☯ The Quantum Complexity ☯ behind Quantum Reality

Hello! My name is Graeme Robertson.

In 1977 I failed a PhD in the Philosophy of Science at Cambridge University, and was not given leave to resubmit a revised dissertation. The title of the thesis was Philosophical Problems of QUANTUM ONTOLOGY.

So I would like to thank the Scientific and Medical Network for this opportunity to redeem myself a little, and explain my understanding of QT a bit better.

The talk is called 'The QUANTUM COMPLEXITY behind Quantum Reality'. It is divided into 3 parts: an outline of the **essentials of quantum theory**, a discussion of some **glaring problems** of interpretation, and my shocking **philosophical conclusions**.

1.1 In 1900 it became clear to Max Planck, and in 1904 it became even clearer to Albert Einstein, that radiation transfers energy in **quanta** of definite amounts.

Radiation behaves like a stream of **particles** of energy $E = h\nu$, where ν is the frequency and h is a tiny constant 6.6..x10^{-34} kg m^{2} s^{-1}. For a given frequency, each quantum is a definite amount of energy.

In 1913, in order to account for atomic spectra, it became clear to Neils Bohr that angular momentum L, changes in precise **jumps**. $L = n\hbar$, where n is a positive integer and $\hbar \equiv h/2\pi$ for convenience.

In 1925 Werner Heisenberg altogether abandoned the notion of microscopic particle trajectories, and represented position and momentum by transformation **matrices**, **X** and **P**, leading to MM.

1.2 Meanwhile, in 1924 Louis de Broglie proposed to let **particles** assume **wave** properties by assigning momentum $p = h/\lambda$, where λ is the wavelength. He proposed waves of the form $e^{-i(Et - \mathbf{p.x})/\hbar}$ by an amazing leap from ordinary waves of the form $e^{-i(\omega t - \mathbf{k.x})}$.

Up to then most physicists passionately believed that light was a wave phenomenon, and that massive particles were NOT waves.

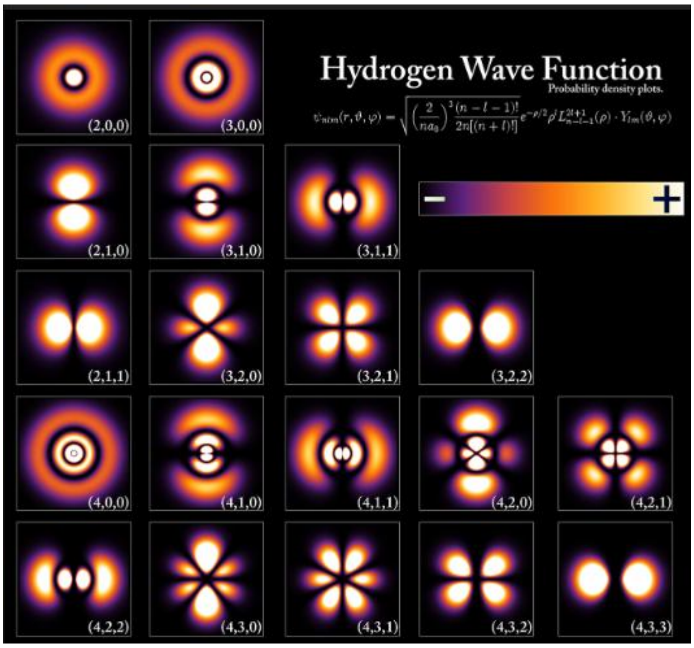
In 1925 Erwin Schrödinger replaced position and momentum variables in the equation for time-independent total energy $E = KE + PE = p^2/2m + V(x)$ with operator $x\circ$ and differential operator $-i\hbar\partial_x$ acting on a wave function which is usually denoted by $\Psi(x)$.

$$-\hbar^2/2m\ \partial_x\partial_x \Psi + V(x)\Psi = E\Psi$$

He also represented time and energy with $t\circ$ and $i\hbar\partial_t$ giving a time-dependent equation for $\Psi(x,t)$. This approach is called WM.

$$-\hbar^2/2m\ \partial_x\partial_x \Psi + V(x)\Psi = i\hbar\ \partial_t \Psi$$

Both these equations were incredibly successful at reproducing the hydrogen atom spectrum, although the ontological meaning of the '**wave function**', which changes **causally** in the wave equation, was, and still is, extremely unclear. (The origin of this choice of operators can be understood by way of a Fourier transformation.)



1.3 In 1928 Paul Dirac formulated a **relativistic** wave equation which incorporated intrinsic spin and accounted for the hydrogen spectrum “fine structure”. DE unexpectedly predicted antimatter.

Dirac found a way to square root and quantize $E^2/c^2 - p^2 = m^2c^2$

$$i\hbar\gamma^{\mu}\partial_{\mu}\,\Psi = mc\,\Psi$$

MM, WM and Dirac theory are unified in **functional analysis** where Ψ is a vector (or ray) in Hilbert space, whose basis vectors Ψ_i are **functions** and whose scalar elements α_i are **complex numbers**. Vector spaces evolved from rectangular 3D (i,j,k) axes, to curvilinear 3D (e_i,e_j,e_k) axes, to nD orthogonal functions (sin x, sin 2x, sin 3x...) to

$$\Psi = \Sigma_i\alpha_i\Psi_i\,,\ \ \alpha_i \in \mathbf{C}\,,\ \ \Psi \in \mathcal{H}$$

1.4 In QT, self-adjoint (Hermitian) **linear operators** $\underset{.}{\hat{A}}$ represent observables, and they ‘project’ **real values** a_i from **basis states** Ψ_i

$$\underset{.}{\hat{A}}\,(\,\Psi_i\,) = a_i\Psi_i\ \ ,\ \ a_i \in \mathbf{R}$$

This is the **eigenfunctions** and **eigenvalues** equation which is central to QT. ‘eigen’ means ‘the same’ since $\underset{.}{\hat{A}}$ leaves this state unchanged.

1.5 The **superposition principle** says that linear combinations of solutions to Schrödinger’s equation are also solutions. So observe $\underset{.}{\hat{A}}$:

$$\underset{.}{\hat{A}}\,(\alpha_1\Psi_1 + \alpha_2\Psi_2\,) = \overbrace{\underbrace{\alpha_1 a_1\Psi_1 + \alpha_2 a_2\Psi_2}_{\text{or}}}^{\text{and}}$$

Unlike ordinary waves, only one eigenvalue and its eigenfunction is actually realised on measurement, thus effecting a **collapse of the wave function** from ‘a_1 **and** a_2’ to ‘a_1 **or** a_2’.

Superposition (**and**) is only valid if there is no way to know, even in principle, which result, if any, actually happened.

Therefore causality only applies to unobserved systems.

In 1926 Max Born realised that the probability of getting result a_1 is given by $|\alpha_1|^2$ and the probability of getting a_2 is $|\alpha_2|^2$.

Ψs are normalised to 1 and $\alpha_1^2 + \alpha_2^2 = 1$ to conserve probability.

1.6* Note in passing that the local U(1) gauge invariant (GI) transformation, $\Psi \rightarrow e^{i\theta(x)}\Psi$, leaves $|\Psi|^2$ and, therefore all predictions, **unchanged** because $\Psi^*\Psi \rightarrow e^{-i\theta(x)}\Psi^* e^{i\theta(x)}\Psi = \Psi^*\Psi$.

This fact, when exploited, miraculously yields EM, and even the basics of the SM of particle physics with GI $U(1)xSU_2xSU_3$.

In 1922 Theodor Kaluza also miraculously showed how to produce Maxwell's equations (EM) from 5D GR.

These ideas, GI and 5D GR, are fundamental to ST which needs 26D GR to quantize it, and a lot of GI symmetry (E_8xE_8) to tame it.

1.7 Back in 1888 Schwarz proved mathematically an inequality which leads to a relation between the standard deviations of 2 self-adjoint linear operators A and B, saying that the products of their standard deviations, in some state Ψ, is no less than ½ of the modulus of the mean value of their commutator.

$$sd_\Psi(A).\ sd_\Psi(B) \geq \tfrac{1}{2}|\mu_\Psi\ [A,B]|$$

1.8 In 1926 Heisenberg realised that his matrices didn't necessarily commute because the order in which certain pair of observables are measured could affect the outcomes. He found that the commutator of his position and momentum matrices is actually a constant (times the unit matrix),

$$[\mathbf{X},\mathbf{P}] = i\hbar$$

This may be verified using the differential operators $x\circ$ and $-i\hbar\partial_x$ on some general state Ψ: $[\mathbf{X},\mathbf{P}]\Psi = (x\circ(-i\hbar\partial_x) - (-i\hbar\partial_x)\,x\circ)\Psi = i\hbar\Psi$

Then employing the Schwarz inequality immediately led Heisenberg to his famous **uncertainty principle**:

$$\Delta x.\Delta p \geq \tfrac{1}{2}\hbar$$

In the same year, Heisenberg's revelation led Bohr to the concept of **complementarity** which attempts to justify the implication that a fully prepared pure wave function, Ψ, contains everything relevant **that we can possibly know**. There are basic limits on simultaneous knowledge of 2 non-commuting observables.

1.9 There are 3 fundamental mathematical objects in LA: **operators** and their corresponding **eigenfunctions** and **eigenvalues**.

In QT an **operator** embodies some particular observable, and acts like a measurement on a system. If successive measurements always reproduce the same measured result, then the system is said to be in an **eigenstate** (eigenfunction) of that observable's operator.

Each eigenstate is associated with a real (rational) number, or **eigenvalue**, whose value is one possible result of the measurement.

After each measurement of an observable, the Schrödinger equation may have to be solved again, or the system may have to be prepared again in the same original state unless it is in an eigenstate.

1.10 In practice, a measurement is usually considered to be an irreversible act of amplification. However, it is believed that a superposition is only valid if there is no way **in principle** to know the result of the measurement.

If information, which is apparently lost in the collapse of the wave function, is accessible in principle, then the interaction is insufficient to destroy the possibility of interference, and the measurement is therefore not actually a measurement at all.

1.11 So, in summary, the introduction of **complex-valued** functions and **non-commuting** observables implies inescapable **uncertainty**, and that implies the necessity to talk in terms of **probabilities,** which in turn implies the need for an **epistemological collapse**, if not an **ontological collapse**, of the wave function.

2.1 In December 1926, Einstein famously wrote to Born saying that “God does not play dice!” Einstein demanded determinism.

Still, Bohr continued to argue that particles do not have well defined properties until they are measured.

To which Einstein, quite understandably, responded, “How does the universe know someone is measuring something?” and later to a friend, “Does the Moon .. exist only when I observe it?”

2.2 In 1935, EPR wrote in Phys. Rev. that, “In a complete theory there is an element corresponding to each element of reality.”

If one can predict with certainty the simultaneous values of position and momentum of a particle **without in any way disturbing it**, then that should prove the need for **hidden variables** in QT.

EPR described a particle splitting into 2 equal parts which then fly apart. If someone measured the momentum of one part, then the momentum of the other would be known **exactly** by conservation of momentum. And if one measured the position x of the first part at a certain time, then the position of the second would be known to be **exactly** –x at that time. Thus EPR argued that QT is manifestly incomplete because x and p clearly both exist simultaneously exactly.

2.3 But in 1964 John Bell considered 2 spatially separated ‘**entangled**’ particles, which had once interacted as described by EPR.

The particles appear to have **correlated** properties such that measuring one, instantaneously affects the state of the other.

Bell proved, via an inequality, that if QT is correct, then certain predicted correlations defy classical intuitions about causality and locality. QT is at odds with the assumptions of local realism (no instantaneous effects) and the existence of determinate local hvs.

Bell intended to eliminate ‘the observer’ from physics, as was the desire of many other physicists and philosophers such as Henry

Margenau and Karl Popper. But Bell failed.

In 2022 John Clauser won the Nobel Prize for consistently violating Bell's inequality in numerous experiments since 1972.

These results suggest that the correlations between entangled particles are inherently **non-local** and cannot be explained by any deterministic model. (BTW this doesn't conflict with SR.)

2.4 Further, in 1967 Kochen and Specker published a proof that there is no way to assign well-defined values to certain properties of particles in a consistent realist manner that is independent of **how** they are measured.

More precisely, there can be no hidden variables that determine behaviour independent of the measurement **context**.

You can't easily embed a quantum logic in a classical logic.

2.5 Meanwhile, back in 1926 Schrödinger declared, "If we are going to stick to this damned quantum jumping then I regret that I ever had anything to do with QT!"

Schrödinger hated the notion of collapse of the wave function.

2.6 In 1935 Schrödinger produced his cat to illustrate the paradox of superposition. The cat can't be alive **and** dead at the same time! It doesn't accord with everyday experience. (Of course the necessity of keeping a cat alive in total isolation from its surroundings is already a monumental feat, as the makers of quantum computers well know.)

However, in 1999 Markus Arndt demonstrated quantum **interference** with buckyballs, each made of 60 carbon atoms.

In 2010, physicists at Santa Barbara built a tuning fork the size of a typical computer screen pixel, and put it into a **superposition**.

In 2020, physicists at MIT showed the effects of quantum fluctuations in laser light on a 40kg mirror. The fluctuations moved the mirror a measured 10^{-20}m. (It was for a graviton interferometer.)

Also superfluidity and superconductivity show that quantum effects are not restricted to tiny particles, so **where is the division between quantum and classical realms**?

2.7 In 1961, Eugene Wigner proposed that a friend covertly observes a supercat. Wigner then considered whether he could believe that his friend was in a superposition of states right up until he was asked the big question “Is the cat dead or alive?”

Wigner concluded that his friend’s **consciousness** already must have collapsed the supercat, even before he was asked.

2.8 Meanwhile, in 1952 Bohm developed a hvt which restores particle trajectories and determinism. Sounds good, doesn’t it?

In his theory, particles are **guided** by the Schrödinger wave, and are controlled by an additional complicated energy potential. However, the theory, while being ontologically more comfortable, gives no predictions different from QT, and it is **non-local** too.

This approach is reminiscent of early reactionary attempts to rescue Newtonian gravity from GR by significantly complicating Newtonian gravitational forces. It can be done, but it is unsightly.

Everyone tries to preserve treasured concepts like reality, but Bohm later significantly changed his tune, as did Schrödinger.

2.9 In 1957 Hugh Everett (aka EWG) proposed the many-worlds interpretation (not to be confused with the multiverse). It is deterministic and local at the expense of an **infinite** number of worlds. (Sean Carroll estimates there are only 10^10^122 – which is over a googolplex! A googol is 10^{100} and a googolplex is 10^{google}.)

EWG claimed that there is NO collapse. There is never any collapse. Every possible outcome of a measurement is realised in some metaphysical world, somewhere. You are in this one, with me.

This is introducing any amount of stuff just to retrieve pseudodeterminism, because **no** predictions of QT are changed. Causality of the Schrödinger evolution **IS** the determinism of this ‘manyverse’.

2.10 In 1981 Ghirardi, Rimini and Weber proposed a **spontaneous collapse** theory in order to regain classical realism and prevent macroscopic superstates. It claims that collapse occurs randomly at a rate of about 10^{-8} times /s in any small volume of around 10^{-15} cc.

This mechanism is introducing absolute **randomness** in order to fix something else – reality as we know it.

2.11 In recent years there has been much hope that the concept of quantum **decoherence**, introduced by Dieter Zeh in 1970, will solve the measurement problem (viz. the collapse of the wave function).

This approach argues for the **appearance** of wave function collapse by loss of coherence (or information) to the environment, like frictional losses or like dissipation of water waves.

But without any collapse, the wave function, in its frictionless domain of mathematical purity, never forgets - meaning that all that seems real, in principle may be undone since no interference effects are ever finally lost, even in big things with 10^{23} atoms.

An example is John Wheeler’s delayed-choice quantum eraser.

2.12 In summary, there have been many attempts to rationalise QT, or replace it with something better. But nothing can improve on the fabulous mathematical successes of QT, and none of the various proposed interpretations of QT is totally convincing.

On the negative side, David Mermin just said, “Shut up and calculate.”

On the more poetic side, Aristotle said, “Each thing is a kind of unity, and potentiality and actuality taken together exist somehow as one.”

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3.1 Consider the metaphysics of Immanuel Kant (1724 - 1804). He attempted to reconcile the 2 current conflicting theories of knowledge of the 18th C: that of the British empiricists like Locke, Berkeley and Hume who believed knowledge came from **perceptual experience**, and that of the Continental rationalists like Descartes and Leibnitz who believed knowledge came from **reason alone**.

Kant concluded that there are 2 sources of knowledge: sensibility and understanding.

For Kant there are 2 epistemological levels. There is a phenomenological level which reveals a **contingent sequence of events** which is our everyday world. There is also a transcendental level which holds an a priori scheme of causation of **things-in-themselves** – noumenal objects of pure thought that we cannot know.

Consciousness, for Kant, is the synthetic unity of the manifold of perceptions.

3.2 Now identify **eigenvalues** with the ordinary world of **phenomena** – of **real measures** of ordinary experience. All is real.

Identify **eigenfunctions**, and wave functions in general, with the world of **noumena** – things as they are in themselves, independent of sensory perceptions and cognitive faculties, and beyond the reach of human cognition.

Kant's noumenon sets boundaries on what can be known by human cognition, a bit like the limitations in the wave function.

3.3 Further, the mathematical **operators** and the related devices that we construct, or have to observe with, fit well with Kant's notion of **forms of perception**. In particular the 5 senses provide the fundamental structures, or frameworks, through which we experience reality. (Kant added in the 'forms' of space and time.)

Along with the forms of perception are the **categories of understanding** - the fundamental concepts through which we understand and interpret sensory input.

Kant argued that our knowledge is actively shaped and organised by our forms of perception and categories of understanding, a bit like the quantum operators that represent observables and define meaning by the (experimental) arrangement.

3.4 So, returning to the primary conceptual problem in QT, where and when does the **collapse of the wave function** occur?

☯ Is it **at the first macroscopic object** in the von Neumann chain of amplification, as Bohr and Heisenberg originally assumed?

☯ Or is it **at the first conscious observer**, as Wigner and von Neumann first thought?

☯ Or, if QT is a universal theory, isn't it the case that the only obvious place for a split to be is **at or in myself**. In oneself.

3.5 Consider carefully the nature of **consciousness**.

How many consciousnesses are there? As many as there are living awake human brains? NO.

Consciousness is singular. Consciousness is this **immediate experience** one is having right now. (If you think differently, then just take this as my definition of consciousness.)

As far as I am concerned, consciousness can't be put in a bag and sent to China, unless I get in the bag.

One's immediate awareness **IS** consciousness – no more and no less. Consciousness is always here, never there; it is always now, never then. Ours is the only consciousness we do **or can** experience.

If you are following me in this argument, then you should agree that **YOU CAN** immediately empirically verify that **there is only one**

consciousness in the universe!

I submit that the only collapse is at or in oneself, in that empty space between nothing and something, oblivion and vigilance...

3.6 When one opens one’s eyes and ears, the whole universe ‘collapses’ immediately into a complete and consistent reality.

It silently and continually snaps into one’s reality from a kind of collective unconscious, a wave function, a quantum complexity.

You create reality by forcing a phenomenal world out of the noumenal world by application of your senses, innate or extended.

The noumenmon binds us together into a consistent irreducible whole so that there can be no contradictory evidence in truth.

One is back (after 500 years of Copernicus) at the centre of the universe.

3.7 So, because the wave function is complex, **ignorance is theoretical** – that is, one is necessarily ignorant of so much.

Because superposition is intangible, **interphenomena are not objective** – that is, between phenomena are only noumena.

Because every experience is derived from a pure universal state, **one is complete sense** – and the best one can possibly do is to have a balanced set of complementary senses, physical and mental.

One is the perfect observer. (Not God.)

3.8 Because probability is fundamental and inescapable, **are we free?** This is an important question for moral philosophers.

Might we be able to harness, through the quantum Zeno effect, the freedom that we actually feel? Really? Might we?

Zeno argued that a flying arrow actually never moves, and Aristotle concurred with, “If all that occupies the same space is at rest, and if that which moves occupies such space at any moment, the flying arrow is at rest.”

Cynically, we might add, “.. and the watched pot never boils!”

Also we might want to complain that the infinite series 1 + ½ + ¼ + ⅛ +... is only and exactly equal to 2, no more, because some infinite series are finite sums, therefore the arrow **can** move.

Anyway, according to the quantum Zeno effect, introduced in 1974 by Fonda and Ghirardi, by continuous (repeated) observations one can effectively **freeze** (or slow down) evolution of the noumenon, which evolves through the Schrödinger equation.

At the level of the nervous system, one can imagine that such control of just one important nerve might be sufficient to gain macroscopic control of something big and useful, like a finger.

3.9 I attempt to elaborate on this kind of thing in my book:

Unity Consciousness and the Perfect Observer

which was self-published in 1995 and is available for £5, or as a free PDF, from my web site at http://robertson.uk.net where you will also find the script for this talk (plus a few random extra notes).

Beware, my website has no security certificates, but don’t worry because there is no way to enter any data so you are pretty safe. And your antivirus may complain, but there are no known viruses in any of the files or executables that you might download. My coding is in APL characters which are a wee bit weird and suspect from the point of view of most antivirus software. Hence alerts.

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Also beware if you are philosophically or politically correct. ☺

Thank you so much for listening.

NOTES:

Rafael Bombelli introduced **imaginary numbers** in 1572 for solving quadratic and cubic equations. They owe their existence to the efficacy rather than the credibility of the square root of -1. A clue about the origin of complex numbers in quantum physics comes from talk of waves. In 1822 Joseph Fourier claimed that any continuous or discontinuous function of time could be represented by a **complex-valued function** of frequencies. Likewise, a state $\Psi(x)$ representing a superposition of eigenstates of the position operator **X** may be transformed into a complex-valued state representing a superposition of momentum (wavelength) eigenstates $\Phi(p)$ of the momentum operator **P**.

$$\Phi(p) = h^{-½} \sum_x e^{-ip.x/\hbar}\, \Psi(x), \text{ and inversely, } \Psi(x) = h^{-½} \sum_p e^{ip.x/\hbar}\, \Phi(p)$$

This effected a unique conversion from one basis to another, showing that a general state vector is independent of any particular observable (operator) until an experiment has been devised and prepared and ready to go, and the appropriate basis chosen for the relevant observable operator.

The origin of the **operators** chosen by Schrödinger can be understood as follows. Starting in the position representation we can define an operator **X** which acts on the wave function $\Psi(x)$ to give x times $\Psi(x)$, i.e.

$$\mathbf{X}\,(\Psi(x)) = x\,\Psi(x)$$

Equally valid is the momentum operator **P** in the momentum representation, i.e.

$$\mathbf{P}\,(\Phi(p)) = p\,\Phi(p)$$

Then changing the representation by a Fourier transformation leads naturally to the identification

$$\mathbf{P}\,(\Psi(x)) \equiv -i\hbar\, d/dx\, (\Psi(x))$$

Similarly for energy and time, the natural differential operator representing energy in the time representation is $i\hbar\, d/dt$, i.e.

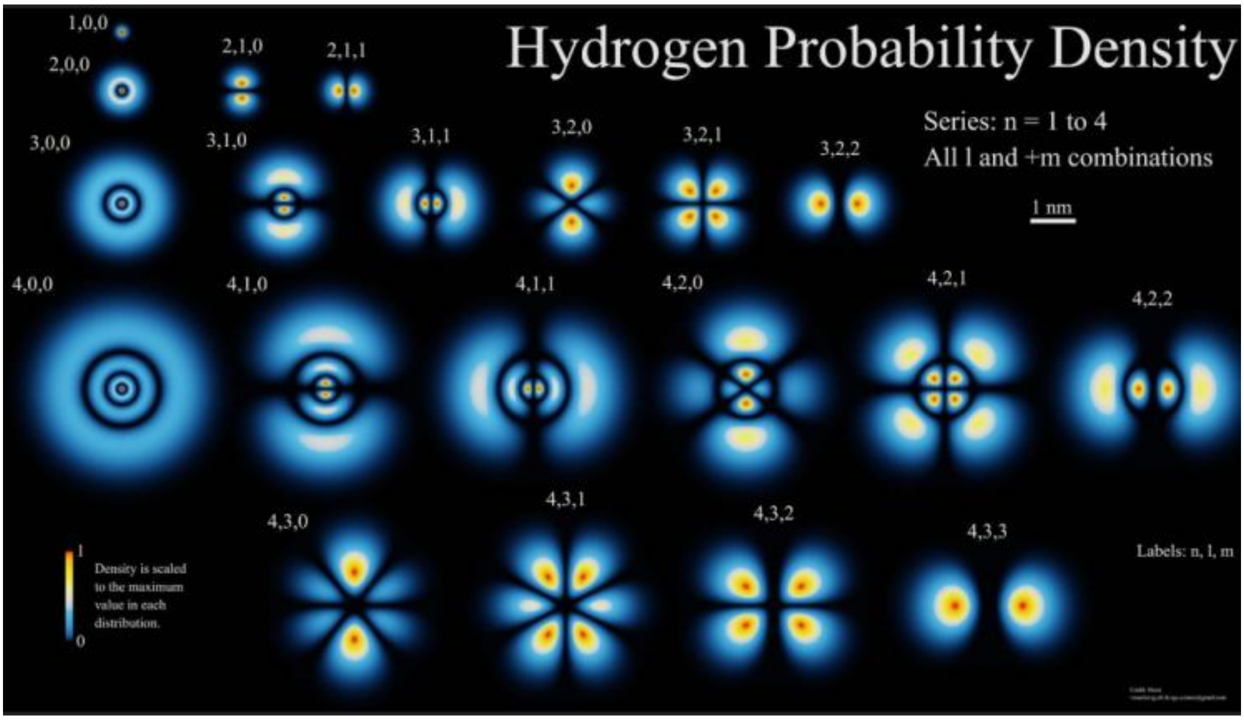
$$\mathbf{E}\,(\Psi(t)) \equiv i\hbar\, d/dt\, (\Psi(t))$$

If we take $V(x)$ to be that for **simple harmonic motion**, $V(x) = ½kx^2$, then we can solve the resulting equation for $\Psi(x)$ exactly. In this beautifully clear situation we can write solutions in terms of creation and annihilation operators on 'ladder' states. This has profound implications for quantum field theory, which ultimately describes fundamental particles in terms of such creation and annihilation operators on the vacuum state. The various fundamental particles are quantized oscillations of that particular type of particle's quantized complex field at x and t.

If we take PE, $V(\mathbf{r})$, to be that for a simplified **hydrogen atom**, $V(\mathbf{r}) = -ke^2/\mathbf{r}$, then we can solve the resulting differential equation for $\Psi(x,y,z)$. In this case we can write solutions in terms of relevant well-known sequences of functions, such as the Associated Laguerre polynomials and the Spherical Harmonic functions, giving the energy eigenstates of the atom in the position representation.

$$\Psi_{nlm}(r,\vartheta,\varphi,) = R_{nl}(r)\, Y^{m}{}_{l}(\vartheta,\varphi)$$

These solutions are beautiful. They are the electron wave functions for the first few atomic orbitals in an orthonormal basis of the energy eigenstates in the position representation, all in spherical coordinates. The wave function probability densities are calculated by $|\Psi_{nlm}|^2$.



Uncertainty Principle. The simultaneous measurement of position, x, and momentum, p, (or certain other pairs of variables, called complementary variables) of a quantum object is subject to an inherent limitation such that if Δx is the uncertainty of position, and Δp is the uncertainty of momentum, then the product $\Delta x.\Delta p$ is necessarily greater than ½ of a quantity of order one Planck. It is only equal to $\frac{1}{2}\hbar$ in the special case where the distributions are Normal (bell curves).

Complementarity. A quantitative phenomenon is complementary to another if certainty of the theoretically expected observable value of one quantity necessarily implies uncertainty in the expected value of the other

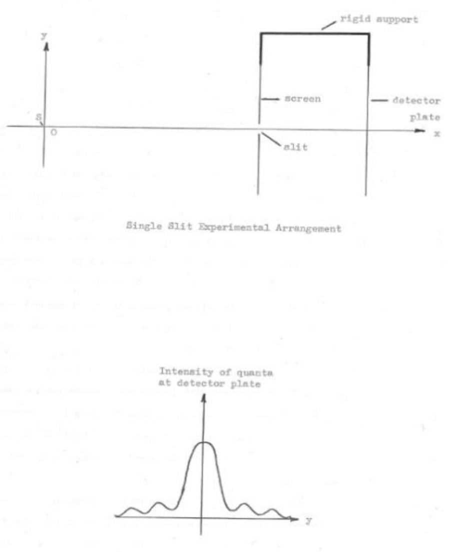
Superposition Principle. All linear combinations of possible states are also possible states, but an actual measurement of the observable in question will result in one particular eigenstate of the operator, together with the corresponding eigenvalue, the result of the measurement in *real* terms.

Interference Terms. $\Psi(x) = \Psi_1(x) + \Psi_2(x) \quad \therefore \quad |\Psi(x)|^2 = \Psi^*(x)\Psi(x) = |\Psi_1|^2 + |\Psi_2|^2 + \Psi_1{}^*\Psi_2 + \Psi_2{}^*\Psi_1$

Wave-particle duality is a very general property of microscopic objects, of appearing under one of two contradictory aspects, that of waves or that of particles as the experimental context dictates. (The interchangeability between wave behaviour and particle behaviour is even more pronounced in high energy quantum field theory where particles with non-zero rest-mass may be created and destroyed almost as easily as photons.)

The arrangement in Fig 1 can measure wave properties, arrangement in Fig 2 cannot.

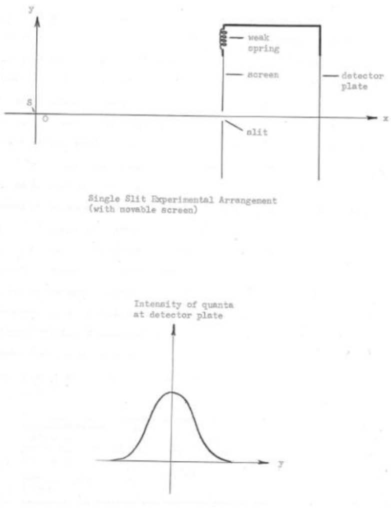
Figure 1



Single Slit Experimental Arrangement

Diffraction pattern

Figure 2



Single Slit Experimental Arrangement (with movable screen)

Non-interference pattern

REVISION QUESTIONS:

Is QT a universal theory?
Does an electron interfere with itself, and only with itself?
Is it the case that everything that can happen will happen?
Can a cat be dead and alive at the same time?
Can an electron be in 200 places at once?
Is it the case that empty space isn't empty?
Is movement an illusion in the block universe of special relativity? (extra marks)

CAUTIONARY TALES:

In 1932 Niels Bohr said, “Those who are not shocked when they first come across quantum theory cannot possibly have understood it.”

Bohr implied that there is no quantum world. There is only an abstract quantum physical description.

Later, Bohr and John Wheeler agreed, “If you are not completely confused by quantum mechanics, you do not understand it.”

Then in 1965 Richard Feynman said, “If you think you understand quantum mechanics, then you don't understand quantum mechanics.” And another time, he said, “I think I can safely say that nobody understands quantum mechanics.”

David Mermin thought he had the final word on the meaning of it all when he said in 2004, “Shut up and calculate.”