Atomic lithium vapor laser isotope separation

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An atomic vapor laser isotope separation in lithium was performed using tunable diode lasers. The method permits also the separation of the isotopes between the \(^6\)Li\(D_2\) and the \(^7\)Li\(D_1\) lines using a self- made mass separator which includes a magnetic sector and an ion beam designed for lithium.

Keywords: Laser, isotopic separation.

Se ha realizado una separación de isótopos en vapor atómico de litio usando láseres de diodo sintonizables. El método permite la separación de los isótopos entre las líneas \(^6\)Li\(D_2\) y \(^7\)Li\(D_1\) usando un separador de masas que incluye un sector magnético y un haz de iones diseñado para litio.

Descriptores: Láser, separación isotópica.

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Introduction

Lithium isotopes are important for fission and fusion reactors [1]. We present the study of isotope separation method using an inexpensive diode laser. We used a two-step selective photoionization method [1–6]. The method permits the full separation of the different isotopes. This applies also for the case in that the lines of the different isotopes overlap.

Experiment

The experimental apparatus contains a vacuum chamber for the lithium beam. The beam of lithium atoms was produced by evaporating metallic lithium from a heat-pipe cell (Comstock, Mod. HP-802). The vapor flows from the heat-pipe cell into the vacuum and is collimated by a 0.5 cm circular aperture disposed at 30 cm from the connection between the heat-pipe cell and the vacuum chamber. The circular aperture acts as a neutral beam collimator and was placed 5 cm behind a Pierce extractor which is the entrance of a mass selector. The collimator and extractor were held at the same positive potential. The region between them is used as the laser ionization region. A CW diode laser (NewFocus, Model 6200) used for isotope selective excitation was focused into the neutral lithium beam, while for ionization of the excited atoms we focused the fourth harmonic of a Nd:YAG laser (Lee Laser, Mod. 815TQ) deployed in the counter propagating direction. The focusing area for the red light was \((11 \pm 1) \times 10^{-9} \text{m}^2\) and \((16 \pm 0.7) \times 10^{-9} \text{m}^2\) for the UV and were determined experimentally. More details on the laser system are given before [6].

Laser produced ions enter into a self made mass selector which consists in an ion gun combined with a magnetic sector. The entrance of the gun is a Pierce extractor held at \(V_p = 572 \pm 1 \text{ V}\) which causes a divergent emitted ion beam. The ion beam is focused with an Einzel lens system into the entrance of a magnetic sector. To calibrate the mass selector we have used a lithium ion cell (Heat-Wave Model Std.250xxx) containing a mixture of \(^6\)Li and \(^7\)Li isotopes. The lithium ion cell was installed and floated at the entrance of the Pierce extractor. The focusing voltage was \(V_f = 464 \pm 1 \text{ V}\), and determined experimentally. To measure the mass spectrum we disposed a 2.5 mm section copper wire which was moved by a gear system connected to rotary motion feedthrough with stepper motor (MDC, Model BRM275-03). The ion current reaching the wire was measured by a picoampermeter (Keithley, Mod. 485) and recorded via GPIB to a PC as a function of the wire position. With the mass spectra obtained by this way we could replace the wire at the exit of the sector by two 9 mm width cooper plates separated by 1 mm which serves as mass 6 and mass 7 collectors. In the experiment where the ions were produced by the lasers the ion cell was removed and replaced by the neutral beam and collimator described above. The lasers were focused just behind the Pierce element. The average current at the \(^7\)Li collector was measured with a picoampermeter (Keithley, Mod. 485) connected with a GPIB interface to a personal computer and recorded with a self made Labview5.0 application. The current of the \(^6\)Li isotope was recorded simultaneously with the same software and interface using a more sensitive picoampermeter (Keithley, Mod. 595). As the time required by our system to take the data for each pair of current values was 652 ms, we have changed the wavelength of the diode laser by moving the grating with a PZT using a slow triangular wave generator (HP, Mod. 3310B). The time to scan one complete spectrum was about 15 minutes, in order to get enough resolution at the ionization spectra. The wavelength was monitored with an optical wavemeter (Burleigh, Mod. WA4500). The total number of ions produced at the ionization area were obtained.
from an absorption measurement and compared to the ions collected at both plates behind the magnetic sector. In this case the transmittance was measured at saturation with the same laser intensity used at the current measurement. This was done at resonance and slightly off resonance to avoid etalon effects.

To determine the density of neutral lithium atoms we removed the focusing lens and reduced further the intensity by means of a neutral density filter. The spectrum was recorded using an optical powermeter (Newport, Mod. 1815C) and a digital storage oscilloscope (LeCroy, Mod. 9314A). The background light was subtracted. The absorption path length was determined from fluorescence measurements in [7].

**Background**

The number of ions $N_i$ produced after each UV pulse can be estimated using the result of an absorption measurement [6]

$$N_i = \frac{\alpha P_i P_e (1 - T)}{A}$$

where $\alpha = \frac{\sigma_i T_{UV}}{h^2 \nu_e \nu_i} = \frac{17100 m^2}{W^2}$, $P_i$ is the average UV laser power, $P_e$ the exciter power, $T$ is the exciter transmittance at the coincidence area $A$ of both lasers in the interaction region, $\sigma_i = 7 \times 10^{-22} m^2$ [2], $T_{UV}$ is the period of the UV laser pulses of the ionizing laser, $h$ is Planck’s constant and $\nu_e, \nu_i$ are the excitation and ionization frequencies respectively.

The transmittance is defined by $T = I_{on}/I_{off}$ where $I_{on}$ is the transmitted intensity with the laser in resonance and $I_{off}$ is the input intensity or the laser intensity slightly off-resonance. In this case the measurement is in the saturation region. The density $n$ of the lithium vapor can be obtained using the integral of the absorption coefficient over each line [5] when the laser intensity is low enough.

**Results**

A typical resonance ionization mass spectrum obtained at the plates behind the sector at the $^6\text{Li}$ and $^7\text{Li}$ collectors is shown in Fig. 1. The hyperfine structure of the isotopes can be resolved. The incident red laser power was $P_{off} = 4290 \mu W$ and $P_{on} = 4030 \mu W$ (considering losses in the windows) and $P_i = 50 m W$. With these considerations we obtained an upper limit for the ion number $N_i = 1.39 \times 10^7$ which corresponds to a current of 11 nA. The density of the neutral lithium beam was determined from the absorption spectra. In this measurement the intensity of the laser used for excitation was kept low enough to avoid saturation effects and optical pumping (1 W/cm$^2$ is convenient). We obtained $n = 3.2 \times 10^{16} m^{-3}$.

**Discussion and conclusions**

We have measured the laser isotope separation of lithium atoms using a tunable diode laser and a high repetition rate Nd:YAG laser. The narrow linewidth of the diode permitted us to resolve the different lithium isotopes including their hyperfine structure. The line $^7\text{Li}D_1$ was resolved from the $^6\text{Li}D_1$ using a mass selector in combination with the laser selective ionization. The mass spectrometer and ion collector previously calibrated with an ion cell gave a separate laser ionization spectra of each isotope.

![Figure 1. Typical resonance ionization mass spectrum obtained at the plates behind the sector at the $^6\text{Li}$ and $^7\text{Li}$ collectors.](image-url)