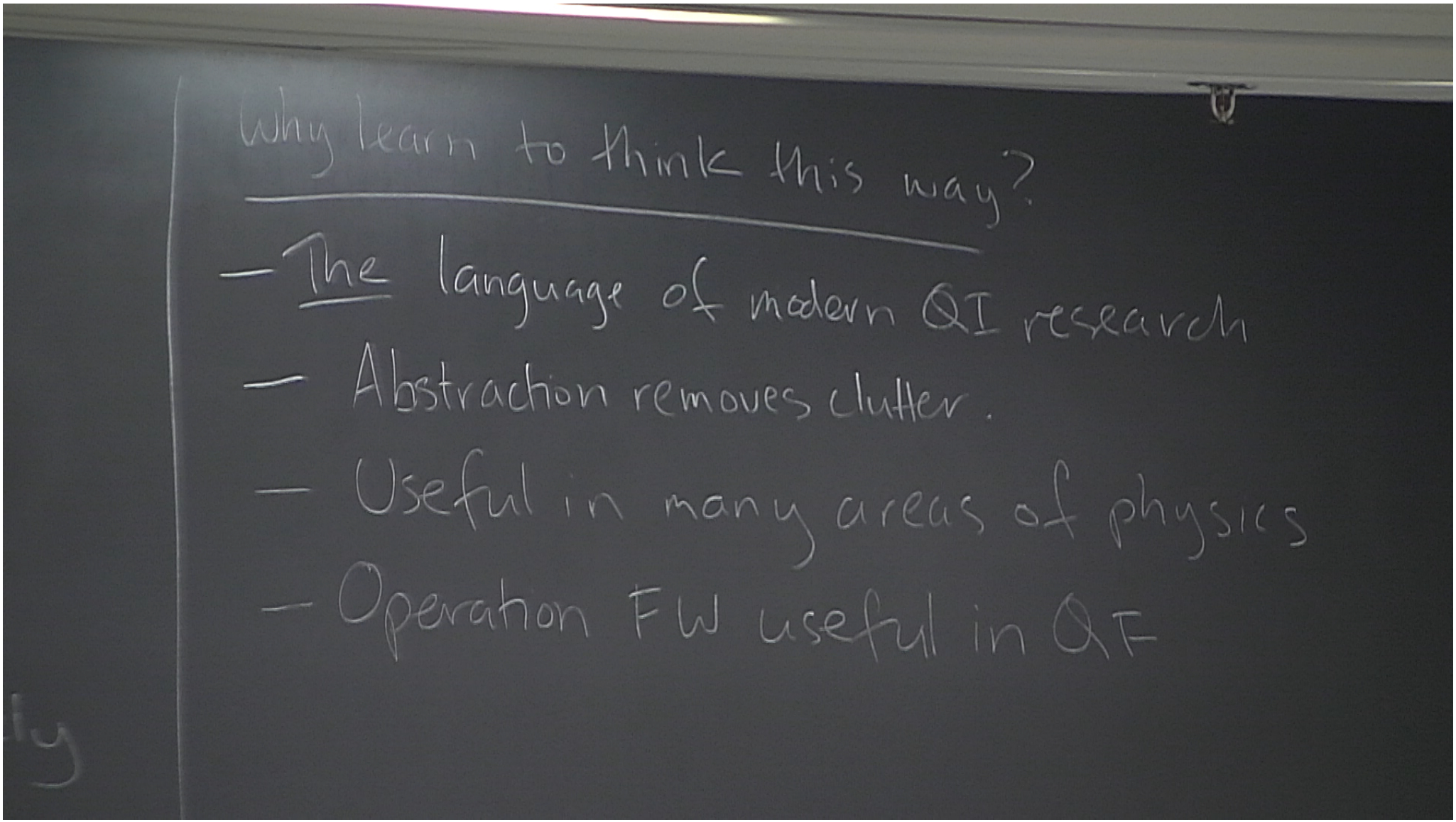
Basis H/V polarization of a photon.



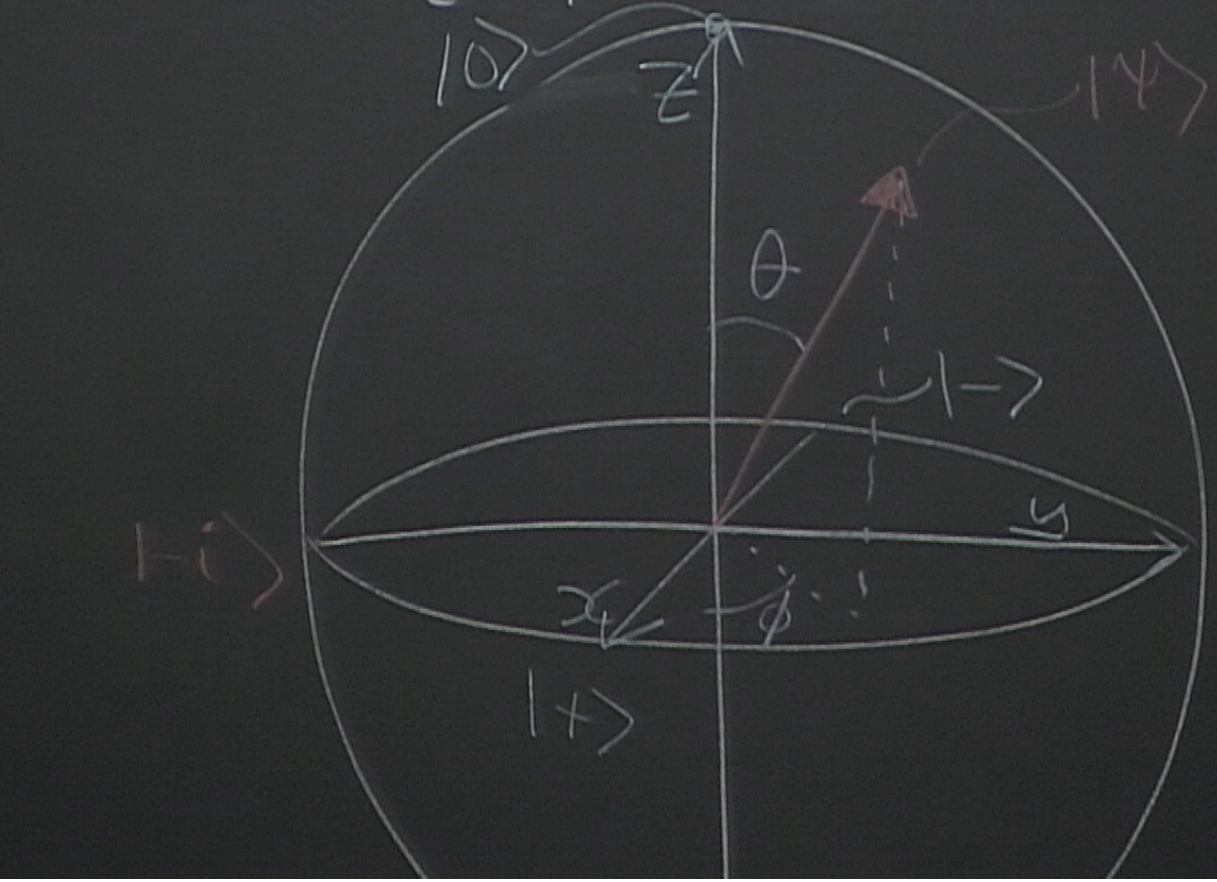
Half wave plate → π

Quarter wave plate → π/2

W: Ideal postulates
Quantum State Tomography
T: Realistic Postulates
F: Composite systems & Entanglement
M: Purification & Dilations
T: Putting it all together (q. control of single qubit)
W: Review concept map.
Fun topic in QI (teleportation, no cloning theorem)


Why learn to think this way?
- The language of modern QI research
- Abstraction removes clutter.
- Useful in many areas of physics
- Operation FW useful in QF

Arbitrary Pure state. $|\psi\rangle =$



where