two concepts of classicality

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■ plan of the talk

I. a new concept of classicality

II. randomness

III. discussion

one

a new concept of classicality

▪ old concept of classicality

usually: classical states are given a priori.

$$|\psi\rangle = \sum_i \alpha_i |i\rangle$$

these states have a priori classical meaning, e.g. $|\text{up}\rangle$ or $|\text{down}\rangle$

leads immediately to the question:

how does $|\psi\rangle$ assume one of the classical states $|i\rangle$?

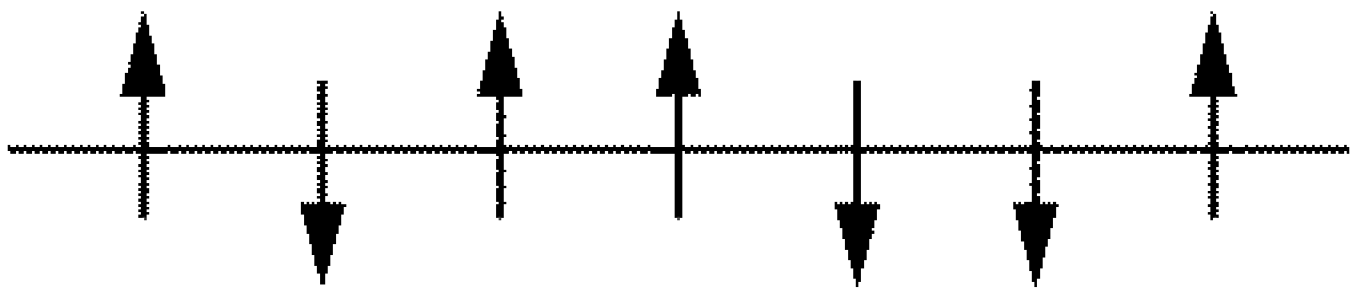
i.e. it leads to the measurement problem

a simple example

quantum ising model:

$$\mathcal{H} = (\mathbb{C}^2)^{\otimes N}$$

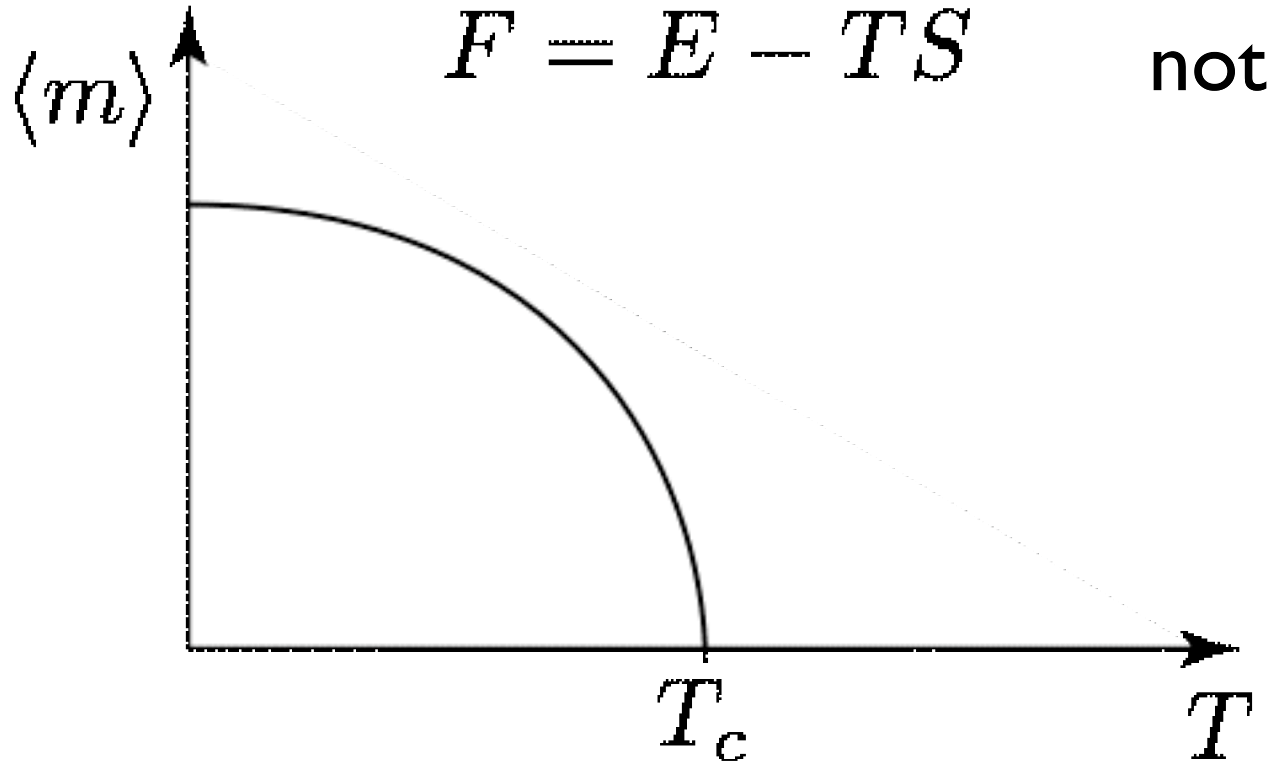
$$\boldsymbol{H} = \sum_{\langle i,j \rangle} \boldsymbol{\sigma}_i \cdot \boldsymbol{\sigma}_j$$



▪ phase transition

$$F = E - TS$$

not ordered



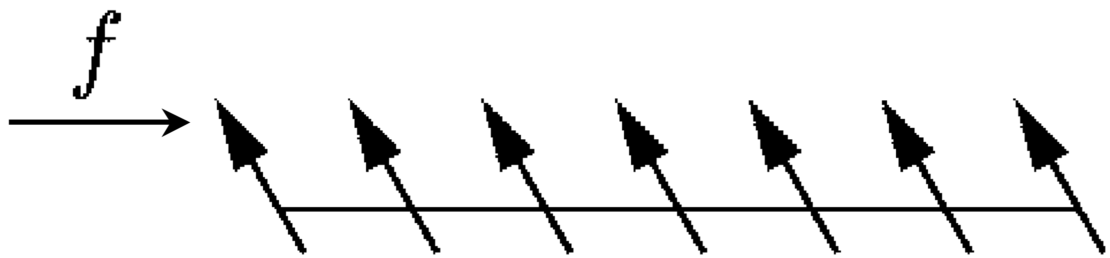
ordered

order parameter: $\theta_o \in$ Bloch sphere

▪ generalized rigidity

ordered phase has new property:

$$\frac{\delta F}{\delta \theta} = f \neq 0$$



generalized rigidity

the system pushes back

■ interaction of two systems

imagine two systems with order parameters

$$\theta_1 \text{ and } \theta_2$$

their interaction is best described by a term

$$\theta_1 \cdot \theta_2$$

θ + generalized rigidity

= objective property

■ classical property

Def.: (**classical property**) An order parameter θ s.t

$$\frac{\delta F}{\delta \theta} \neq 0$$

is called a classical property.

Classicality becomes a *dynamical* property of a large quantum system.

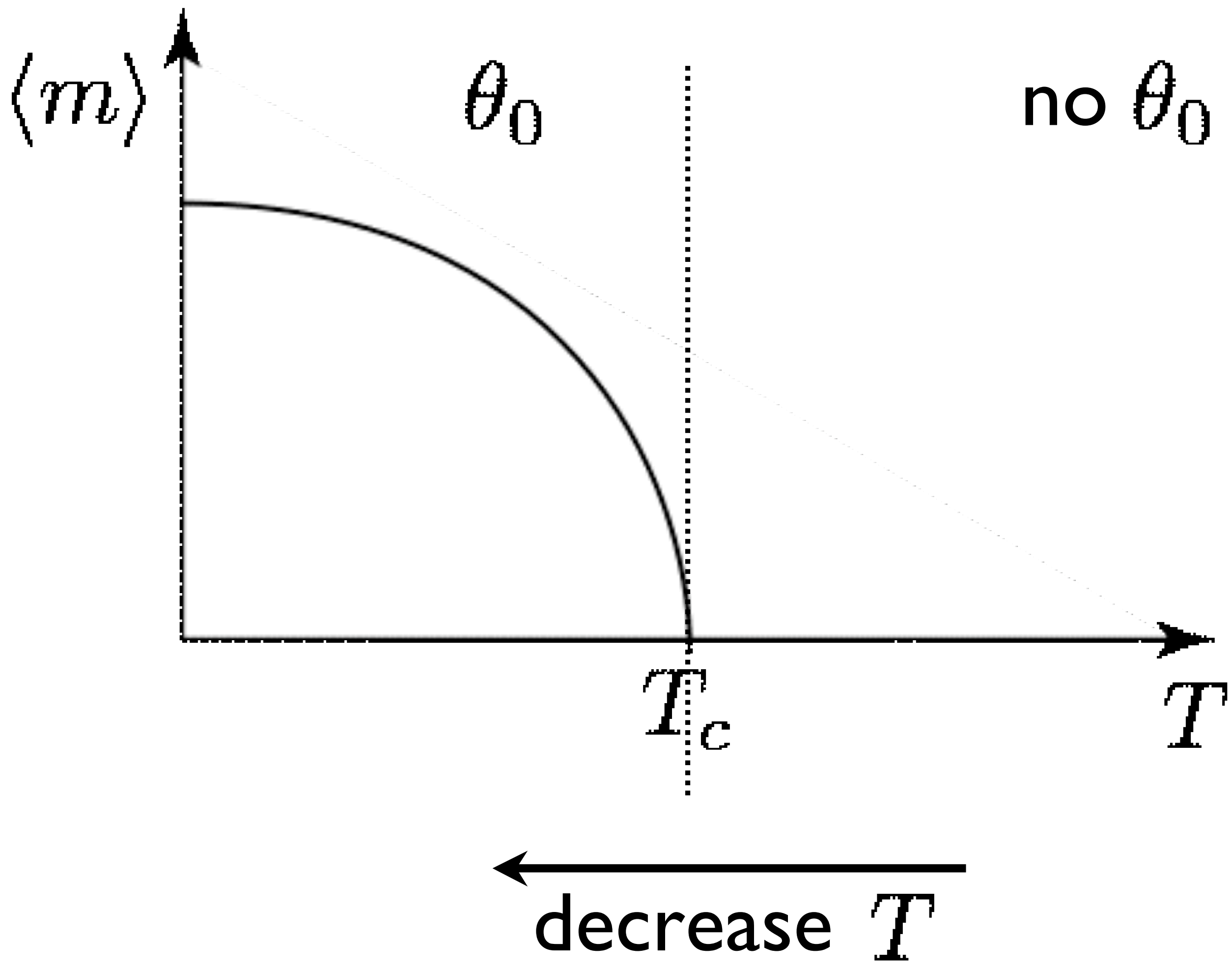
▪ a comparison

classical classicality		quantum classicality
YES	classical states a priori?	NO
YES	basis of classical states?	NO
NO	classical states dynamical?	YES
NO	classical states push back (gen. rigidity)?	YES
YES	Quantization a good idea?	NO

two

randomness

■ the transition

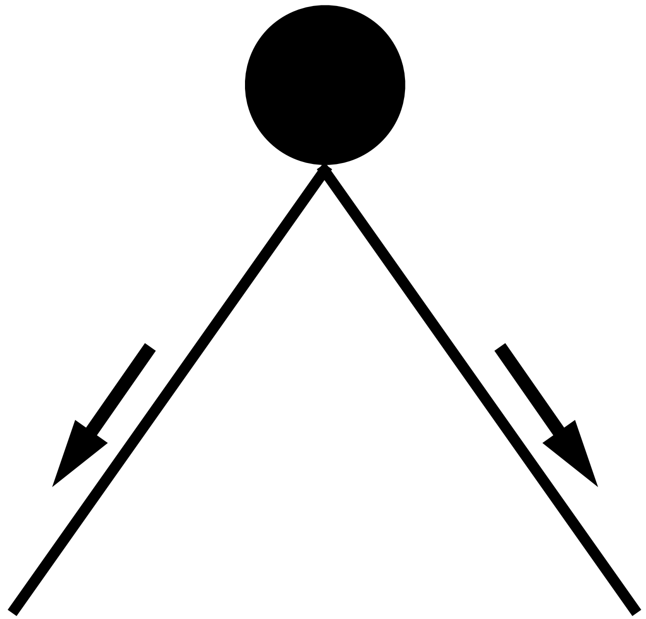


discontinuous transition

▪ probability

$$F_{\text{before}}$$

$$F_{\text{after}} = F(\Theta)$$



transition very *sensitive* to the environment.

claim: this is the source of the probabilistic character of quantum mechanics.

three

discussion

■ what went wrong?

why does

$$|a\rangle|N\rangle \longrightarrow |a\rangle|A\rangle \qquad |b\rangle|N\rangle \longrightarrow |b\rangle|B\rangle$$

not imply

$$(\alpha|a\rangle + \beta|b\rangle)|N\rangle \longrightarrow \alpha|a\rangle|A\rangle + \beta|b\rangle|B\rangle$$

?

we have not taken into account the environment. the new experiment is a new role of the dice. *linearity does not apply.*

■ symmetry of environment

"isn't the environment symmetric?"

yes, but only in an *ergodic* sense.

instead of

$$g \cdot |\mathrm{env}\rangle = |\mathrm{env}\rangle$$

we have

$$g \cdot \frac{1}{\Delta T} \int_{\Delta T} dt \; U(t)|\mathrm{env}\rangle = \frac{1}{\Delta T} \int_{\Delta T} dt \; U(t)|\mathrm{env}\rangle$$

for ΔT large enough.

non-symmetric fluctuations are amplified.

The symmetric state exists but is unlikely

⟶ broken ergodicity.

■ remark on the born rule

since we assume the structure of hilbert spaces together with its inner product we can derive the born rule, i.e.

$$p_i = |\alpha_i|^2$$

using arguments of d. deutsch, d. wallace, and s. saunders.

see also, od quant-ph/0603202.

■ the problem

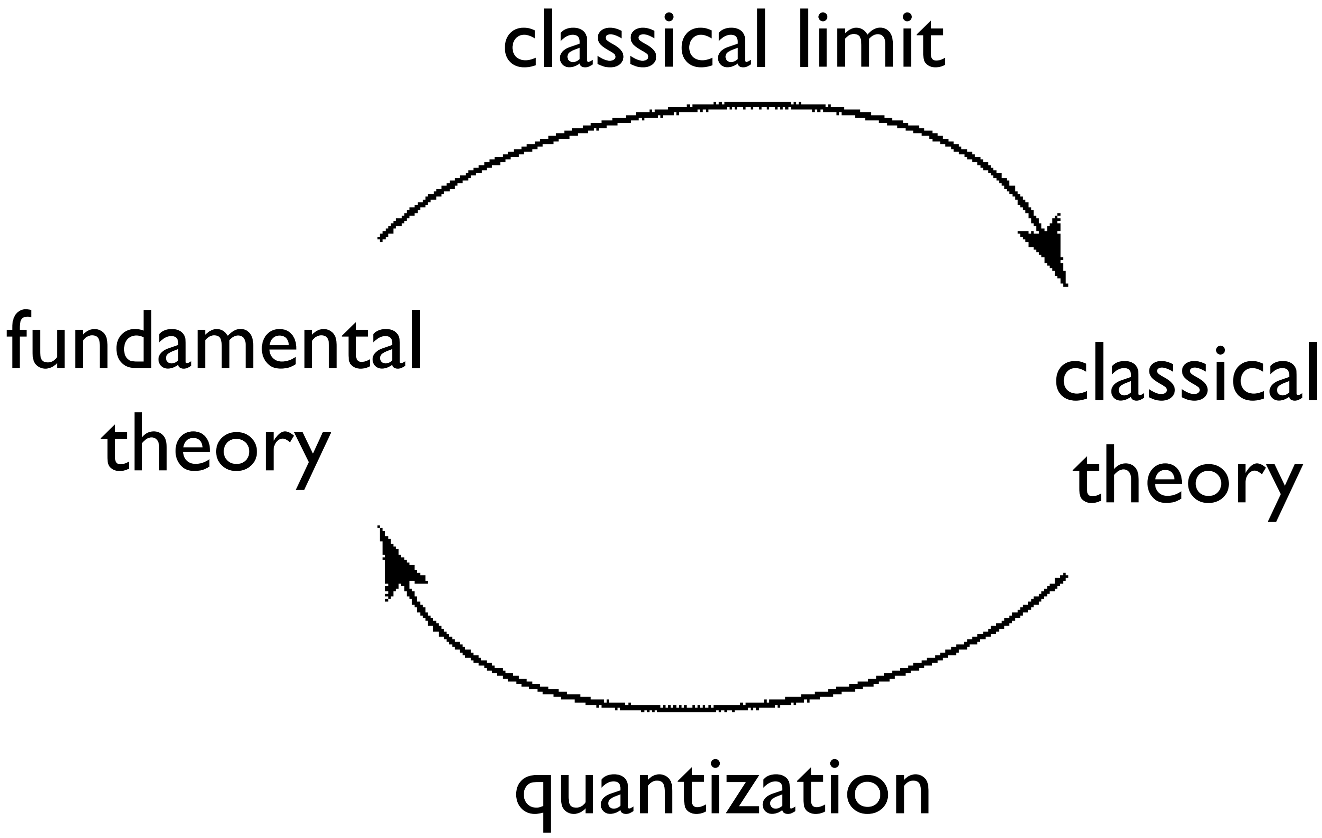
classical world $\subset$ quantum kinematics

$\longrightarrow$ measurement problem

instead:

Classicality is a *dynamic* property of a large quantum system

■ don't quantize



this circle does not close here.

start with a quantum theory (wen, volovik, ...)

■ environment & decoherence

roles of environment

- dump for energy/entropy
- bring it close to transition
- provide *randomness*

decoherence to keep it classical