بحث مادة ليزر

LASER COOLING

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Introduction:

Lasers were invented about 50 years ago. They are able to heat, vaporize, cut and weld material. However, during the past ten years, two Nobel prizes (in 1997 & 2001) in physics were related to the use of laser for *cooling*.
In this paper, we will describe how lasers can be used to cool atoms by benefiting from the Doppler effect. Further cooling is induced by using a magnetic trap or by dye lasers.

We know that atoms are always moving in random directions with velocity around 1400 km/hr at room temperature, and their velocity is proportional to atoms square root of temperature.

$$v_{rms} = (3RT/M)^{1/2}$$

where R is the gas constant, M is the molar mass and T is the temperature. So if we measure the body temperature we can determine the atoms' velocity and vice versa.
It is difficult to study fast atoms because they disappear from the area being observed. To reduce the velocity we need to minimize the atoms' temperature. But gases condense to transfer to liquid then to solid at low temperature which means the bonds between atoms become more complicated and hence study is still difficult. So we need to keep the density low (even at very low temperature) and a mechanism that gives temperature near the zero Kelvin because the velocity still high even near 270 Kelvin.
Laser cooling is the technique which we need! But we know that if we shine a beam of light on a body, it gets hotter because it absorbs the light and transforms to heat. But here the technique involves a series of absorptions and emissions that cause a decrease in the atoms' velocity.

Laser cooling is a technique that uses light to cool atoms to a very low temperature. The simplest form of laser cooling is the so called *Optical Molasses.*

Type and wavelength of laser:-

The type and wavelength are chosen such that they suit the atoms which will be cooled. For example, for sodium vapor, λ = 589.0 nm is used. For Rb and Cs vapors, λ is approximately 780 and 852 nm, respectively.

Why the laser is used her rather than the ordinary light?

In this application we need light of certain wavelength (frequency).

Doppler Effect:-

An atom absorbs a photon if its energy equals the difference between the ground state and the excited state of the atom. The energy of the photon depends on its frequency.

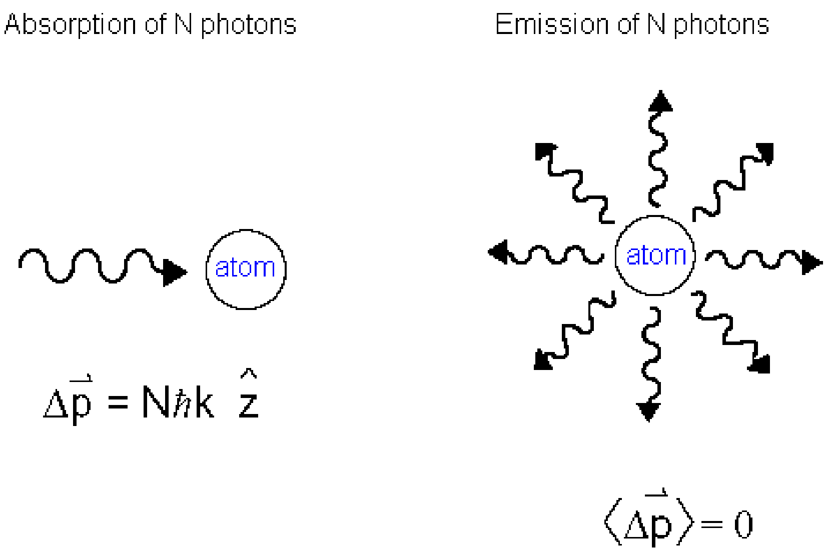
$$E=h\nu$$

The moving atom will "see" the photon frequency (ν) different from the actual frequency (ν_o), and this depends on the atom's velocity. The suitable frequency for an atom moving toward the photon is less than (red-shifted) that for a stationary atom; this is due to the so-called *Doppler effect*, and is described by the following relation:

$$\nu = \nu_o (1+v/c)^{1/2} / (1-v/c)^{1/2}$$

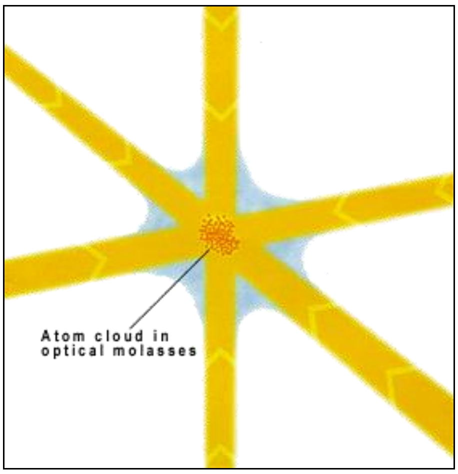
The absorption-emission mechanism:-

When a laser beam (of suitable frequency) collides an atom moving toward the beam, the atom may absorb the laser photon energy, and recoil. This leads to the slowing of the atom. In the proves, the electron in the atom will jump up to a higher level. Then, it spontaneously de-excites, and jumps back down and the atom emitting a photon with certain momentum. This give the atom a small recoil velocity; however its direction is random. After many absorptions and emissions the momentum changes due to *absorption*; however change due to spontaneous emission averages to zero. After a few absorptions, the atom's velocity decreases and the atom will no longer be in resonance with the laser. This is because the atom "sees" the incoming photon with a frequency less than when the atom was moving fast and it reaches the lowest temperature using Doppler effect.



Laser beams arrangement:-

Six laser beams opposed in pairs are arranged in three directions at right angles to each other. This way, atoms moving in any direction my absorb photons from a laser beam such that it will be pushed back into the area where the six laser beams intersect. At the intersection region, atoms move as in thick liquid, and the name *optical molasses* is suggested.



Can we cool atoms to temperature that is lower than the Doppler temperature?

We can do that using either:-

1- Zeeman effect (**Zeeman tuned cooling),** or
2- Dye laser beam (**chirped cooling**).

1-Using Zeeman effect (Zeeman tuned cooling)

Zeeman effect:-

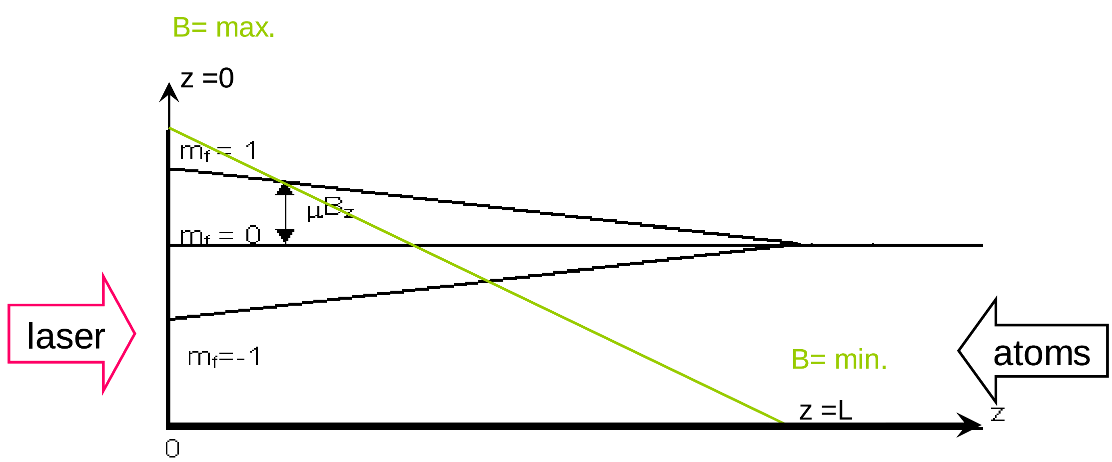
The energy sublevels have the same energy value in the absence of the magnetic field. E.g. the level p (ℓ =1) contains three states (m_ℓ =1,-1,0) with the same energy. But if we apply an external magnetic field **B,** the energy differs in each state. The Zeeman splitting (ΔE) can be described by:-

$$\Delta E = m_\ell (e\, h/4\,\pi\, m)\, B$$

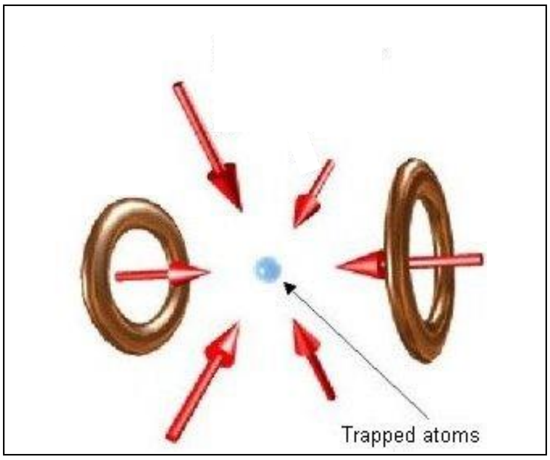
Where m_ℓ is the magnetic quantum number and h is Planck's constant. *e* is the magnitude of the electronic charge and m is the mass of the electron. Hence, for the m_ℓ = -1 state, decrease in energy levels is proportional to B. That is, as the magnetic field increases, the state is shifted down with respect to m_ℓ = 0 state. So the energy difference between m_ℓ = -1 and the level s decreases.

In an nut-shell, the magnetic field shifts the energy level of the m_ℓ = -1 down such that it is again in resonance with the impinging laser beam.

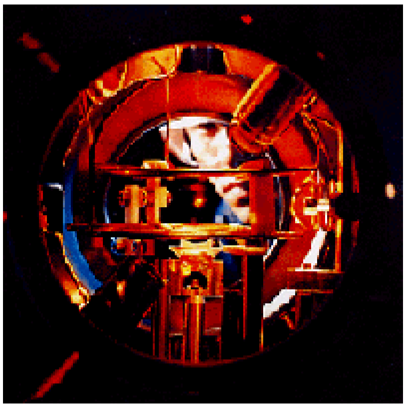
If the atom is moving from the right to the left along z-axis (see figure), its energy decreasing as it approaches the laser beam. However, it then becomes off resonance and there is no further absorption. Applying magnetic field gradient with minimum value at a certain position z = L and maximum at z=0, we can decrease the atomic states energy levels as it move from z=L to z=0 such that it is always in resonance and absorbing of the beam. But differently, as its velocity decreases, it continues to "see" the incoming frequency as suitable for absorption of photons. This is called *magnetic trap*.



Increasing of ΔE with increasing of the magnetic field.



Magnetic trap & optical molasses "magneto-optical trapping."



A collection of sodium atoms (yellow dot in middle of picture) trapped in a MOT.

2-Using dye laser beam (chirped cooling).

The dye lasers give a wide rang of frequencies and are tunable. So, we can increase the frequency as the atom's velocity decreases. This will keep the atom in resonance with the laser.

Conclusion:-

In conclusion, lasers not only used for cutting, welding or heating. We have seen how a set of intersecting lasers can be used to cool atoms. The Doppler effect in collaboration with a magnetic trap or dye laser beam can cool the atoms of specific materials as low temperatures as a micro-kelvin. Further cooling may be achieved using the so-called evaporative cooling. This is beyond the scope of this paper.

References:-

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