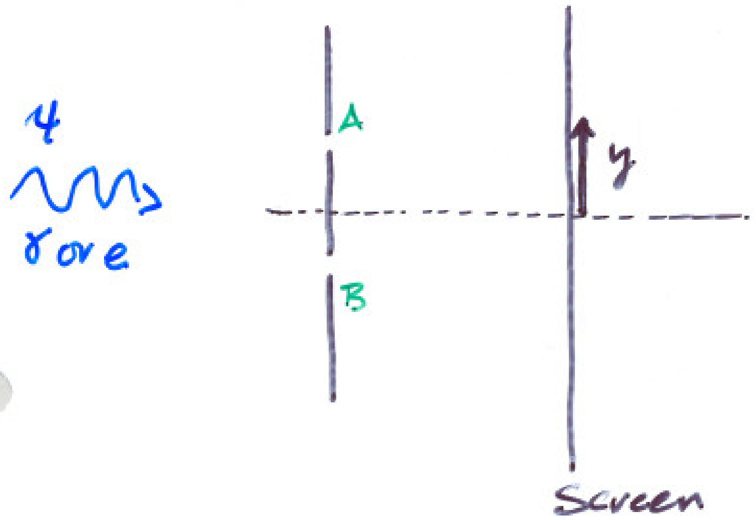
NO CHAPTER... A BIT ON THE CONCEPTUAL ISSUES IN QUANTUM MECH.

WHAT ARE "CLASSICAL" COMMITMENTS?

- OBJECTS EXIST IN SPACE & TIME
  - can be localized, can be counted
  - evolution takes place in space & time
- CAUSALITY
  - every event has a cause
- DETERMINATION
  - every later ~~event~~ state is uniquely determined by an earlier state
- CONTINUITY
  - all process exhibit an initial and final state in space and time.
  - they ~~each~~ inhabit each instant in space and time between these states

The 2 slit returns...



Quantum mechanics predicts – with precision – the probability of finding an electron at y – only the probability → BUT... get only whole γ or e

$\psi = \psi_A + \psi_B$

the wavefunction contains the potential of passing through A and/or B.

$$|\psi|^2 dy = \left(|\psi_A|^2 + |\psi_B|^2 + 2\psi_A\psi_B\right) dy$$

interference creates the fringes

Try to identify the slit -- ask a question about localization (a particle-like question) -- the interference (the wave-like character) goes away.

What causes the indeterminant ψ to become the real, classical THING of a whole electron or photon on the screen?

$\psi_{BEFORE} \longrightarrow \psi_{AFTER}$

- full of potential
- everywhere

- potential gone → actual
- a single "here" spot on the screen

"Copenhagen" answers: A MEASUREMENT.

a measurement is... an observation.

→ the "observer" seems to play a role in making reality.

Said another way--

What is the state of the electron/photon before the measurement (before being observed)?

"Copenhagen" answers: not a meaningful scientific question.

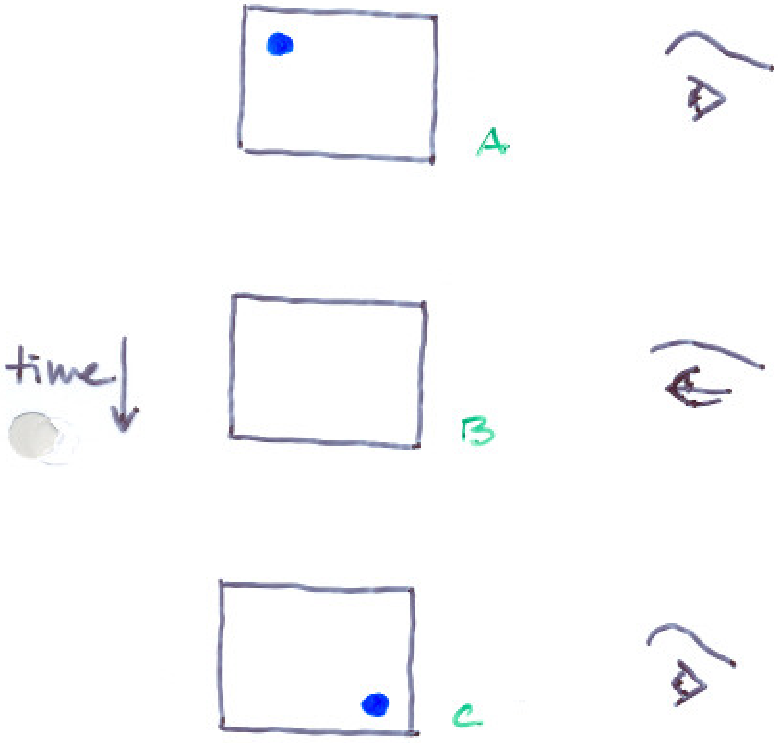
Wanna know? Make a measurement.

The Schrödinger equation precisely predicts the behavior of ψ

But Born taught us that the connection to the world is $|\psi|^2$ ... a probability.

What you see is what you get.

but what you get can only come from what you see.



where is • between A & C?

can't be certain.

In some sense, Bishop Berkeley has returned.

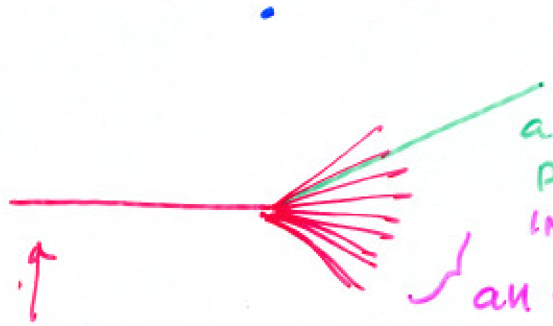
Tied to the Uncertainty Principle...

"Copenhagen" insists: objects possessing both a specific position and specific speed cannot be said to exist

→ don't exist? That's for you to decide!

A STRANGE "ARROW OF TIME"

PAST NOW FUTURE



a measurement picks a particular outcome
IN YOUR WORLD

all the others? OTHER WORLDS?

wave function for past, observed objects is decided

observation/measurement "collapses" the wavefunction

wavefunction for <u>any</u> object carries all potential with it

The "Many Worlds Interpretation" of QM

→ totally consistent with everything

no "measurement problem"

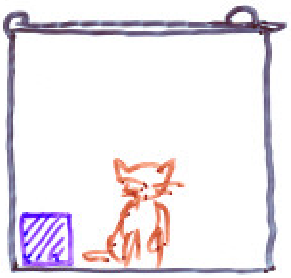
The price? A weird view of ∞ worlds popping up everywhere, everytime.

This famously disgusted Einstein and Schrödinger

opposed to

Bohr, Heisenberg, Born.

Schrödinger famously facetiously proposed the cat paradox in 1935.



The Schrödinger Cat.

- half-life of 60 min
- creates an electrical connection which releases a hammer
- breaking a vial of poison

after 60 minutes, is the cat alive or dead?

→ 50-50 chance that this is so.

- Copenhagen Interpretation?

  cannot ask.

- Von Neumann

  consciousness only causes ψ to collapse

- Many Worlds Interpretation

  cat both alive and dead

- Einstein and Bohm

  missing information, or another, hidden variable in QM -- when found, would make a well-behaved prediction

1935 also, Einstein, Rosen, Podolsky postulated an experiment designed to destroy the Copenhagen Interpretation

identical

$A \to B + C$

"EPR Paradox"

O can make a measurement on C.

- okay, measure the momentum precisely.

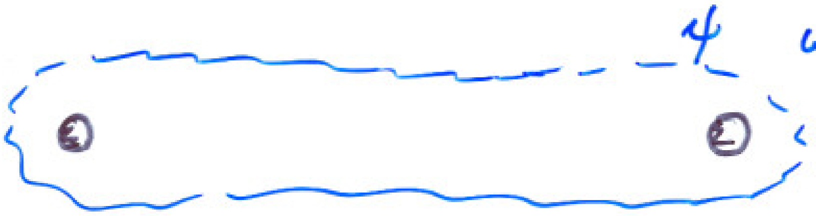
  ⇒ the position of C becomes completely undetermined.

BUT ALSO Copenhagen says that this makes the position of B completely unknown.

→ hidden variables applied BY experiment.

Einstein wrong.

Modern interpretation



"entanglement"

→ Bottom line –

- most adhere to Copenhagen Interpretation
- none believe in Hidden Variables
- some willing to acknowledge the MW interpretation

CHAPTER 9 STATISTICAL PHYSICS

an experiment... a bit of plastic & a bit of chalk.

hold your breath...

Kinetic Theory & Boltzmann's Approach

Remember, for an ideal Gas we found

$$\langle K \rangle = 3/2\, kT$$

– now let molecules have a variety of velocities and E's
→ continuum.

$n(\vec{v})d\vec{v}$ = number of molecules per unit volume having velocity between $\vec{v}$ and $\vec{v}+d\vec{v}$
$n(\vec{v})$ is the number density per unit volume

molecules per unit volume $= n = \int n(\vec{v})\, d\vec{v}$

or.. can work in probabilities...

$$f(\vec{v})\, d^3\vec{v} = n(\vec{v})\,\frac{d^3\vec{v}}{n}$$

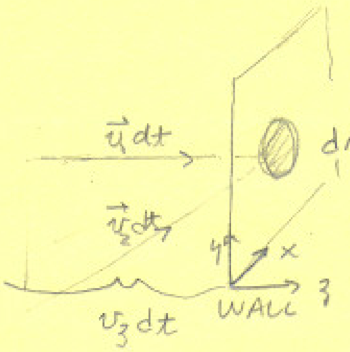
probability of finding a molecule with $\vec{v}$ to $\vec{v}+d\vec{v}$

$$f(\vec{v})\, d^3\vec{v} = f(\vec{v})\, dv_x\, dv_y\, dv_z$$

$f(\vec{v})$ is the probability density function.

$$f(\vec{v}) = \frac{n(\vec{v})}{n}$$

Remember, averages: $\langle \vec{v}^2 \rangle = \int \vec{v}^2 f(\vec{v})\, d^3\vec{v}$



each can contribute to pressure on dA during dt by transferring p_3 during that time.

the momentum transfer due to molecules with $\vec{v}$ between $\vec{v}$ and $\vec{v} + d\vec{v}$ is

$$(2mv_3)\left[n(\vec{v})\,d^3\vec{v}\right](dA\; v_3\, dt)$$

$$= 2m\, dA\, dt\; v_3^2\; n(\vec{v})\, d^3\vec{v}$$

The total Δp transferred

$$\Delta p = 2m\, dA\, dt \int_{\substack{\text{all } \vec{v} \\ +v_3}} v_3^2\, n(\vec{v})\, d^3\vec{v}$$

$$\text{Pressure} = \frac{\Delta p}{dt\, dA} = P = 2m \int v_3^2\, n(\vec{v})\, d^3\vec{v}$$

no preferred direction $\Rightarrow$ $n(\vec{v}) = n(v)$ v - speed.

$v_3 > 0$ $\Rightarrow$ all speed $\times \frac{1}{2}$

$$P = \frac{2m}{2} \int_{\text{all}} \frac{(v_3^2 + v_y^2 + v_x^2)}{3}\, n(v)\, d^3\vec{v} = \frac{m}{3} \int v^2 n(v)\, d^3\vec{v}$$

$$P = \frac{1}{3} m n \underbrace{\int d^3\vec{v}\, v^2 f(v)}_{\langle v^2 \rangle}$$

$$= \frac{2}{3} n \int d^3 \, \frac{1}{2} m v^2 f(\vec{v})$$

$$P = \frac{2}{3} n \langle K \rangle \quad \Rightarrow \quad \langle K \rangle = \frac{3}{2} kT = \frac{1}{2} m \langle v^2 \rangle$$

need $f(v)$ to go further

f only depends on the speed.
So probabilities are independent for v_x v_y or v_z

$$f(v_x, v_y, v_z) = h(v_x)\, h(v_y)\, h(v_z)$$

$$= f(v_x^2 + v_y^2 + v_z^2)$$

what kind of function works? Take log.

$$\ln h(v_x^2) + \ln h(v_y^2) + \ln h(v_z^2)$$
$$= \ln f(v_x^2 + v_y^2 + v_z^2)$$

which implies

$$h(v_i^2) = \text{constant } e^{-Bv_i^2}$$

so

$$f(v) = C e^{-B(v_x^2 + v_y^2 + v_z^2)} = C e^{-Bv^2}$$