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Use Of The Relativistic Doppler Effect To Detect Temperature By Laser

A.H. Abdelrahman[1*], Ferial Hamed Elneel Esmail[2], Alfadel Mahmoud Yosif Abdelrahim [3], Hasabalrasoul Gesmallah Ismail Hamza 4. Hleima Faddal Ezaldein Rewais[5], Mubarak Dira Abdalla 6

[1]*Department Of Physics, College Of Science, Qassim University, 51452 Buraidah, Saudi Arabia*
a.yassin@qu.edu.sa
[2]*University Of Bakht Alruda- Faculty Of Science- Department Of Physics- Eldeewim, Sudan*
[3]*Department Of Physics, Faculty Of Education, University Of Al-Butana, Sudan*
[4]*Department Of Physics And Mathematics, Faculty Of Education, Gezira University, El-Hasaheisa, Sudan*
[5]*Department Of Physics, Faculty Of Science, University Of Kordofan, Sudan*
[6]*Department Of Physics, Faculty Of Science, Sudan University Of Science And Technology*

Abstract

The relativistic Doppler effect relates the source's motion to the change in its frequency, in terms of the source's speed and the speed of light in a vacuum. For law source speed, this relation is linear. Considering the gas as a source and using momentum conservation in atom-photon interactions, a useful expression for the photon-gas energy-collision process was obtained. This expression showed that for a gas having temperature T1, the temperature is directly related to the maximum frequency and the maximum intensity shift. Thus, the laser can, in this case, be used as a temperature sensor

Keywords: *relativity, Doppler effect, light, laser, photon, temperature, temperature sensor, momentum conservation*

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Introduction .I

A laser is a light beam that produces an intense, directional, single-frequency beam of light. The term "laser" stands for Light Amplification by Stimulated Emission of Radiation. Lasers work by exciting atoms or molecules to release photos through the so-called stimulated emission of radiation in a specific direction. In this process, the incident photon forces an excited atom with the same excitation energy as the photon to emit a photon with the same frequency, direction, and phase as the incident photon. This process creates a coherent beam of light with unique properties [1,2,3]. Lasers have many applications in medicine and telecommunications [4].

One of the most important applications of lasers is for cooling. Laser cooling includes several techniques in which atoms, molecules, and small mechanical systems are cooled using laser light. The directed energy of lasers is often associated with heating materials, e.g. laser cutting, so it can be counterintuitive that laser cooling often results in sample temperatures approaching absolute zero. It is routinely used in atomic physics experiments where laser-cooled atoms are manipulated and measured, or in technologies, such as atom-based quantum computing architectures [4]. A cold, trapped cloud of hydrogen atoms can be used to test quantum electrodynamics and to make precise measurements of fundamental physical constants [5,6]. The preparation of a BEC of atomic hydrogen in a magnetic trap is among the earliest attempts [7]. The measurement of the 1S–2S transition in a magnetic trap of hydrogen was done as one of the earliest techniques [8], besides antihydrogen [9] and in a beam [10]. Recently, the 1S–3S [11] and the 2S1/2–8D5/2 [12] transitions of hydrogen were measured with unprecedented precision. The magnetic slowing of paramagnetic hydrogen was also proposed [13]. Unfortunately, these experiments are limited by motional effects. The precision can be improved by measuring dilute ultracold hydrogen samples tightly trapped in an optical potential. A new treatment for such samples is based on the fragmentation of hydride molecules [14] and ions [15]. Various studies have examined the relationship between lasers and temperature. Some of them are concerned with the laser cooling. One of them is the theoretical study of the feasibility of laser cooling for the molecule LuF at the fine-structure level of approximation. The results of the internuclear distances of the $X^3\Sigma_{0+}$ and $(1)^3\Pi_{0+}$ states show the candidacy of the molecule LuF for direct laser cooling. Franck– Condon factors, the radiative lifetimes, the total branching ratio, the slowing distance, and the laser cooling scheme study prove that the molecule LuF is a good candidate for Doppler laser cooling [16]

In another work, isotopes of 7Li were investigated using grey molasses operating on their respective D1 atomic transitions [17]. The results show that sub-Doppler cooling can be achieved using two distinct Λ-type transitions, in which the upper level can be either of the two $2^2\,P_{1/2}$ hyperfine states. A temperature of 85 μK was obtained with atom numbers of 10^8, and phase-space densities in the range of 10^{-6} 10^{-5} for both isotopes. These conditions provide a good starting point for loading the mixture into an optical dipole trap and performing evaporative cooling to quantum degeneracy. The influence of a strongly inhomogeneous magnetic field used for trapping neutrals on the trapping and laser cooling of a single Ca+ ion in a radiofrequency ion trap is studied theoretically using molecular-dynamics simulations based on multilevel rate equations. The inhomogeneous magnetic field couples the different components of the ion motion and introduces position-dependent Zeeman splitting. Laser cooling was found to work efficiently as the ion samples different magnetic field strengths and directions along its trajectory. The present study provides detailed insights into the ion-cooling dynamics in combined magnetic and radio-frequency electric fields [18]. The integration of a laser cooler onboard an observation satellite study focuses on size, weight, and power (SWaP) criteria at both the satellite payload and platform levels. Its goal is to assess the interest in using an optical cryocooler instead of a mechanical cryocooler for low Earth orbit (LEO) infrared observation missions. A preliminary spaceborne laser cooler (LC) architecture comprises two parts. The first part is the cooling head, based on state-of-the-art cooling crystals 10%Yb: YLF and an astigmatic multiphase cavity. The second part is the cryocooler optoelectronics, based on redundant laser diodes and fibre-coupled to the cooling head. The cooling power is estimated for a small focal plane, accounting for the thermal load of an infrared detector and the parasitic heat fluxes within the cryostat. The required optical and electrical powers of the laser cooler are then estimated by considering the crystal efficiency, thermal link losses, and optoelectronic efficiency.

The overall impact of a laser cooler is that, even with high power requirements, the reduction in mass and internal volume enables small satellite payloads [19]. The work of Habib [20] focuses on developing a theoretical model. Using fluid-mechanical laws and treating atoms as harmonic oscillators subjected to gas and photon pressures, a useful expression for the cooling conditions of nano-quantum systems was derived. The findings indicated that the atom density, cooling degree, photon density and frequency affected the cooling process. Dense and high cooling degree require increasing the applied photon density, the frequency, or both. A useful expression for cooling conditions in quantum nanosystems was derived by Habib [21] using the energy conservation law, treating atoms as harmonic oscillators subject to gas and photon pressures. The findings indicate that the atom density, as well as the photon density and frequency, affected the cooling process. High cooling degree requires decreasing the gas density, increasing the applied photon density, or the frequency, or both.

One of them was developed by Suman et al. [22]. He developed a compact sensor using a tunable diode laser near 1850.5 nm to measure H O absorption for wide-range temperature diagnostics. The sensor can determine temperatures ranging from 600 to 1800 K and pressures from 3.5 to 103 kPa, with a relative error between 2%–3.5%. The numerical simulations confirmed suitability for temperatures between 500 and 2500 K. Xu Anheng et al. [23] measured the thickness of the lithium battery coating using a laser triangulation-based sensor. An algorithm based on threshold judgment and multi-scale wavelets is implemented to reduce high-frequency noise in lithium battery film thickness systems. The measurement is useful for different lengths and discontinuous coating thickness measurements.

A highly sensitive temperature-sensing array is prepared by Qi Li [24]. It includes all laser direct writing (LDW) methods, using laser-induced silver (LIS) as electrodes and laser-induced graphene (LIG) as a temperature-sensing layer. A finite element analysis (FEA) photothermal model incorporating a phase transition mechanism is developed to investigate the relationship between laser parameters and LIG properties, providing guidance for laser processing parameter selection with laser power of 1–5 W and laser scanning speed (greater than 50 mm/s). The measurement errors of simulation and experimental data for the widths and thickness of LIG are less than 5% and 9%, respectively.

All these attempts, aside from using a laser as a temperature or thickness sensor, demonstrated the feasibility of fabricating a laser sensor using mechanisms other than those described in the papers. This paper theoretically proposes fabricating a temperature sensor based on the Doppler effect, which appears to be easier than other techniques. This model is exhibited in Section 2. Sections 3 and 4 concern the discussion and conclusion.

Laser cooling conditions and temperature sensor:

The Doppler effect in SR relates the new frequency f ' to the original frequency given by:

(1)

Where v stands for the source or observer speed, while c represents the speed of light in a vacuum.

We multiply both sides inside the square root by , one gets:

(2)

In many experiments, the speed v is considerably smaller compared to the speed of light c, such that
: (3)

In this case, equation (2) is reduced to
(4)

Consider if the photon collides with a gas atom or is absorbed by it. Let the mass of the gas atom be $m_{a,}$ and its speed be v. For the photon, the mass m_p is related to its frequency according to the reflection:
(5)

When the photon momentum is completely transferred to the gas atom, the momentum conservation reads
: (6)

Inserting (6) in (4) gives
: (7)

Multiplying both sides by h and using (5) gives
: (8)

According to the kinetic theory of gases, for one degree of freedom, the gas having temperature T in Kelvin degrees satisfies:
(9)

Therefore, equation (8) reduces to
: (10)

This equation represents the interaction of a single photon with a single atom. In general, if photons having inside density n are incident on a gas with density n_a, such that the density of the scattered photon is n'. in this case, equation (10) becomes
: (11)

The two equations can be easily understood with the aid of the Doppler effect and black body radiation. According to the Doppler effect equations (4) and (11), the thermal energy increases the atom's speed, which in turn increases the frequency and the photon energy. The emission of higher frequencies can also be readily understood using blackbody radiation and conventional spectroscopic principles. According to these principles, a photon of frequency can cause electrons to jump, say, from the ground to the first excited state. When such an electron collides with a moving atom, the electron can gain more energy to jump, say, to the second excited state. If the electron returns to the ground state, the liberated photon will have a higher frequency f ' according to equations (80 and (11). When the source moves away from the observer, equation (1) reads
(12)

Thus, repeating the same steps yields
(13)

using equation (11) in (13) becomes
(14)

Discussion .II

Relativistic Doppler effect relation (1), which indicates how the relative motion of the observer with respect to the light source can change the light frequency. This relation was simplified for lower velocities v compared to the speed of light c in equation (4). Using the equality of the relativistic photon energy to the photon Planck energy, together with momentum conservation for the photon-atom collision, a useful expression for the gas energy effect on the photon frequency was found in equation (8). With the aid of the kinetic theory of gases in (9) a useful expression which related photon frequency change to the gas temperature T1 was found in equation (10). This relation can be explained using the atomic collision process. The collision of an atom with a photon having energy will increase its energy by an amount kT, according to equations (9) and (10). This is similar to the Compton effect, but here the electron is replaced by an atom, and the energy is absorbed by the photon rather than lost. It also resembles the non-linear optical behaviour when a photon of energy hf is absorbed by the atom, causing an electron to jump from the ground state to the first excited state. When this atom collides with another atom, knocking an electron, it moves to the higher second excited state. When this electron returns to the ground state, the liberated photon has energy hf'. given by equations (8,10). The two equations (8,10) describe the behaviour of the photon when the atom, which acts as a source, moves towards the observer, thereby moving in the same direction as the photon. These equations (8,10) can be generalized for photons having density na as shown in equation (11). However, when the source moves away from the observer, the atom and the photon move in opposite directions, and the Doppler shift yields relations (12) and (13). The photon energy is lowered. The fact that the photon and the atom move in opposite directions can, fortunately, give the same result as far as the collision in this case, which lowers the photon frequency.

Conclusion .III

The relativistic Doppler effect of light can be used, together with the conservation of momentum, to show how gas temperature can affect light frequency and intensity. It can increase or decrease the light frequency or intensity depending on whether the gas atom moves in the same direction as the light or in the opposite direction.

References

William T. Silfvast, Laser Fundamentals, Second Edition, Copyright By William T. Silfvast, UK (2004) .[1]

A.H. Abdelrahman, Lasing Due To The External Field And Target's Permeability And Conductivity”, IOSR Journal Of Applied Physics (IOSR-JAP 8 (5), 05-11, 2016. .[2]

Mubarak M. Ahmed1,2, Abdelaziz Hagar Abdelrahman1,2*, Elhadi Mohieldin3, Samia Omer Yagoub1, Effect Of Diode Laser 810nm In Hardness Of Dental Ceramic, Optics And Photonics Journal, 4, 104-112 Published Online May 2014 In Scires. Http://Dx.Doi.Org/10.4236/Opj.2014.45011 .[3]

Markolf H. Niemz, 'Laser Tissue Interactions Fundamentals And Applications, Third Edition, Copyright By Springer-Verlag, Berlin (2007) .[4]

H. J. Kimble, “The Quantum Internet,” Nature, 453, 1023–1030, 2008. .[5]

S. Kuhr, “Quantum–Gas Microscopes: A New Tool For Cold–Atom Quantum Simulators,” Natl. Sci. Rev., 3, 170–172, 2016. .[6]

C. Monroe, J. Kim, “Scaling The Ion Trap Quantum Processor,” Science, 339, 1164–1169, 2013. .[7]

C. Regal, D. Jin, “Creation Of Ultracold Molecules From A Fermi Gas Of Atoms,” Nature, 424, 47–50, 2003. .[8]

B. Demarco, D. Jin, “Onset Of Fermi Degeneracy In A Trapped Atomic Gas,” Science, 285, 1703–1706, 1999. .[9]

M. Greiner, O. Mandel, T. Esslinger, T. W. Hänsch, I. Bloch, “Quantum Phase Transition From A Superfluid To A Mott Insulator In A Gas Of Ultracold Atoms,” Nature, 415, 39–44, 2002. .[10]

I. Bloch, J. Dalibard, S. Nascimbène, “Quantum Simulations With Ultracold Quantum Gases,” Nat. Phys., 8, 267–276, 2012. .[11]

M. Zwierlein, “Ultracold Fermi Gases With Emergent SU(N) Symmetry,” Phys. Today, 72(5), 40–47, 2019. .[12]

W. S. Bakr, J. I. Gillen, A. Peng, S. Fölling, M. Greiner, “A Quantum Gas Microscope For Detecting Single Atoms In A Hubbard-Regime Optical Lattice,” Nature, 462, 74–77, 2009. .[13]

J. F. Sherson Et Al., “Single-Atom-Resolved Fluorescence Imaging Of An Atomic Mott Insulator,” Nature, 467, 68–72, 2010. .[14]

D. Greif Et Al., “Site-Resolved Imaging Of A Fermionic Mott Insulator,” Science, 351, 953–957, 2016. .[15]

El-Kork, N., Almasri Alwan, A., Abu El Kher, N., Assaf, J., Ayari, T., Alhseinat, E., & Korek, M. Laser Cooling With The Intermediate State Of Spin–Orbit Coupling Of The Luf Molecule. Scientific Reports, 13(1), 7087, (2023). .[16]

De Jongh, T., Dash, G., Dixmerias, M., Salomon, C., & Yefsah, T. Simultaneous Sub-Doppler Laser Cooling Of 6 Li And 7 Li Isotopes. In APS Division Of Atomic, Molecular And Optical Physics Meeting Abstracts (Vol. 2022, Pp. S04-007). 307, (2022). .[17]

Karl, R., Yin, Y., & Willitsch, S. Laser Cooling Of Trapped Ions In Strongly Inhomogeneous Magnetic Fields. Molecular Physics, 122(1-2), 2199099, (2024). .[18]

Vicente, R., Nogues, G., Niot, J. M., Wiertz, T., Contini, P., & Gardelein, A. Impacts Of Laser Cooling For Low Earth Orbit Observation Satellites: An Analysis In Terms Of Size, Weight And Power. Cryogenics, 105, 103000. (2020). .[19]

Habib. A. H, Mubarak Dirar Abdalla, Najwa Idris Ahmed, Einas M.A. Widaa, Elharam A. E. Mohammed, Laser Cooling Conditions Dependent On The Photon Density And Frequency Using Quantum Cooling Model Based On Fluid Laws And Treating Atoms As Strings, Journal Of Advances In Physics Vol 23, ISSN: 2347-3487, (2025) .[20]

Habib. A. H, Mubarak Dirar Abdalla, Najwa Idris A. Aadham, Einas M.A. Widaa, Elharam A. E. Mohammed, Quantum Model Based On Fluid Energy Laws And String Solution For Laser Cooling Dependent On The Photon Density And Frequency, Journal Of Advances In Physics Vol 23, ISSN: 2347-3487, (2025). .[21]

Suman Ai, Zhenyu Xu, An Huang, Hao Deng, R Ranong Niu Ruifeng Kan, A Wide-Range Temperature Sensor With A Single Diode Laser Based On H_2O Absorption Spectra Near 1850.5 Nm, Frontiers In Physics, Optics And Photonics, Volume 12 – 2024 Https://Doi.Org/10.3389/Fphy.2024.1488578 .[22]

Xu Ancheng, Xu Qingquan, Chen Gong, Zhu Xifang, Zhang Hua And Liu Xiaojun, Laser Online Thickness Measurement Technology Based On Judgment And Wavelet De-Noising, Sensors & Transducers, Vol. 168, Issue 4, Pp. 137-141, April 2014 .[23]

Qi Li1 · Ruijie Bai2 · Lianbo Guo3, Yang Gao1, All Laser Direct Writing Process For Temperature Sensor Based On Graphene And Silver, Frontiers Of Optoelectronics (2024) 17:5 Https://Doi.Org/10.1007/S12200-024-00108-4 .[24]