ME-557 LASER MATERIAL PROCESSING
LASER COOLING

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Abstract

Laser usually made up of light typically used to heat the substances but contrastingly to what we might think,lasers can also be used to cool down things too.In this paper we mainly focus on what exactly a laser is,how we cool the substances using laser,the way the velocity is related to temperature,doppler effect and its advantages.Laser cooling is actually a wide field which includes a wide spectrum of techniques for cooling down the atomic and molecular samples.The results show that by decreasing the momentum we can reduce the velocity and further the temperature gets reduced.

1. Introduction

Light Amplification By Stimulated Emission of Radiation in short is known as laser.In other words let us have a red light we will get red photons in all the directions and now when we point all these in same direction there we get a laser of red colour and we can create this by using stimulated emission.If we think about laser we can encounter them in various different ways or read about them or seen them.As amplified light with high intensity with a small focussing diameter produces more heat so as per our understanding Laser must heat the material and widely used in laser cutting,2d 3d printing,laser surgery,laser weapons,laser in movies etc.Laser basically heat things up.They interact and they get absorbed by the material and Absorption of the intense light causes intense vibration of atoms or molecules inside the substance.

2. How does temperature affect velocity of a particle

Temperature is directly a measure of kinetic energy of particles in a substance.Temperature is directly related to mean speed velocity of a gas.

$$1/2mc^2=3/2kt$$

where,

m=mass of gas

c=root mean square

k=boltzmann constant

t=temperature

So to cool a particle down we simply need to slow it down.Laser cooling is based on the fact that when an atom absorbs and re-emits the photon there will be a change in the momentum.Light has momentum in addition to energy even without mass.Let us assume an atom moving in one direction and atom absorbs a photon moving in the other direction,the photon momentum gets transferred to the atom,the electron inside the atom absorbs photon and moves to an excited energy state as electron cannot be in excited state for much time,it re-emits the photon in random direction and comes back to the ground state.This even slow down the atom speed.As velocity decreases temperature will automatically be reduced.

3. Methodology

Doppler Cooling:

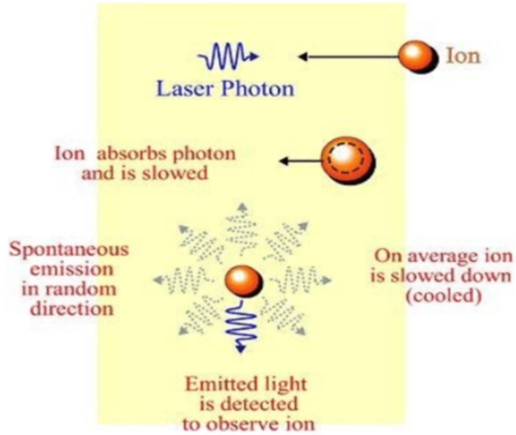
Doppler cooling is one of the most common, general and famous technique used in laser cooling to initiate the cooling. In this, the atoms are slowed down, and eventually cooled by use of laser cooling. Both wave nature and particle nature of the light need to be taken into account for understanding the laser cooling of atoms.

Doppler cooling is a mechanism that can be used to trap and slow the motion of atoms to cool a substance. The relativistic doppler effect is the change in frequency (and wavelength) of light, caused by relative motion of the source and the observer. But as we know that laser light i s coherent in nature, i.e all the photons in the laser beam have the same frequencies, and are in the same phase and move in one single direction. Therefore, to provide different frequencies, we need to use different kinds of lasers.

Concept of energy absorption by atoms:

Atoms have a unique set of energy levels. Any atom can not be in between those energy levels. A minimum amount of energy is required by atoms to move to higher energy levels. Every atom has a property to absorb the electromagnetic energy at a particular frequency. Thus each atom can absorb or emit photons which have certain energy and frequency. Other photons with wrong energy or frequency will have no effect on atoms. This property of energy absorption of atoms is very important in laser cooling methods.

1. **1-D interaction of Laser Photon with the atom:**



As already mentioned above, if the energy of the photon of laser beam is equal to the energy difference of the ground and excited state of an atom, then the photon will be absorbed by the atom. And after some time, it will emit the same energy associated with the photon that was absorbed into some random direction and come down to ground state.

When an atom absorbs a photon, its momentum increases in the direction of the laser beam. When the photon is emitted by the atom, the atom's momentum changes in the opposite direction of the photon's emitted direction.

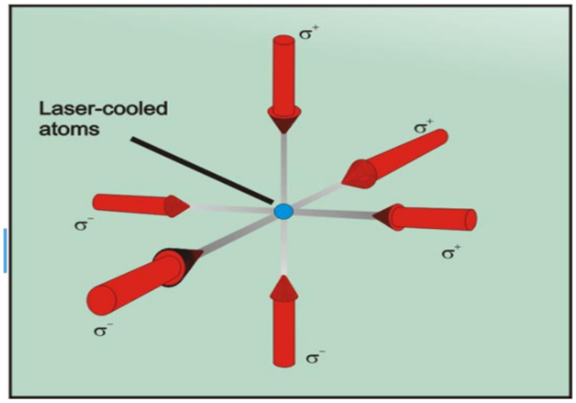
If the atom emits photons in random directions after each absorption, the atom's momentum will only vary in the direction of the laser beam. Because of the released photons, the atom's averaged momentum change will be zero.

2. **Laser Beam pairs in 3-D:**

Only those atoms travelling in the opposite direction of the laser beam experience a drop in speed in the case described above.

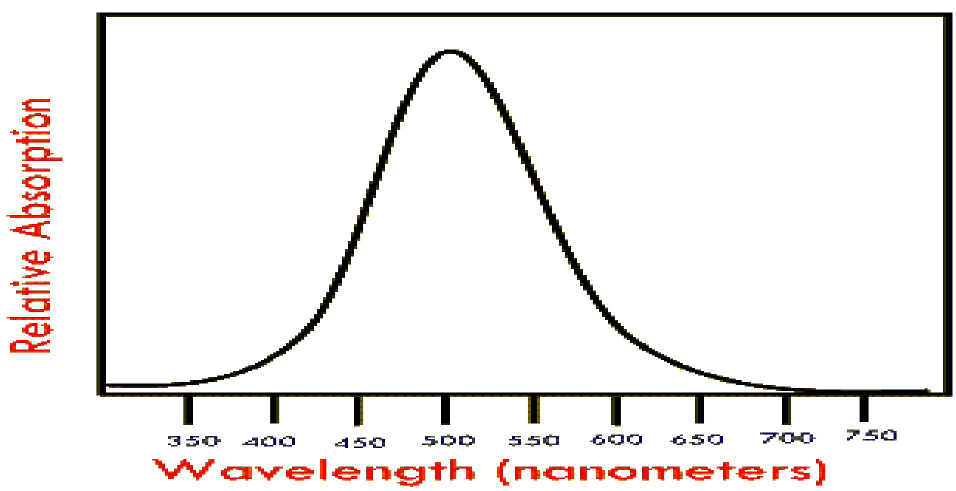
As a result, we select a frequency lower than that required to excite the atom. As the atoms move away from the laser source, they will encounter a lower magnitude doppler shifted frequency laser beam and will thus not absorb photons. However, if the atom moves closer to the laser, it will be exposed to higher magnitude doppler shifted frequency photons, which will excite the atom. As a result, two lasers pointing in the same direction are employed. A laser beam on one side will slow the atom travelling towards it, while the other laser beam on the other side will slow the atoms moving in the opposite direction.

In 3-D, three orthogonal laser pairs are used in the same way.



3.Absorption probability curve

Atoms will observe photons of only a few wavelengths,like it depends on how close the wavelength of photons is with the transition wavelength.So atom speed is also crucial here,atoms having a unique magnitude of speed will absorb the photons.The below curve shows the photon wavelength and absorption probability.Its a lorentzian curve width of the curve is natural line width of transition.



4. **Limitations of doppler**

- Minimum temperature

  Minimum temperature achievable is doppler limit.By spontaneous emission of photons ,the atom will get momentum from random directions.This leads to zero the mean velocity.Whereas the mean squared velocity will not become zero in random directions.Moreover the absorbed photons will gain some moment,thus we cannot absolute zero.

- Sub-Doppler cooling

We can decrease temperature below the doppler limit with sisyphus cooling,sympathetic cooling techniques,furthermore the doppler cooling applies efficiently to the two level structures.But for hyperfine structure we use other modes of cooling.

- Minimum concentration

The concentration should be very low,so that excited electrons should not scatter with each other. There may be a possibility that excitation leads to kinetic energy by electrons coming to ground state with extra energy.And it totally works against the cooling process.

- Atomic structure

Laser cooling for hyperfine structure and also for molecules having rovibronic coupling,and for cooling those layers frequency locked lasers are required which are very much expensive and complex,and even some atoms are rarely cooled with a repump laser.

5. Applications

1) High-resolution spectroscopic measurements by the elimination of Doppler broadening.
2) Ultracold atoms.
3) Quantum optics research.
4) applications in quantum information technology.
5) ultraprecise measurement of gravitational fields.
6) Lithography.
7) Optical molasses.
8) To focus on the atom beam.

6. Reference

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