분과초청VI2 Proceedings of the Optical Society of Korea Annual Meeting 2001 (2001. 2. 15~16)

Separation of Neutral Molecules by the Dipole Force of a Focused Nonresonant Laser Pulse

집광된 비공명레이저펄스의 쌍극자힘에 의한 중성 분자들의 분리

BUM SUK ZHAO, SUNG HYUP LEE, HOI SUNG CHUNG, SUNGU HWANG
WEE KYUNG KANG,[1] and DOO SOO CHUNG
School of Chemistry, Seoul National University, Seoul 151-747, Korea
[1]Department of Chemistry, Soongsil University, Seoul 156-743, Korea
dschung@snu.ac.kr

We demonstrate the first separation of neutral molecules using optical forces. Unlike laser atomic cooling or optical tweezers, optical separation technique requires the manipulation of only one component of the molecular motion. Thus the mixtures can be separated, in principle, with less complex schemes. When an intense nonresonant laser beam is focused onto a beam of molecules, the interaction between the laser electric field and the induced dipole moment of a molecule invokes a mechanical force on the molecule proportional to the field gradient and the molecular polarizability (α) to mass (m) ratio α/m. The focused laser beam is thus equivalent to a molecular prism which disperses the beam of molecules depending on the value of α/m.

Our optical separation instrument, which has been described in detail in the previous paper,[1] consists of two parts, a molecular prism and a time-of-flight mass spectrometer (TOFMS) with a 2-dim imaging detector. Nonresonant laser pulses from a 1064-nm Nd:YAG laser of 8 ns pulse duration (τ) and 16 μm waist radius (ω_0) are focused into the ion acceleration region of the TOFMS where they intersect a pulsed, skimmed supersonic beam of neutral benzene and nitrogen oxide molecules. These nonresonant laser pulses act as a molecular prism which is based on the principle of the induced dipole force. Then the molecular rays deflected by the molecular prism are crossed a dye laser pulse which ionizes molecules through multiphoton-ionization processes. We choose the center of focus, propagating directions of laser and molecular beam as the origin, x-axis and z-axis, respectively. Molecular ions are focused onto the front of a microchannel plate (MCP) which is gated by a -500 V pulse. Ions amplified by MCP and hitting a phosphoscreen at the back of MCP are detected by a photomultiplier tube and a CCD camera.

The 2-dim images of molecular ions allow us to deduce the trajectories of neutral molecules. The position of neutral molecules which have passed through the molecular prism at ($y=y_0$, $z=0$) at time t can be represented by the y-z coordinate ($y_0 + \Delta v_y(y_0)t$, $v_z t$), where $\Delta v_y(y_0)$ is the velocity change along the y-axis given by[2]

$$\Delta v_y(y_0) = \frac{2\sqrt{2\pi}U_0 y_0 \exp(-2\,y_0^2/\,\omega_0^2)}{m\omega_0 v_z\sqrt{1+2\ln 2(\omega_0/v_z\tau)^2}} = \Delta Y/\mathrm{TOF}, \qquad (1)$$

where U_0 is the maximum stark shift and m the mass of a molecule. Since the velocity of a molecular ion is almost equal to the velocity of the parent neutral molecule, the position of neutral molecules can be deduced from the position of molecular ions (y_0 + ΔY, v_z × TOF), which in turn can determined from the image shift ΔY and TOF to the detector.

Figure 1 shows the result of separating benzene and nitrogen oxide with a molecular prism. The maximum stark shift U_0 is proportional to the polarizability α and peak intensity I_0 of a laser pulse.[3] Therefore, the velocity change of a molecule is proportional to the polarizability to mass ratio (α/m) of the molecule. Due to the difference in α/m values, the two molecular species are deflected into different angles, spatially separated and reaches different positions on MCP at time t = TOF. A vertical line indicates the position of image peak obtained without the molecular prism. Benzene of a larger α/m value is more deflected than nitrogen oxide of a smaller α/m value. This figure represents the separation of benzene and nitrogen oxide molecules at time 47.71 μs. A chromatographic resolution of 0.78 between the two peaks is obtained with the molecular prism formed by a circularly polarized pulse of 80 mJ.

In summary, we have made a molecular prism consisting of a far-off-resonant nanosecond Nd:YAG laser pulse which disperses a mixture molecular beam just as an optical prism does a white light beam. This molecular prism opens up a new and potentially useful separation protocol of optical force chromatography.

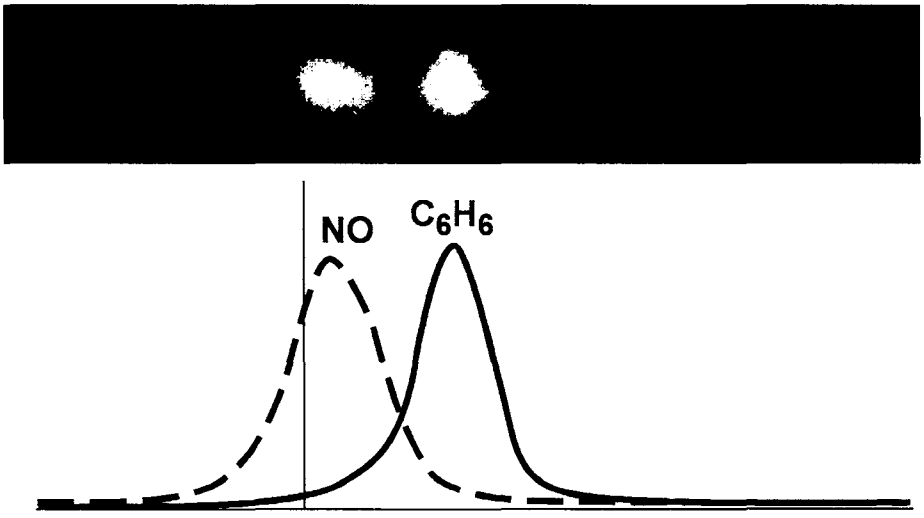

Figure 1. Optical separation of NO and C_6H_6. The chromatographic resolution between the two peaks is 0.78.

[1] B. S. Zhao, H. S. Chung, *et al.*, Phys. Rev. Lett., 85, 2705 (2000).
[2] H. Stapelfeldt, H. Sakai, *et al.*, Phys. Rev. Lett., 79, 2787 (1997).
[3] B. Friedrich and D. Herschbach, Phys. Rev. Lett., 74, 4623 (1995).