Title: Two concepts of classicality in quantum mechanics

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Abstract:

plan of the talk

I. a new concept of classicality

II. randomness

III. gravity

IV. discussion

plan of the talk

I. a new concept of classicality

II. randomness

III. gravity

IV. discussion

one

a new concept of classicality

■ a simple example

quantum ising model:

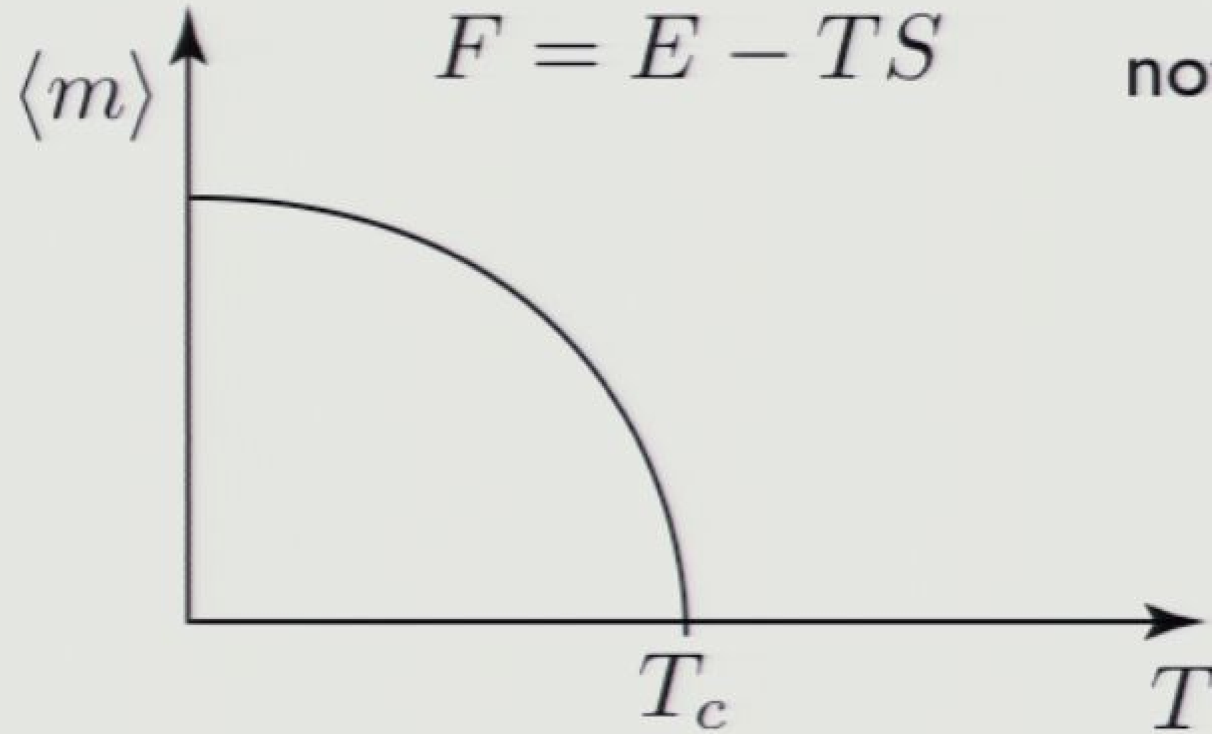
$$\mathcal{H} = (\mathbb{C}^2)^{\otimes N}$$

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

▪ phase transition

$$F = E - TS$$

not ordered



ordered

order parameter: $\theta_o \in$ Bloch sphere

generalized rigidity

ordered phase has new property:

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

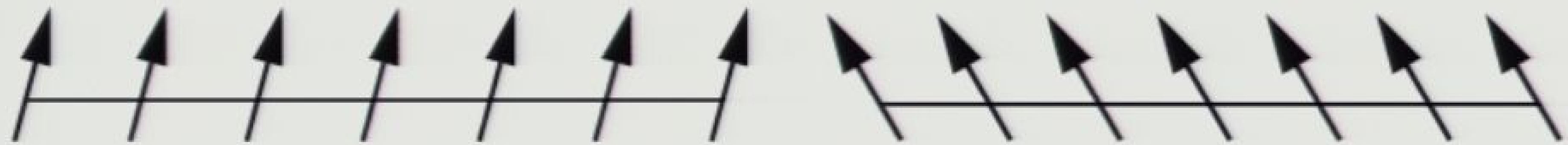
generalized rigidity

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

- more is different, really.

■ gravity

- you can not have a classical object without disturbing the vacuum: gravity
- inertial mass = gravitational mass?

$$m_i \simeq \int_{\partial C_i} (\nabla \theta) d\sigma$$

■ 0th level

groundstate

characterized by

$$\theta_0$$

the vacuum

▪ interaction of two systems

imagine two systems with order parameters

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

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= objective property

■ interaction of two systems

imagine two systems with order parameters

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

their interaction is best described by a term

$$\theta_1 \cdot \theta_2$$

$\theta +$ 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.

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

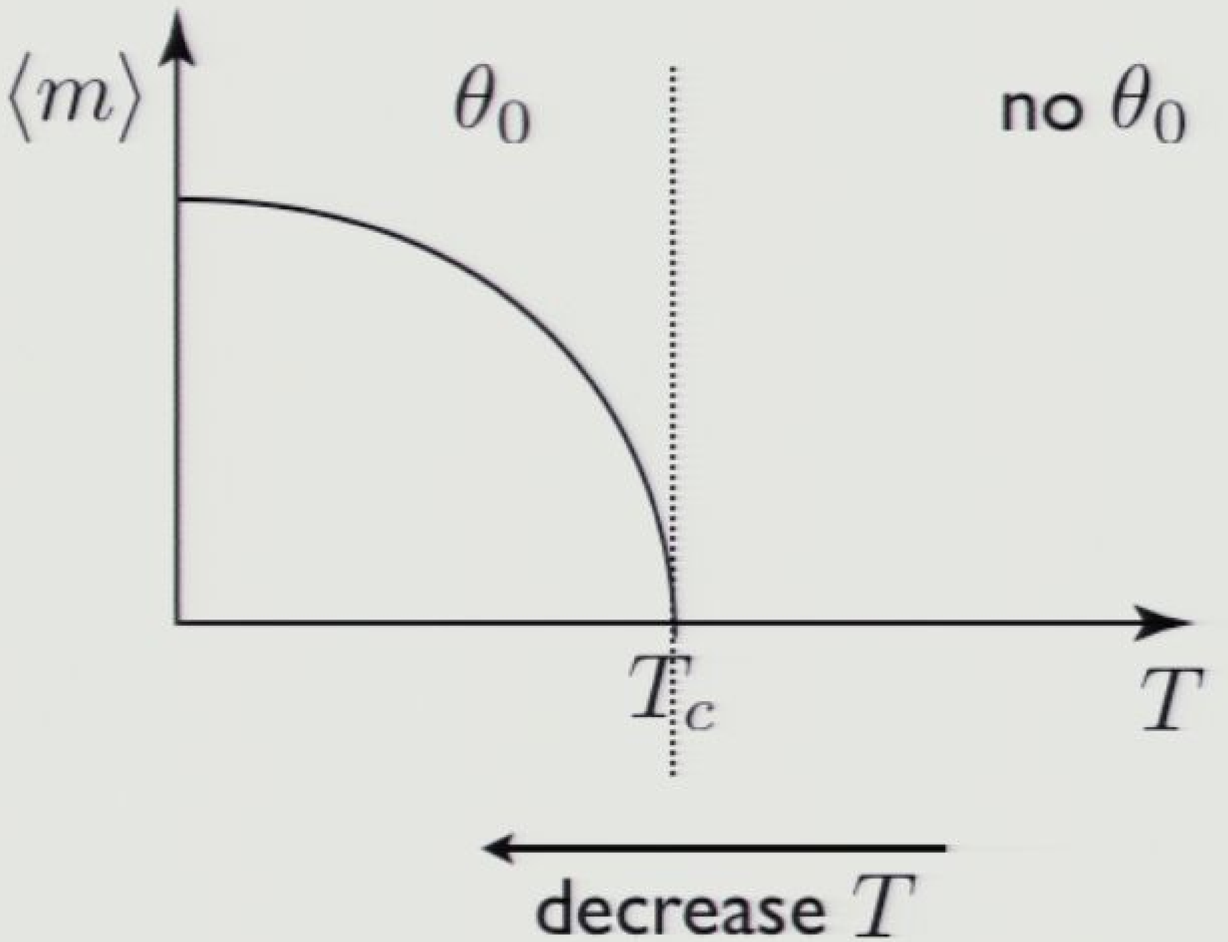
a comparison

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

■ sensitivity

add small magnetic field

$$\sum_i h\boldsymbol{\sigma}_z$$

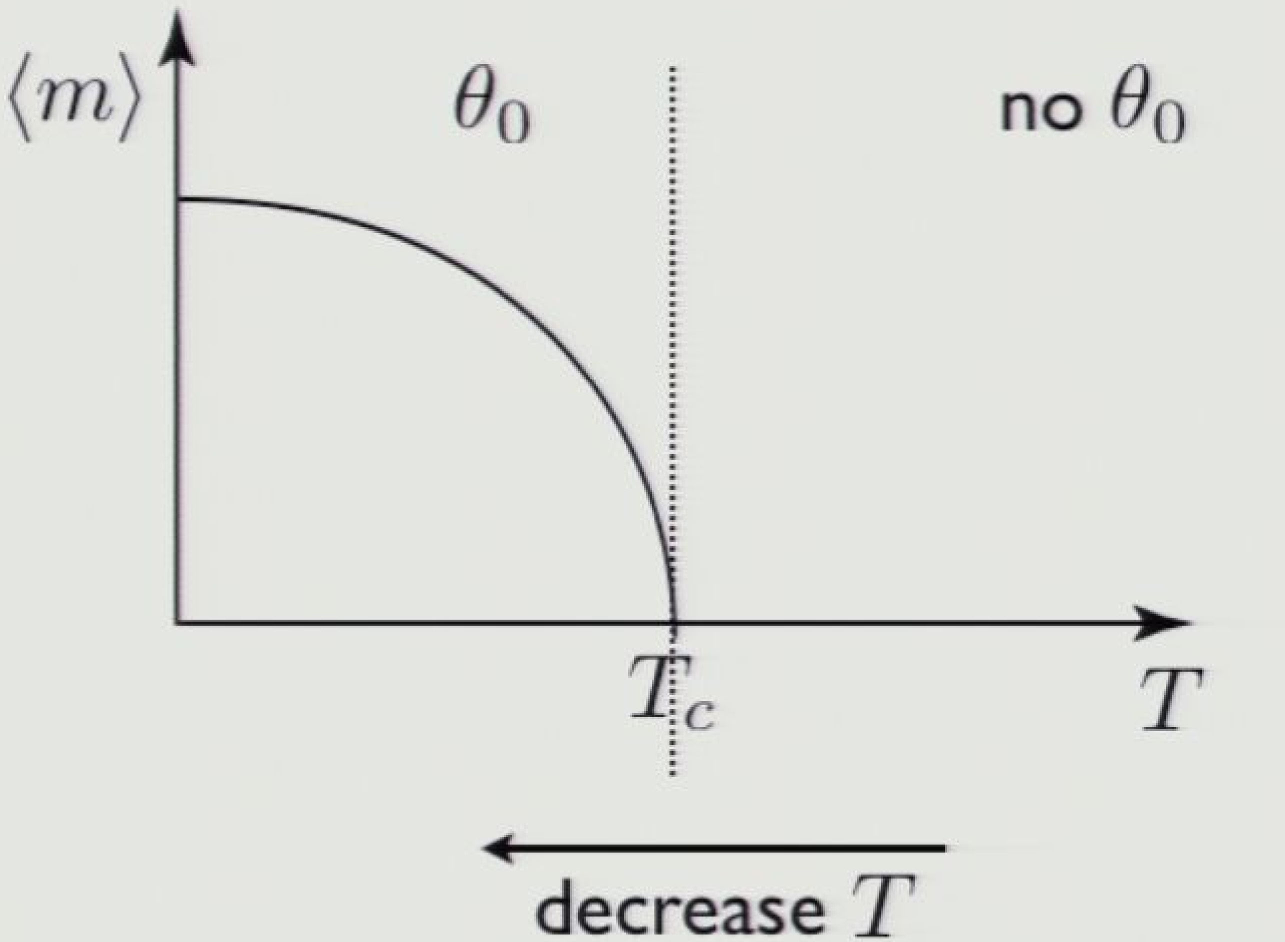
then

$$\langle m \rangle = \lim_{h\to 0} \lim_{N\to\infty} \langle m(N,T) \rangle$$

↑ view h as a small perturbation

as the system approaches the critical temperature T_c the system becomes arbitrarily *sensitive* to the environment.

■ the transition



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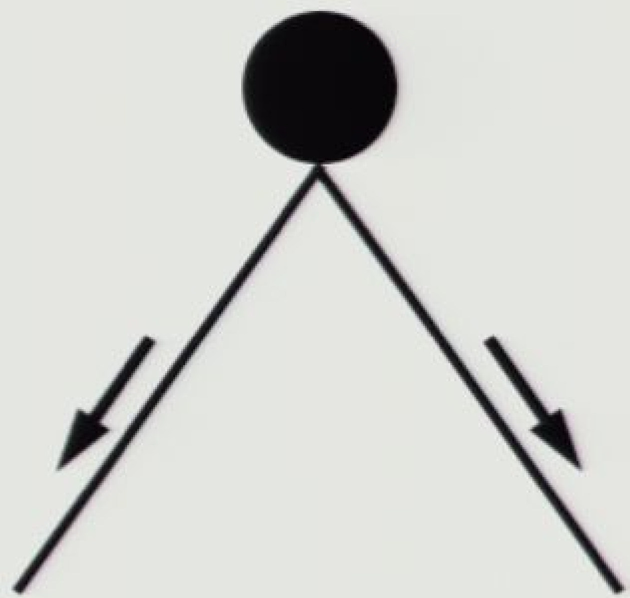
■ probability

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



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

transition very *sensitive* to the environment.

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

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.

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

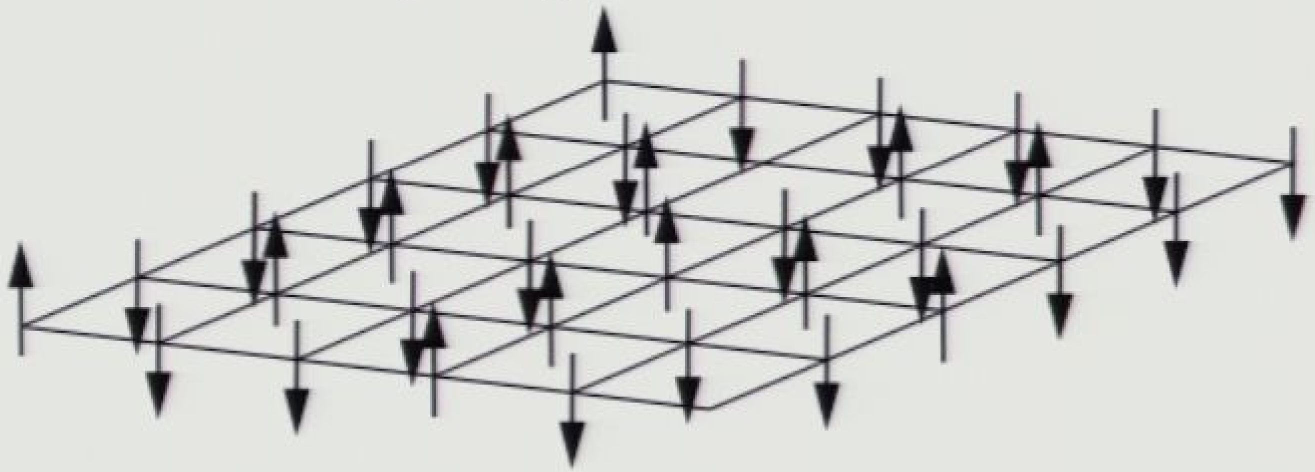
using arguments of d. deutsch, d. wallace, and s. saunders.

see also, od quant-ph/0603202.

three

■ setup

three dimensional spin systems on a lattice



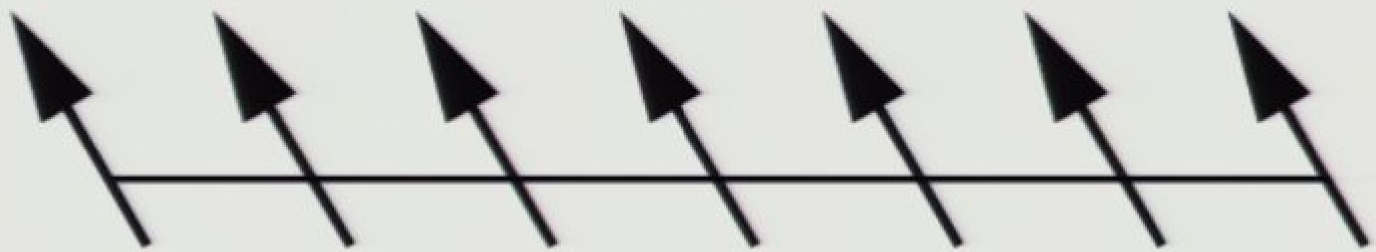
examples:

(i) ising model (+ modifications)

(ii) stringnet condensates (a la wen)

■ 0th level

groundstate



characterized by

$$\theta_0$$

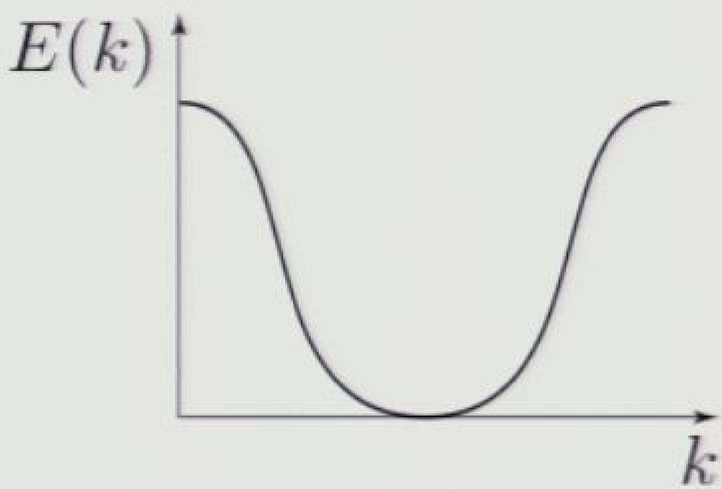
the vacuum

■ 1st level

excitations

$$|k\rangle = \sum_n \exp\left(2\pi i \frac{nk}{N}\right) |0 \; \ldots 0 \; 1 \; 0 \; \ldots \; 0\rangle$$

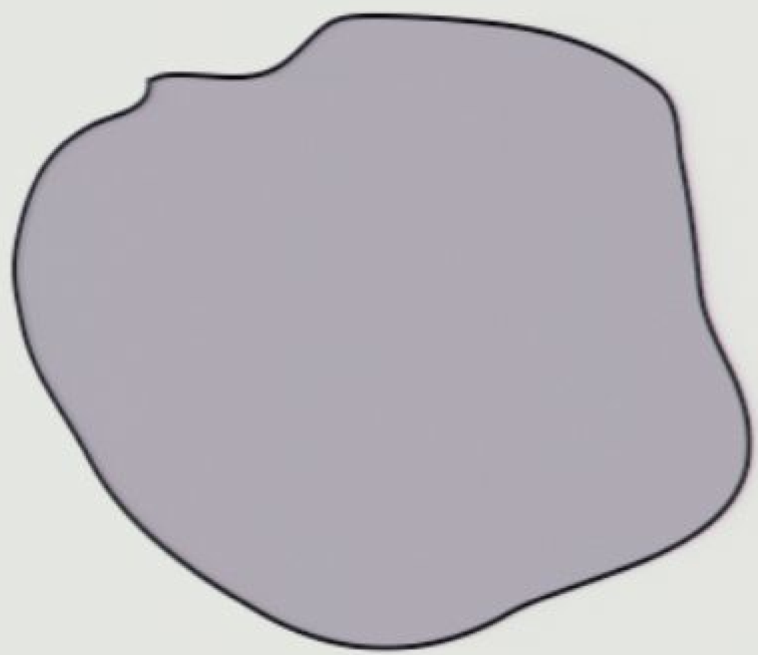
excitation implies
$\theta \neq \theta_0$



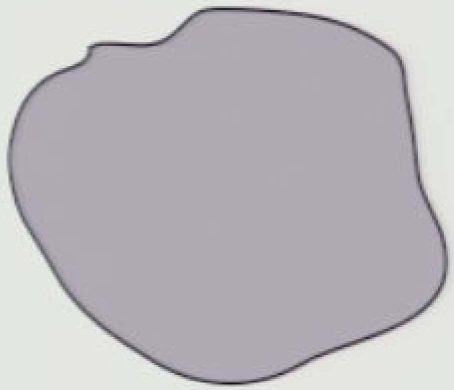
elementary particles

■ 2nd level

classical object = bound state of excitations



■ overview

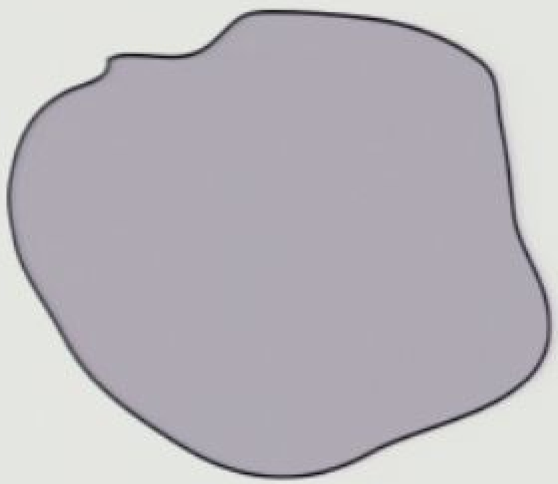


bound/classical states — level 2

$|k\rangle$ — excitations — level 1

θ_0 — ground state — level 0

■ the argument



internal relativity

how does the system look like from the inside?

- constant speed of light

  → Lorentzian metric

- Newtonian gravity in low speed limit

  → metric is curved

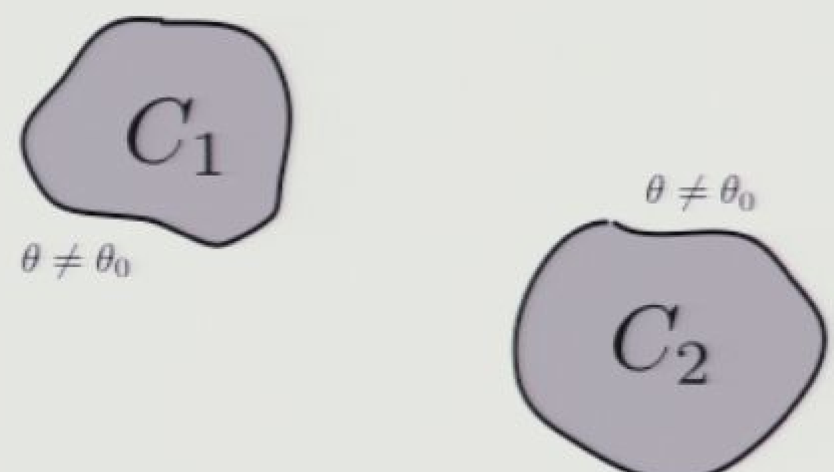
newton's law

$$E \simeq \int d^3x \, (\nabla\theta)^2$$

$$\frac{\delta E}{\delta\theta} = \Delta\theta = 0$$

$$F \simeq \frac{m_1 m_2}{r^2}$$

$$m_i \simeq \int_{\partial C_i} (\nabla\theta) d\sigma$$



■ internal relativity

how does the system look like from the inside?

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  ⟶ Lorentzian metric

- Newtonian gravity in low speed limit

  ⟶ metric is curved

four

discussion

■ the problem

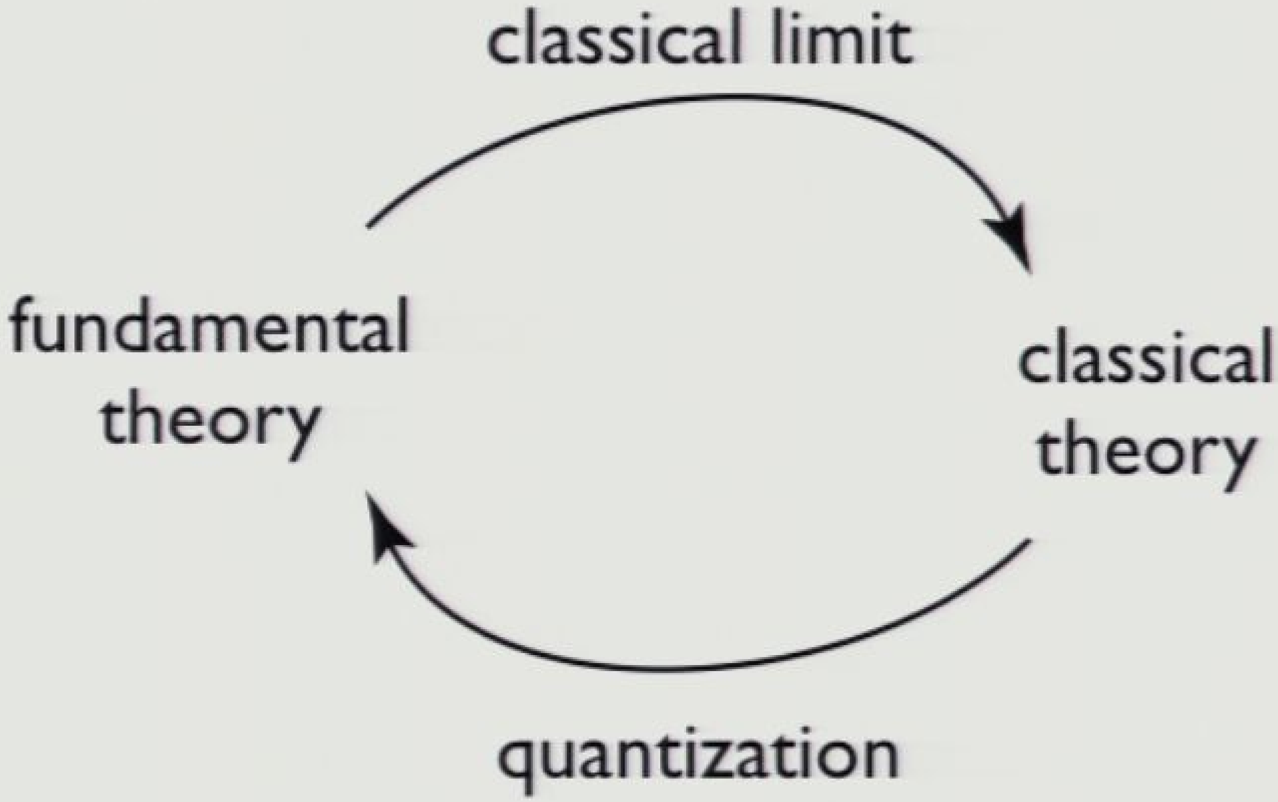
classical world $\subset$ quantum kinematics

⟶ 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

gravity

- you can not have a classical object without disturbing the vacuum: gravity
- inertial mass = gravitational mass?

$$m_i \simeq \int_{\partial C_i} (\nabla \theta) d\sigma$$

two

randomness

■ generalized rigidity

ordered phase has new property:

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