Quantum Illusions and Time
Joan Vaccaro
Quantum States

Photons (particles of light)

- polarisation of $\mathbf{E}$ (electric field):
  two orthogonal directions
• arbitrary polarisation

• superpositions
placement of “one thing on top of another”

• measurement
• superposition of two positions

Opaque absorber with 2 slits

\[ |U \rangle \text{ upper} \]

\[ d \]

\[ |L \rangle \text{ lower} \]

\[ \text{interference pattern} \]

\[ \text{photons pile up here one at a time} \]

\[ \propto \frac{1}{d} \]

\[ \text{but NOT here} \]

\[ \text{need many photons for verification} \]
Experiments

- photons 1802 Young
- electrons 1926 Davisson, Germer & Thomson
- atoms 1930 Estermann & Stern
- neutrons 1945 Wollan & Shull
- bucky balls 2002 Zeilinger
- virus?
- bacteria?
- flea?
- cat?
- people?
Many Worlds

...first a bit of history...

- 1920’s: treatment of radioactive decay

\[ \text{Tr}(\theta_1), \text{Pa}(\theta_1) + \text{Tr}(\theta_2), \text{Pa}(\theta_2) + \text{Tr}(\theta_3), \text{Pa}(\theta_3) + \text{Tr}(\theta_4), \text{Pa}(\theta_4) + \cdots \]

possible tracks $\text{Tr}(\theta)$ & paths $\text{Pa}(\theta)$ of single particle

but only one track per particle is seen
Copenhagen Interpretation:

- 1927: Bohr and Heisenberg in Copenhagen

when experimenter looks at cloud chamber its state **collapses**

\[
\begin{align*}
\text{Tr}(\theta_1), \text{Pa}(\theta_1) + \text{Tr}(\theta_2), \text{Pa}(\theta_2) + \ldots + \text{Tr}(\theta_3), \text{Pa}(\theta_3) + \ldots
\end{align*}
\]

see only **one** track
Schrödinger’s Cat

radioactive atom + Geiger detector
Schrödinger’s Cat

09:30

radioactive atom + Geiger detector

hammer trips and breaks vial of poison

cat dies
**Schrödinger's Cat**

Partial decay leads to **superposition state**

until experimenter looks inside box and **state collapses**

50% chance  **OR**  50% chance
I don’t like it and I’m sorry I ever had anything to do with it.

Schrödinger collapse is **not described** by any *dynamical* process (with forces, potentials etc.)

50% chance $\text{hi kitty}$ OR 50% chance $\text{oh no...}$
Everett 1957 (50th anniversary year)

- applying quantum mechanics to universe (cosmology)
- no external observers (experimenters) to collapse state

We need new toy example

- don’t know how to treat “no life process” (dead) and “life process” (alive) as physical states
The cat that may (or may not) be fed
The cat that may (or may not) be fed
The cat that may (or may not) be fed

Why don’t we see this superposition?
This is what happens when we look…

here kitty-kitty…

GU 2007 Quantum Illusions and Time
This is what happens when we look...

...so how do we see superpositions
The dropped cat experiment (with catchers)
- how to “see” a superposition

probability

interference
The dropped cat experiment (with catchers) - how to “see” a superposition
The dropped cat experiment (with catchers) - how to “see” a superposition

Parameters

\[ d = 0.1 \text{m} \]
\[ \Delta x = 1 \text{m} \]
\[ m = 10 \text{ kg} \]
\[ L = 10^{67} \text{ m} \]
\[ t = 10^{26} \text{ y} \]
we never even try to do this kind of experiment
- need control (& disentangle atom… from cat etc.)
- but, importantly, need to repeat it many times to build up interference pattern

separate “worlds” evolve…

the poor but happy world

the rich but sad world

the perception of “one single world” is an illusion
David Pegg’s quantum theory of time

- canonical approach to quantising gravity
- **Wheeler-deWitt** - equation:
  - universe is in a stationary state
  - no motion – **frozen dynamics**
  - energy is well known (zero)

- Heisenberg uncertainty principle
  - if you know **position** $X$ well, **momentum** $P$ is uncertain
  - **energy** $E$ is uncertain
  - **time** $T$ is uncertain

∴ time in the universe must be uncertain

---

• use new set of axes – each axis represents a different time
axes chosen to make projections all equal

\[
|\psi\rangle = |\phi_1\rangle + |\phi_2\rangle + |\phi_3\rangle + |\phi_4\rangle + |\phi_5\rangle + \ldots
\]

History vector – totality of reality – state at all times
• **divide universe** into 2 parts: Clock + Rest
  clock must have **equally spaced energy levels**

  divide universe

  orthogonal clock states

\[
\begin{align*}
| \psi \rangle &= | \phi_1 \rangle + \cdots + | \phi_M \rangle + | \phi_{M+1} \rangle + \cdots + | \phi_P \rangle
\end{align*}
\]

find interval where Clock and Rest are **separate** and **non-interacting**

• rewrite interval in terms of **orthogonal clock states**
• the dynamics of Rest can be written in terms of the time parameter \( t \) defined by Clock: \( \delta t = \begin{array}{c} \text{Clock} \end{array} - \begin{array}{c} \text{Clock} \end{array} \)

\[
\frac{\phi_{M+1} + \phi_{M+2} + \cdots + \phi_P}{R_1 + R_2 + R_3 + \cdots + R_P}
\]

Schrödinger’s equation for dynamics

\[
\frac{\delta \phi}{\delta t} = -\frac{i}{\hbar} \hat{H} \phi
\]
we live at these different times

the perception of “one present” is an *illusion*

does this illusion is on par with the
single world illusion
Puzzle: how does our perception of travelling in time arise?

\[
\begin{align*}
|\mathcal{R}_1\rangle & + |\mathcal{R}_2\rangle + |\mathcal{R}_3\rangle + \cdots + |\mathcal{R}_P\rangle \\
\end{align*}
\]

these states of Rest are non-orthogonal

- this gives a connection between different states of Rest
- but the connection is the same in both directions!

so can’t be sure which one we are in
**Puzzle:** why do we travel in one direction in time?

- anti-particles are the *time reversed versions* of particles

- all anti-particle and particle pairs are time symmetric except for Kaons (K mesons)
Neutral kaons $K^0$ have a lifetime of less than $10^{-6}$ s.

Decay paths:

\[
K^0 \rightarrow e^+ + \pi^- + \nu \quad \text{(more likely)}
\]

\[
\bar{K}^0 \rightarrow e^- + \pi^+ + \bar{\nu} \quad \text{and 
}\]

- equal number of $K^0$ and $\bar{K}^0$ are found to yield different numbers of $e^+$ and $e^-$
- violation of CP & $\therefore$ T symmetry

(CERN 1998)

\[
| \bigcirc \rangle | R_1 \rangle + | \bigcirc \rangle | R_2 \rangle + | \bigcirc \rangle | R_3 \rangle + \cdots | \bigcirc \rangle | R_P \rangle
\]

\[t\]

short lifetime $\quad$ time asymmetric $\quad$ long lifetime
Only unsure of which state in the "future" we are in.

Kaons appear to be responsible for us travelling through time!!!
Conclusion

Many worlds: we exist in many worlds but have the illusion (and pleasures) of only one - but somewhere we are having *a really good time*.

Many times: we exist at many times but have the illusion of only one present which marches steadily toward to our demise! - but consoled by knowing *we still exist at earlier times*.

Free will: even our perception of free will is an illusion – we cant change the future because we already exist there (hopefully) - but we can *enjoy the illusion*.