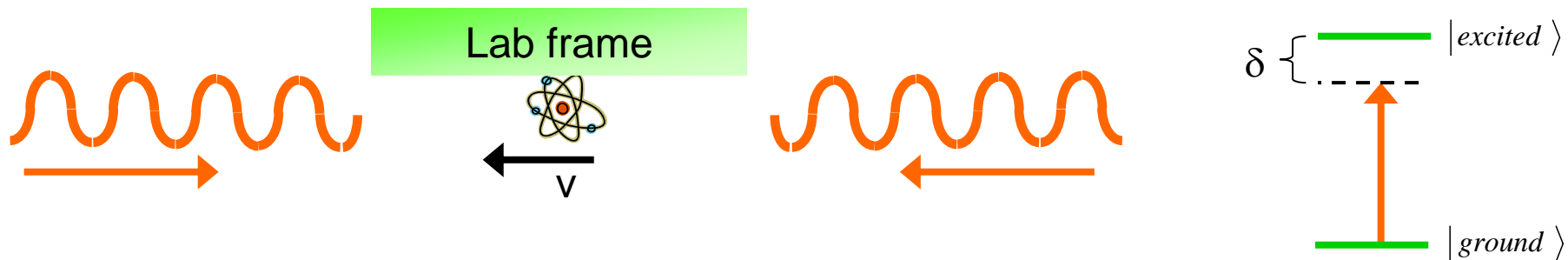


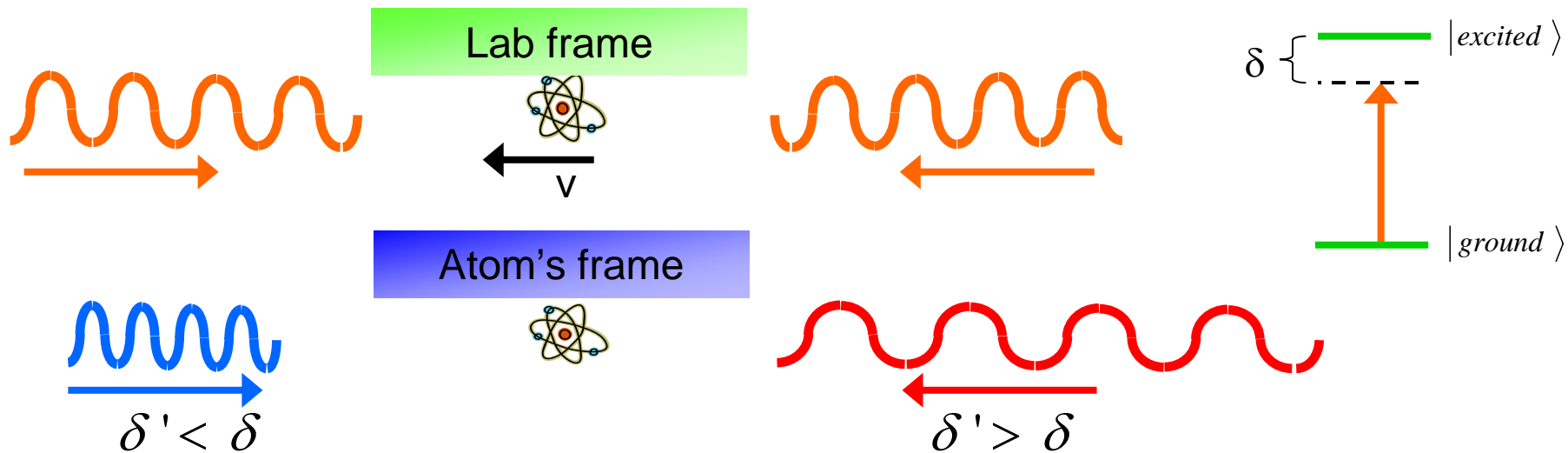
Laser Cooling

1. Doppler Cooling – optical molasses.
2. Doppler temperature.
3. Magneto-optical trap.

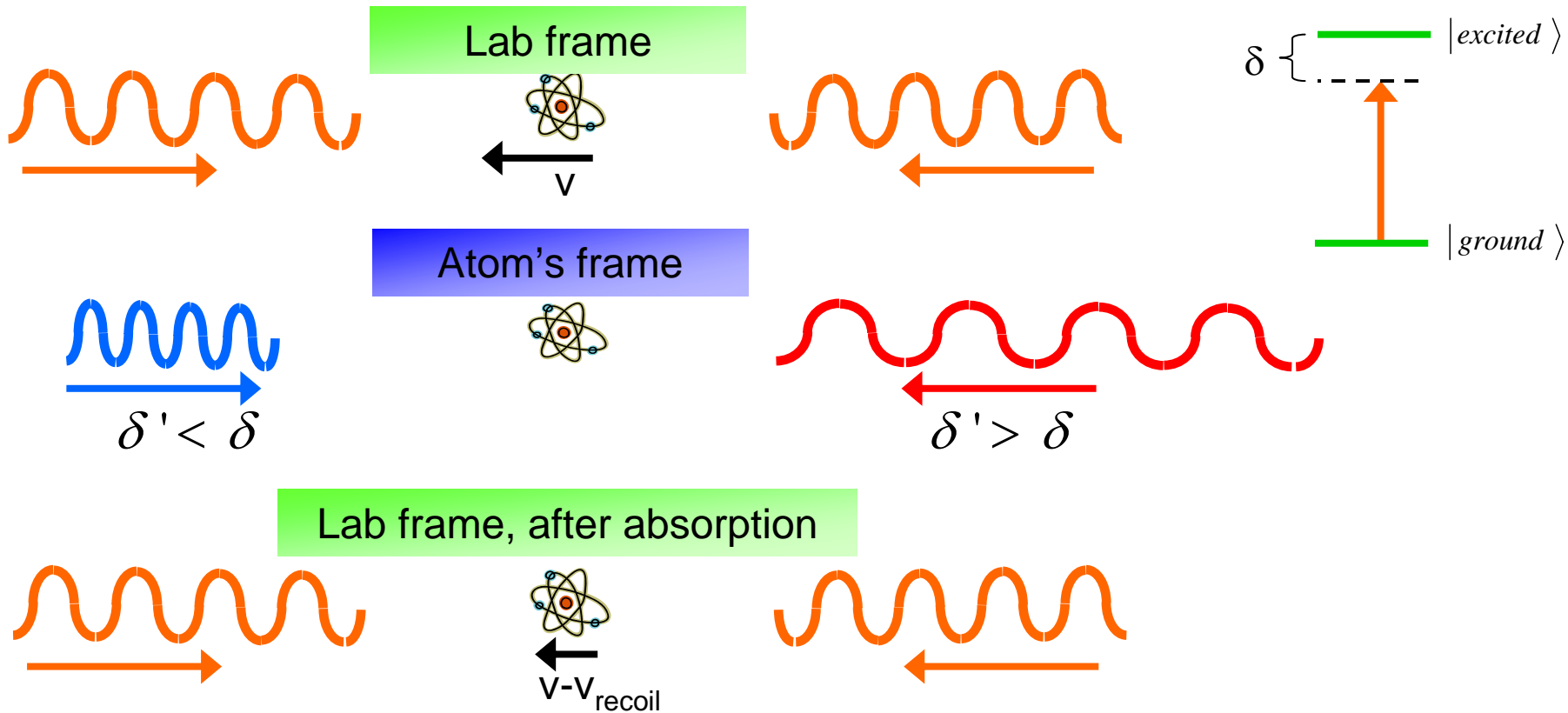
Doppler Cooling: How can a laser cool?



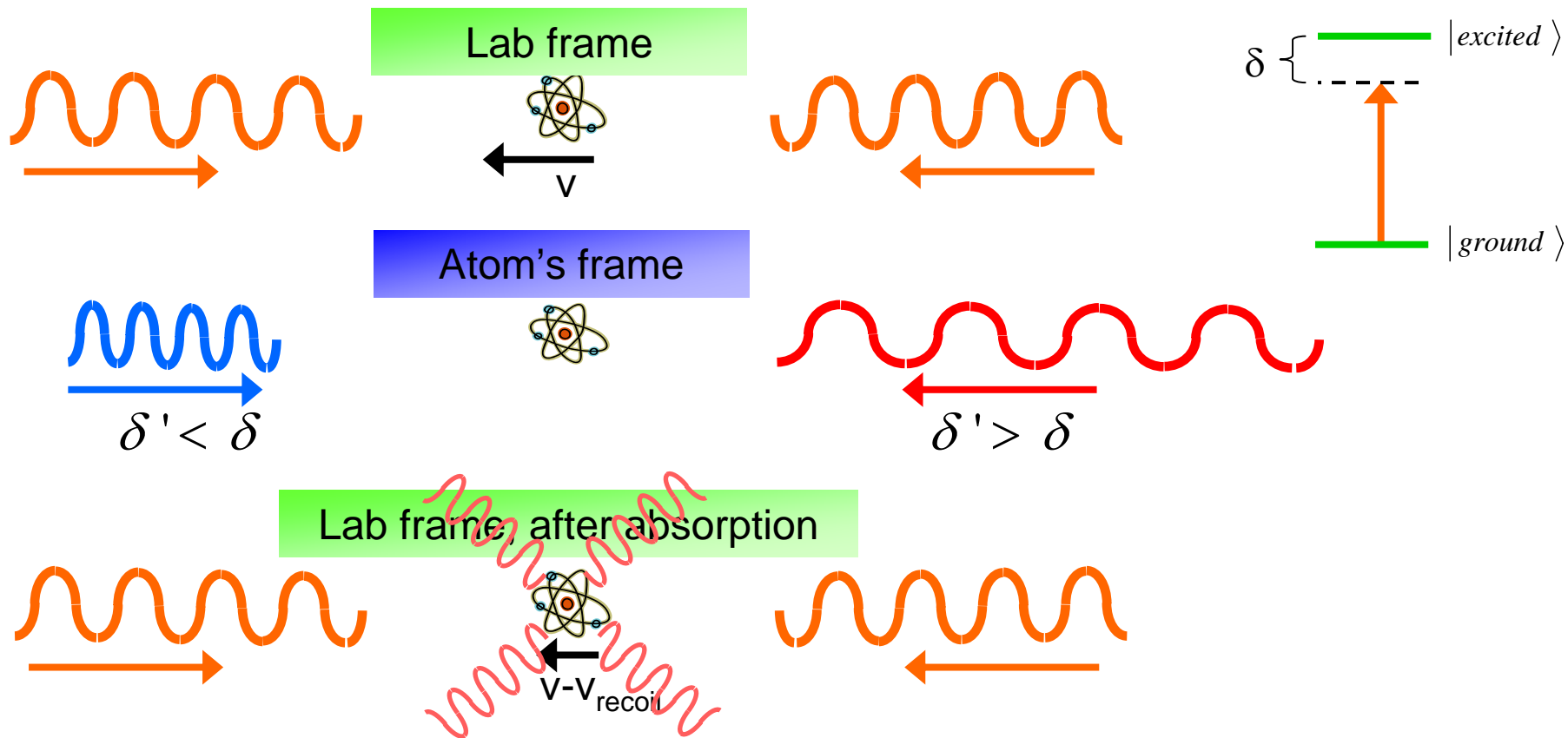
Doppler Cooling: How can a laser cool?



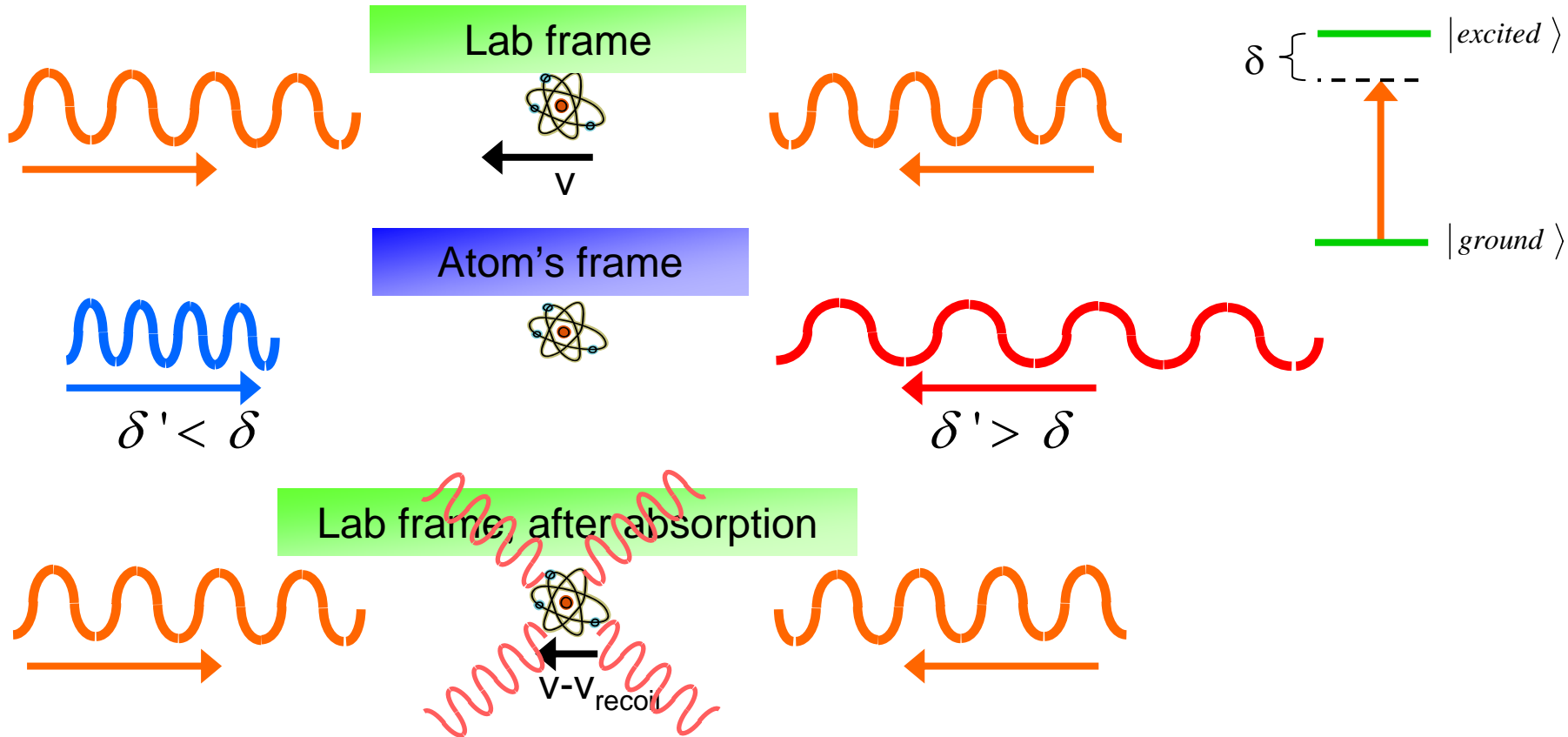
Doppler Cooling: How can a laser cool?



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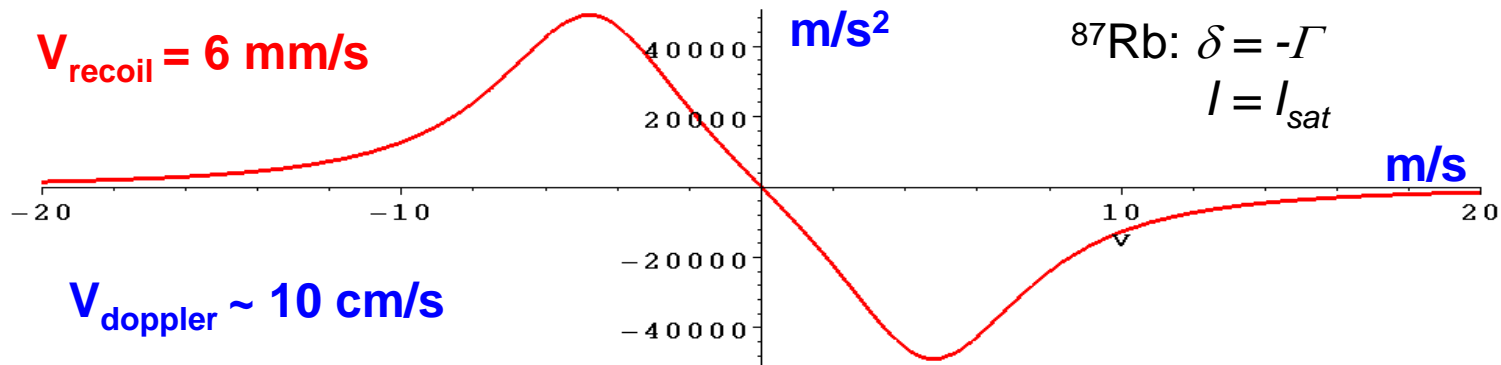
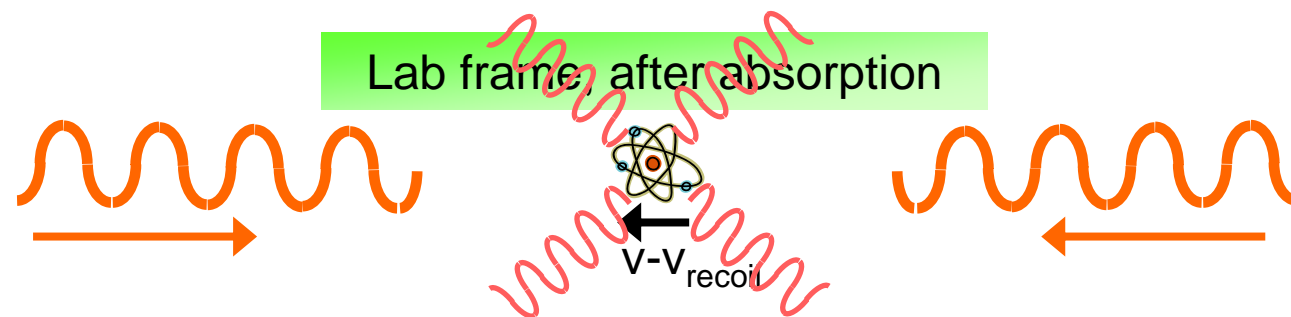
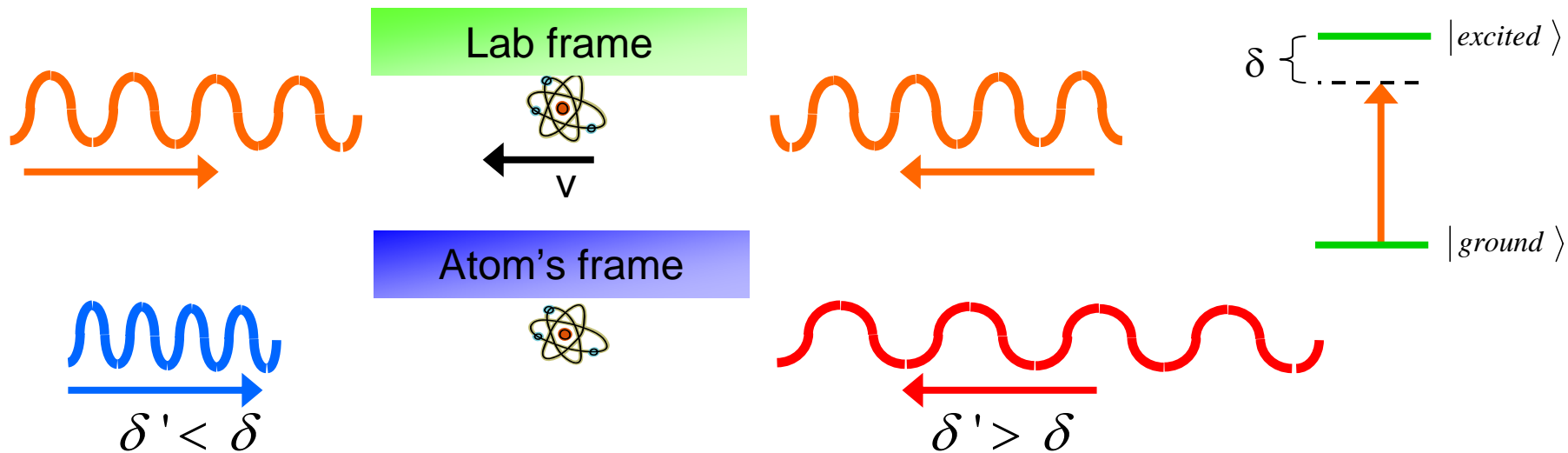


Doppler Cooling: How can a laser cool?



- Absorb a photon \rightarrow atom gets $\hbar\vec{k}$ momentum kick.
- Repeat process at 10^7 kicks/s \rightarrow large deceleration.
- Emitted photons are radiated symmetrically \rightarrow do not affect motion on average

Doppler Cooling: How can a laser cool?



Magneto-Optical Trap (MOT)

Problem:

Doppler cooling reduces momentum spread of atoms only.

- Similar to a damping or friction force (optical molasses).
- Does not reduce spatial spread.
- Does not confine the atoms.

Magneto-Optical Trap (MOT)

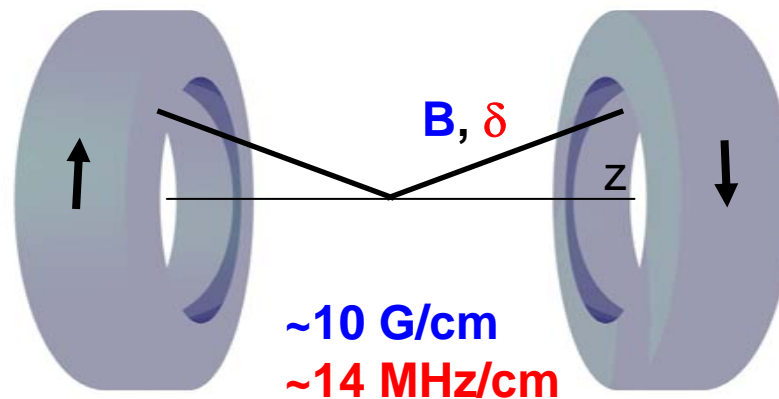
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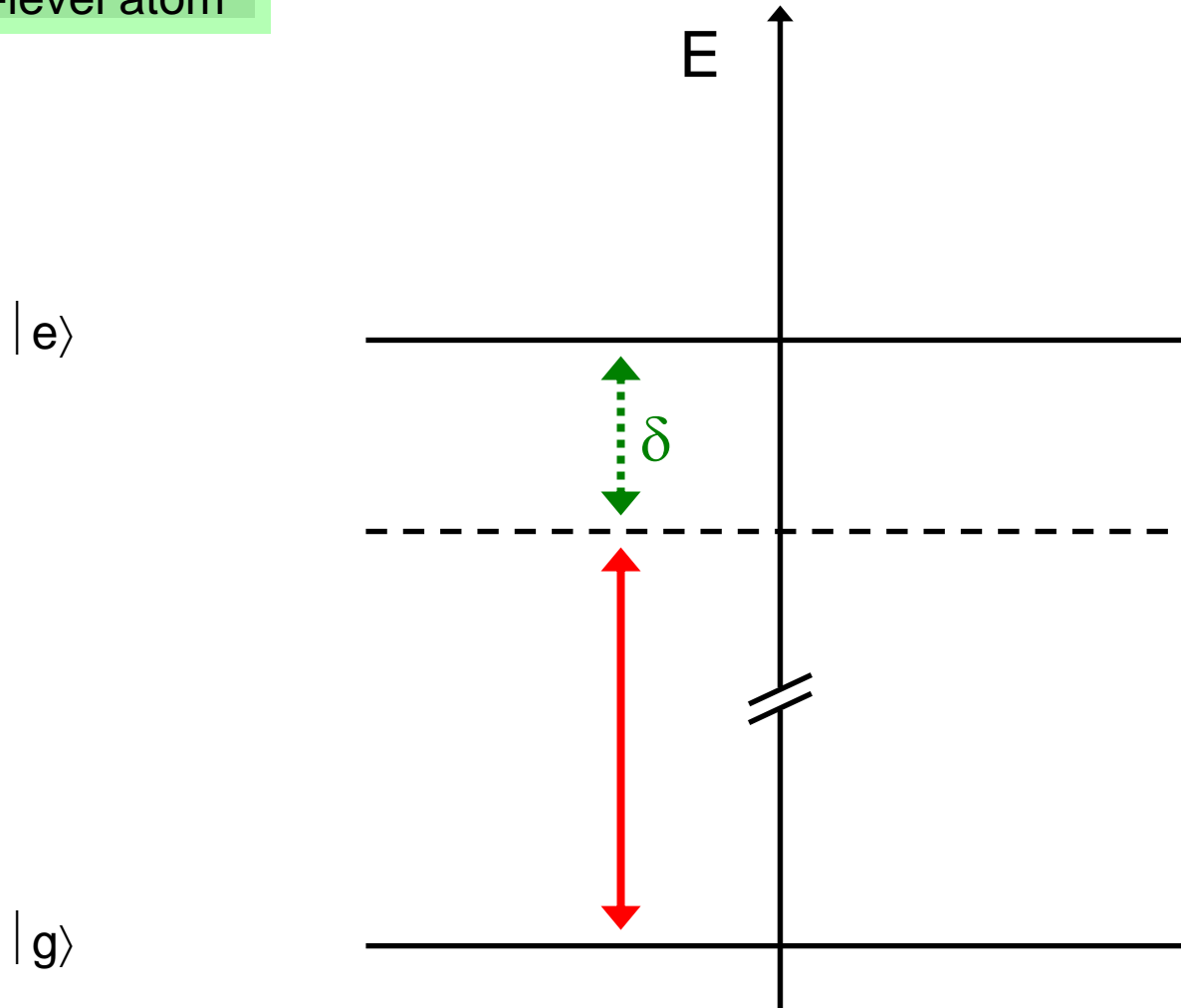
Solution:

Spatially tune the laser-atom detuning with the Zeeman shift from a spatially varying **magnetic field**.

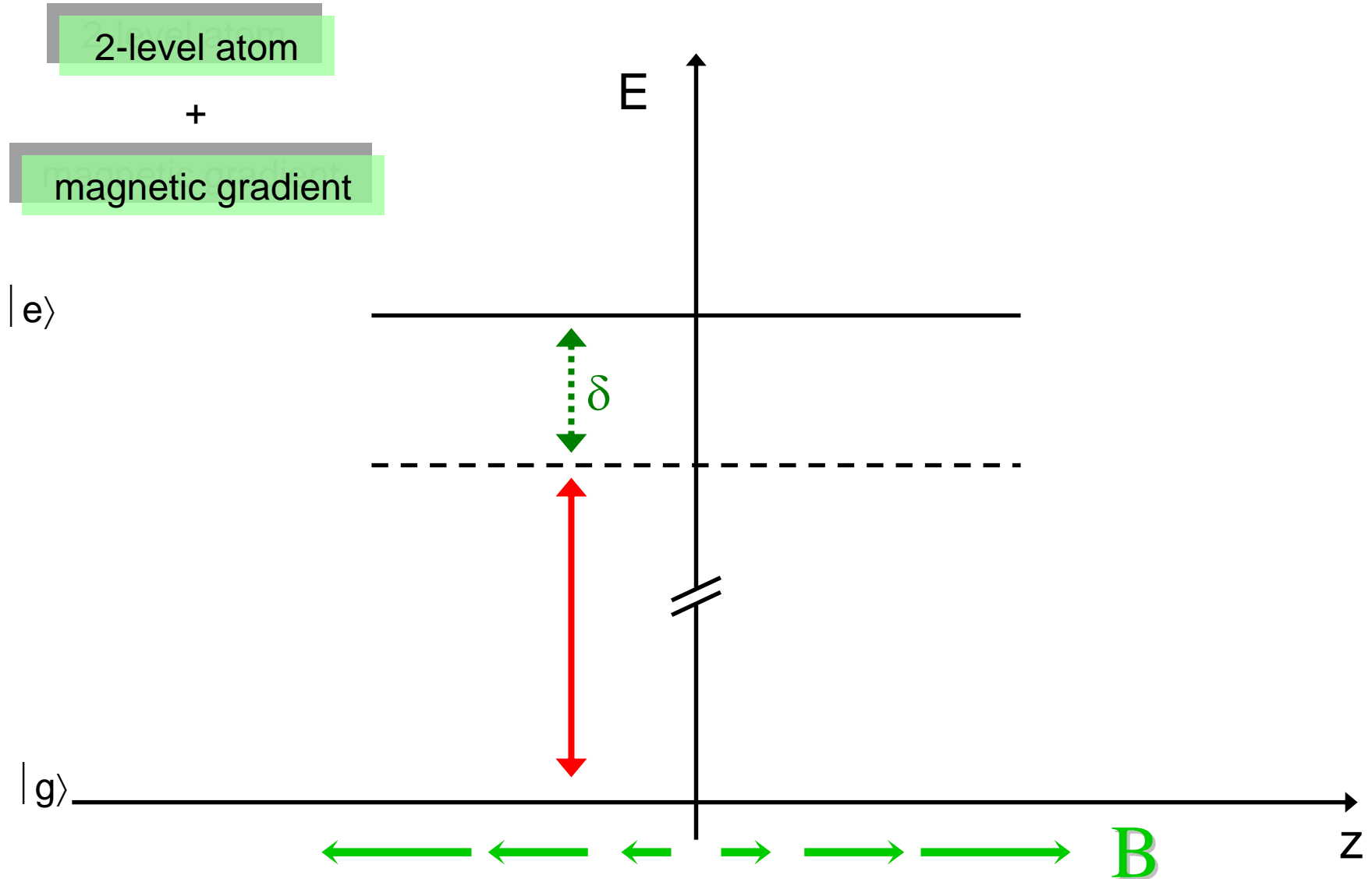


Magneto-Optical Trap

2-level atom



Magneto-Optical Trap



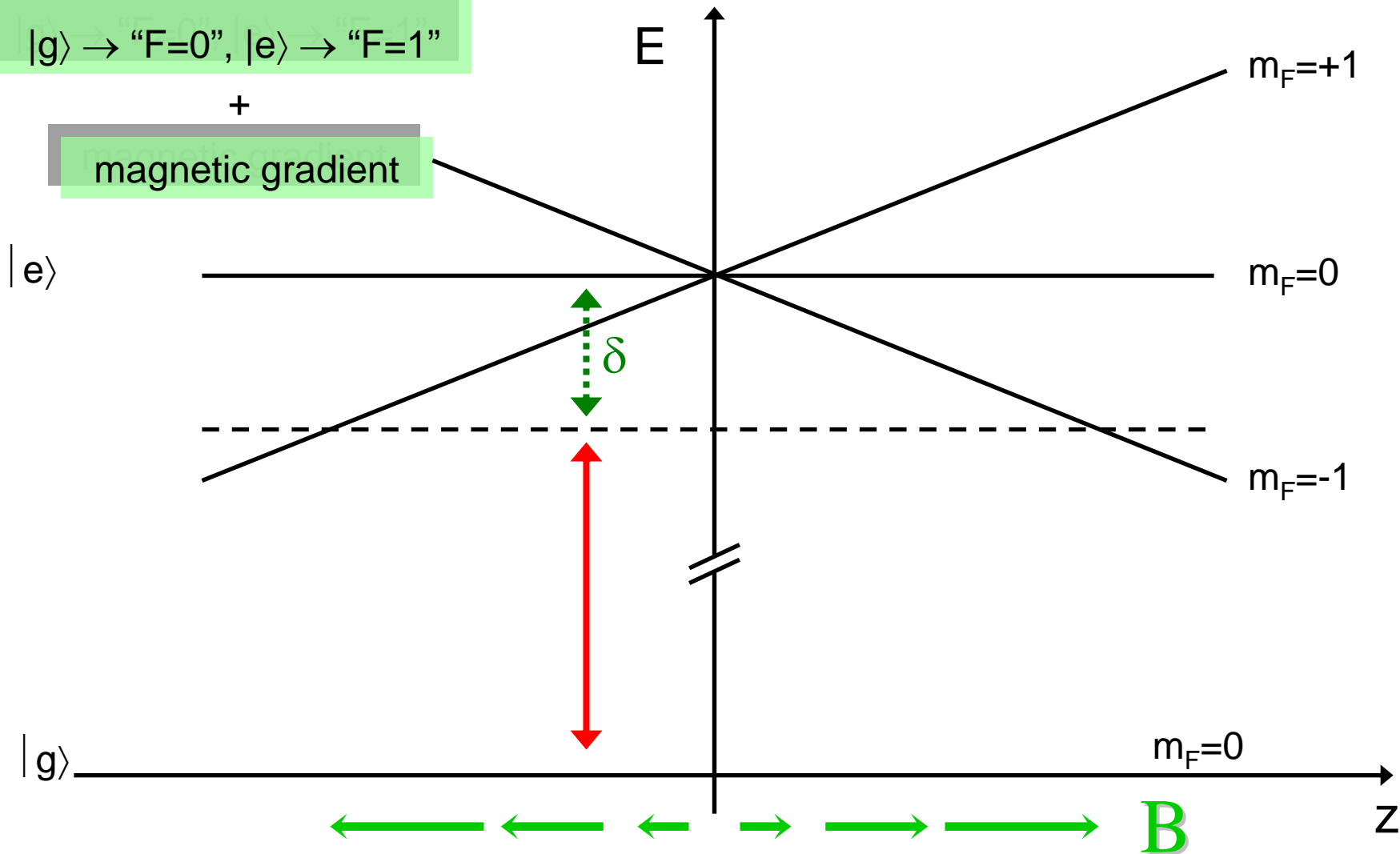
Magneto-Optical Trap

4-level atom

$|g\rangle \rightarrow "F=0"$, $|e\rangle \rightarrow "F=1"$

+

magnetic gradient



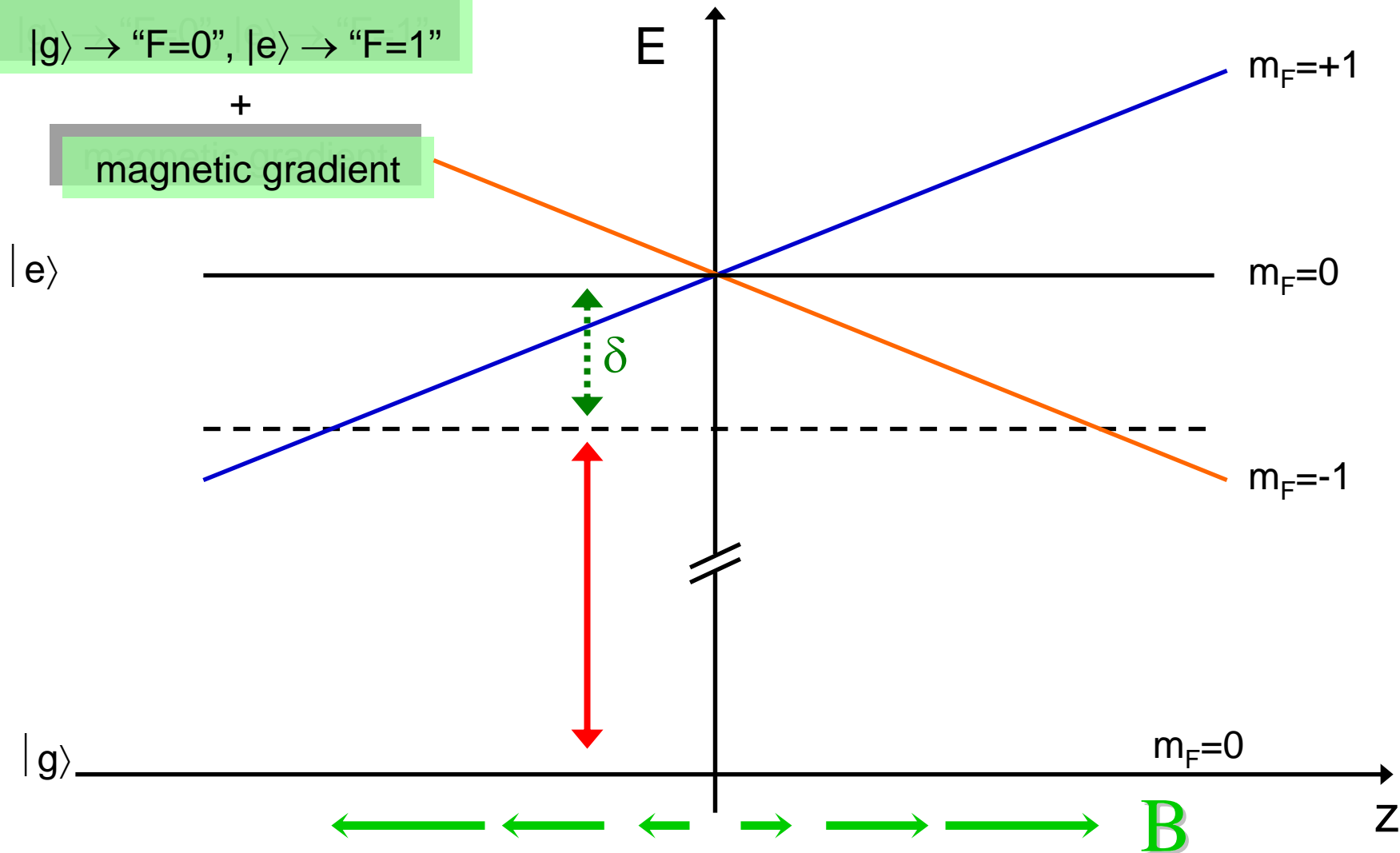
Magneto-Optical Trap

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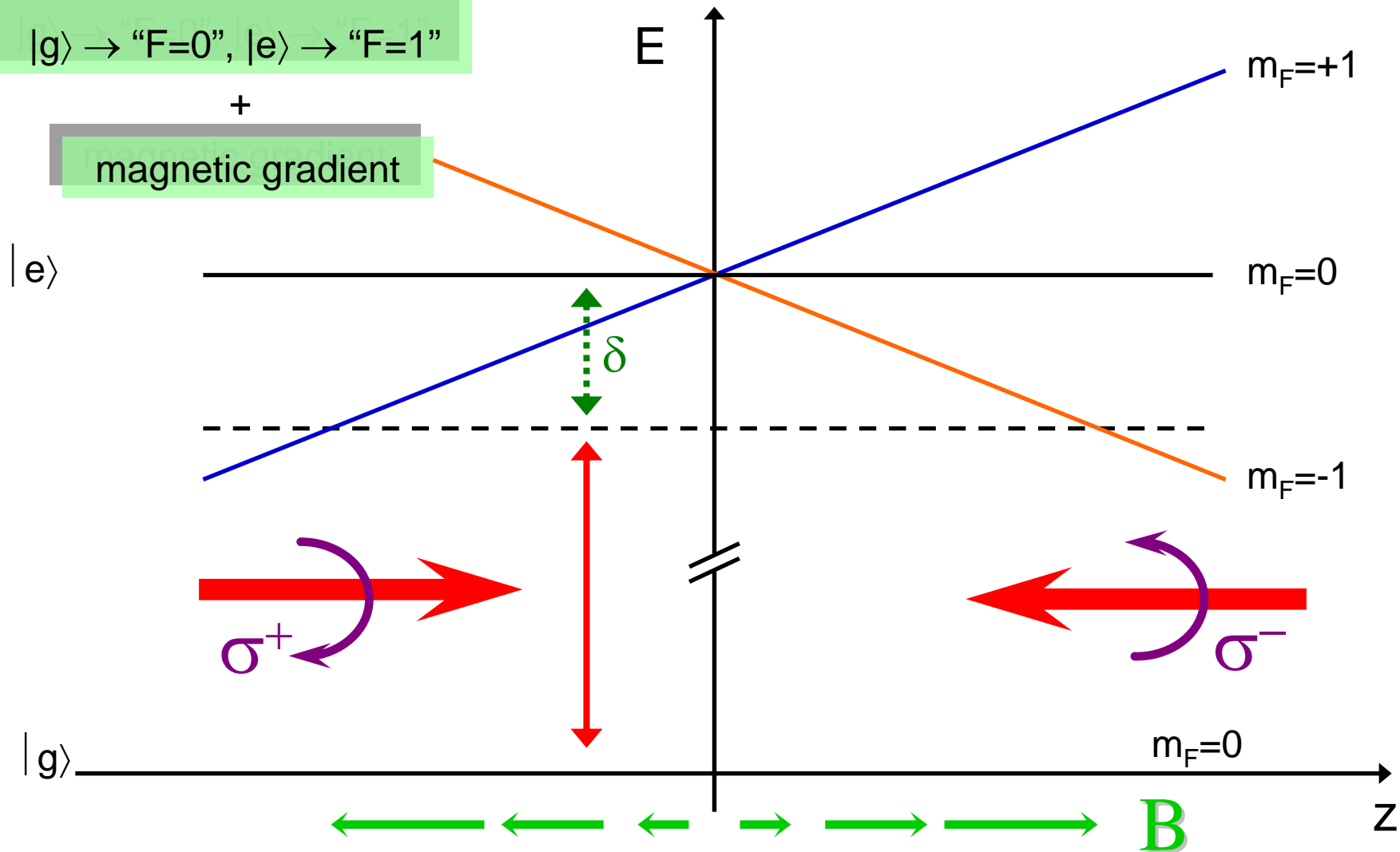
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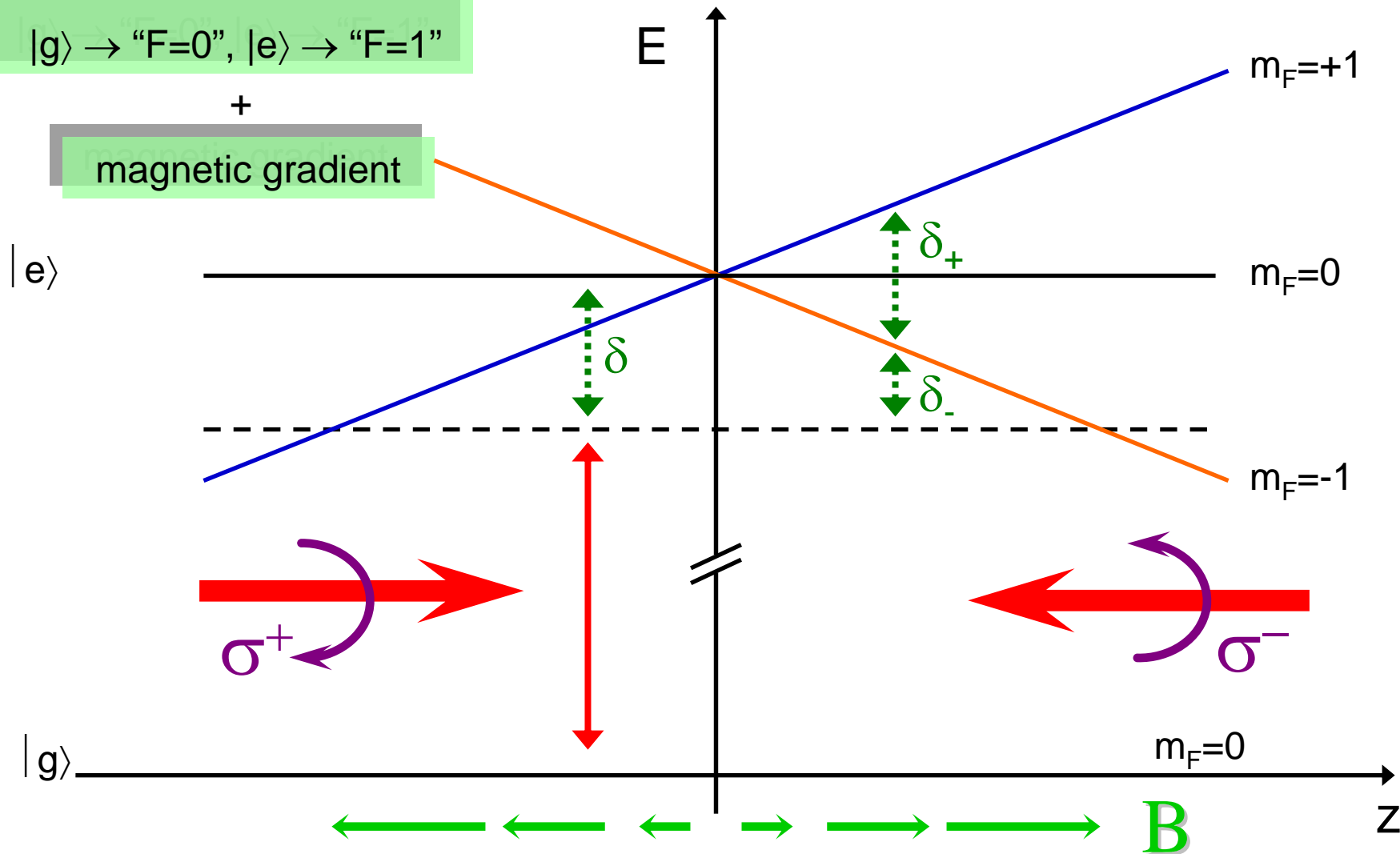
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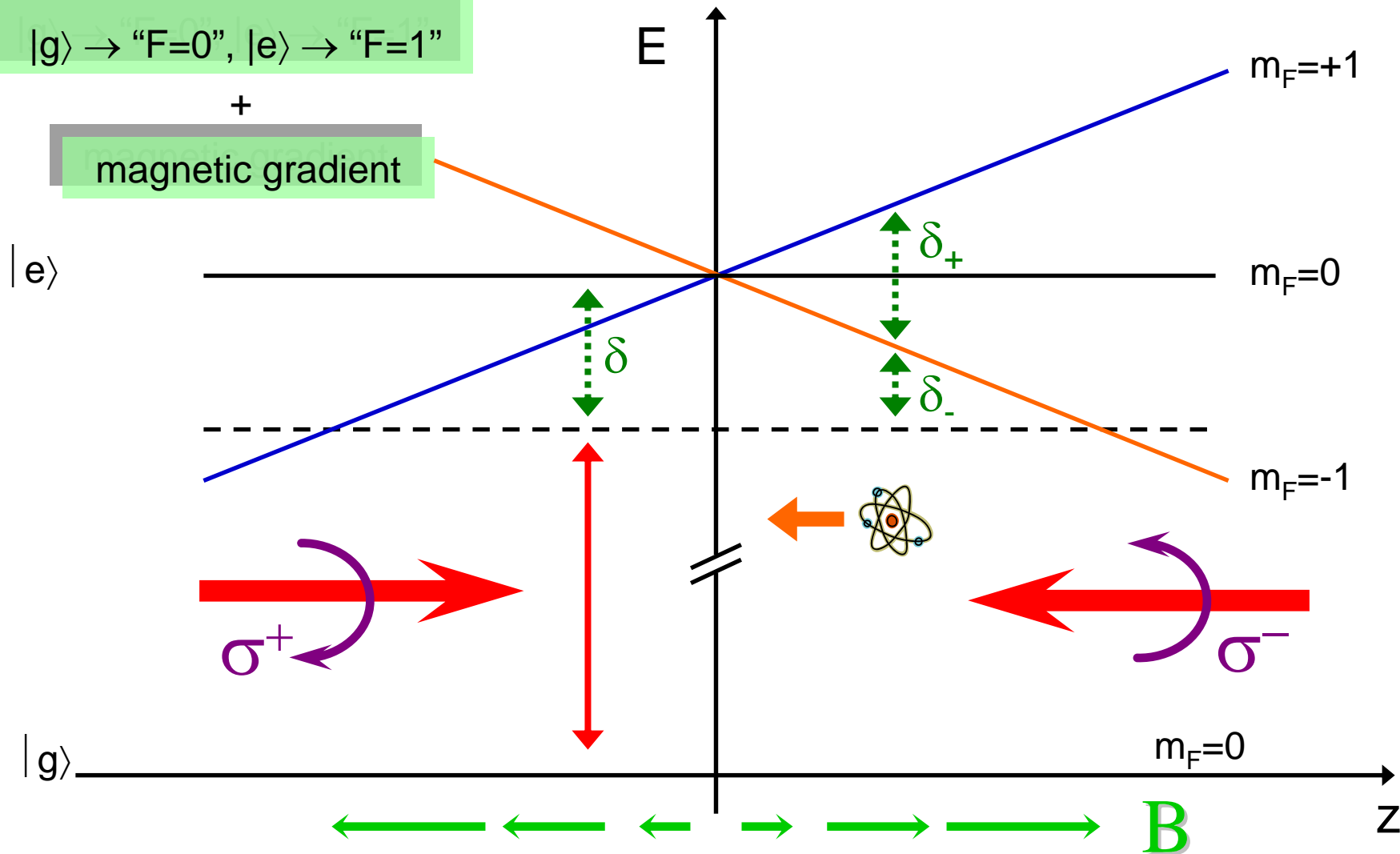
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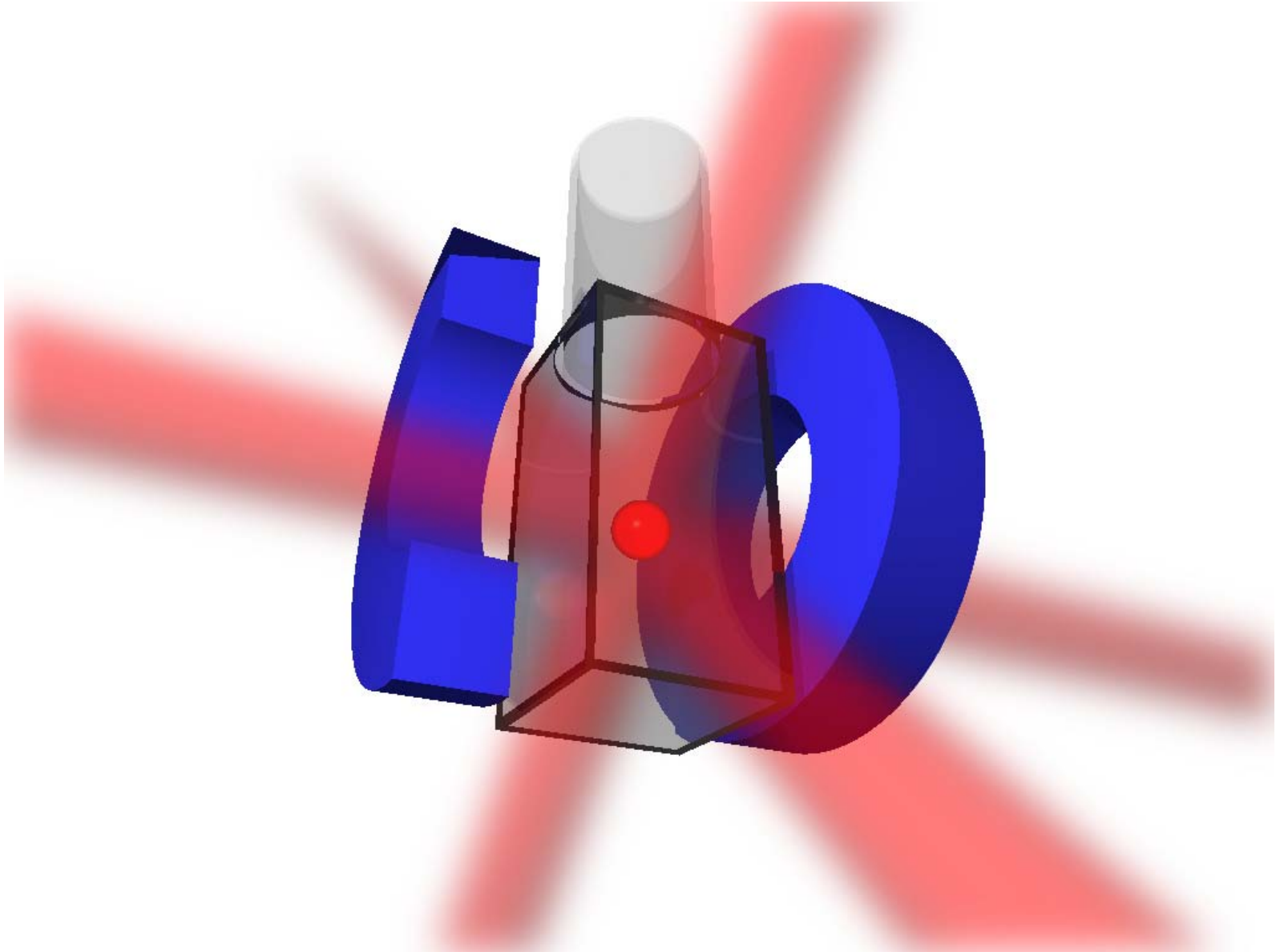
magnetic gradient



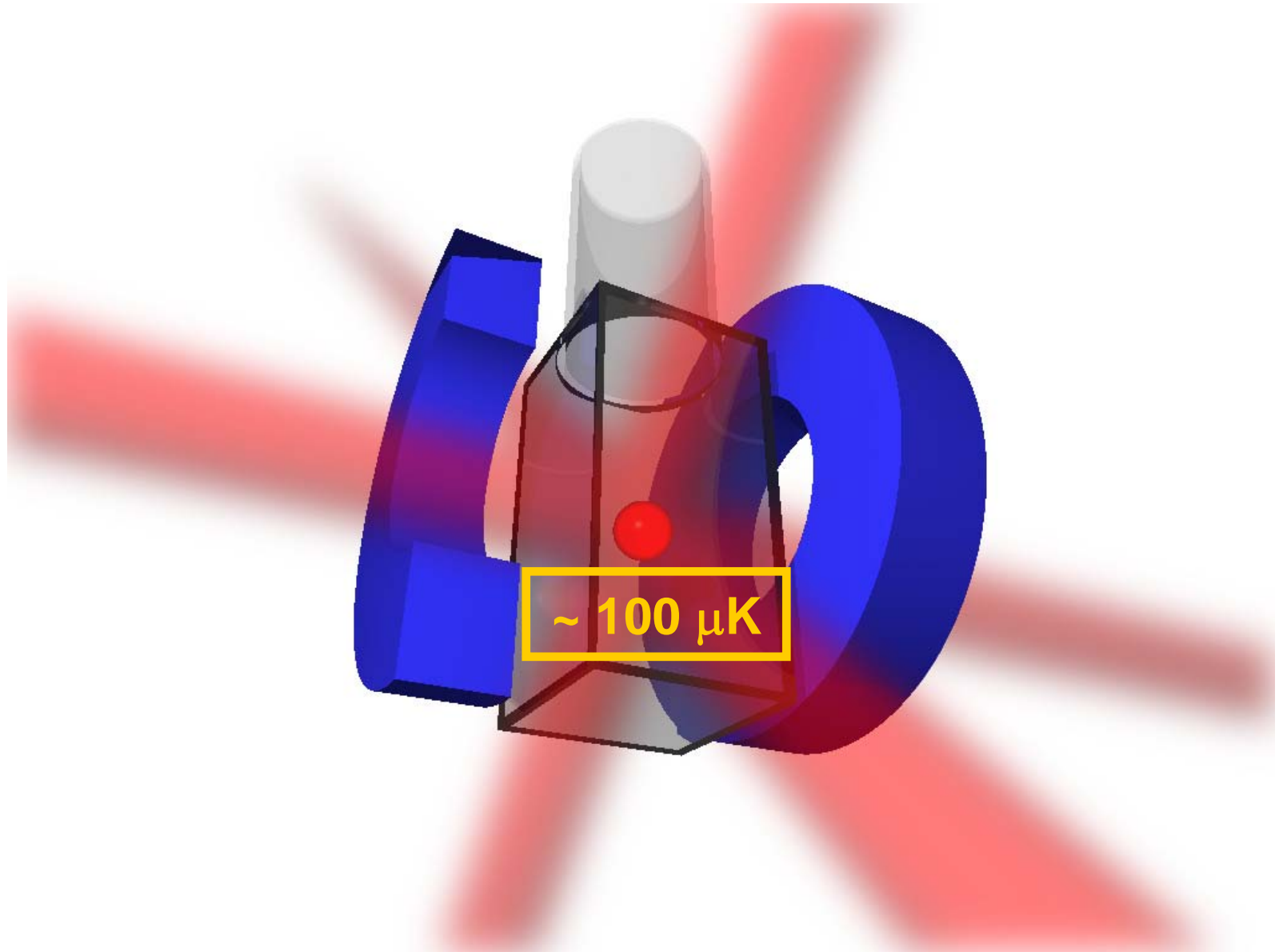
Magneto-Optical Trap (MOT)



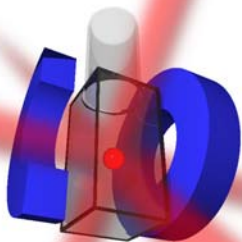
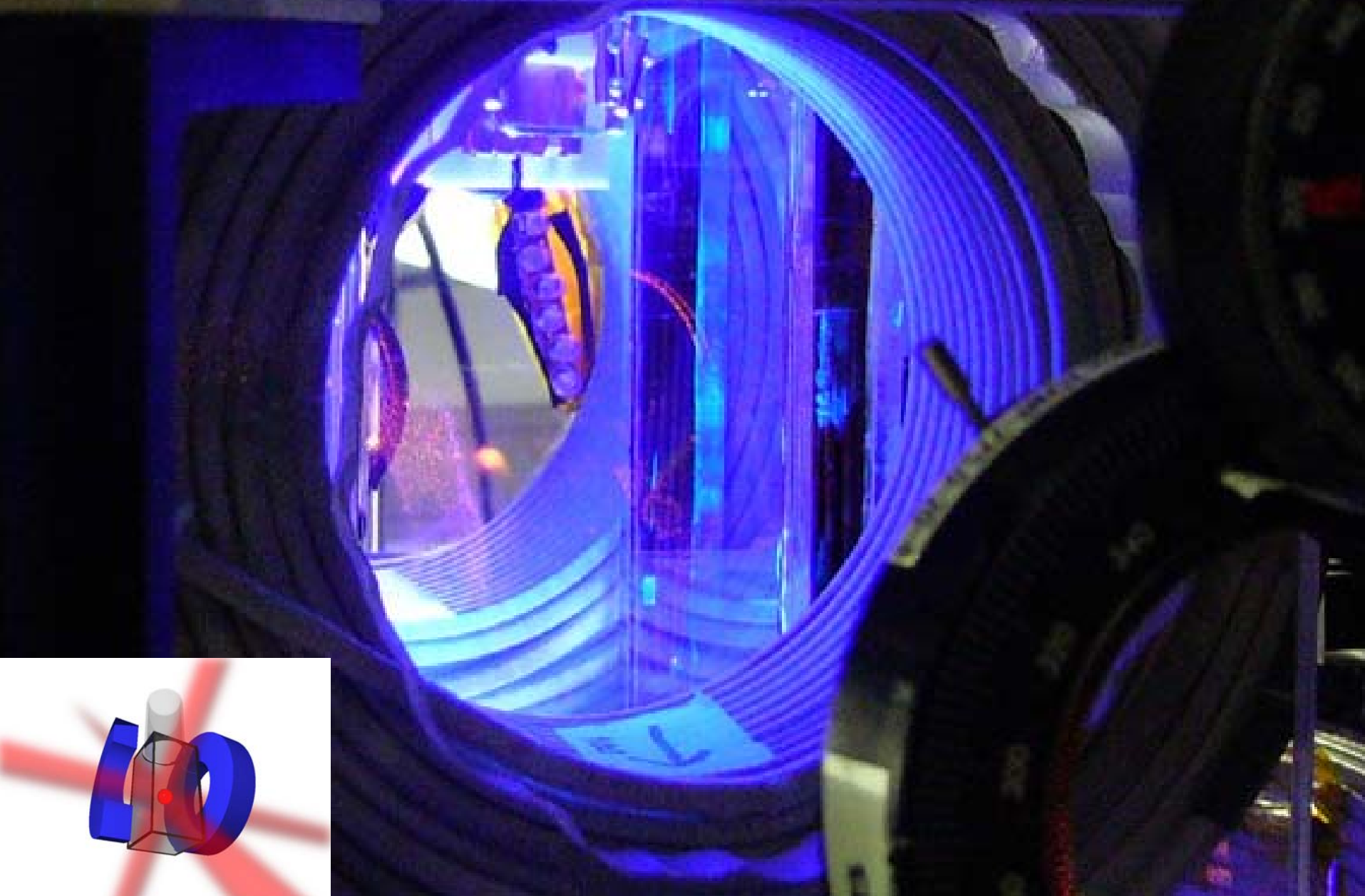
Magneto-Optical Trap (MOT)



Magneto-Optical Trap (MOT)

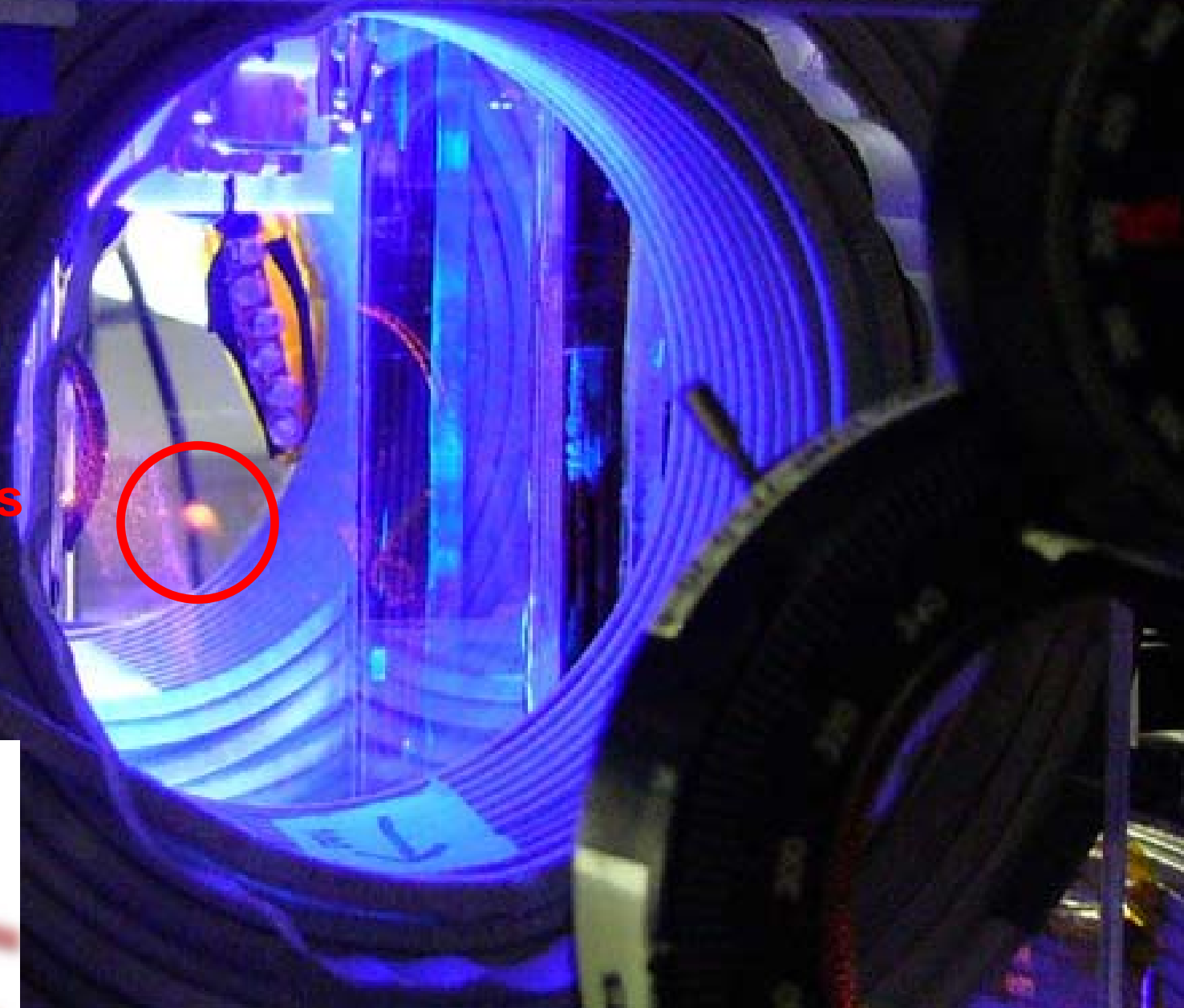
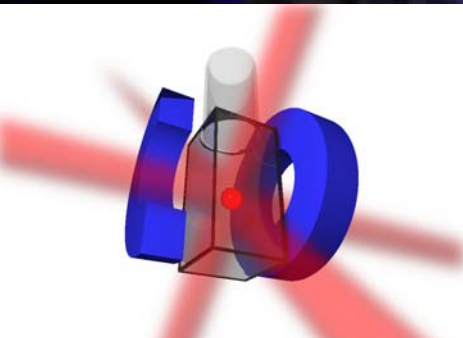


Magneto-Optical Trap (MOT)



Magneto-Optical Trap (MOT)

10^9 ^{87}Rb atoms



Francium MOT

PROBLEM: Accelerator produces only 10^6 Fr atoms/s.

→ Very difficult to work with.

SOLUTION: Attach a Francium Magneto-Optical Trap to the accelerator.

→ Cold Francium is concentrated in $\sim 1 \text{ mm}^3$ volume.

→ With $T < 100 \text{ } \mu\text{K}$, Doppler broadening is negligible.

→ Long integration times.

→ Minimally perturbative environment (substrate free).

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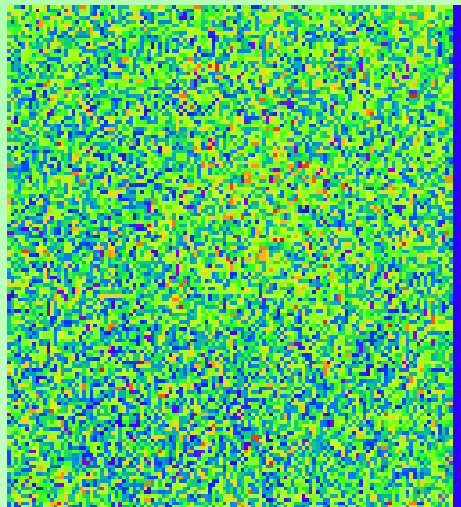
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MOT collection efficiency $\sim 1 \%$

MOT with $\sim 10^5$ ^{210}Fr atoms

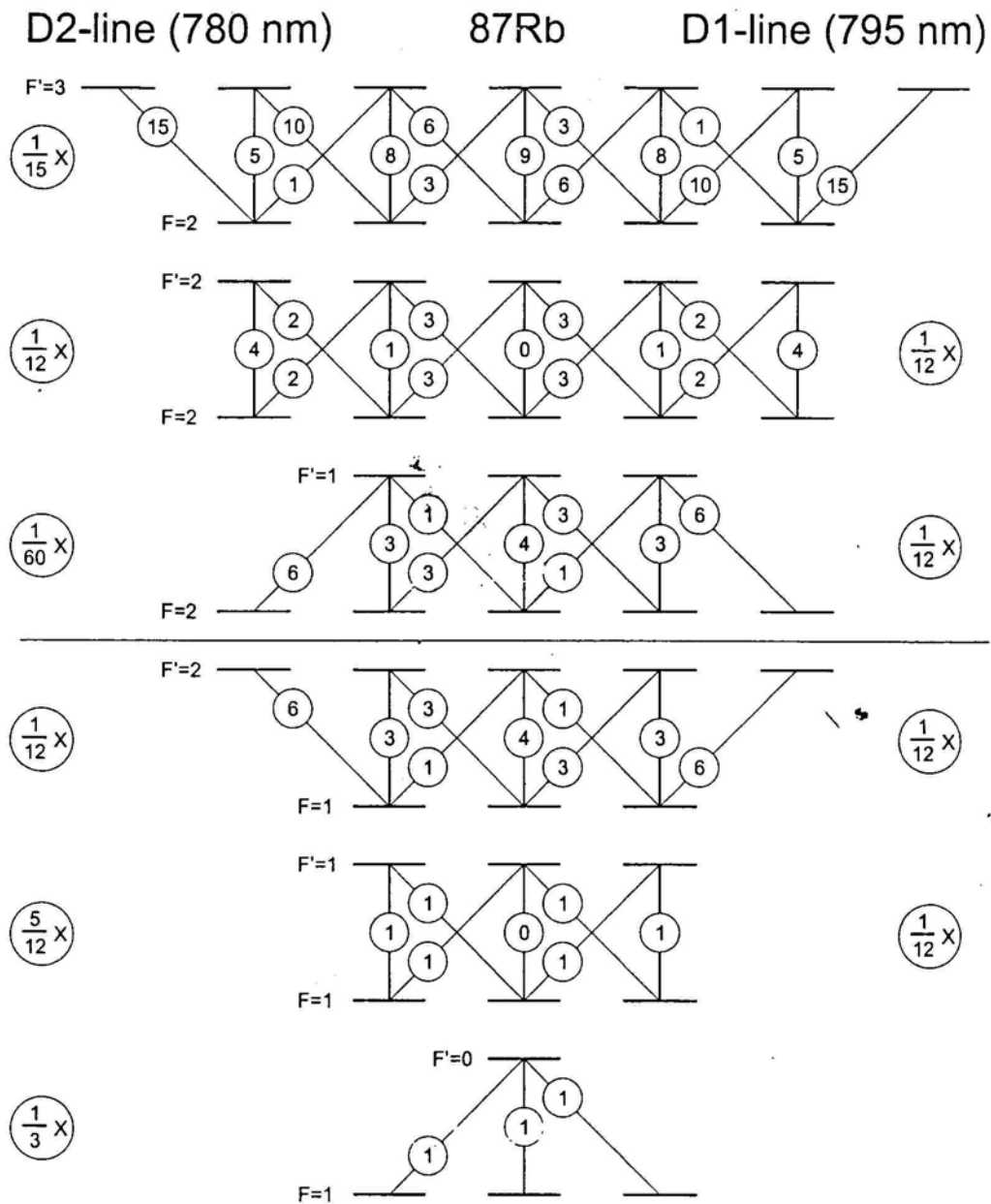


Figure A.2: Branching ratios for ^{87}Rb . Multiply by the circled number in the left(right) column to get the branching ratio for the D2(D1) line.