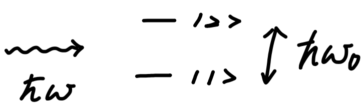
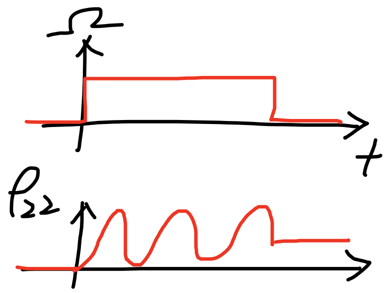
1/22/2024 P471 IAP

Atom interferometry



What's the best way to learn detunning $\Delta \equiv \omega - \omega_0$?

Idea 1: Apply a laser pulse

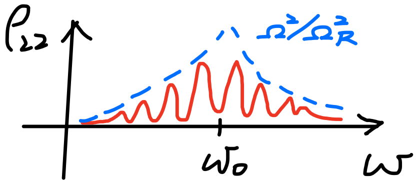


$$H_{RWA} = \begin{pmatrix} E_2 - \hbar\omega & \hbar\Omega/2 \\ \hbar\Omega^*/2 & E_1 \end{pmatrix}$$

$\hbar\Omega = -d\cdot\hat{E}$ $\quad \Omega$: Rabi freq

$$\Rightarrow \rho_{22} \equiv |\psi_2(t)|^2 = \frac{\Omega^2}{\Omega_R^2} \sin^2 \Omega_R t$$

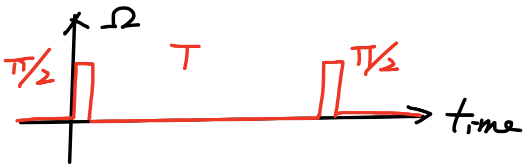
$\Omega_R \equiv \sqrt{\Delta^2 + \Omega^2}$ is generalized Rabi freq



This is Rabi spectroscopy.

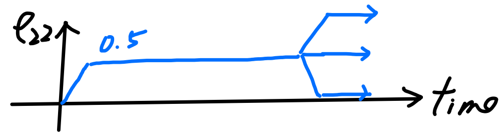
What are the pros & cons?

More useful idea: 2 pulses



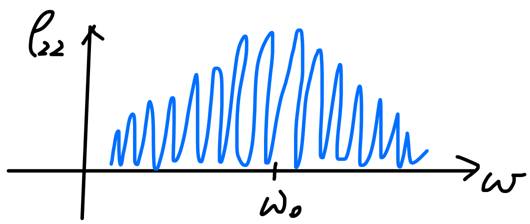
1st π/2 $\quad |1\rangle \to \frac{1}{\sqrt{2}}(|1\rangle + |2\rangle)$

Hold T $\Rightarrow \frac{1}{\sqrt{2}}(|1\rangle + e^{-i\omega_0 T}|2\rangle)$



2nd π/2 $\Rightarrow \frac{1}{2}(|1\rangle + |2\rangle) + e^{-i\omega_0 T} e^{i(\omega T + \phi)}(|1\rangle - |2\rangle)$

$\Rightarrow \frac{1}{2}(1 + e^{i\Delta\phi})|1\rangle + \frac{1}{2}(1 - e^{i\Delta\phi})|2\rangle$



Ramsey's method is empirically advantageous:

- Less sensitive to exp noise
- Phase control to gain sensitivity for small Δ.
- Longer coherence time.

Estimation of sensitivity with N atoms.

For small Δ, we have

$\rho_{22} = \frac{1}{2}(1 + \sin \Delta T)$ ← interrogation time

$\Rightarrow$ freq sensitivity

$\delta\rho_{22} = \frac{T}{2}\delta\Delta$

binary noise $= \frac{1}{\sqrt{N}}\sqrt{p(1-p)}$

$= \frac{1}{2\sqrt{N}}$

$\Rightarrow \delta\Delta = \frac{1}{\sqrt{N}\,T}$

If we repeat exp for $\tau \gg T$.

$\delta\Delta = \frac{1}{T\sqrt{N\tau/T}} = \frac{1}{\sqrt{NT\tau}}$

$\frac{\delta T}{T} = \frac{\delta\omega}{\omega} \approx \frac{\delta\Delta}{\omega_0} = \frac{1}{\omega_0\sqrt{N}\,T} = \frac{1}{\omega_0\sqrt{NT\tau}} = \frac{1}{10^{15}\sqrt{10^6 \cdot 10 \cdot 10^5}} = 10^{-21}$ theory limit