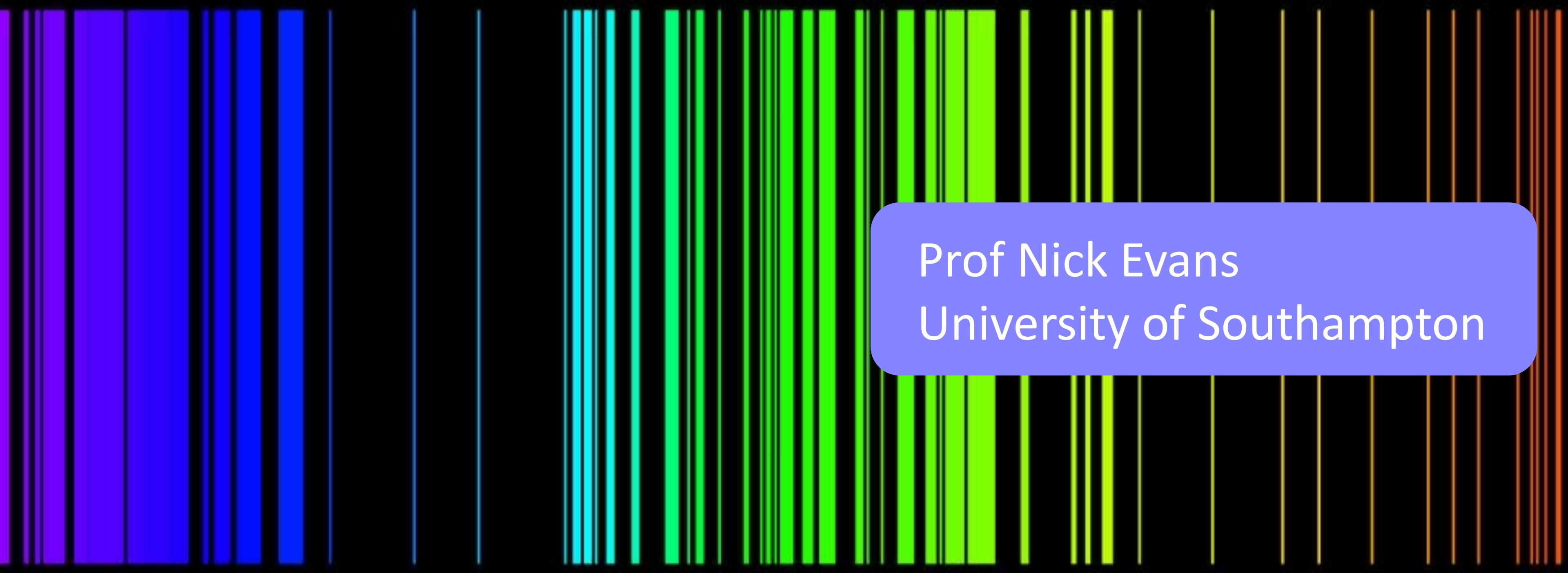
An Introduction to Quantum Physics:

When common sense broke!



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University of Southampton

Where did quantum mechanics come from? What is it?

Why is it weird and should we do anything about it?

Where were we?

Light and electrons show both particle and wave like properties.

$$\psi = A\sin\left(\frac{2\pi p}{h}x - \frac{2\pi E}{h}t\right)$$

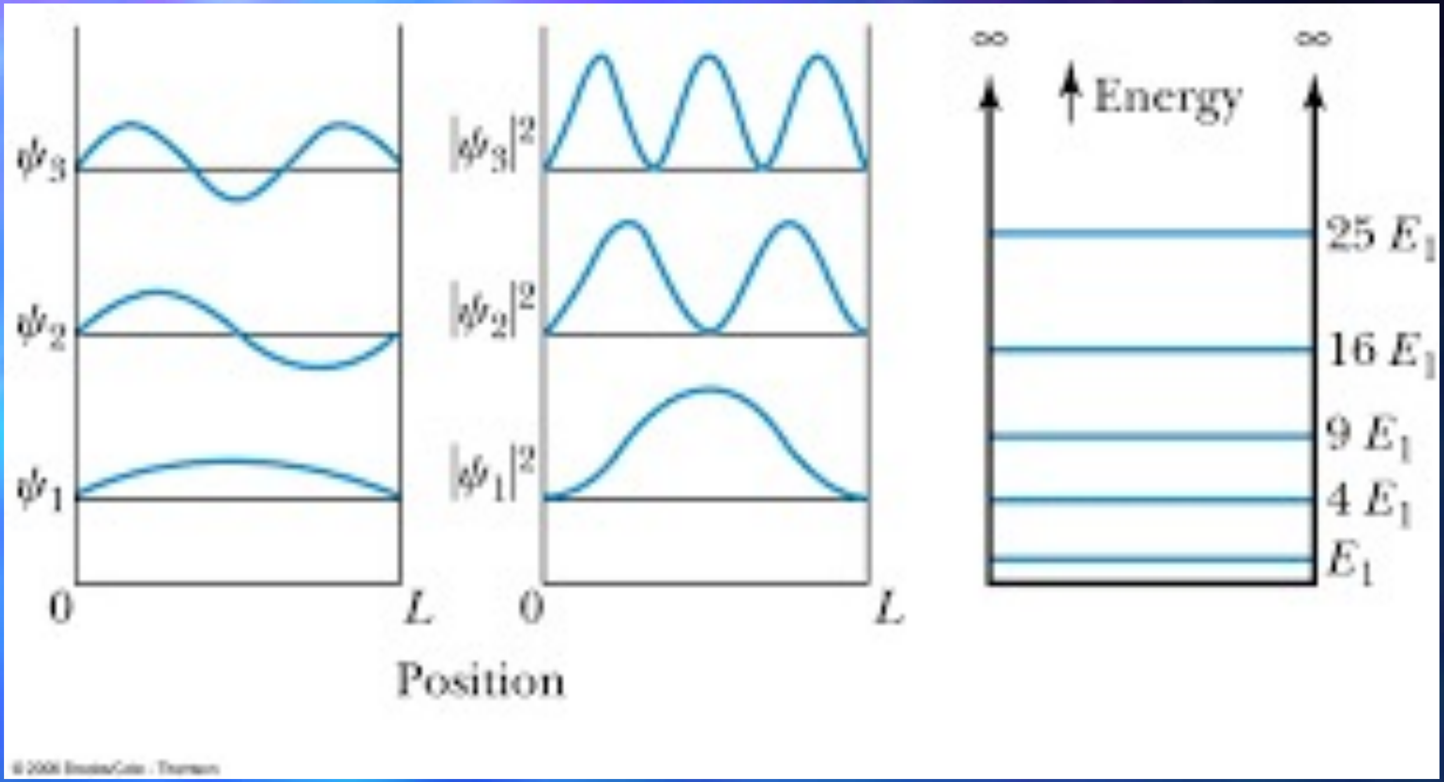
$$E^2\psi = -\left(\frac{h}{2\pi}\right)^2 \frac{d^2\psi}{dt^2}$$

$$p^2\psi = -\left(\frac{h}{2\pi}\right)^2 \frac{d^2\psi}{dx^2}$$

``operators"

$$\frac{-\hbar^2}{2m}\nabla^2\Psi(\mathrm{r}) + V(r)\Psi(\mathrm{r}) = E\Psi(\mathrm{r})$$

Kinetic Energy + Potential Energy = Total Energy



Square well solutions….

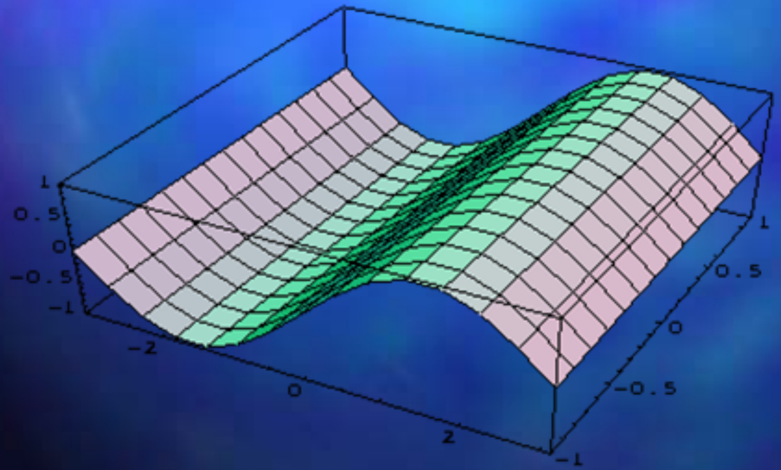
We interpret the second plot as showing us the probability of the particle being at each point in space when we make an observation….

Fermions vs Bosons

Why do some materials seem wave like (light)

& others particle like (electrons)?

We've come to learn that bosons can have any number of quanta in a particular state… so you can build up the wave…



For fermions there can only be one quanta in a given state so they always look bitty…

The Hydrogen Atom

$$\frac{-\hbar^2}{2m}\nabla^2\Psi(\mathrm{r}) + V(r)\Psi(\mathrm{r}) = E\Psi(\mathrm{r})$$

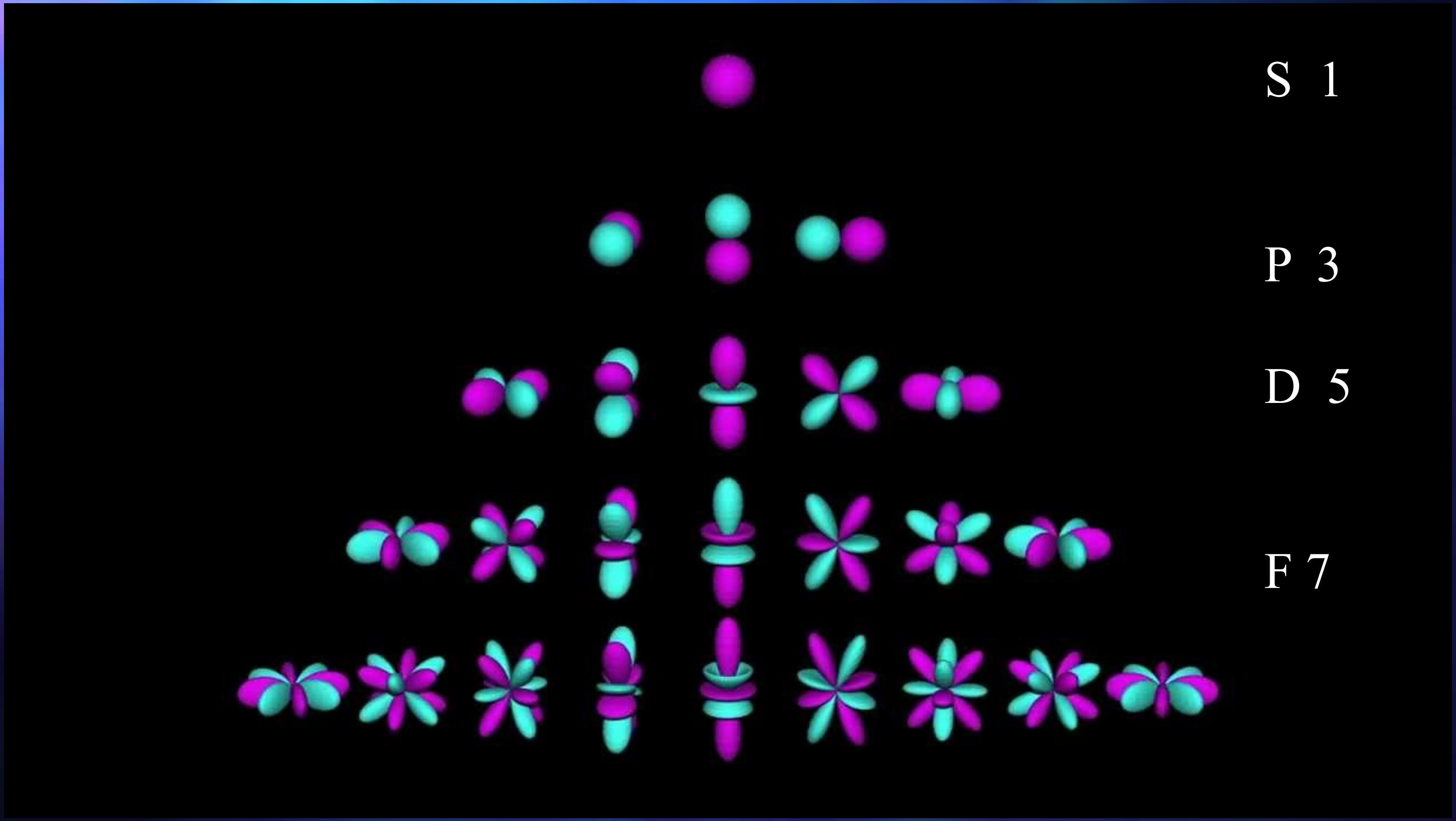
Kinetic Energy + *Potential Energy* = *Total Energy*

$$\nabla^2 = \frac{1}{r^2}\frac{d}{dr}\left(r^2\frac{d}{dr}\right) + \text{angles}$$

$$V(r) = \frac{-e^2}{4\pi\epsilon_0 r}$$

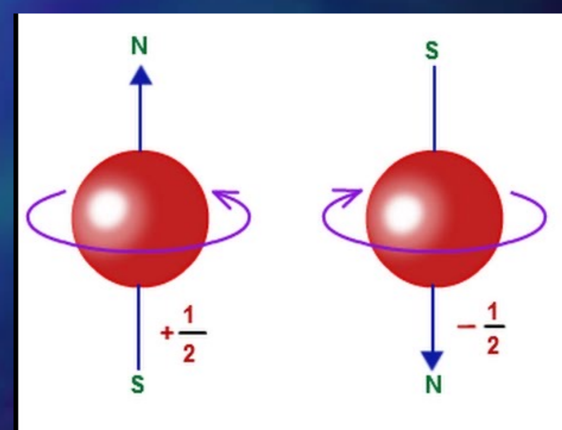
n	ℓ	m_ℓ		$\Psi_{n\ell m_\ell}(r,\theta,\varphi)$
1	0	0	1s	$\frac{1}{\sqrt{\pi}a_0^{3/2}}e^{-r/a_0}$
2	0	0	2s	$\frac{1}{4\sqrt{2\pi}a_0^{3/2}}\left[2-\frac{r}{a_0}\right]e^{-r/2a_0}$

If you look for solutions for a negative charge in orbit around a very heavy positive charge you find these possible states:



1 H																	2 He
3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
55 Cs	56 Ba	57-71	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
87 Fr	88 Ra	89-103	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Cn	113 Nh	114 Fl	115 Mc	116 Lv	117 Ts	118 Og
		57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu	
		89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr	

We beautifully explain the periodic table pattern by stacking fermions in orbitals… except we need an extra 2 fold degeneracy… intrinsic spin…



Beautifully predicts the Balmer spectrum

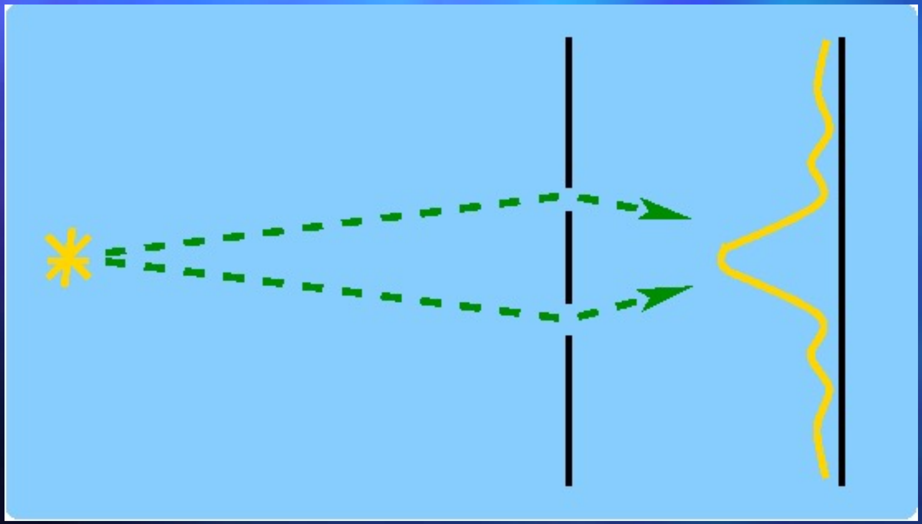
… and breath…

Weird & Wonderful Quantum I

Wave Function Collapse

Our quantum theory describes the evolution of Schroedinger's wave.. perfectly sensibly….

But when we do a measurement it describes the probability of finding a particle somewhere… but how does nature decide?



Don't ask (Copenhagen Interpretation)

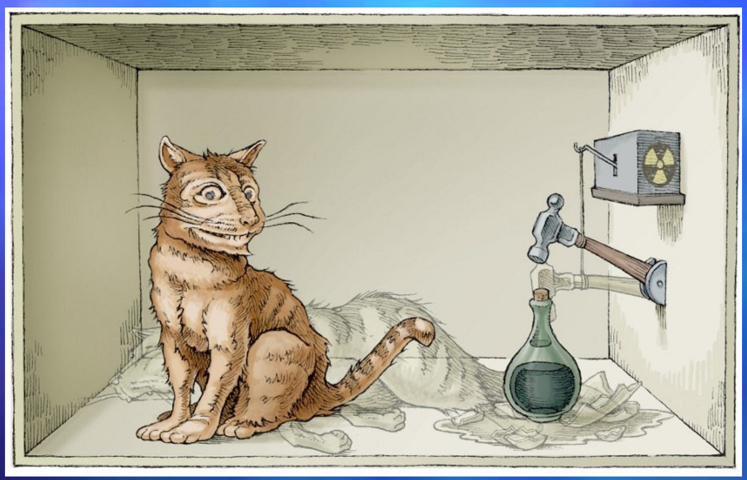
All things happen in a multiverse (Many Worlds)

We're missing something (Hidden variables)

Schroedinger's Cat

The question becomes what is a measurement that collapses the wave function?

You? Me? A Cat? An Atom?



If a probabilistic quantum process controls a real life event then a cat can become 50% alive and 50% dead....

In a quantum lottery every ticket wins in some part of the wave function (is that better?)

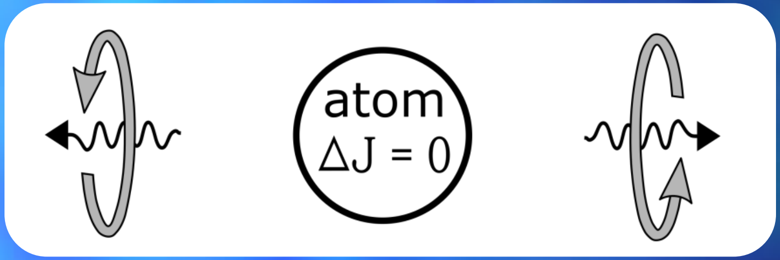
Weird

The truly odd thing here is that no one has ever thought of an experiment that probes this (and wow have people tried!)… or done an experiment where QM doesn't work.

When you do an experiment the wave function collapses and the theory predicts the probabilities perfectly… end of.

Entanglement

An atom can emit two photons



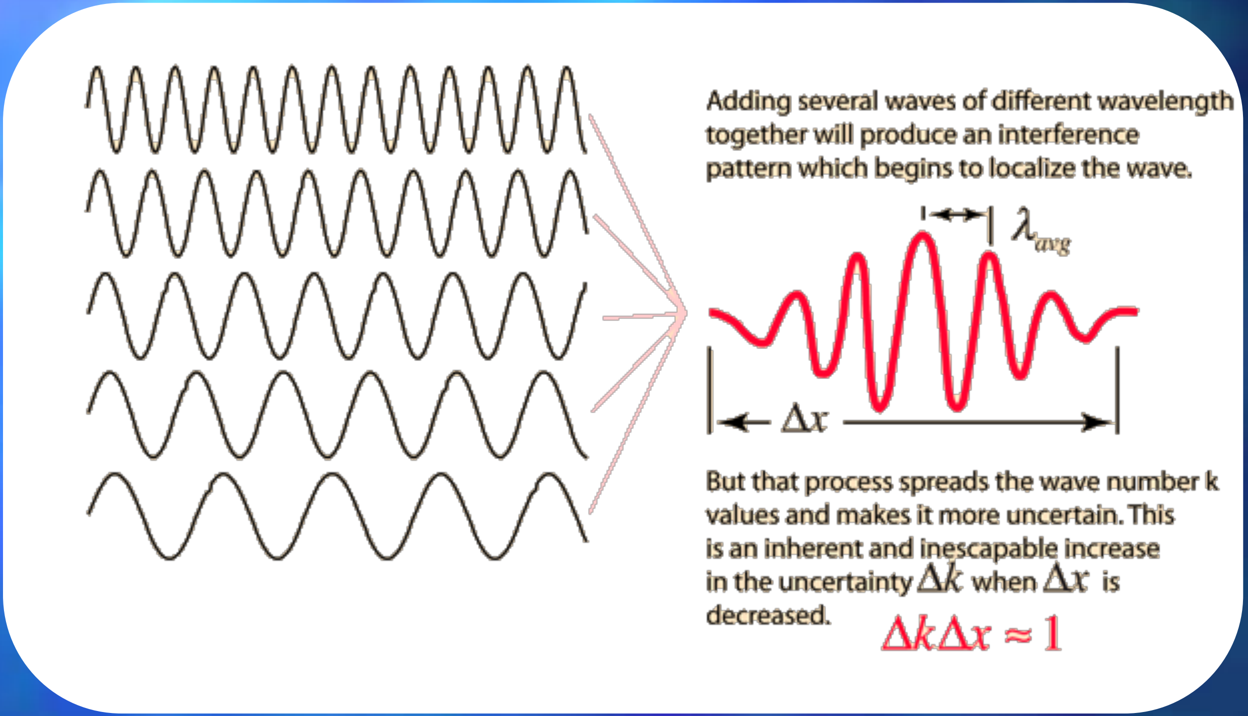
It’s equally likely to swap the polarizations… the photon is 50% spinning left, 50% spinning right… an observer “collapses the wave function” to one or the other…

BUT when it does so the spin of the other guy is fixed also.. that collapse has happened potentially very far away… this leads to faster than light “communication”…

Except that you can’t send information this way…. So again nothing quite breaks…

… and breath…

Damn Your Waves – Give Me Particles!

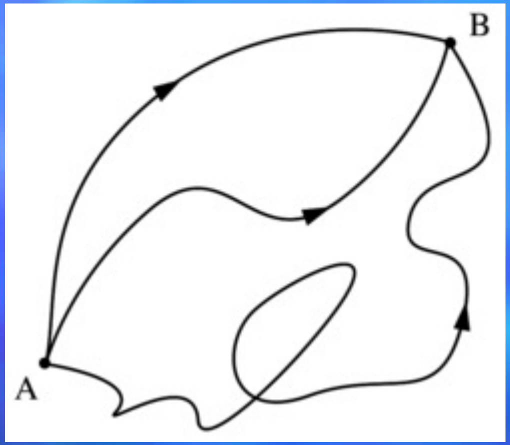


Heisenberg's Uncertainty Principle $\Delta x \ \Delta p > h$

Or equally $\Delta t \ \Delta E > h$

Feynman's Sum Over Histories

Feynman incorporated the Uncertainty Principle into a description of classical particle paths…



The classical path becomes smeared by other paths that the Uncertainty Principle allows

These are very wild on short time scales but much less so over day to day time intervals…

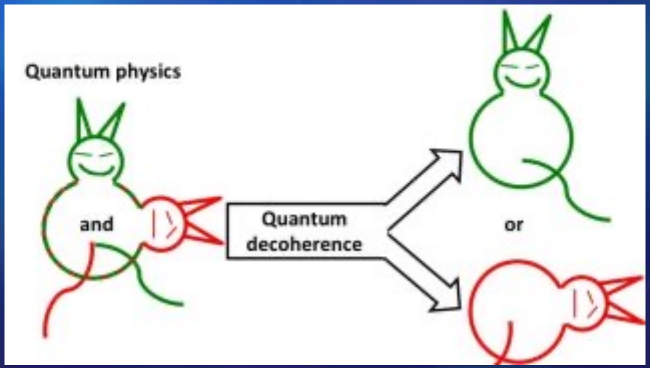
You can have multiple destination points also… and then the theory returns probabilities for the final position… doh.. Wave function collapse is back…

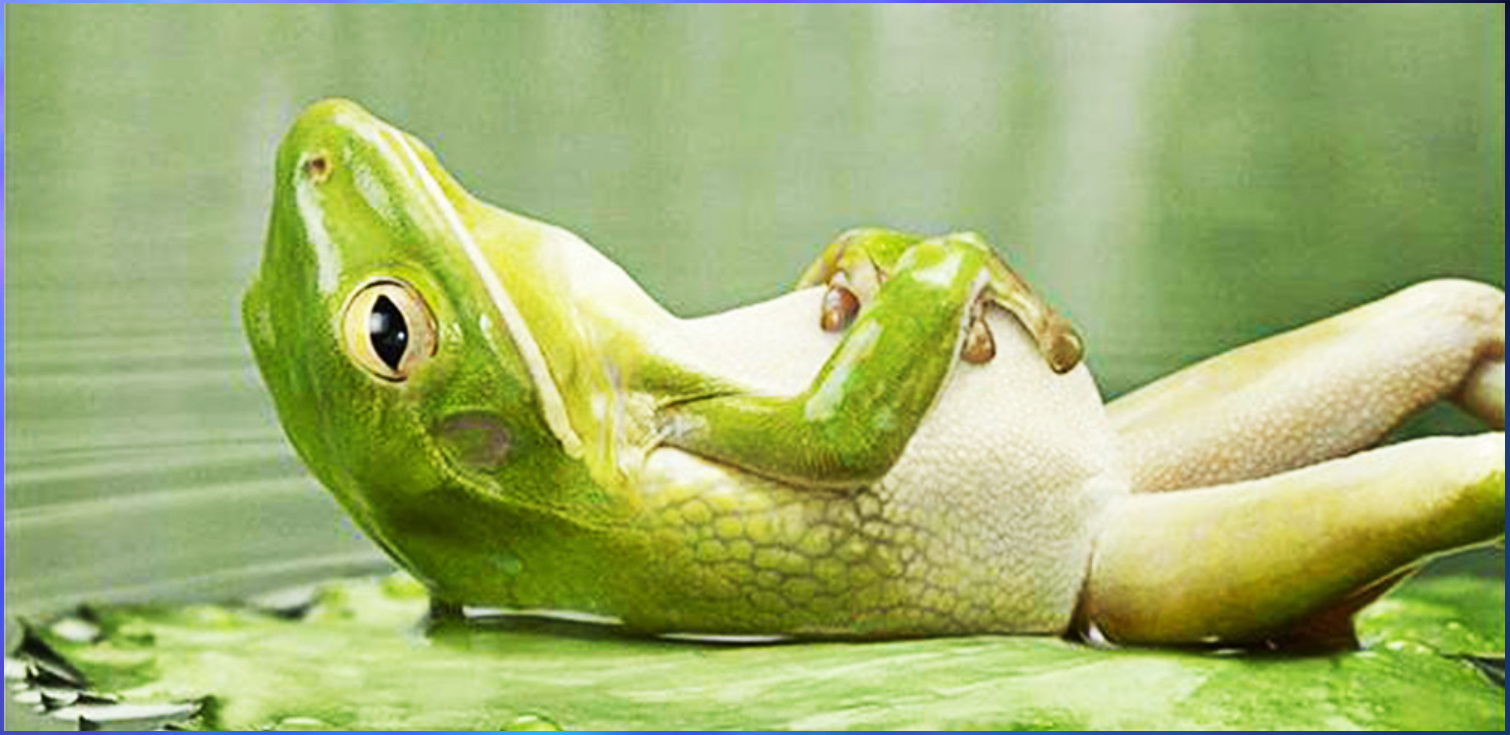
Decoherence

There is an understanding that larger systems become more classical – the ΔE you can borrow in some time gets spread more thinly between many particles in a system so each lies a bit closer to a classical configuration…

This includes the idea of particles making constant measurements on each other… and may explain why the large scale world looks rather classical…

It doesn't solve the Schroedinger cat type set ups though!



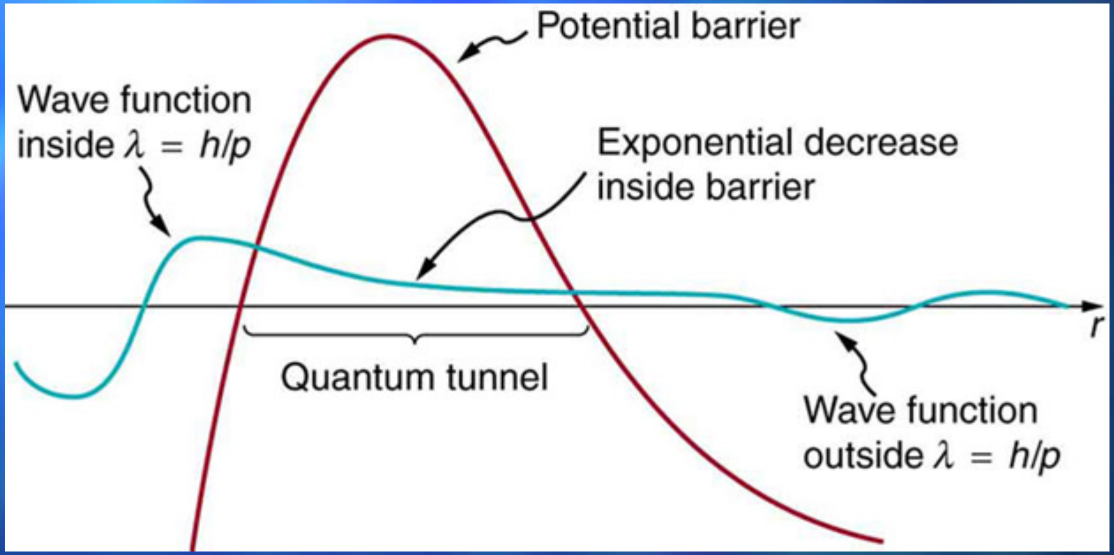


… and relax…

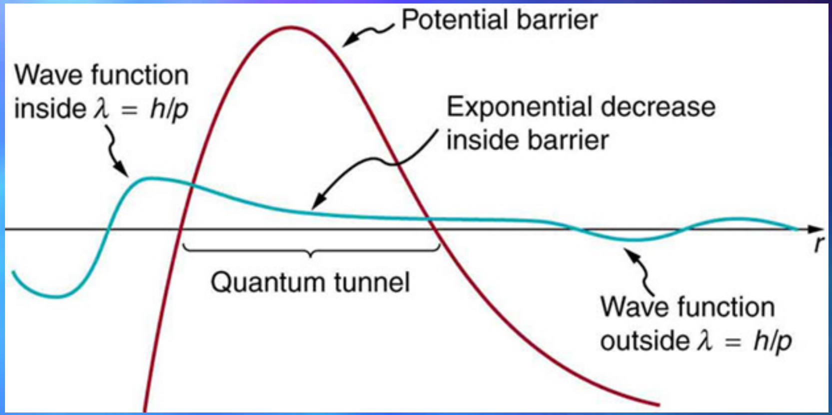
Weird & Wonderful Quantum II

Tunnelling

Apparently magic things can happen on short distance scales due to the wave nature of particles…



We've seen solutions in a well



We've seen solutions in free space

In the central region assume V= constant which is greater than the E of the particle (classically it can't pass)

$$\frac{1}{2m}\left(-\frac{h^2}{(2\pi)^2}\right)\frac{d^2}{dx^2}\psi + V\psi = i\frac{h}{2\pi}\frac{d}{dt}\psi$$

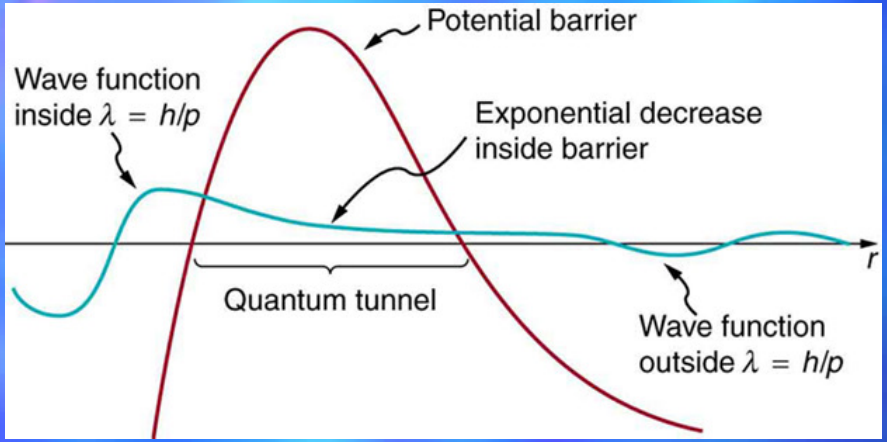
$$\psi = u(x)e^{-i2\pi E/h}$$

$$-\frac{1}{2m}\frac{h^2}{(2\pi)^2}\frac{d^2u}{dx^2} = -(V-E)u$$

$$u = Ae^{-\sqrt{2m}(2\pi)/h\sqrt{V-E}x}$$

It's an exponential decay but not zero…

Tunnelling



This is how radioactive alpha-decay happens….

Protons wouldn't fuse in the sun without tunnelling through the Coulomb repulsion…

…. And its used by some electronics components now…