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 state is uniquely determined by an earlier state

- CONTINUITY
  - all processes exhibit an initial and final state in space and time
  - they "inhabit" each instant in space and time between those states
The 2 slit returns...

Quantum mechanics predicts — with precision — the probability of finding an electron at y — only the probability → **But... yet only whole 5 cm**

\[ \Psi = \Psi_A + \Psi_B \]

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

\[ 141^2\, dy = (14_A^2 + 14_B^2 + 24_A\, 4_B)\, dy \]

*interference creates new 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 indeterminate $\Psi$ to become the real, classical firing of a whole electron or photon on the screen?

$\Psi_{\text{BEFORE}} \quad \rightarrow \quad \Psi_{\text{AFTER}}$

- full of potential
- everywhere

- potential gone $\rightarrow$ actual
- a single "here" spot on the screen

"Copenhagen" answers: A MEASUREMENT.

A measurement is... an observation.

$\Rightarrow$ 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 $\Psi$.

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.
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

wave function for past, observed objects is decided

observation/measurement

"collapses" the wave function

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 disputed Einstein and Schrödinger exposed to
Bühr, Heisenberg, Born.

Schrödinger famously proposed the cat paradox in 1935.

- half-life 86.8 min
- creates an electrical connection which releases a hammer
- breaks a vial of poison

After 68 minutes, is the cat alive or dead?

$\Rightarrow$ 50-50 chance that this is so.
• Copenhagen Interpretation?
  cannot exist

• Von Neumann
  consciousness only causes \( \psi \) 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.

A \rightarrow B + C

"EPR Paradox"

O can make a measurement on C.

- okay, measure the momentum precisely.

\Rightarrow the position of C becomes completely undetermined.

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

\Rightarrow hidden variables apply. 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
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:

\[ \langle K \rangle = \frac{3}{2} kT \]

Now let molecules have a variety of velocities and \( E \)’s → continuum.

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

\[ \pm \text{ molecules per unit volume} = n = \int n(v) \, dv \]

or: can write in probabilities...

\[ f(v) \, d^3v = \frac{n(v) \, d^3v}{n} \]
Probability of finding a molecule with \( \vec{v} \) to \( \vec{v} + d\vec{v} \)

\[ f(v) \, d^3v = f(v) \, dv_x \, dv_y \, dv_z \]

\[ f(v) \text{ is the probability density function.} \]

\[ f(v) = \frac{n(v)}{n} \]

Remember: average:

\[ \langle v^2 \rangle = \int v^2 \, f(v) \, d^3v \]
the momentum transfer due to molecules with \( \vec{v} \) between \( \vec{v} \) and \( \vec{v} + \text{d} \vec{v} \) is

\[
(2m v_3^2) \left[ n(\vec{v}) \text{d}^3 \vec{v} \right] (\text{d}A \text{ v}_3 \text{d}t)
\]

\[
= 2m \text{d}A \text{d}t \text{ v}_3^2 n(\vec{v}) \text{d}^3 \vec{v}
\]

The total \( \Delta p \) transferred

\[
\Delta p = 2m \text{d}A \text{d}t \int_{\text{all } \vec{v}} \text{ v}_3^2 n(\vec{v}) \text{d}^3 \vec{v}
\]

Pressure:

\[
\text{Pressure} = \frac{\Delta p}{\text{d}t \text{d}A} = P = 2m \int_{\text{all } \vec{v}} \text{ v}_3^2 n(\vec{v}) \text{d}^3 \vec{v}
\]

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

\( v_3 > 0 \) \( \Rightarrow \) all \( v \)-speed \( \times \frac{1}{2} \)

\[
P = \frac{2m}{2} \int_{\text{all } \vec{v}} \left( v_3^2 + v_4^2 + v_5^2 \right) n(v) \text{d}^3 \vec{v} = \frac{m}{2} \int v^2 n(v) \text{d}^3 \vec{v}
\]
\[ P = \frac{1}{3} \, m \, n \, \int d^3 \mathbf{u} \, u^2 \, f(v) \]
\[ \frac{1}{\langle u^2 \rangle} \]
\[ = \frac{2}{3} \, m \, n \, \int d^3 \mathbf{u} \, \frac{1}{2} m \, u^2 \, f(v) \]
\[ P = \frac{2}{3} \, m \, n \, \langle k \rangle \quad \Rightarrow \quad \langle k \rangle = \frac{3}{2} \, \hbar \, \frac{1}{T} = \frac{1}{2} \, m \, \langle v^2 \rangle \]

need \( f(v) \) to go further.

\( f \) only depends on the speed.
so probabilities are independent in \( u_x, u_y \) or \( v_x \),

\[ f(u_x, u_y, u_z) = h(u_x) \cdot h(u_y) \cdot h(u_z) \]
\[ = f(u_x^2 + u_y^2 + u_z^2) \]

what kind of function works? Take log.

\[ \ln h(u_x^2) + \ln h(u_y^2) + \ln h(u_z^2) \]
\[ = \ln f(u_x^2 + u_y^2 + u_z^2) \]

which implies

\[ h(u_x^2) = \text{constant} + e^{-B u_x^2} \]

so

\[ f(v) = Ce^{-B(u_x^2 + u_y^2 + u_z^2)} = Ce^{-Bv^2} \]