Quantum Measurement
Zeno Effect

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Modeling Quantum Hardware: open dynamics and control
Universität Konstanz

No phenomenon is a real phenomenon until it is an observed phenomenon.

– John Archibald Wheeler 1970

Historical Note

1900 Plank & Einstein: Blackbody Radiation

1920 Bohr, Heisenberg: Copenhagen interpretation
Born: Probabilistic interpretation $P(m) = |\langle m|\psi\rangle|^2$
Schrödinger: Measurement Problem

1930 EPR Paradox

1932 von Neumann: *Mathematical Foundations of Quantum Mechanics*

1970 Decoherence Theory

Experimental Interest

Projective Measurement

Measurement Operator $\hat{M} = \sum m|m\rangle$ on ψ:

$$p(m) = |\langle m|\psi\rangle|^2$$

$$\psi \xrightarrow{\text{Measuring } m} |m\rangle$$

Neglegting Normalization and Degenercy: POVM Measurement

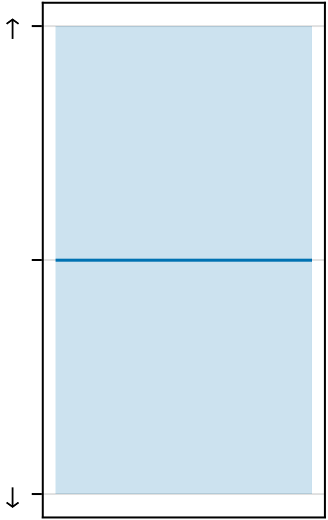
Quantum Computation and Quantum Information, M. A. Nielsen et al. 2010 (2.2.3)

Example: Superposition

$$H = \sigma_z$$

$$|\psi > \propto |\uparrow\rangle + |\downarrow\rangle$$

$\Rightarrow$ Superposition is stable



Example: Superposition

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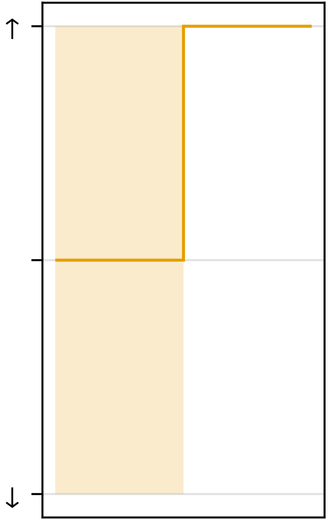
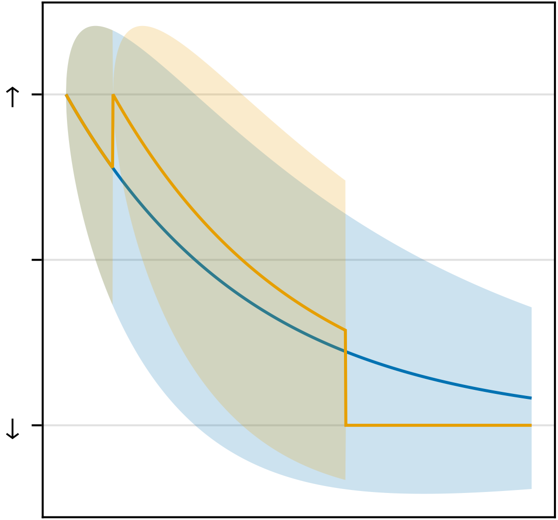
$$M = \sigma_z$$

$\Rightarrow p(\uparrow) = p(\downarrow)$

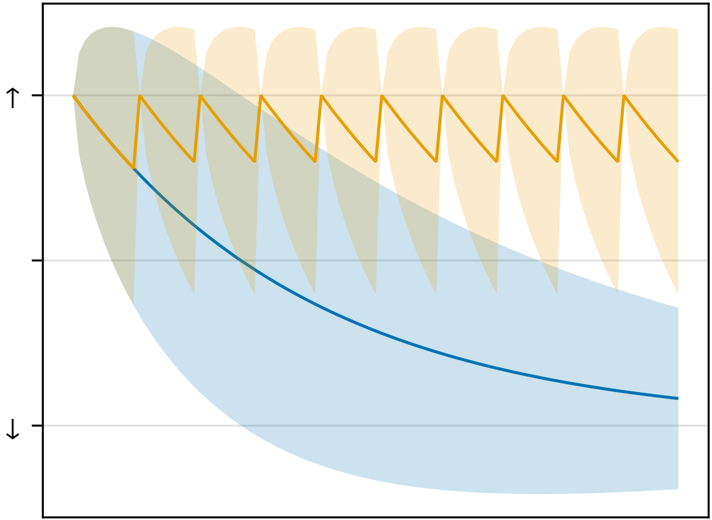


Example: Decay

$$H = \sigma_z$$
$$|\psi > \propto |\uparrow\rangle$$
$$M = \sigma_z$$
$$J = \kappa\sigma_-$$



Example: Zeno



Zeno Effect

- Zeno of Elea (460 BCE): Arrow paradox
- Misra and Sudarshan (1977): “The Zeno’s paradox in quantum theory”

“Quantum Zeno effect explains magnetic-sensitive radical-ion-pair reactions”, Kominis 2009

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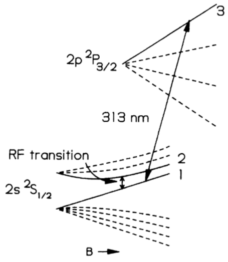


FIG. 2. Diagram of the energy levels of $^{9}Be^{+}$ in a magnetic field B. The states labeled 1, 2, and 3 correspond to those in Fig. 1 .

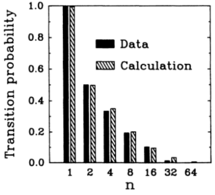


FIG. 3. Graph of the experimental and calculated $1 \rightarrow 2$ transition probabilities as a function of the number of measurement pulses n. The decrease of the transition probabilities with increasing n demonstrates the quantum Zeno effect.

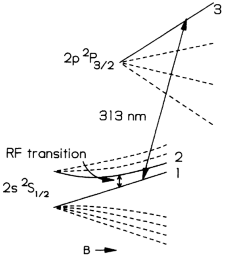
"Quantum Zeno effect explains magnetic-sensitive radical-ion-pair reactions", Kominis 2009

"Quantum Zeno effect", Itano et al. 1990

Zeno Effect

- Zeno of Elea (460 BCE): Arrow paradox
- Misra and Sudarshan (1977): "The Zeno's paradox in quantum theory"
- Experimentally demonstrated (1990) with 5000 $^{9}Be^{+}$ ions at 250 mK
- Used in Magnetometers and possibly birds

"Quantum Zeno effect explains magnetic-sensitive radical-ion-pair reactions", Kominis 2009



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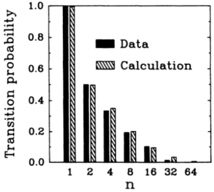

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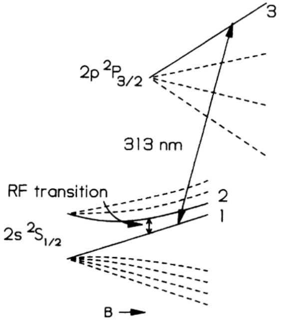
Practical Examples of strong measurements

- Trapped Ions



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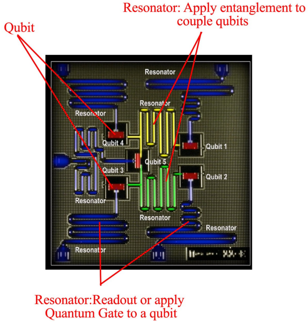

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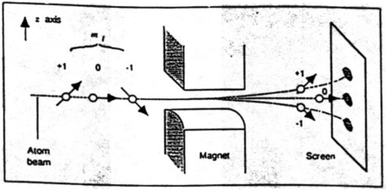

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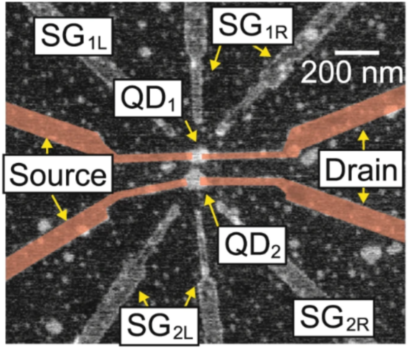
- Quantum Dot Charge Readout



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$\Rightarrow$ Used when the quantum wave function is collapsed into a classical result

Weak Measurement

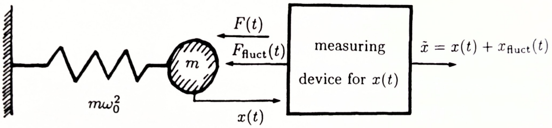
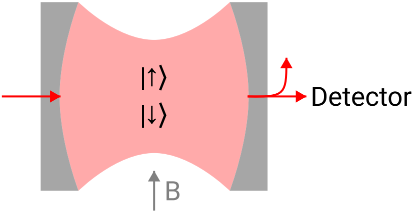


Fig. 8.4 Detection of a classical force by monitoring the coordinate of an oscillator on which it acts.

Quantum measurement, Vladimir Braginsky et al. 1992

Rabi Oscillations Setup



$$H = g\,(a^\dagger a)(\sigma^+\sigma^-) \quad \text{Coupling}$$
$$+\, g_s\,(\sigma^+ + \sigma^-) \quad \text{Magnetic}$$
$$-\, i\beta(a^\dagger - a) \quad \text{Optic}$$
$$J = \kappa\ a \quad \text{Dissipation}$$
$$C = \sqrt{\kappa\eta}\ a \quad \text{Measurement}$$

"Stochastic master equation for a probed system in a cavity", A. E. B. Nielsen et al. 2008

Time evolution