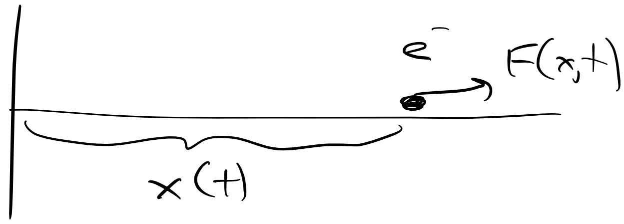
The wave function



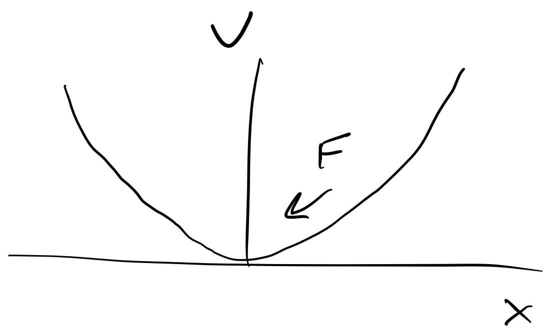
Imagine particle constrained to move along x-axis subject to some force.

Classical Mechanics goal to determine $x(t)$
(Physics Before QM) can get $v(t) = \frac{dx}{dt}$
from there $p = mv$, K.E., etc anything need

How do you get $x(t)$?

- Newtons Laws : $F = ma$

$$F = -\frac{\partial V}{\partial x} \qquad V - \text{potential energy}$$



$$m \frac{d^2x}{dt^2} = -\frac{\partial V}{\partial x}$$

- Initial Conditions $x(0)$ & $v(0)$

Above fixes $x(t)$ for all future times

Newton's Laws are assumed to be true.

- Input/axiom of theory
- Validity ultimately lies in agreement w/ data

Quantum Mechanics

Approaches same problem completely differently

Goal is the "wave function" $\Psi(x,t)$ which we get from a wave equation

"Schrodinger Eq" (Next week)

-) Initial Conditions $\Psi(x,0)$

Above fixes $\Psi(x,t)$ for all future time.

Schrodinger Eq assumed to be true.
- Input/axiom of theory
- Validity ultimately lies in agreement w/ data

Note: Can see immediately that this is going to be hard to square w/ Relativity.

"time" is part of the axioms.

What is the wave function? $\Psi(x,t)$

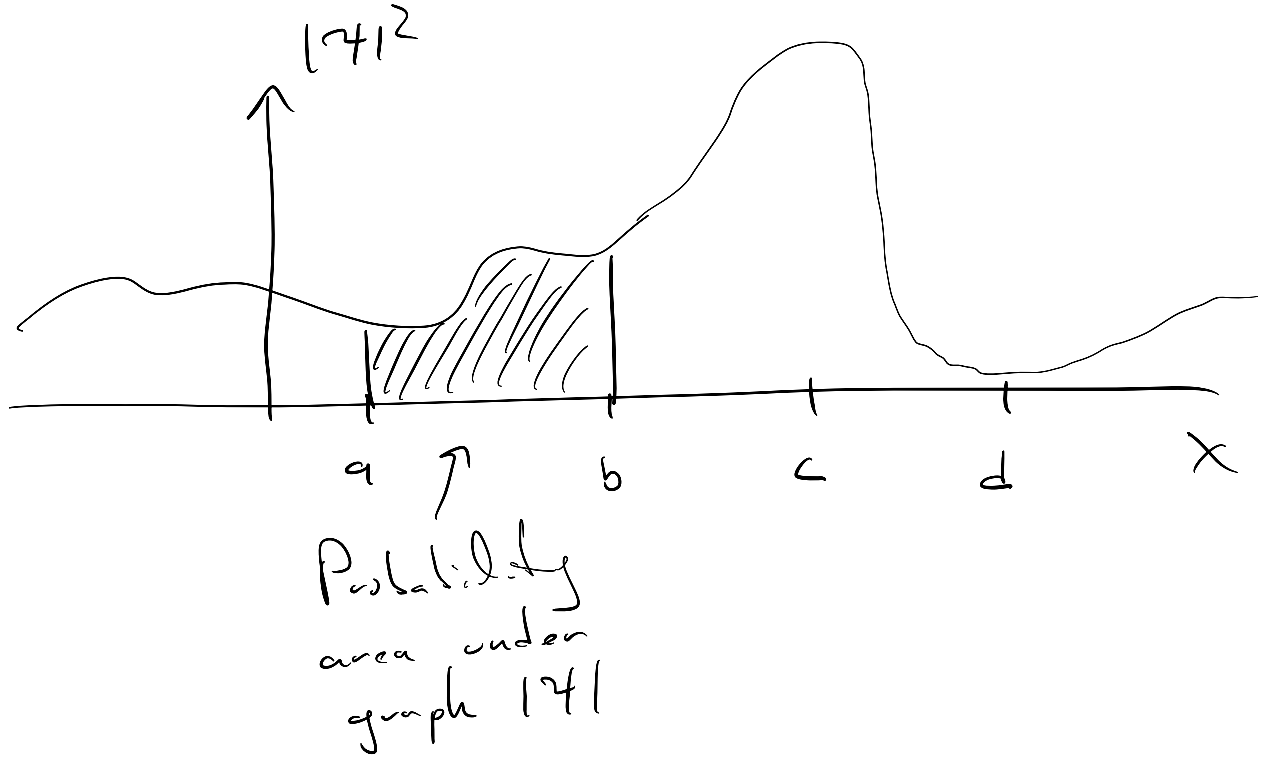
- electron localized (always seen to be at a point)
- wave function is function of x

How can $\Psi(x,t)$ represent a particle?!

Answer (Born): Statistical Interpretation

$|\Psi(x,t)|^2$ gives Probability for finding electron at x & t

$$\boxed{\int_a^b |\Psi(x,t)|^2 dx = \text{Prob. to find electron between } a \text{ \& } b \text{ at time } t}$$



Determinism gone in QM!

Even if you know everything there is to know $\Psi(x,t)$, you still cannot tell with certainty the outcome of an experiment which measures the electron position.

QM only offers statistical information about possible out comes.

This indeterminism deeply unsettling to scientists / philosophers

Natural Question!

Is this a fact of nature? or defect in QM?

eg/ Suppose we do measure the electron at c

Where was the electron just before the measurement?

3 plausible answers, schools of thought

1) <u>Realist</u> "The electron was at c"

- Einstein advocated this
- $\Rightarrow$ QM incomplete
- indeterminacy not fact of nature, reflection of our (QM) ignorance
- Ψ not the whole story. Need some more information "Hidden Variables"

2) <u>Orthodox</u> "electron wasn't really anywhere"

- The act of measurement compels the electron to take a definite position
- Most widely accepted position among physicists
- If correct, something special about "measurement"

3) <u>Agnostic</u> "Refuse to answer"

- should make assertions about "metaphysics"
- "before the measurement" is completely inaccessible to science.
- Good fallback from Orthodox

Until recently (60's) all 3 options viable.

John Bell surprised field by showing that there is an <u>observable</u> difference if the particle had a well-defined position or not (even if unknown)

$\Rightarrow$ <u>agnosticism</u> no longer viable option.

Now experimental question of:

Realist vs Orthodox

Long story here, that we will summarize by saying: Experiments have decisively confirmed the Orthodox point of view.*

* - fine print that I'm skipping over. Again not so important for this course. See Philosophy of QM.

<u>Bottom Line</u>

- The particle simply does not have a well-defined position prior to measurement.
- the measurement <u>creates</u> the specific result.

(limited by statistical weights of Ψ

Repeated Measurements

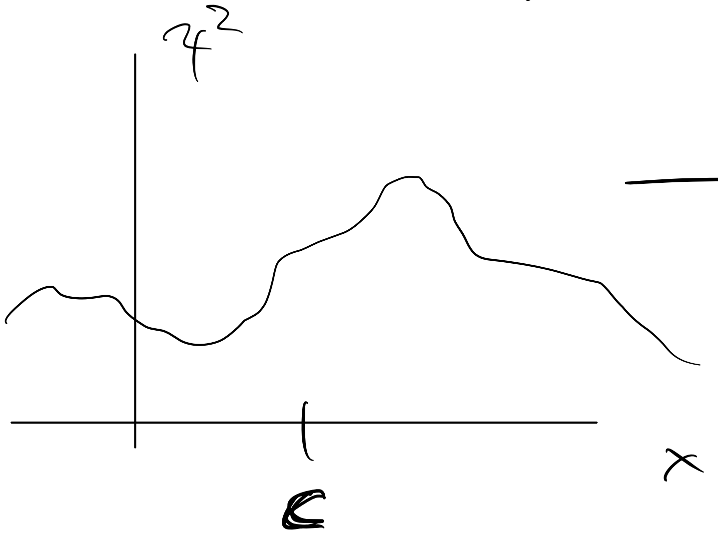
What if we do another measurement directly after the first?

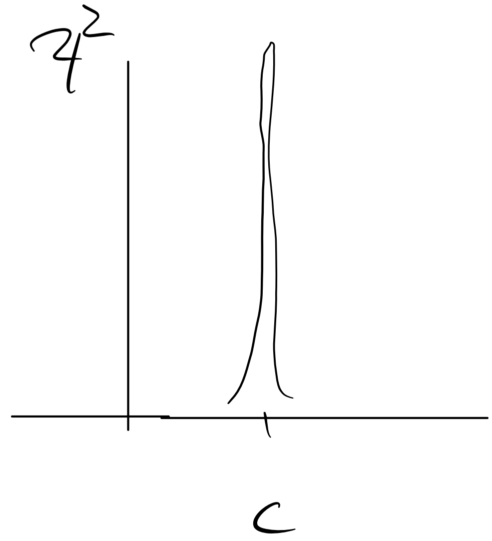
eg: first measurement gives $x = c$

Then a repeated measurement also gives c.

How is this handled in the Orthodox view?

Measurement radically alters ψ.
"Wave-function Collapse"





Spike at c soon spreads via Schr. Eq.

Two Distinct Physical Processes

- Ordinary (deterministic) Ψ-evolution via Schr. Eq.

- "Measurements" Sudden (non-deterministic) Collapse of Ψ to the measured value.

Notes Having Two separate processes is problematic. QM does not say when one applies & when the other applies. Supplies endless fodder for philosophy.

Happy to tell you more about this in office hours :)

This is the textbook description of how QM is "interpreted"

Deeply unsatisfying.

What is a measurement?

Who can do a measurement?

(dogs? / molecules? / other e's?)

Surely whatever is doing the measurement has to also be described by QM

Good answers to these questions/concerns will come back to them at the end of the course.

Next time:

Units done right!