ψ

# What does the Wave Function Describe?

**Ian Thompson**
**Department of Physics,**
**University of Surrey**

**Talk:** http://www.ph.surrey.ac.uk/~phs1it/talks/wfdesc/

**1st & 2nd November, 2000**

1

## The success of quantum mechanics!

- **Good calculational tool!**
- **A framework in which we express our physical theories.**
- **No failures yet found, despite many tests (still ongoing)**
- **BUT:**

**(what) does Quantum Mechanics (QM) tell us about the physical world?**

2

## Features difficult to understand:

- **Wave/particle duality, interference effects, non-locality, etc, as we all know.**
- **But there are more questions:**
  - **Does anything actually happen? Are there actual events independent of our immediate experience?**
  - **Are all measurements really position measurements, even though *precise* positions are never measured!**
  - **What happens after measurements?**
  - **Are actual and virtual events the same or different?**
  - **Are all events really interactions?**

3

## What happens after a measurement?

- **If we measure a 'system' described by wave function $\psi=a_1u_1+a_2u_2$ to discriminate between the $u_i$, and $u_1$ is found to occur:**
- **What happens after to the 'unphysical' $u_2$?**
  - **Equally as real as $u_1$?** **many worlds/Bohm**
  - **Exists, but has no effect?** **decoherence**
  - **Dynamically reduced?** **new physics!**

4

## Dynamical Reduction?

- **If it occurs: When and Why?**
  - **Large sizes?** **No: large superconductors**
  - **Large distances?** **No: photons 20km apart**
  - **Energy differences?** **No: see $\Delta E$ interferences**
  - **Spontaneous?** **(GRW)** **ad hoc**
  - **Mind?** **(Wigner, Stapp)** **cat? virus?**
  - **Gravity: is spacetime classical?** **(Penrose)**
- **Scope for new physics!? ⇒ tests ongoing.**
  - **Any law should be Lorentz-invariant!**

5

## Does wave function describe anything?

- **Relation between observations / experiences?**
- **Does it tell us what exists? What is a 'system'?**
- **We agree that**
  - **cannot use naive models of particles or waves**
  - **assuming a 'material world' leads to problems, if 'material' means 'solid' or 'fluid'**
- **I claim that: if we cannot find any idea of quantum existence, this shows**
  - **not that there is no underlying world,**
  - **but that we lack imagination!**

6

## Form, Substance and Dynamics

- **Back to basic analysis:**
- **There are three categories of terms in physics:**
  - **existential terms**
    - **about what exists**
  - **formal terms**
    - **about the structure & static properties of what exists**
  - **dynamical terms**
    - **about what would happen, in new and/or hypothetical conditions**
    - **only by hypothesizing dynamics, can we deduce the future.**

7

## Examples of Formal Terms

- **shape, number, form, relation, configuration, symmetry**
- **function, field, oscillation, wave, flow,**
- **point, length, area, volume, amplitude,**
- **vector, matrix, operator, Hilbert space, bra, ket,**
- **ratios, relative frequency, probability, ...**

**DESCRIBED BY MATHEMATICS**

8

## Examples of Existential Terms

- **particle, material, matter, corpuscle, body,**
- **fluid, ether,**
- **substance, actuality, reality,**
- **event, interaction, outcome,**
- **person, experience, observation, sensation, thought, feeling, ...**
  - **(we know we exist!)**
- **world, universe, ...**

**DESCRIBED BY ONTOLOGY**

9

## Examples of Dynamical Terms

- **cause, propensity, disposition, power, capability, potentiality,**
- **energy (kinetic and potential),**
- **mass, charge, field coupling,**
- **force, pressure, momentum, impetus, elasticity/rigidity,**
- **(for people: intention, motivation, skill, desire, intelligence, …)**

**Dynamical properties say what *would* happen, even if it does not:**
A force says what acceleration would be caused *if* a mass was acted on.
Electric fields generates a force *if and when* a charge is present.
Quantum propensities give probabilities *if* a measurement is performed.

**DESCRIBED BY (PHYSICAL) LAWS**

10

## Summary of the Three Categories

| Form | Existence | Dynamics |
|---|---|---|
| 1. shape, number, form, relation, configuration,<br>2. function, field, oscillation, wave, flow,<br>3. point, length, area, volume, amplitude,<br>4. vector, matrix, operator, Hilbert space,<br>5. ratios, probability, relative frequency. | 1. mass, particle, material, matter, corpuscle, body,<br>2. fluid, ether,<br>3. substance, actuality, reality,<br>4. event, interaction,<br>5. experience, observation,<br>6. world, universe. | 1. cause, propensity, power, disposition, capability,<br>2. energy (kinetic and potential),<br>3. mass, charge, field coupling,<br>4. force, pressure,<br>5. momentum, impetus, elasticity/rigidity. |

THE TASK OF PHYSICS: To find connections between these, to explain some in terms of others, to describe the structure and dynamics of what exists.

11

## Complete Physical Theory?

- **Our challenge is to describe the quantum world in existential and dynamical terms, not just formally.**
  - **That is, talk of 'wave function' or 'probability amplitude' is not really sufficient.**
  - **Existence must contain/imply some dynamics!**
  - **We want to say 'what exists' as well as 'what form' it has:**
    - **What exists with the wave function as its form?**
    - **What is its dynamics?**

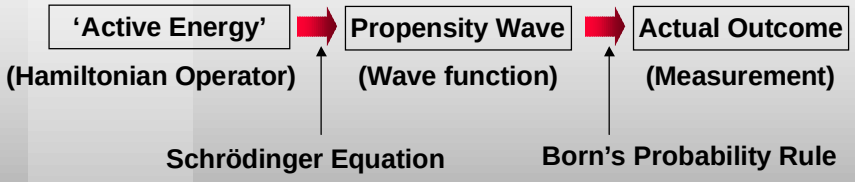
12

## New idea: 'Dynamic substance'

- **Try to derive 'existence' from 'dynamics'**
- **For example:**
  - **'electromagnetic force field',**
  - **'potential energy field'**
  - **'matter is a form of energy'**
  - **wave function is a 'propensity field'**
    - **propensity to interact, or**
    - **propensity to choose actual outcome**
- **Propensity (of some kind) is substance**

13

## Revisit: Hamiltonian Quantum Mechanics




- **Energy operator generates the wave function,**
  - **according to Schrödinger's time-dependent equation**
- **Propensity wave generates the actual measurement**
  - **according to Born's Probability Rule for $|\psi|^2$**
- **Actual measurements = selections of alternate histories**
- **'Energy', 'propensity waves' are two kinds of propensity.**

14

## Measurements are 'Actual Selections'

- **Actual measurements are selections of alternate histories**
  - **Unphysical alternatives actually removed by some (undiscovered) dynamical process.**
  - **This sets to zero any residual coherence between nearly-decoherent histories, if a branch disappears.**
- **Different alternatives $u_i$ often summarised by an operator A of which they are distinct eigenfunctions: $Au_i = \alpha_i u_i$, and labeled by some eigenvalues $\alpha_i$ .**

15

## 'Nonlocal Hidden Variables' in ordinary QM:

- **'Energy', 'propensity' and 'actual events' are all present, though hidden, in a 'generative' sequence.**
- **Energy and propensity exist simultaneously, continuously and non-locally.**
- **Actual events are intermittent.**
- **Does this describe QM as we know it?**

**General connection:**
Continuous existence ⇒ determinism
Intermittent existence ⇒ indeterminism

**(why?)**

16

## What does the wavefunction describe?

- **The wavefunction describes dynamic substances, which are configuration-fields of propensity for alternate histories.**
- **The wavefunction of an 'individual particle' $\Psi(\mathbf{x},t)$ describes the 'isolated' propensity for $\mathbf{x}$-dependent decoherent alternatives if these were initiated at time $t$.**

17

## Wholeness and Non-locality

- **The propensity fields:**
  - **extend over finite space regions and time intervals, so are non-local,**
  - **act to select just one actual alternative,**
    - **subsequent propensity fields develop from the actual alternative selected,**
  - **'whole' substances, but:**
  - **usually contain many 'virtual substances' (see later) in whole 'unitary compound'**
    - **So express using configuration space, not in 3D.**
    - **We need further analysis of 'quantum composition'.**

18

## Multiple Generative Levels

- **Description of ordinary quantum mechanics requires the idea of 'multiple generative levels'**
- **General idea:**
  - **'Multiple generative levels' are a sequence A→B→C → .. in which A 'generates' or 'produces' new forms of B using the present form of B as a precondition.**
  - **Then B generates C in the same way,**
  - **and so on until end when nothing is active.**

19

## Multiple Generative Levels II: Reality

- **In the general case, Multilevel Propensities are 'parallel processes' all equally real.**
  - **Level B, for example, is not just an approximate description of successive forms of other levels A or C.**
  - **Neither is B a microscopic constituent of either of levels A or C.**
  - **Rather, levels A, B, C,... are real processes 'in parallel' that interact with other by relations of 'generation' and 'pre-condition'.**

20

## Principles, Causes and Effects

- The sequence 'energy → propensity → actual event', does not have the three levels playing homogeneous roles as in the general case A→B→C
- If we look in more detail, we see:
  - energy ≡ 'principle'
    - Conservation of energy via H governs the process
  - propensity ≡ 'cause'
    - Time evolution and propagation of influence
  - actual event ≡ 'effect'
    - The final result
- Pattern appears to be: Principle ➡ Cause ➡ Effect

21

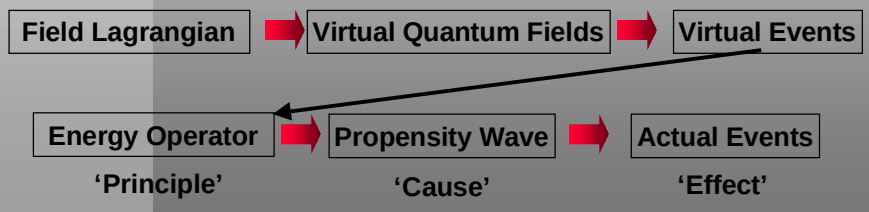
## Potentials from Virtual Particle Exchange

- Where does the Hamiltonian come from? We cannot just invent it!
- We know that the potential energy part of the Hamiltonian really comes from field-theoretic virtual processes. What are these events?
  - Kinetic energy, also, has a mass which is 'dressed' by virtual processes.
- Propose: *the Energy Operator is itself 'generated' by (further) previous levels*.

22

## Propensities for Virtual Processes

- **Propose: 2 linked sets each of three generative levels**
  - **both with (broadly) corresponding processes,**
  - **i.e. still in pattern 'Principle ➨ Cause ➨ Effect'.**
- **Virtual processes (in some way) 'generate' the terms of the Energy Operator (the Hamiltonian).**




23

## Virtual 'Principle ➨ Cause ➨ Effect'

- **The field-theoretic Lagrangian + Variational Principle starts the generative sequence.**
- **Propagating field quanta (virtual quantum field substances),**
  - **e.g. photons, gluons, quarks, leptons, ...**
  - **derived from the Lagrangian by a Variational Principle.**
  - **generate virtual events when interacting.**
- **Virtual events (of quantum field theory) are point events which generate the potential energy part of the Hamiltonian operator.**
  - **They do not all *actually* occur because, for example, they *may* generate potentials that are never active in the selected sequence of *actual* outcomes.**

24

## Virtual and Actual Events

- **VIRTUAL EVENTS**
  - Point events
    - (not=point measurements)
  - Interactions
  - Microscopic interactions
  - Continuous
  - Deterministic (apparently)
  - Contribute to alternate futures
  - Have intrinsic group structure (e.g. gauge invariance, renormalisation)
- **ACTUAL EVENTS**
  - Visible events in history
    - (e.g. measurement)
  - Selections
  - Macroscopic decoherence
  - Discrete
  - Probabilistic
  - Definitely occur (or not)
  - Have branching tree structure

25

## Complications: are all the stages needed?

- **Some physicists try to derive probabilities of actual outcomes directly from field theory, without a Hamiltonian or potential. Is the idea of a potential only an approximation suitable for some energy scales?**
  - I would ask: Are there not still some roles for mass, kinetic and potential energy, & energy conservation?
  - I agree that a Hamiltonian (etc) is a 'composite object', whose detail reflects its genesis:

'Natural things are more complicated,
and more beautiful, the more you look into them'

26

## A BIGGER Picture?

| *General Principle?* | *Formative Fields?* | *Formative Events?* | *(Formative?)* Principle | *Spacetime formation?* |
|---|---|---|---|---|
| Lagrangian | Virtual Quantum Fields | Virtual Events | (Virtual) Cause | **Some speculative ideas!** |
| 'Active Energy' | Propensity Fields | Actual Selections | (Actual) Effect | |
| Principle | Cause | Effect | | |

27

## Conclusions

- **I hope that this is an accurate classification of the several 'stages' in nature, as seen in QM.**
  - **Should help to understand quantum physics and what really goes on.**
  - **We can find 'what the wave function describes', if we think carefully and with imagination.**
- **More work needed to understand the mathematical substructures at each level,**
  - **We should look for new physics (new theories and new experiments).**

28