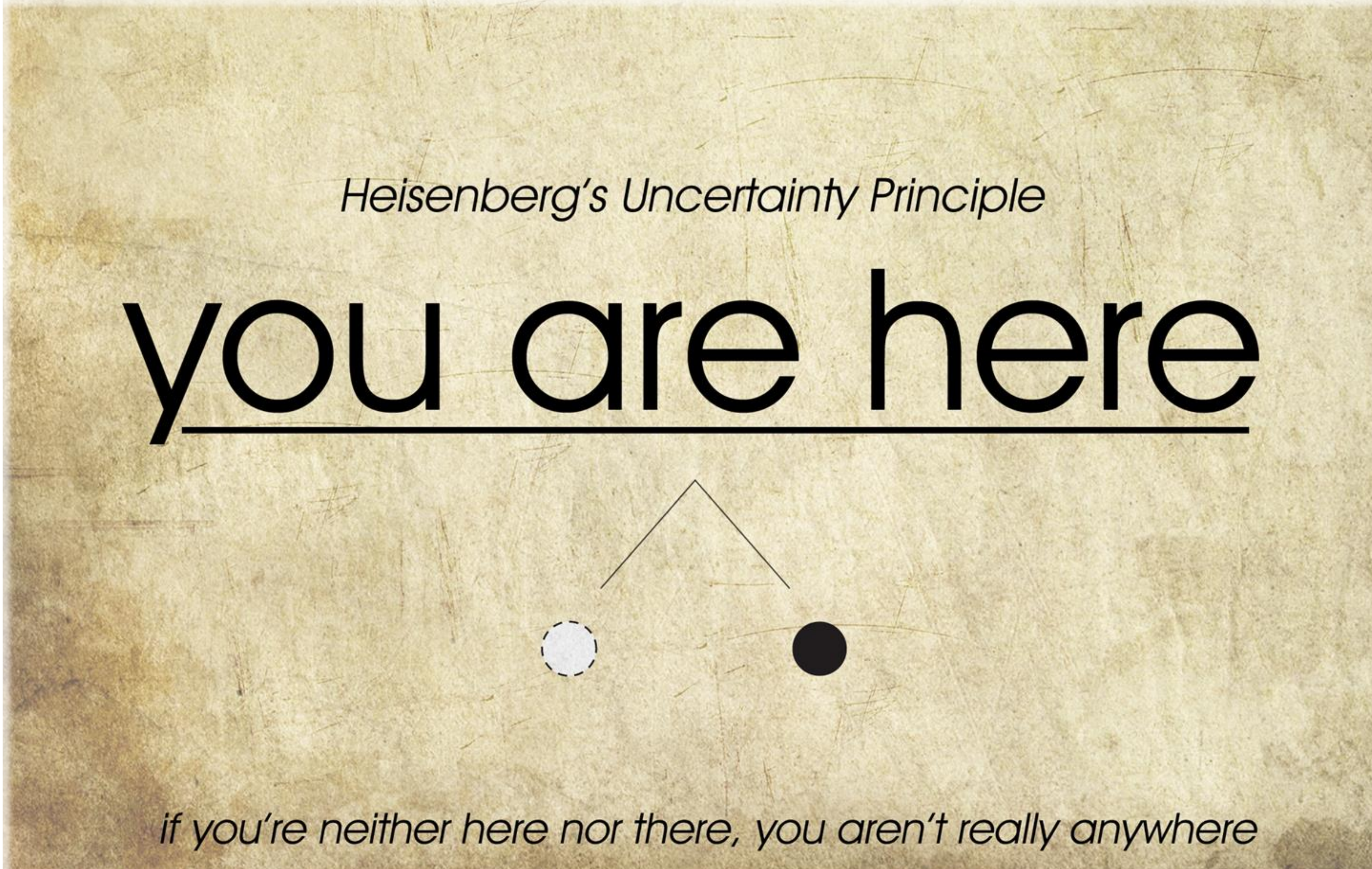
How to Cheat Heisenberg?

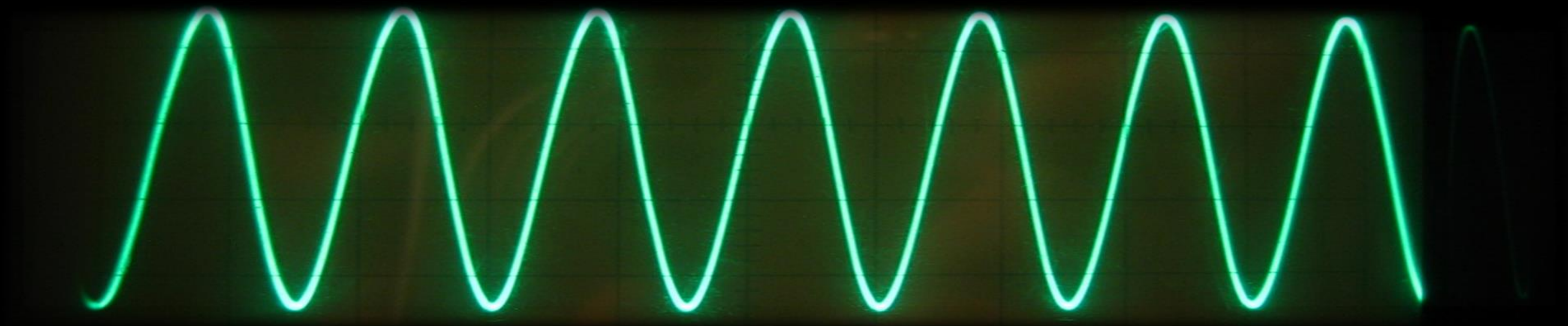
-By Kushagra Nigam

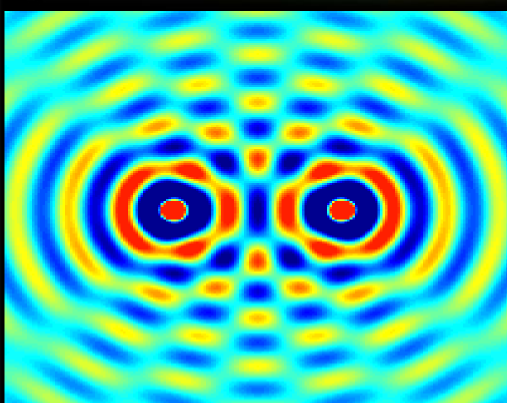


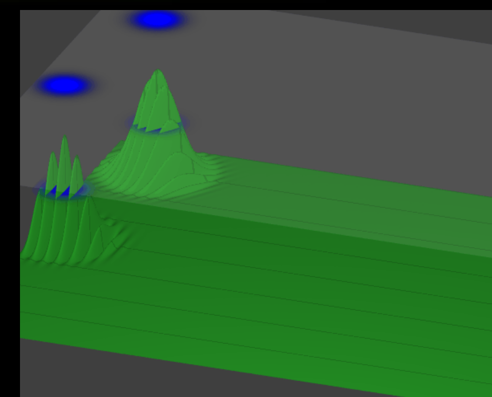
Goals Of Seminar

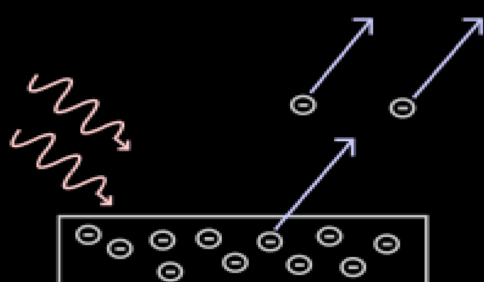
- *To illustrate Coherent States and how they depict classical behavior.*
- *To understand Quantum to Classical Transition in limit $\hbar \to 0$.*
- *To illustrate squeezed states and their Classical Analogue using ensemble of oscillators.*

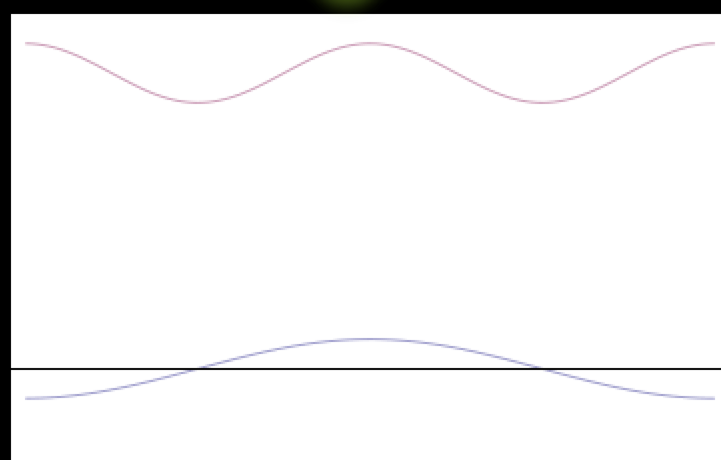
Uncertainty Principle

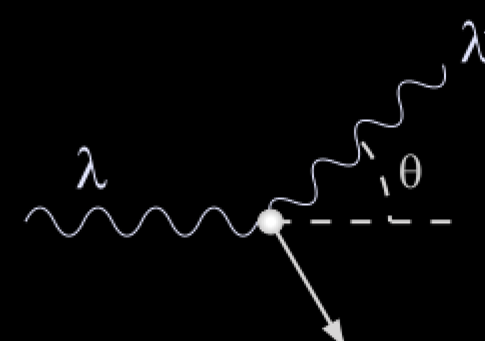












Quantum Harmonic Oscillator

$$\hat{H} = \frac{1}{2}k\hat{x}^2 + \frac{\hat{p}^2}{2m}$$

$$a^\dagger = \sqrt{\frac{mw}{2\hbar}}\left(\hat{x} - \frac{i}{mw}\hat{p}\right)$$

$$a = \sqrt{\frac{mw}{2\hbar}}\left(\hat{x} + \frac{i}{mw}\hat{p}\right)$$

$$a^\dagger a = N$$

$$\hat{x} = \sqrt{\frac{\hbar}{2mw}}(a^\dagger + a)$$

$$\hat{p} = \sqrt{\frac{\hbar mw}{2}}\ \frac{(a^\dagger - a)}{i}$$

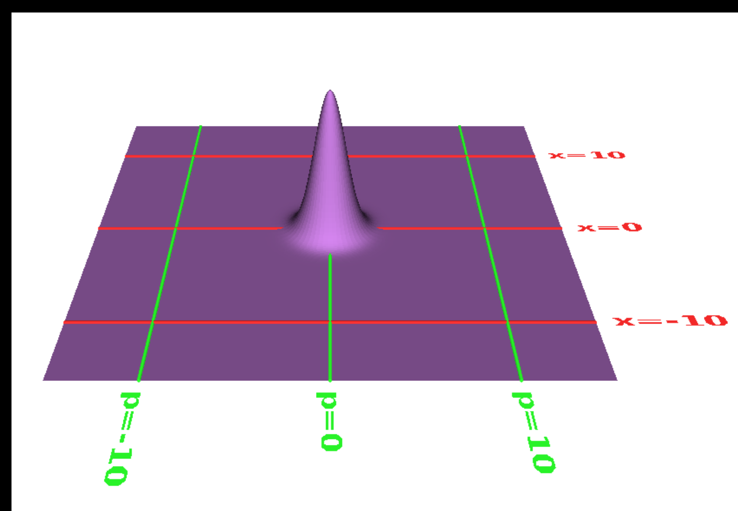
$$[a, a^\dagger] = 1$$

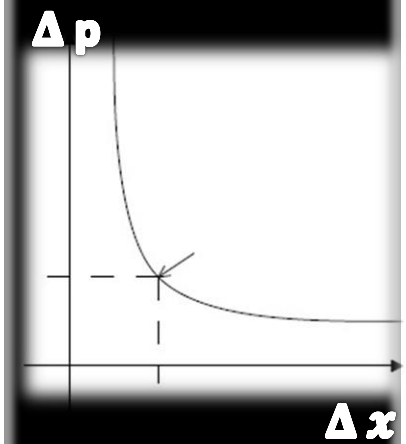
$$\Delta x = \sqrt{\left(n + \frac{1}{2}\right)\frac{\hbar}{mw}}$$

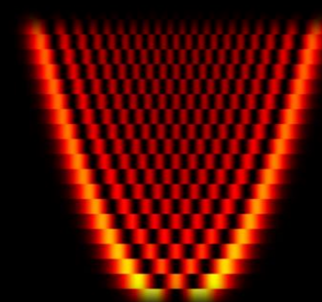
$$\Delta p = \sqrt{\left(n + \frac{1}{2}\right)\hbar mw}$$

Points to Note:

- *Stationary States - Mean and Variance are fixed*
- *Superposition is Non –stationary*
- *E and B fields exhibit same behavior as x and p in standing modes inside resonance cavity.*







How to Cheat Heisenberg? PART-2

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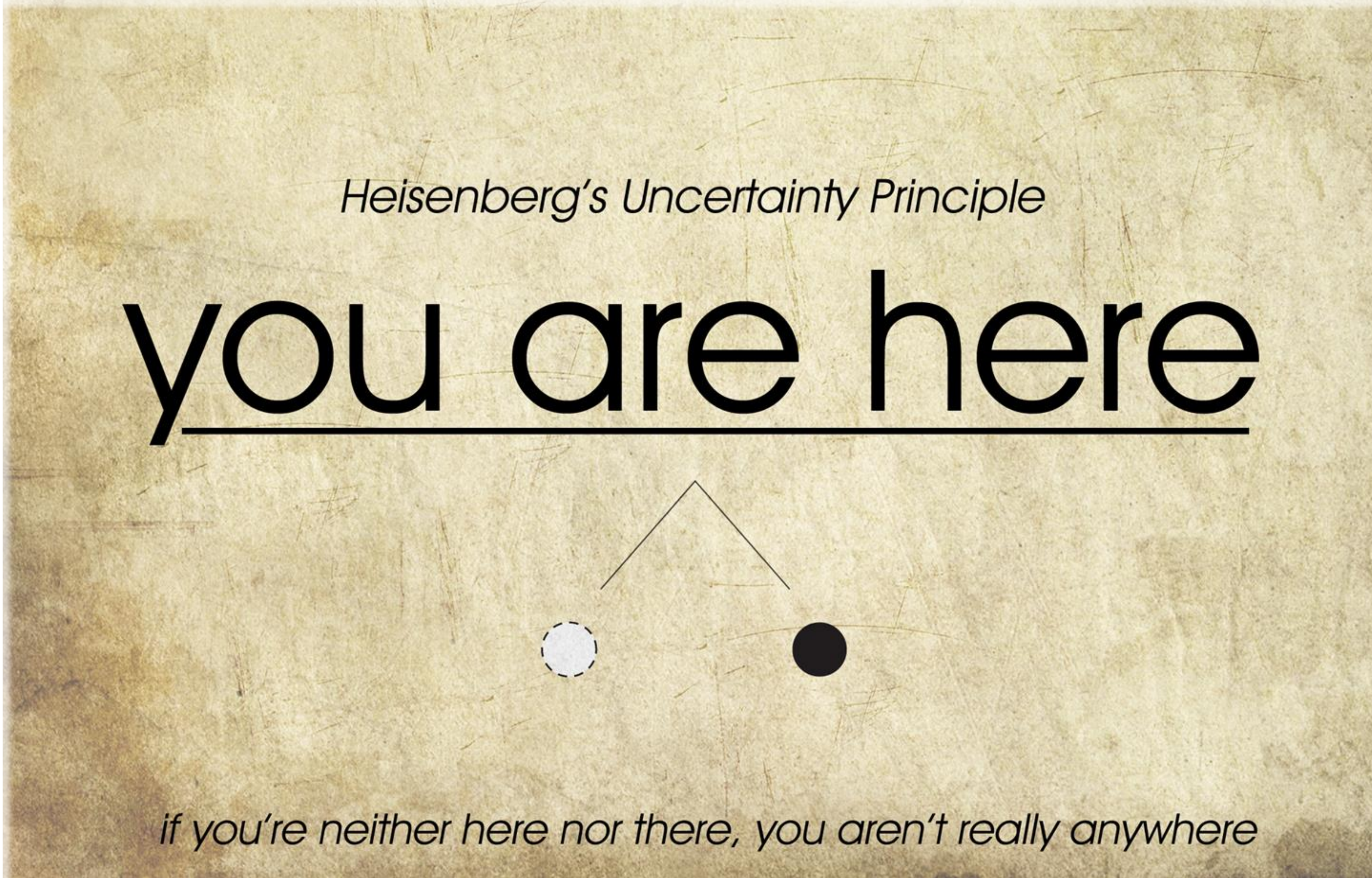


Coherent States

$$\hat{H} = \frac{1}{2}k\hat{x}^2 + \frac{p^2}{2m}$$

$$a^\dagger = \sqrt{\frac{mw}{2\hbar}}\left(\hat{x} - \frac{i}{mw}\hat{p}\right)$$

$$a = \sqrt{\frac{mw}{2\hbar}}\left(\hat{x} + \frac{i}{mw}\hat{p}\right)$$

$$a^\dagger a = N$$

$$\hat{x} = \sqrt{\frac{\hbar}{2mw}}(a^\dagger + a)$$

$$\hat{p} = \sqrt{\frac{\hbar mw}{2}}\;\frac{(a^\dagger - a)}{i}$$

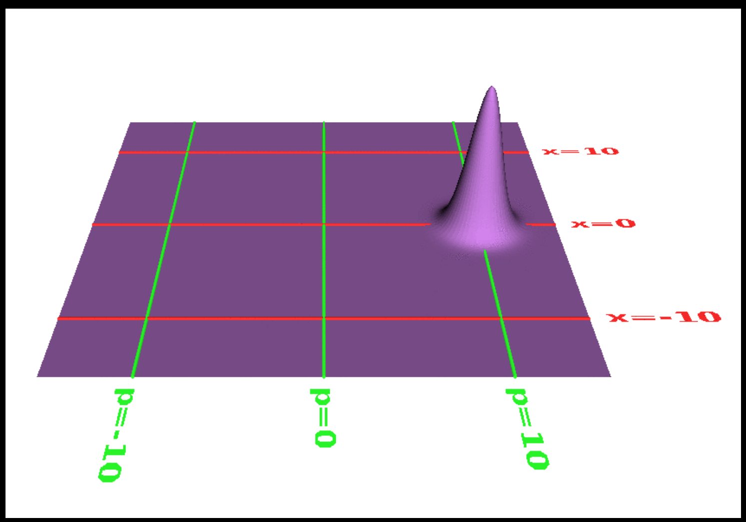
$$[a, a^\dagger] = 1$$

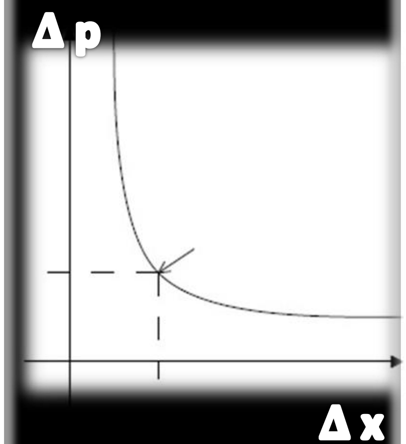
$$\Delta x = \sqrt{\frac{1}{2}\frac{\hbar}{mw}}$$

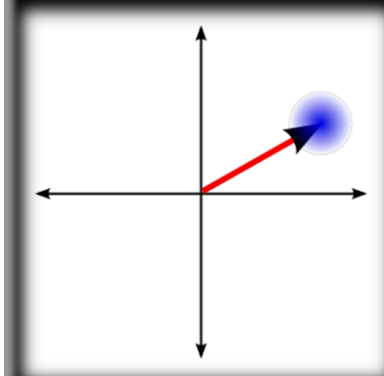
$$\Delta p = \sqrt{\frac{1}{2}\hbar mw}$$

Points to Note:

- *Overcompleteness and non-orthogonality.*
- *Mean oscillates with time.*
- *Classical reduction in limit $\hbar \to 0$.*
- *Laser itself is a coherent beam of bosons.*
- *Optical Laser – Boson is photon*
- *Atomic Laser – Boson is Atom.*







Squeezed States

$$\hat{H} = \frac{1}{2}k\hat{x}^2 + \frac{\hat{p}^2}{2m}$$

$$a^\dagger = \sqrt{\frac{mw}{2\hbar}}\left(\hat{x} - \frac{i}{mw}\hat{p}\right)$$

$$a = \sqrt{\frac{mw}{2\hbar}}\left(\hat{x} + \frac{i}{mw}\hat{p}\right)$$

$$a^\dagger a = N$$

$$\hat{x} = \sqrt{\frac{\hbar}{2mw}}(a^\dagger + a)$$

$$\hat{p} = \sqrt{\frac{\hbar mw}{2}}\ \frac{(a^\dagger - a)}{i}$$

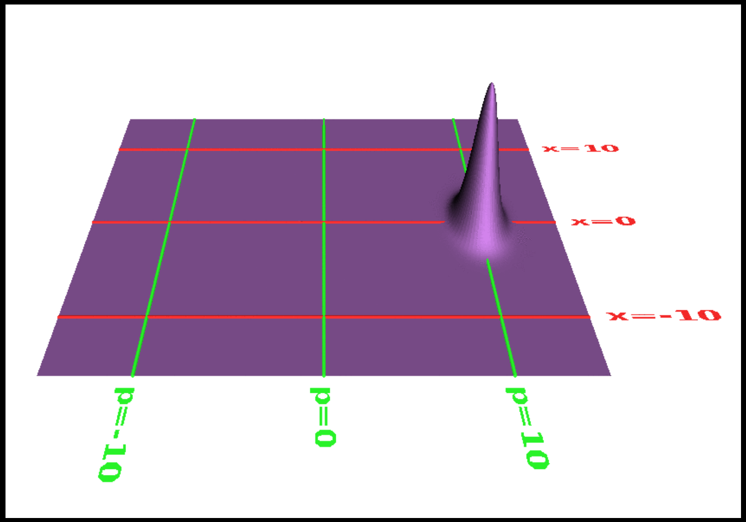
$$[a, a^\dagger] = 1$$

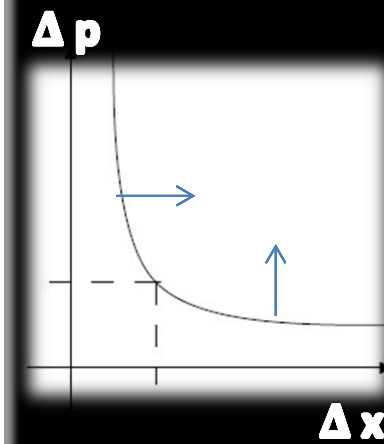
$$\Delta x >/< \sqrt{\frac{1}{2}\frac{\hbar}{mw}}$$

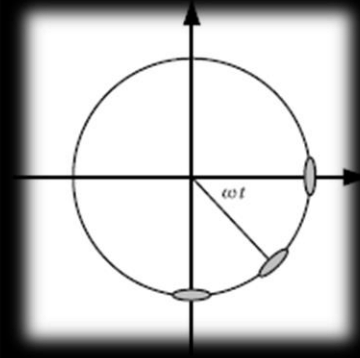
$$\Delta p </> \sqrt{\frac{1}{2}\hbar mw}$$

Points to Note:

- ***Both Mean and Variance oscillates with time.***
- ***Classical Analogy with Ensemble of Oscillators.***







Black Board Mode

$$\hat{H} = \frac{1}{2}k\hat{x}^2 + \frac{\hat{p}^2}{2m}$$

$$a^\dagger = \sqrt{\frac{mw}{2\hbar}}(\hat{x} - \frac{i}{mw}\hat{p})$$

$$a = \sqrt{\frac{mw}{2\hbar}}(\hat{x} + \frac{i}{mw}\hat{p})$$

$$a^\dagger a = N$$

$$\hat{x} = \sqrt{\frac{\hbar}{2mw}}(a^\dagger + a)$$

$$\hat{p} = \sqrt{\frac{\hbar mw}{2}}\ \frac{(a^\dagger - a)}{i}$$

$$[a, a^\dagger] = 1$$

$$\Delta x = \sqrt{\frac{1}{2}\frac{\hbar}{mw}}$$

$$\Delta p = \sqrt{\frac{1}{2}\hbar mw}$$

Overcomplete Frames

$$\hat{H} = \frac{1}{2}k\hat{x}^2 + \frac{\hat{p}^2}{2m}$$

$$a^\dagger = \sqrt{\frac{mw}{2\hbar}}\left(\hat{x} - \frac{i}{mw}\hat{p}\right)$$

$$a = \sqrt{\frac{mw}{2\hbar}}\left(\hat{x} + \frac{i}{mw}\hat{p}\right)$$

$$a^\dagger a = N$$

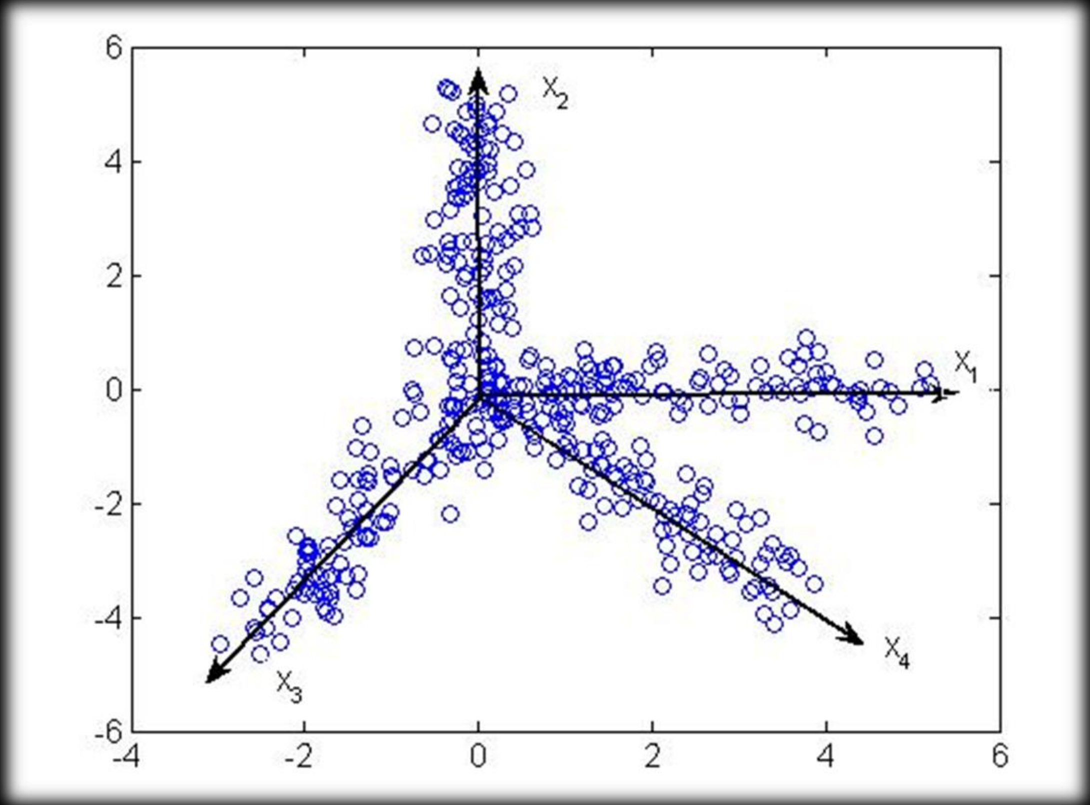
$$\hat{x} = \sqrt{\frac{\hbar}{2mw}}(a^\dagger + a)$$

$$\hat{p} = \sqrt{\frac{\hbar mw}{2}}\ \frac{(a^\dagger - a)}{i}$$

$$[a, a^\dagger] = 1$$

$$\Delta x = \sqrt{\frac{1}{2}\frac{\hbar}{mw}}$$

$$\Delta p = \sqrt{\frac{1}{2}\hbar mw}$$



Conclusion

One Simply Cannot Cheat
Mr. Berg
but he still can be manipulated!!