Physics 123 - April 17, 2013

Today - Quantum Weirdness

Giancoli, chapt 38

Check out article on BB

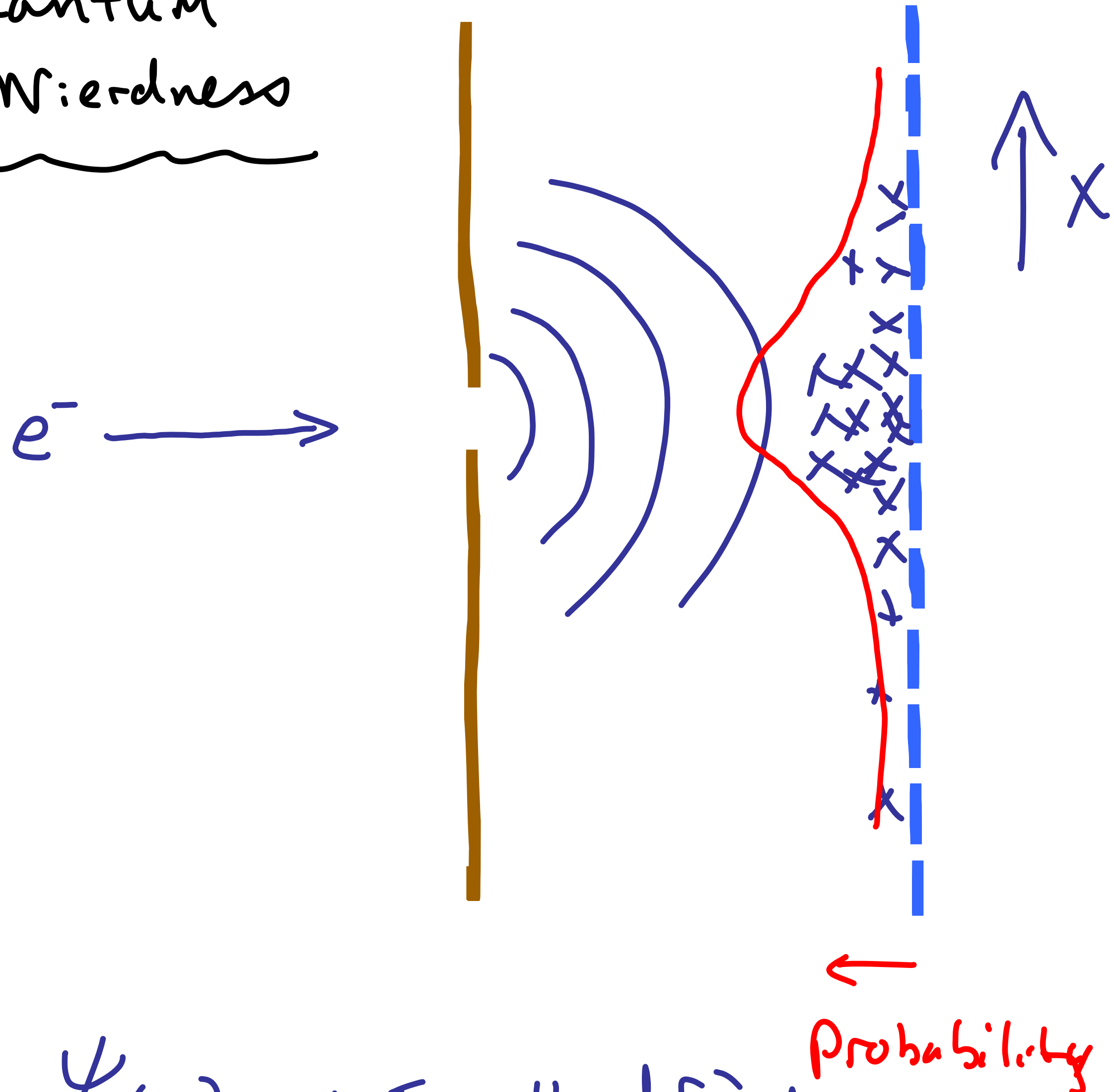
Byrne - The Many Worlds of Hugh

Today + Monday - H atom

Many electron atoms

Giancoli, chapt 39

Quantum Wierdness



$\psi(x)$ not well defined

$\psi^2(x)$ is well defined $\rightarrow$ probability

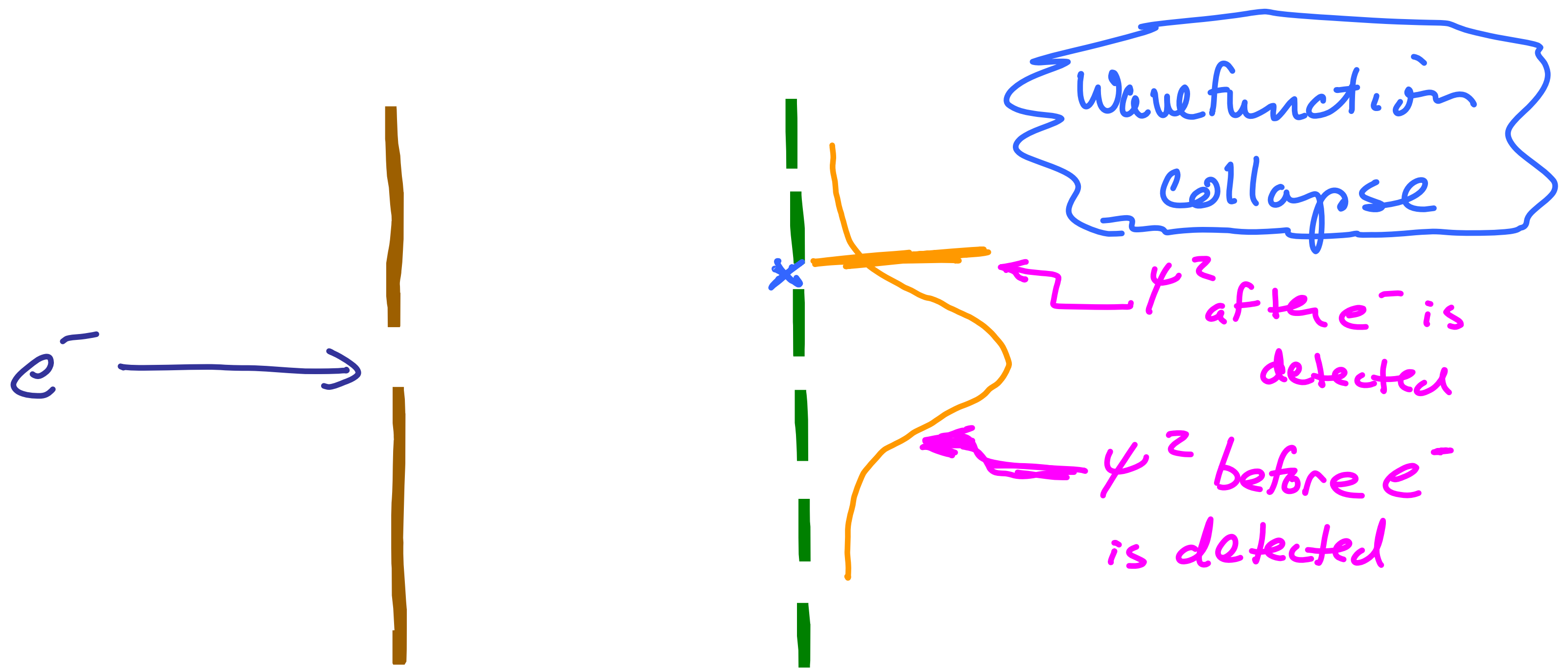
Max Born   German (1882-1970)

1954 Nobel Prize in physics

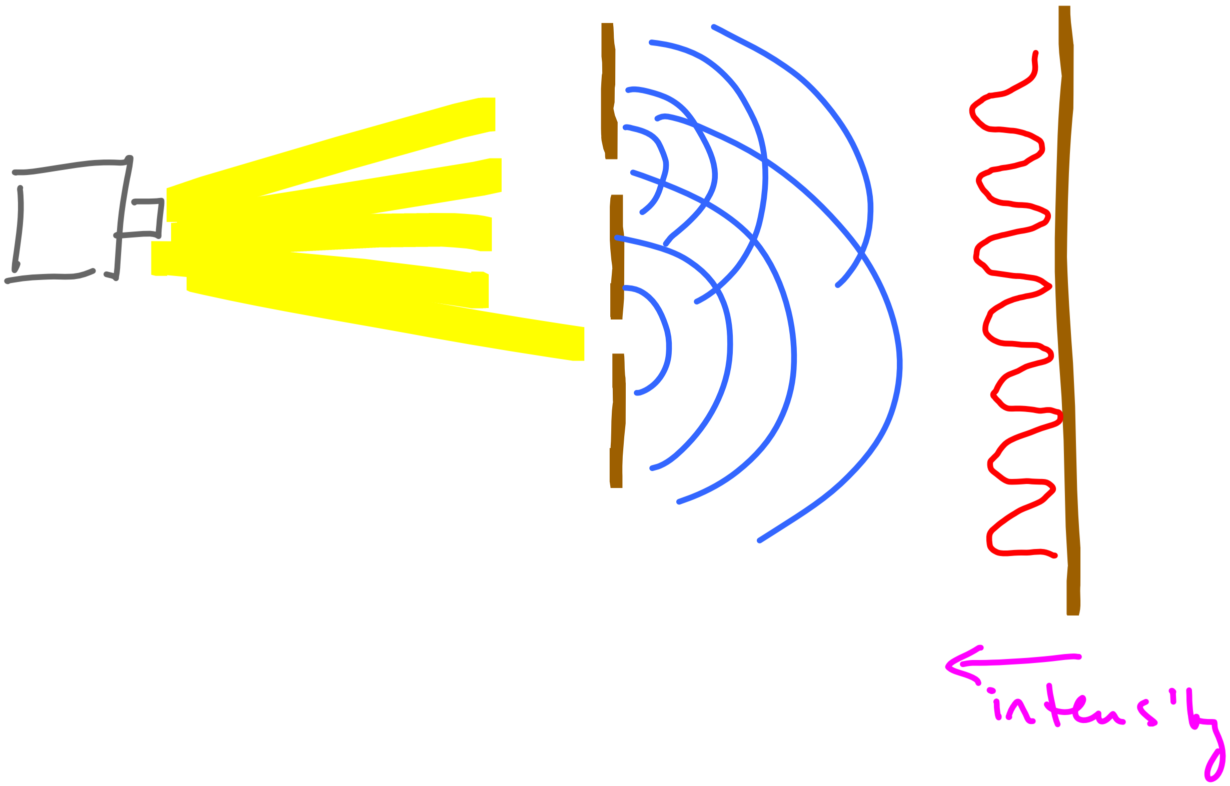
"For his fundamental research in quantum mechanics, especially for his statistical interpretation of the wavefunction"

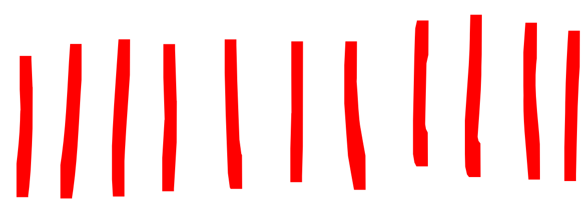
$\psi(x)$ wave function

$\psi^2_{(x)}$ ~ probability of finding particle in region of space

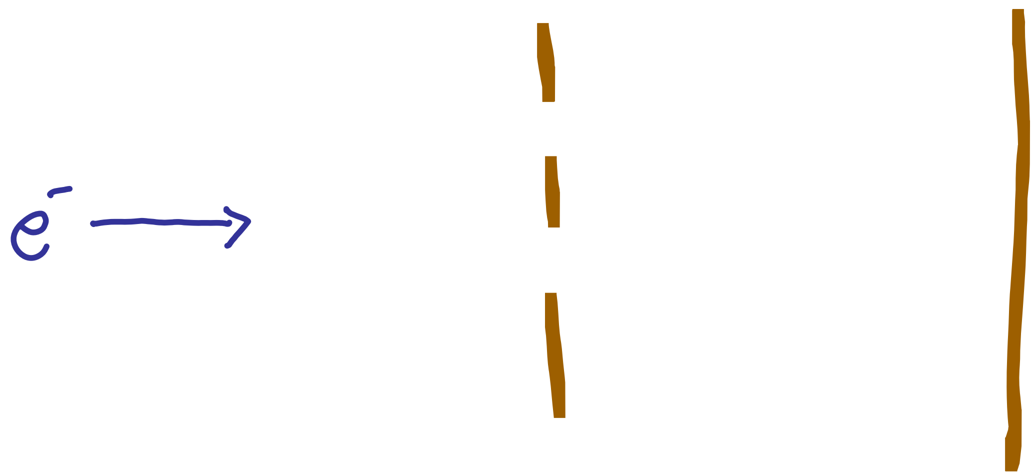


Once electron hits the film/Detector we know with 100% certainty where the electron hits
- So wavefunction has to "collapse"

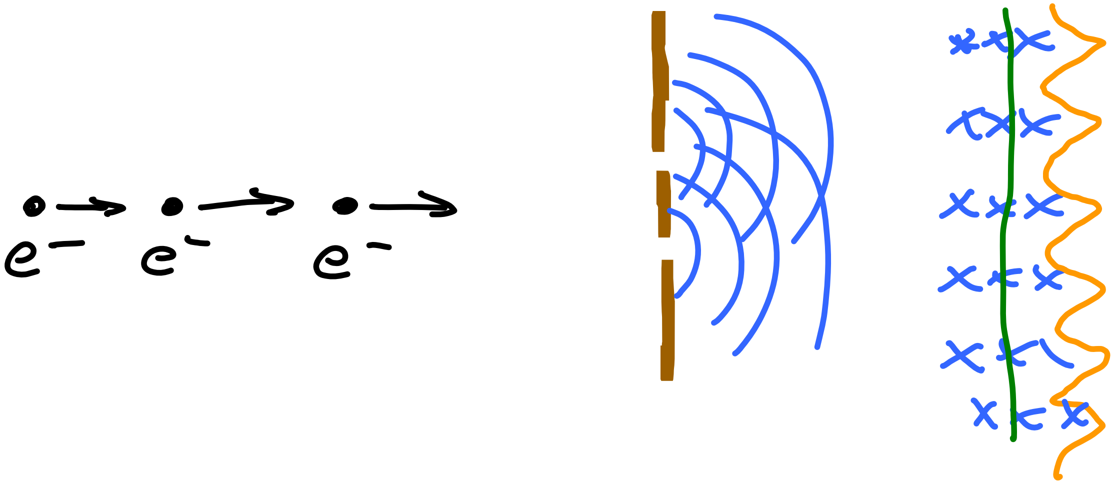




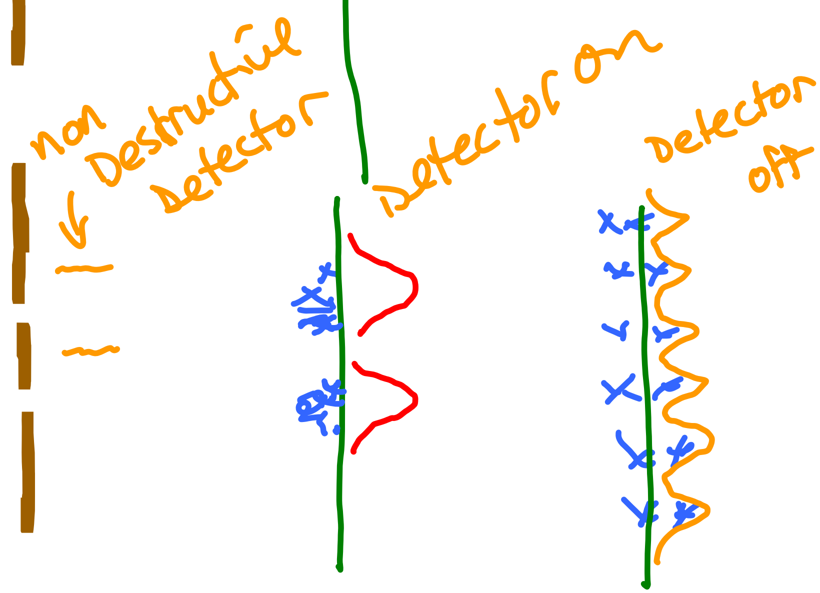
get same even if 1 photon at a time



Get same even if $1e^-$ at a time

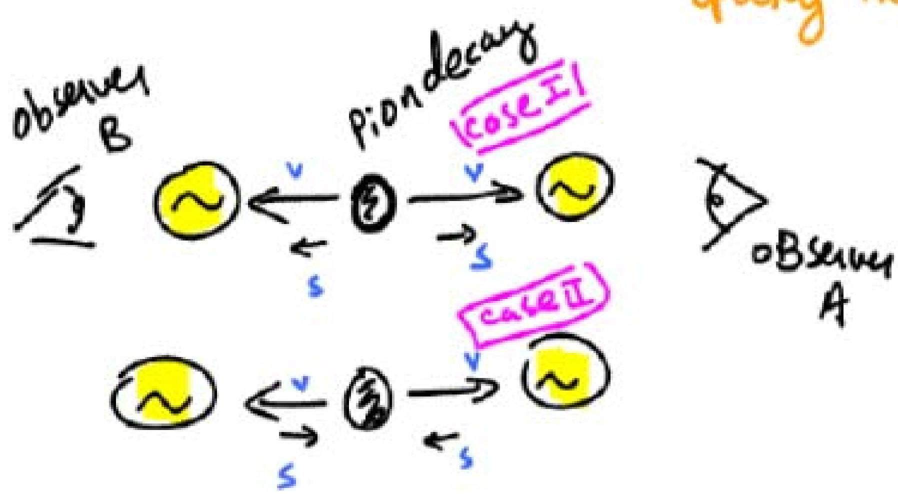


just determining the slit that the e^- passes thru (even with non-destructive detector) is sufficient to collapse the wave function.



EPR Paradox — Einstein, Podolski, Rosen 1935

"Spooky Action at a distance"



photon spin = 1

Two photons are produced at once — They are correlated.

If one has spin one way the other has spin the other way.

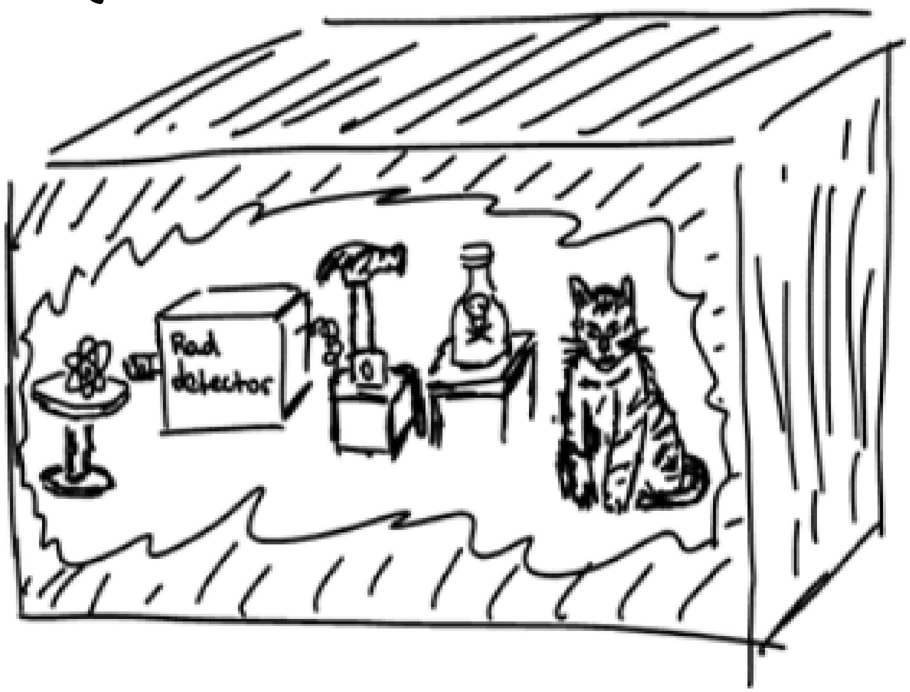
They are in an "entangled quantum STATE"

When observer A observes the spin of photon — The wavefunction collapses and the spin of the photon observer B will observe is determined.

But collapse instantaneous and observers A + B far apart

Does this mean information conveys faster than speed of light?

Schrödinger's Cat



thought experiment
nucleus has 50:50 chance of decaying + killing the cat.
What is the "state" of the cat before box opened?

Copenhagen Interpretation

$$\text{nucleus quantum state} = \frac{1}{2}(\text{decayed}) + \frac{1}{2}(\text{not decayed})$$

$$\text{cat state} = \frac{1}{2}(\text{dead}) + \frac{1}{2}(\text{alive})$$

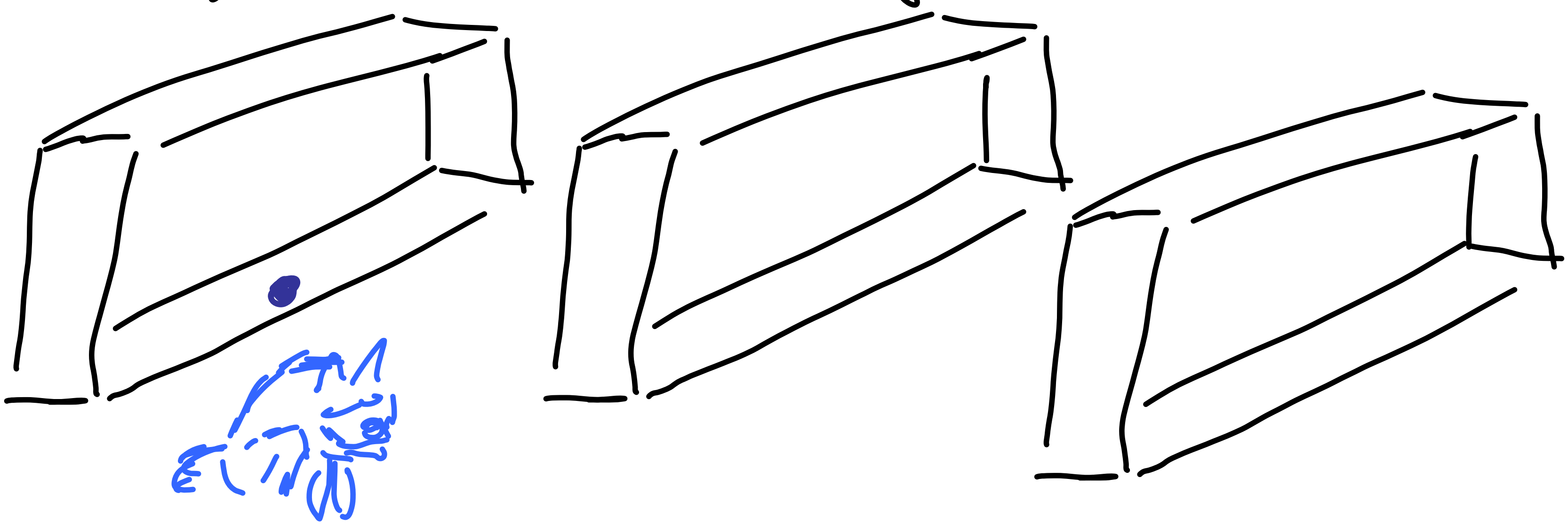
Hugh Everett (1957)

Bryce DeWitt 1960's + 70's

→ Many Worlds interpretation

Overall wavefunction does not collapse. It evolves in time. "Decoherence" forces wavefunction to evolve into different streams that do not interact.

Dog, ball, shelf analogy



Ψ might include both upper and lower shelves

But dog only experiences lower shelves

QUANTUM Field Theory → Exchange force

Giancoli:
Chapt 43
section 2

Time Independent Schödinger equation (1d, nonrelativistic)

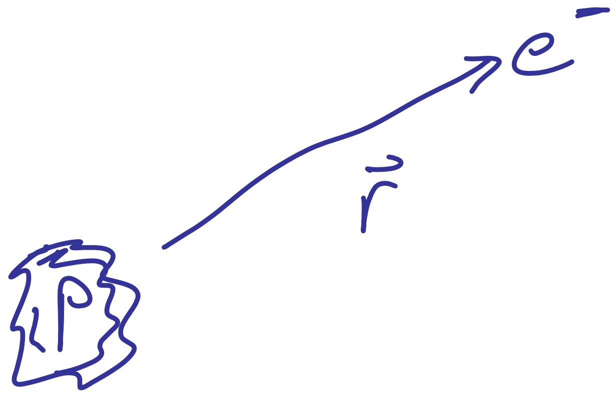
$$-\frac{\hbar^2}{2m}\frac{\partial^2 \psi(x)}{\partial x^2} + V(x)\,\psi(x) = E\,\psi(x)$$

$|\psi(x)|^2\, dv \equiv$ probability of finding particle in dv

$\int_{\text{all space}} |\psi(x)|^2\, dv = 1$ Particle is Someplace

Sub in for V, Solve for ψ and E

H atom



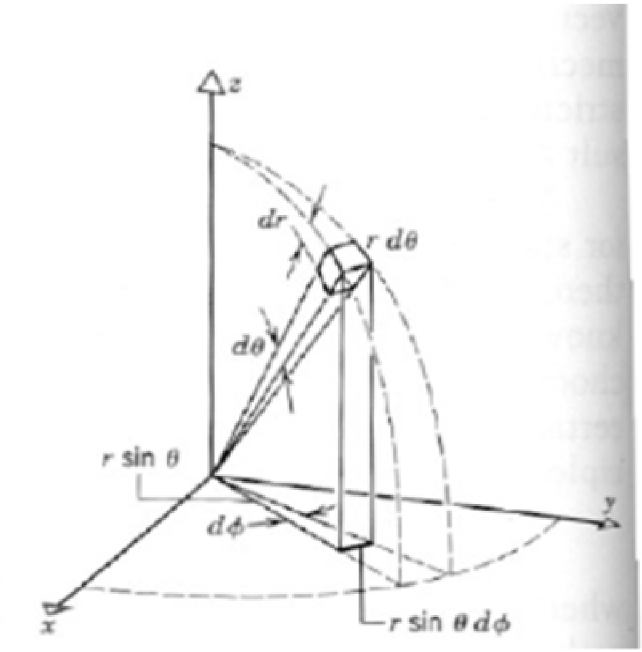
$$V(r) = \frac{1}{4\pi\epsilon_0}\frac{|e|^2}{r^2}$$

Schr. eqn in 3d

$$-\frac{\hbar^2}{2m}\nabla^2\psi + V\psi = E\psi$$

plug in V and solve

need to use spherical polar coordinates



$$\psi \longrightarrow \psi(r, \theta, \phi)$$

$$V(r) = -\frac{1}{4\pi\epsilon_0}\frac{|e|^2}{r^2}$$

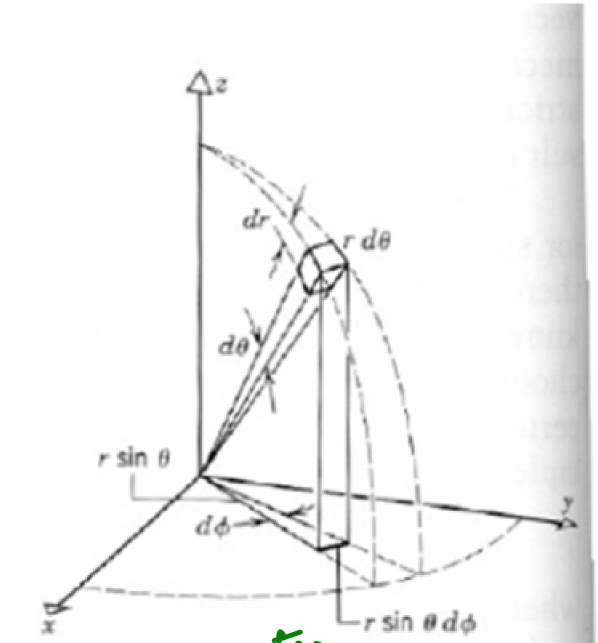
$$-\frac{\hbar^2}{2m}\left[\frac{1}{r^2}\frac{\partial}{\partial r} r^2 \frac{\partial \psi}{\partial r} + \frac{1}{r^2 \sin^2\theta}\frac{\partial^2 \psi}{\partial \phi^2} + \frac{1}{r^2 \sin\theta}\frac{\partial}{\partial \theta} \sin\theta \frac{\partial \psi}{\partial \theta}\right] - \frac{1}{4\pi\epsilon_0}\frac{|e|^2}{r^2}\psi = E\psi$$

Now solve

Can be solved exactly ...

$\psi(r,\theta,\varphi) \rightarrow \psi(R)\,\psi(\Theta)\,\psi(\Phi)$

Can separate Schr. equation into eqns for $\psi(R)$, $\psi(\Theta)$, $\psi(\Phi)$ + solve



"Energy" or "principle" quantum # $n = 1, 2, 3 \ldots$

"orbital" quantum # $l = 0, 1, \ldots n-1$

"Magnetic" quantum # $-l, -(l-1), \ldots 0, 1, \ldots, l-1, l$

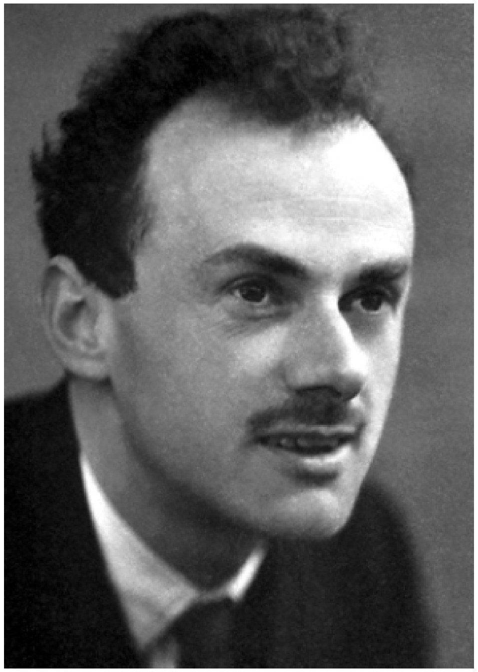
Bound system
↳ Discrete states

R, Φ, Θ parts tied together

n ⤳ similar to Bohr's n

Table 7.1 Some Hydrogen Atom Wave Functions

n	l	m_l	$R(r)$	$\Theta(\theta)$	$\Phi(\phi)$
1	0	0	$\frac{2}{a_0^{3/2}} e^{-r/a_0}$	$\frac{1}{\sqrt{2}}$	$\frac{1}{\sqrt{2\pi}}$
2	0	0	$\frac{1}{(2a_0)^{3/2}}\left(2 - \frac{r}{a_0}\right) e^{-r/2a_0}$	$\frac{1}{\sqrt{2}}$	$\frac{1}{\sqrt{2\pi}}$
2	1	0	$\frac{1}{\sqrt{3}(2a_0)^{3/2}} \frac{r}{a_0} e^{-r/2a_0}$	$\sqrt{\frac{3}{2}} \cos\theta$	$\frac{1}{\sqrt{2\pi}}$
2	1	± 1	$\frac{1}{\sqrt{3}(2a_0)^{3/2}} \frac{r}{a_0} e^{-r/2a_0}$	$\frac{\sqrt{3}}{2} \sin\theta$	$\frac{1}{\sqrt{2\pi}} e^{\pm i\phi}$



P.A.M. Dirac - on the development of quantum mechanics

"The underlying laws necessary for the mathematical theory of a large part of physics and the whole of chemistry are thus completely known."