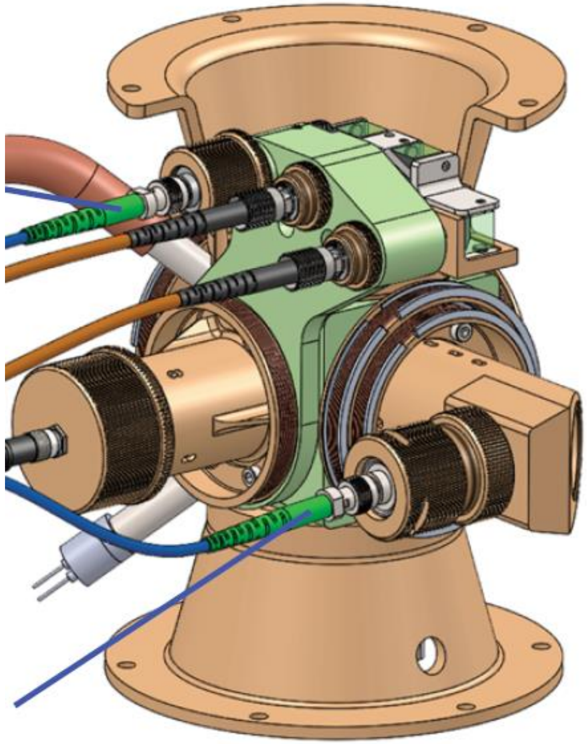

[1]

Accelerometer Compact cold-atomic

Presentation: Sensor Orientation

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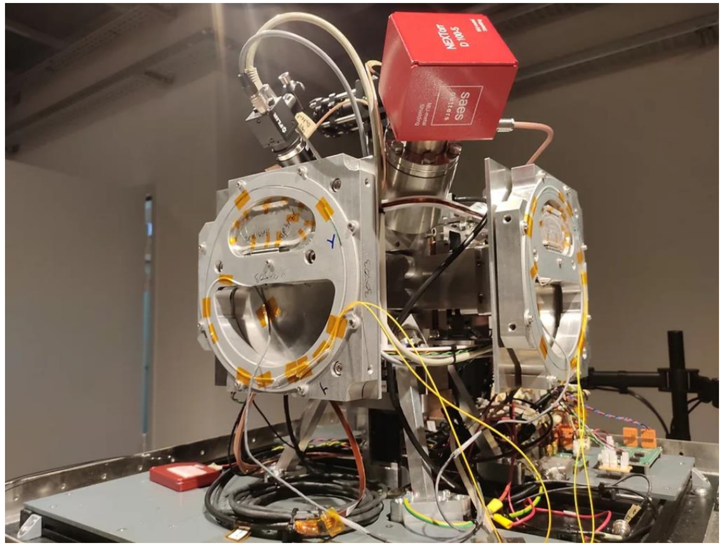
Contents

Introduction

- Compact cold atomic accelerometer is a quantum sensor.
- It uses a precise laser pulses to split and recombine matter waves from atoms.
- Using interference (*Mach-Zender*) between two atomic matter waves.



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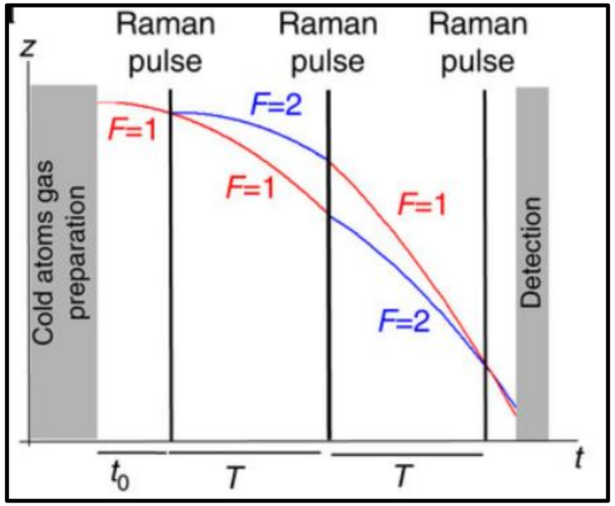

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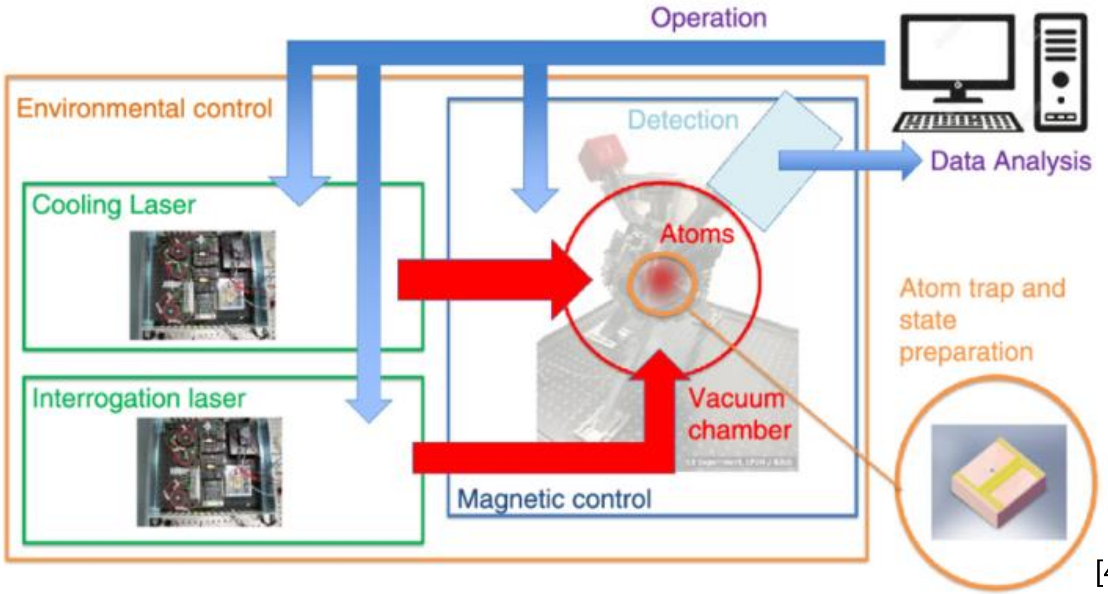
Principe

Setup

1. Vacuum and atom isolation
   - Confined in a vacuum chamber
2. Cooling and Trapping
   - Cooling laser system to slow the atoms
   - Atoms are trapped using a magneto-optical trap
3. Atom preparation
   - Prepares atoms in a specific state
   - Get ready for the interferometry measures
4. Measurement phase
   - Atoms go through a **pulse sequence.**
   - A photodetector is present at the end to catch the **interferometry**



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Principe

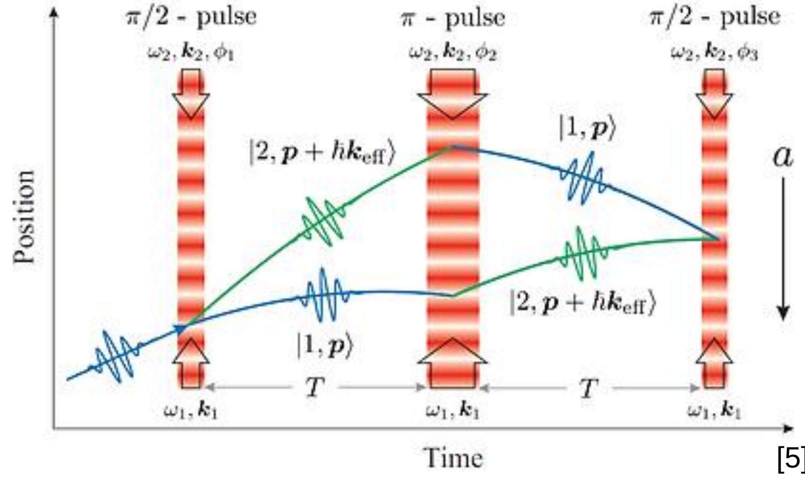
Atom interferometry concept for accelerometer

1. Laser Induced momentum or free fall
   - Atoms are released from a trap and begin falling
   - Raman or Bragg laser induced a momentum
2. Pulse sequence
   - Creates a superposition of two momentum
   - Swaps the path of the two waves
   - Recombine the two waves and detect the phase shift
3. Phase shift
   - Each wave moves on a different path due to the momentum and the acceleration

$$P(\Delta\Phi) = \frac{N_e}{N_e + N_f} = P_0 - \frac{C}{2}\cos(\Delta\Phi)$$

4. Measurement
   - At the second π/2-pulse, the interference encodes the phase shift.

$$\Delta\phi = -\overrightarrow{k_{eff}} \cdot \vec{a}T^2 \rightarrow \vec{a} = -\frac{\Delta\phi}{\overrightarrow{k_{eff}}T^2}$$



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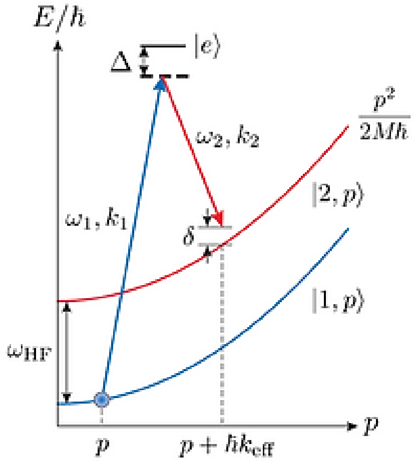

1. Atom Cooling & Trapping
- Atoms (e.g. Rubidium) are laser-cooled to microkelvin temperatures in a **magneto-optical trap (MOT)**.
- Confined in a **vacuum chamber** to avoid collisions.

2. Atom Preparation
- Atoms are optically pumped into a specific **quantum state**.
- Sometimes **launched upward** for longer measurement time (atomic fountain).

3. Interferometry Pulse Sequence

Performed with **Raman or Bragg lasers**, aligned along the axis of interest:
- Time between pulses: T
- Momentum difference: $h\vec{k}eff$

4. Phase Accumulation
- Each wavepacket travels a different path under **acceleration a**.
- Resulting **phase difference**:
- $\Delta\Phi=-\vec{k}eff\cdot\vec{a}T$^2

5. Detection
- Atoms interfere and fall into final states $|1\rangle$or $|2\rangle$.
- You measure **population ratio** to determine $\Delta\Phi$:
- $P=1/2(1+C\cos(\Delta\Phi))$
- P: transition probability
- C: contrast, visibility of the interfernce

6. Acceleration Calculation
- Using:
- $\vec{a}=-\Delta\Phi\vec{k}effT2a=-keffT2\Delta\Phi$
- You extract **absolute acceleration** — precise and drift-free.

Summary:

Cold atom interferometry uses laser pulses to split, redirect, and recombine atomic wavepackets. The phase shift from these trajectories reveals inertial acceleration, enabling ultra-precise gravimetry and navigation.

Advantages

	No friction	Operation inside a vacuum chamber Only inertial forces are sensed, no mechanical contact
	No drift	Long-term accuracy without recalibration Ideal for long duration application
	Absolute measurement	No external calibration needed Based on Physical constants
	High sensitivity at low frequency	Suited for the detection of slow or weak signals Critical for geophysics and gravity surveys

Limitations

Low bandwidth	Not usable for real-time motion tracking (~1-10Hz)
Complexity	Bulky, fragile and not yet field-hardened Needs shielding and isolation
High cost	Limited to research Smaller version (~30’000$) Larger version (~500’000$)
Hard to integrate	Not ideal for long-term unattended deployment Hard to integrate with classical sensors

Applications

Geophysics and Gravimetry

- Mapping underground structure
- Volcano monitoring and earthquake detection
- Glacier and groundwater movement tracking

Space missions

- Gravity field mapping
- Inertial navigation in deep space
- Precision attitude orbit control

GPS-denied Navigation

- Submarines, aircraft, underground vehicles
- Complements or replaces classical IMUs

Civil engineering and Infrastructure

- Detects underground structures
- Monitors structural stability

Geophysics and Gravimetry:

Cold atom accelerometers are highly sensitive to tiny changes in gravitational acceleration, making them powerful tools for geophysical exploration. They can detect subsurface features like cavities, aquifers, and mineral deposits by measuring gravitational gradients. They are also used to monitor volcanic activity and earthquake risk by detecting mass redistributions, as well as to track glacial shifts and groundwater movements with long-term stability

Space missions:

In space, where GPS isn't available, cold atom accelerometers provide absolute inertial measurements for navigation and orbit control. Their high precision and drift-free performance make them ideal for mapping planetary gravity fields and enabling deep-space navigation in missions that require autonomy, stability, and high sensitivity over long durations.

GPS-denied Navigation:

In environments where GPS signals are unreliable or unavailable — like submarines, underground vehicles, or spacecraft — cold atom sensors can serve as the core of an inertial navigation system. Unlike classical gyros or accelerometers, they offer drift-free performance, making them valuable as references or calibration tools in hybrid IMUs (Inertial Measurement Units).

Civil engineering and Infrastructure:

Cold atom accelerometers can be deployed in the field to detect underground structures such as tunnels, sinkholes, or voids that threaten infrastructure. Their long-term stability also allows them to monitor deformation or instability beneath bridges, dams, railways, or urban areas. Their use is non-invasive, reducing the need for drilling or heavy surveying.

Conclusion

- **Quantum precision, no drift:**

  Measurement of the acceleration absolutely with no recalibration needed.

- **Ultra-sensitive to slow signals:**

  Ideal for gravity, geophysics and space missions.

- **Still in experiment:**

  Primarily used in research. Not yet fully commercialized.

Thank you for your attention

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