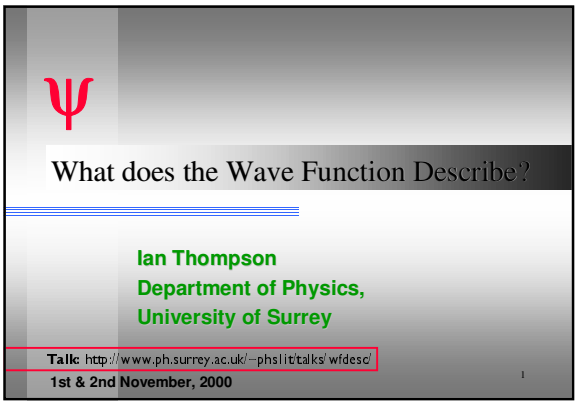
What does the Wave Function Describe?
Ian Thompson
Department of Physics,
University of Surrey
Talk: http://www.ph.surrey.ac.uk/~phslit/talks/wfdesc/
1st & 2nd November, 2000
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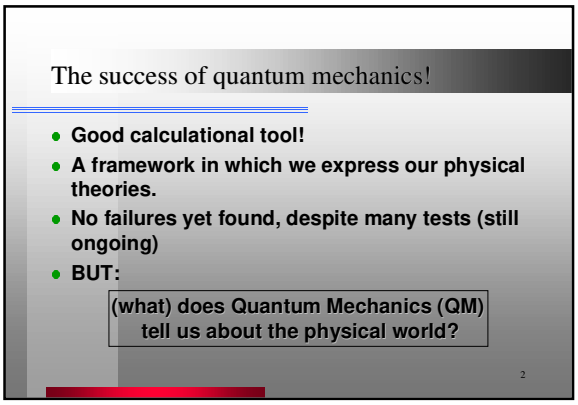
The success of quantum mechanics!
Good calculational tool!
A framework in which we express our physical theories.
No failures yet found, despite many tests (still ongoing)
BUT:
(what) does Quantum Mechanics (QM) tell us about the physical world?
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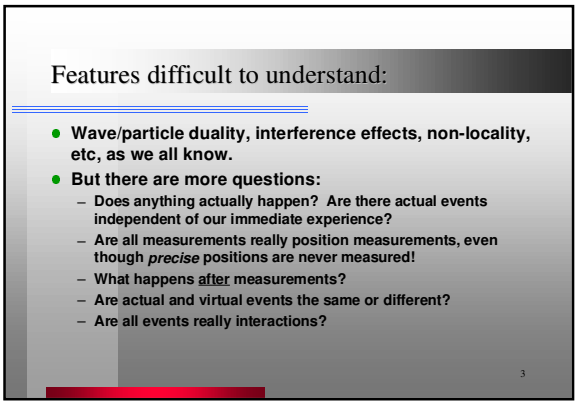
Features difficult to understand:
Wave/particle duality, interference effects, non-locality, etc, as we all know.
But there are more questions:
Does anything actually happen? Are there actual events independent of our immediate experience?
Are all measurements really position measurements, even though 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 $\psi = a_1 u_1 + a_2 u_2$ 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!

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Dynamical Reduction?

- If it occurs: When and Why?
  - Large sizes? No: large superconductors
  - Large distances? No: photons 20km apart
  - Energy differences? No: see ΔE 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!

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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!

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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.

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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

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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

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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

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Summary of the Three Categories

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

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.

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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?**

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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

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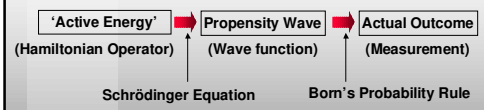
Revisit: Hamiltonian Quantum Mechanics



- 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.

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: $\mathrm{A}u_i = \alpha_i u_i$, and labeled by some eigenvalues α_i .

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'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?)

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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.**

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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'.**

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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.**

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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'.**

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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**

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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.***

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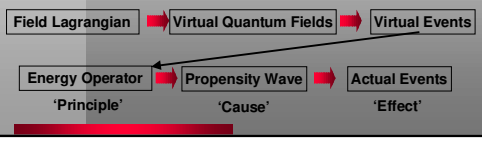
Propensities for Virtual Processes

- **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).**



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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.**

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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

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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'

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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		

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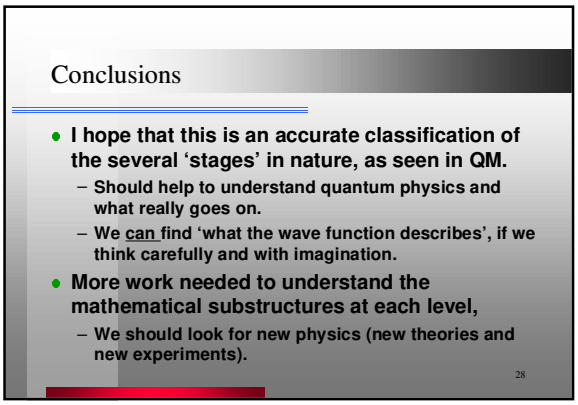
Conclusions
I hope that this is an accurate classification of the several 'stages' in nature, as seen in QM.
Should help to understand quantum physics and what really goes on.
We can find 'what the wave function describes', if we think carefully and with imagination.
More work needed to understand the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