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Topic: Laser cooling and trapping

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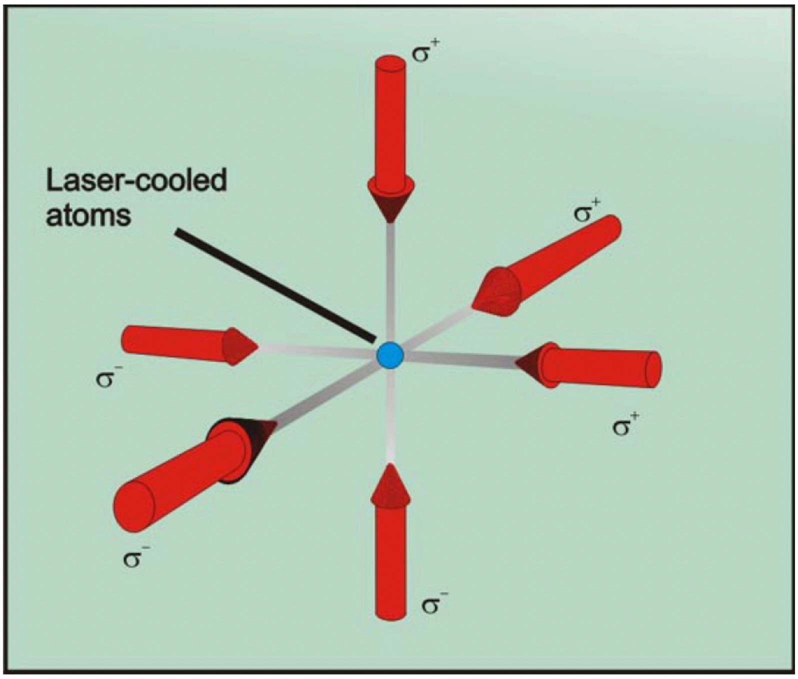
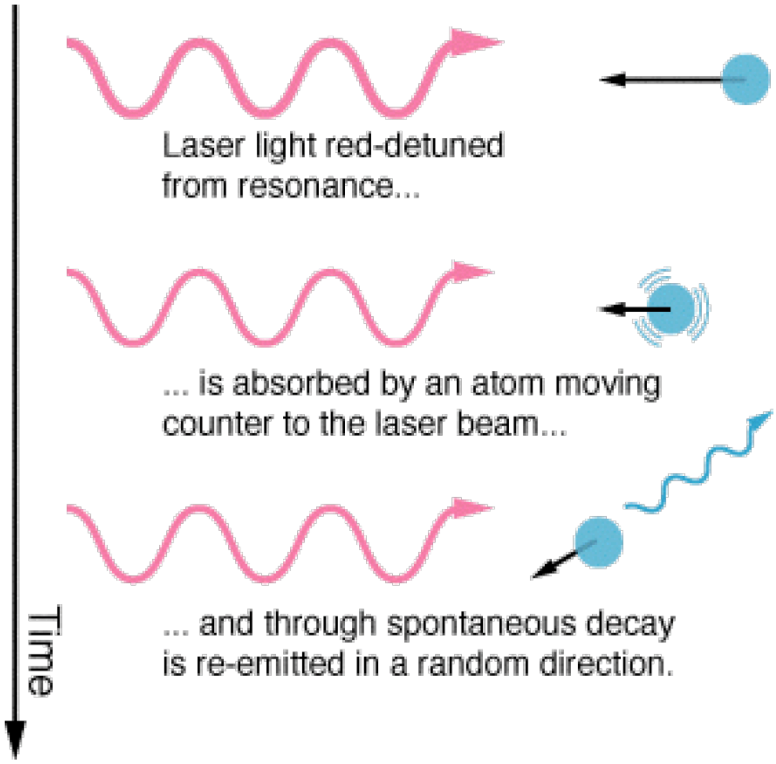
Laser cooling is an exciting phenomena of atomic and optical Physics. The energy of atom is decreased i.e. cooled and trapped using high energetic photon beams in laser cooling and trapping process. For the discovery and successful demonstration of laser cooling, Nobel prize was awarded in the year 1997.

The first important aspect of laser cooling is that why it is so important and attracted so much attention of the scientific community. There are few reasons behind this. The first is unavailability of slow atoms and ions for experimental observation. The atoms and molecules move at a very high speed (~ 300 m/s) at room temperature. The only way to slow them down is to decrease the temperature. But, it is observed that N_2 atoms has speed of 150 m/s at 77 K and He atoms have speed of 90 m/s at 4 K temperature. Hence, at lower temperature no molecules are left in gas phase. As a result, all measurements have to be done for rapidly moving atoms where doppler effect, and relativistic time dilation plays a crucial role and broaden the spectral lines. Also, the observation time become very limited due to fast moving atoms. In order to study atoms without measurement artefacts, laser cooling and trapping become very much important. Below the basic processes of laser cooling and trapping are described.

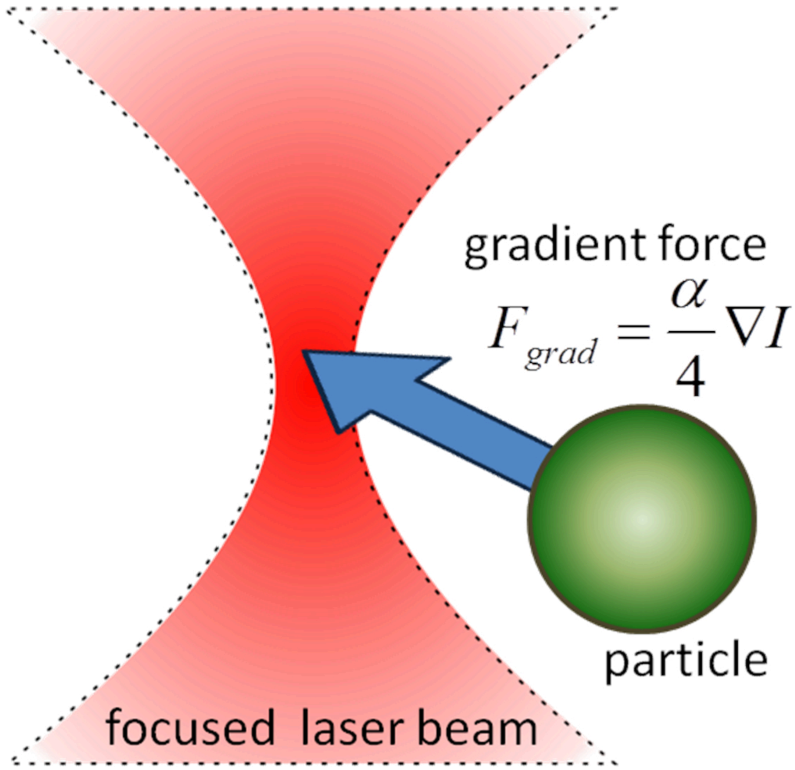
(a) **Laser cooling:** There are several methods of laser cooling. Among them, the most common is doppler method to cool down neutral atoms. In this method, multiple laser beams are used together towards to a common centre where the beam of atoms are concentrated. As shown in the figure below six simultaneous laser beams consisted of three orthogonal pairs are focused at a point. First, let's focus only on a single incident beam. The atom can absorb the laser photon if the energy (or frequency) of the photons in the laser beam matches the difference between the excited state and ground state of the atom. The excited atom, after absorbing the photon, will soon return to its ground state and release a photon that has the same energy as it has received, but in a random direction. During the above process, there will be modification in the momentum of the atoms. The atom's momentum will increase in the direction of the laser beam when it absorbs the photon. Once more it will undergo a change in momentum upon emitting a photon, and it will recoil in the opposite direction to the photon. A net change in momentum in the direction of the laser beam will occur if an atom absorbs photons from the beam repeatedly, with each absorption resulting in a random photon being emitted by the atom. As the photons are released in every direction, the average change in momentum caused by the photons will be zero. Hence, using the above method the atom beam coming towards the laser beam can be cooled down. But because atom, molecules in a gas move randomly in all directions, it is necessary to control whether or not it absorbs the photon depending on the atom moving



opposite to or in the direction of the laser beam. Here we deliberately choose a photon frequency which is lower than the absorption frequency of the atom. The atoms moving in opposite direction of the photons will see a higher frequency whereas the atoms moving in the direction same as photon will experience a lower frequency due to doppler effect. Hence, if we use a orthogonal pair of laser beam in opposite directions one laser beam will slows down the atoms moving in one direction while the another laser beam will slows down the atoms moving in opposite direction. Three pairs of mirror are used to slow down in three dimensions. Using this method, atoms can be cooled down to few tens of micro Kelvin temperature.



(b) **Laser trapping**: The basic process of laser cooling also involve trapping of atoms using laser. In laser trapping, the atoms behave to be placed inside a highly viscous fluid which resists their free motion. The frequency of the laser beam must be lower than the resonant frequency of the atom. Trapping a neutral atom is a bit tricky process. Before discussing the trapping process, let us recapitulate how a a piece of paper is attracted towards a pen that is rubbed against hair. In this case, the pen which is rubbed against hair develops accumulation of positive charges at one end. Now if we bring the piece of paper near the pen, the static charges inside the paper get redistributed and negative charges come nearer to the pen while positive charges go to the farthest point from it. Therefore, a local maxima of electric field is generated near the positive end of the pen and paper pieces stick to it due to strong attractive force. Although it is not possible to have local maxima in electric field generated by static charges, highly focused laser beam is able to produce alternating electric field having a local maxima. If the electric field does not change very rapidly, the neutral atom redistribute its charge and get attracted to the local maxima of the electric field at focus point of the laser beam. This is how the neutral atoms get trapped at the focus of the laser beam.



Apart from laser cooling and trapping of neutral atoms there is another method, named as Sisyphus cooling, which is used to cool down ions or charged particles. In Sisyphus cooling the electric field of laser beam and ion interact with each other. The ions experience an time-dependent force which is proportional to the rate of change of laser intensity.

(c) **Use of laser cooling and trapping**: The phenomena of laser cooling and trapping is a versatile phenomena and hence, have numerous applications. Few of them are mentioned below:

(i) Laser cooling is used to produce ultra cold atoms that are useful to study Bose-Einstein condensation, superfluidity etc.

(ii) Ultra cold atoms are also heavily used in high precision measurements such as atomic clock, quantum computing and quantum cryptography.

(iii) Laser cooling and trapping are used to create optical trap where atoms or ions are trapped in a tightly focused laser spot. These optical traps are utilised in atomic and molecular Physics.