Construction of a Magneto-Optical Trap to Create Ultracold Rubidium Ensembles

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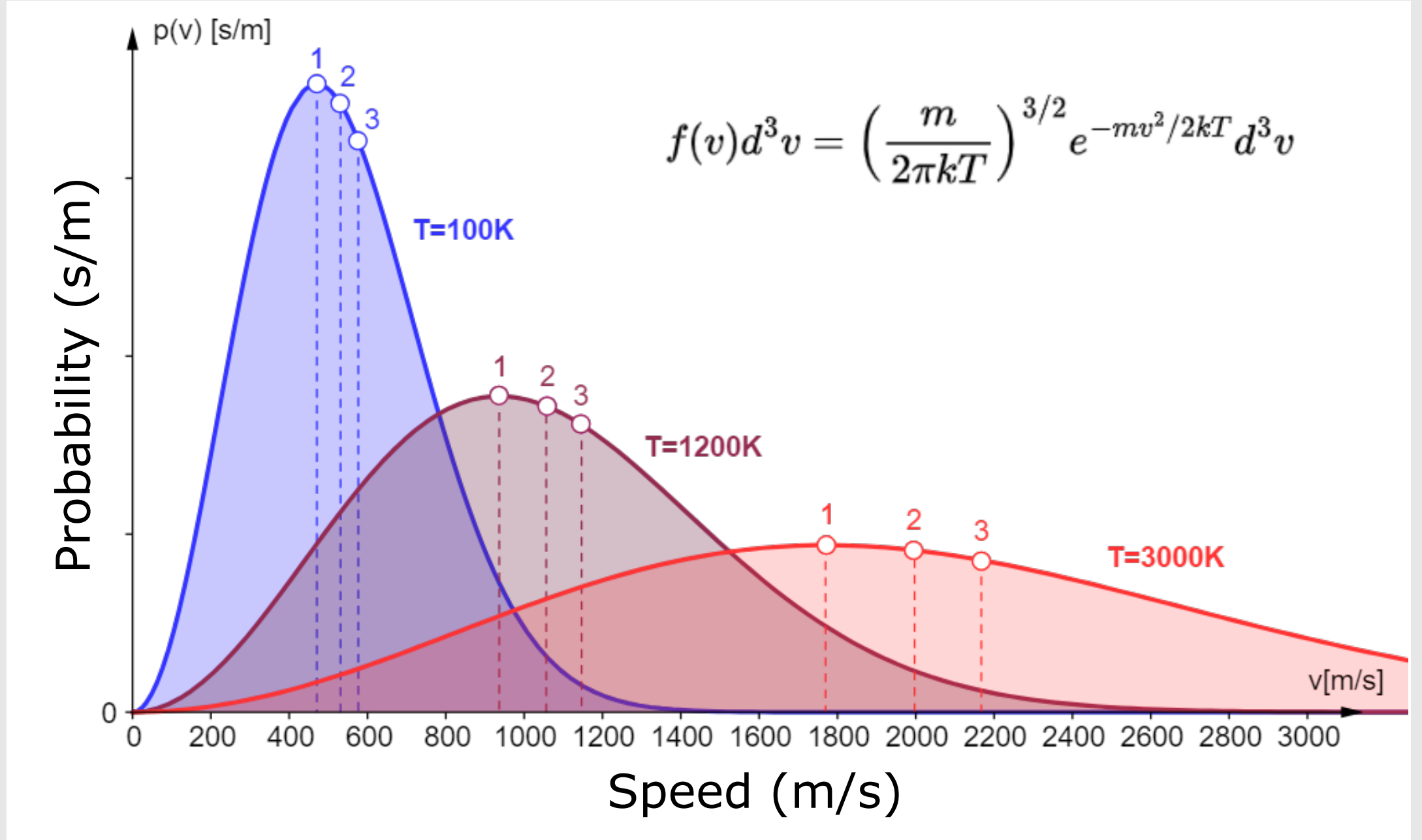
Introduction

- The function of the Magneto-Optical Trap (MOT) is to trap and cool neutral atoms (in this case, Rubidium) to roughly 10μK. For comparison, outer space is 2.7K!
- Why cold atoms? Hot atoms are highly incoherent and impractical for many quantum physical experiments. Even at room temperature, atoms move at hundreds of meters per second.
- With cold atoms, coherence times are very long. A low rate of atomic collisions and slow movement speeds mean that atomic interactions and fundamental quantum properties can be observed over much greater periods of time.
- This makes cold atoms an ideal substrate for many atomic-molecular-optical (AMO) experiments.

What is temperature?

- Temperature is a notoriously strange quantity in physics, as it has many different definitions and is undefined at the scale of individual atoms.
- The speeds of individual atoms in a gas are distributed according to the Maxwell-Boltzmann distribution:

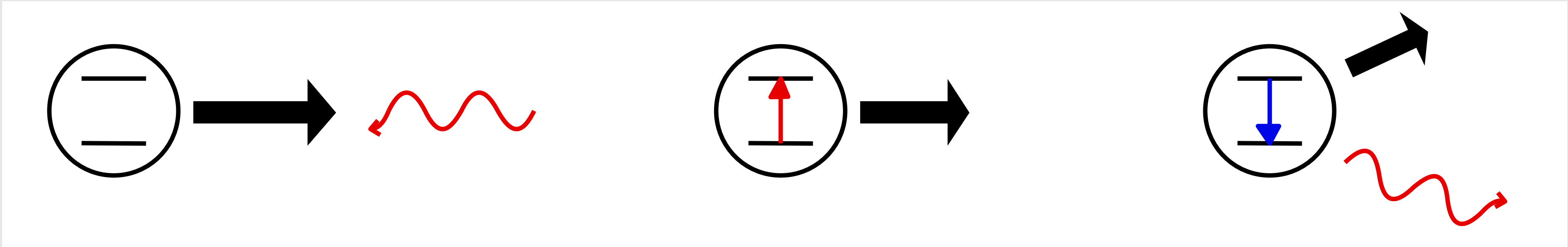


Sample Maxwell-Boltzmann distributions by MikeRun, distributed under a CC-BY-SA-4.0 license.

- The mean value of the speed distribution is proportional to the square root of temperature.
- Thus, the temperature of a gas is proportional to the average atomic speed squared, meaning that a sample of atoms can be cooled by decreasing the average speed.

Laser Cooling (They can do that?)

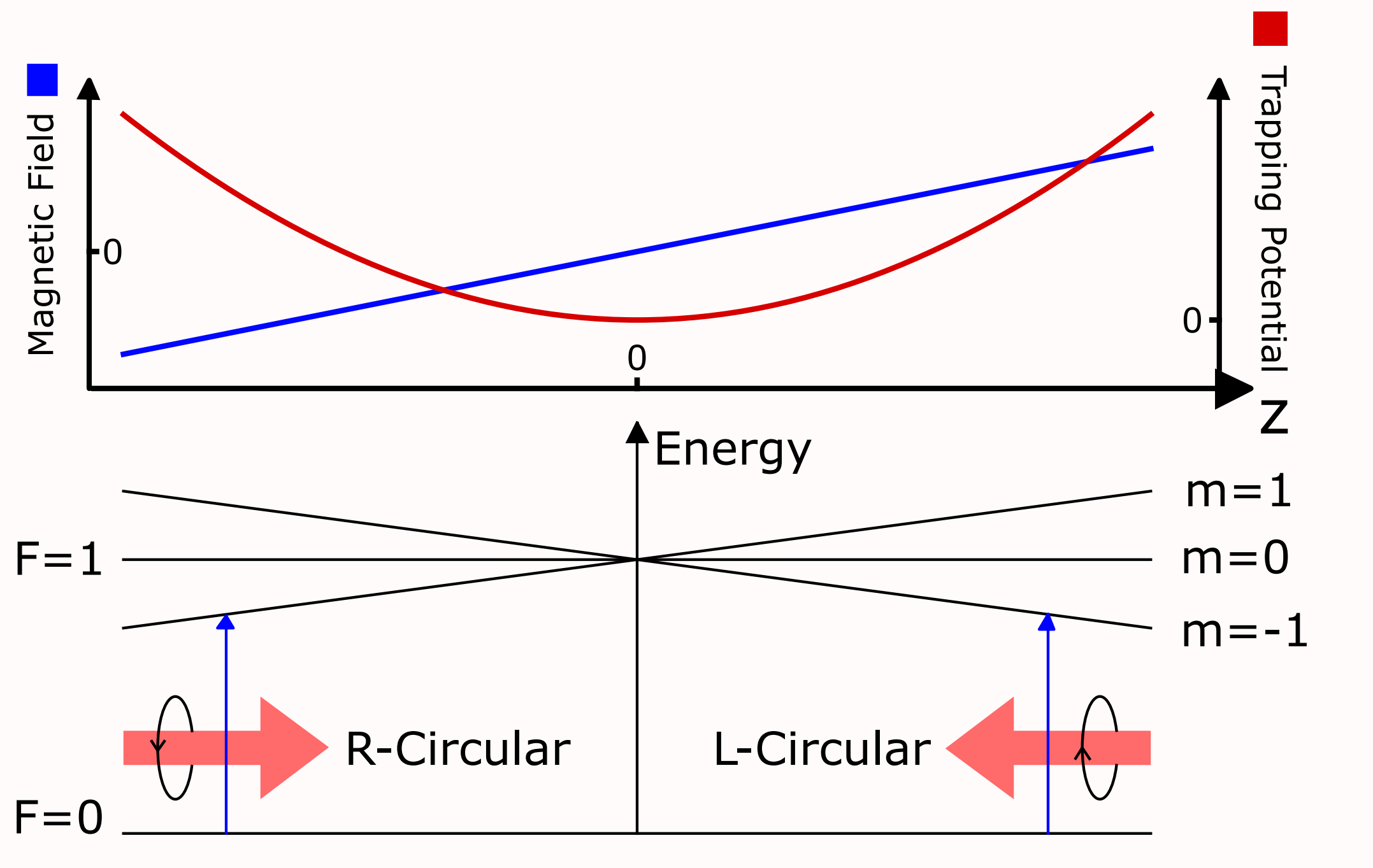
- Contrary to what you may believe about lasers, they can actually be used to cool atoms using a method known as Doppler cooling.
- When an atom absorbs a photon, it receives a momentum kick in the direction that the photon was travelling.
- Doppler cooling involves shining atoms from all directions with lasers at a frequency detuned slightly below an atomic resonance.
- For Rubidium, the resonance of interest is at 780 nm (384 THz).
- Atoms moving towards the laser sources will see the photons Doppler shifted up in frequency, which are more likely to be absorbed.
- This ultimately results in a decrease in the average speed of the atoms in the cross section of the lasers.
- This region of slowed (cold) atoms is called an optical molasses.



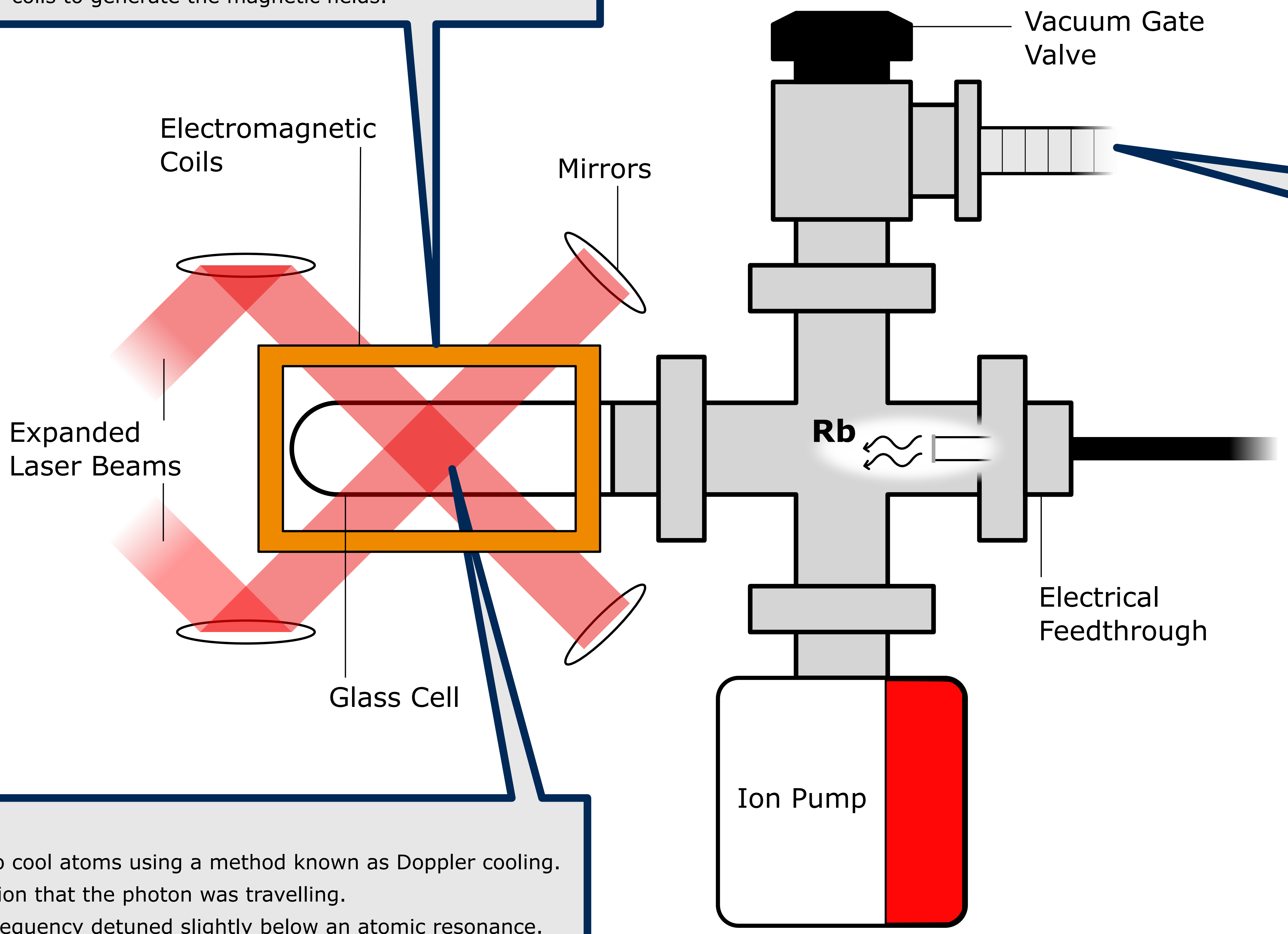
Simplified model of absorption and spontaneous emission of a photon by a 2 level atom with momentum consdirations.

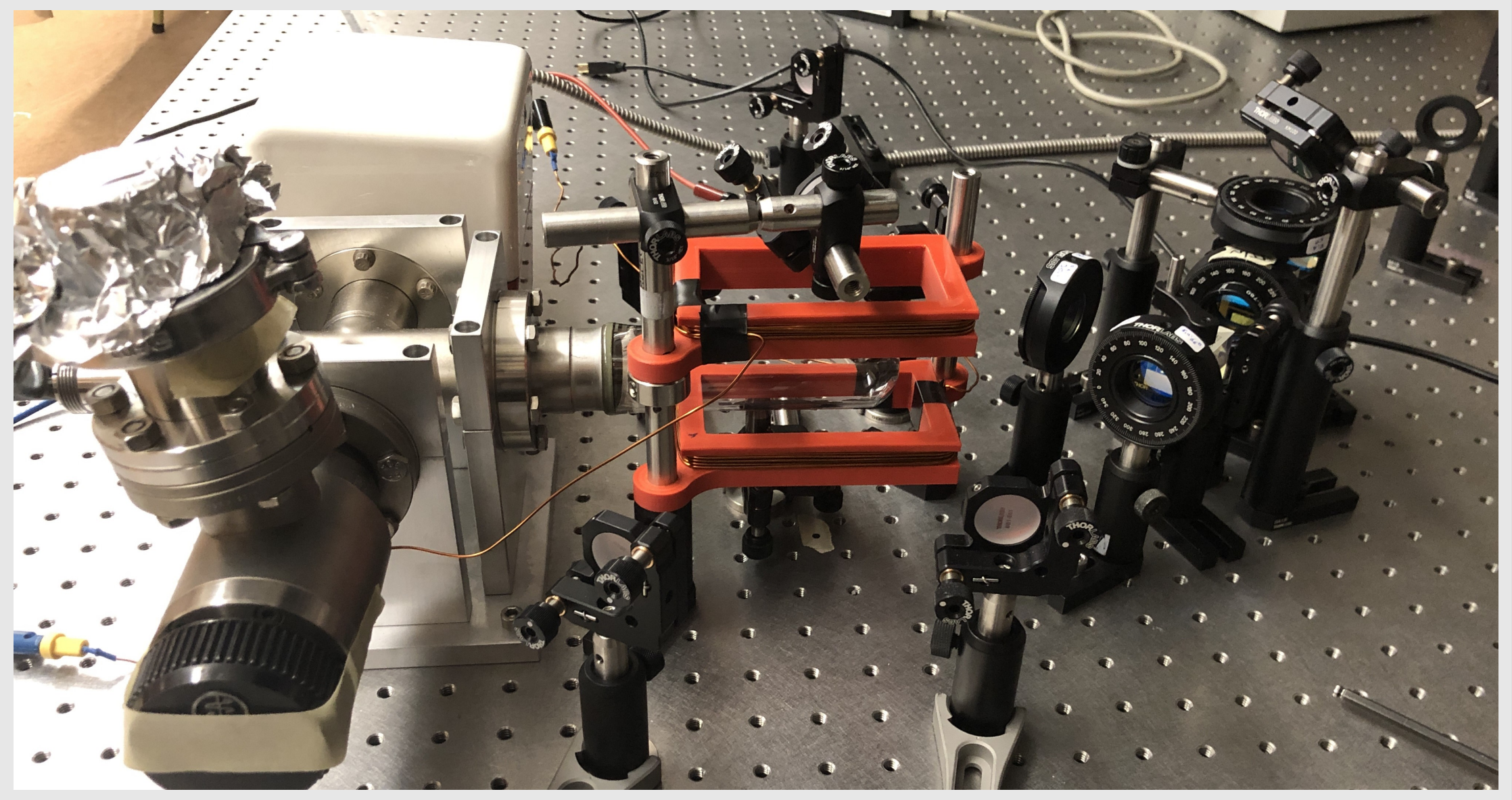
Magnetic Trapping

- We require a dense cloud of cold atoms, but Doppler cooling does not condense atoms, only slows them.
- Applying a linear magnetic field with a zero crossing at the intersection of the lasers adds a position dependance to the laser force that increases in intensity further from the center point.
- This effectively creates a restoring force that condenses the Rubidium atoms to the center of the trap.
- A linear magnetic field can be achieved with an anti-Helmholtz configuration, where two circular electromagnetic coils with antiparallel currents are separated by a distance equal to the radius of the coils.
- For our setup, we've chosen to use two rectangular coils to generate the magnetic fields.



Simplified model of the magnetic field and trapping potential





Magneto-Optical Trap. Image by Hayden Snauwaert

Extra Details (for those who must know)

- Circularly polarized light carries angular momentum. R-circular photons carry +1 angular momentum and L-circular photons carry -1 angular momentum.
- Magnetic fields cause Zeeman splitting of the hyperfine levels of rubidium.
- For the Rubidium transition of interest, in a positive magnetic field, the degeneracy of the hyperfine levels will split in such a way that the energy gap corresponding to the absorption of a photon with -1 angular momentum shrinks.
- This means that a Rubidium atom in a positive magnetic field will feel more force from an L-circular polarized beam.
- The polarity is reversed for negative magnetic fields, so atoms will feel more force from R-circular polarized beams.
- Thus, by circularly polarizing the light depending on the polarity of the magnetic field, a position dependance can be added to the laser force.

Vacuum System

- The MOT cloud must be suspended in a very diffuse vacuum to minimize external disturbances such as thermal diffusion.
- Vacuum components are individually cleaned with soap, ethanol and acetone then assembled and heated to hundreds of degrees for multiple days in order to bake off any residual chemicals and machining oils.
- A 3 stage pumping system including a rotary vane pump, a turbomolecular pump, and a sputter-ion pump is used to draw a vacuum down to 10^-11 atmospheres of pressure.
- A Rubidium chromate filament attached to an electrical feedthrough releases Rubidium atoms into the vacuum chamber when a current is run through it.

Conclusions and the Future

- We are constructing a Magneto-Optical trap to trap ultracold clouds of Rubidium.
- These cold, dense atomic vapours are an ideal environment to probe the quantum nature of atoms.
- There are many experiments that are planned to be done in the MOT cloud:
  - Electromagnetically Induced Transparency (EIT). We can slow/stop light in the MOT cloud and store the quantum state of light.
  - Four-Wave-Mixing in the MOT. Allows for the production of squeezed states of light which have applications in metrology.
  - Observing the Giant Kerr Effect, which has applications for quantum-optical logic gates.

Current Status

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