Time Dilation Phenomenon
In Saturated Absorption Spectroscopy Of Potassium

Authors: Kyle Tse(謝嘉豪), Jheng-Yu Li (李政諭), Ye-Li Le(李易麟)
Instructor: Yung-Fu Chen(陳永富)
TA: Ya-Po Yang(楊雅博), Po-Han Chen(陳柏瀚), Kuan-Hsun Chiang(江冠勳)
Department of Physics, National Central University

ABSTRACT

People have been trying hard to demonstrate time dilation with high costs and complicated methods. In 1960, Mössbauer utilized the relativistic Doppler effect to change the energy of gamma rays to reach the resonance frequency and demonstrated the resonant absorption of some atoms. We propose a novel way to show it which involves frequency shift in saturated absorption spectroscopy. In our experiment, we found out the Doppler broadening caused by thermal motion of atoms and derived Boltzmann constant.

THEORY

1. Saturated absorption spectroscopy :
   Atoms should have thermal motion if the temperature is above 0 K, the transition frequency shifts by Doppler effect, hence the absorption spectroscopy is broadened. To resolve the narrow transition line, one can apply two counter-propagating laser with the same frequency but different power on the atoms. The transmittance of the lower power laser (probe) increases at the exact transition frequency and forms a Lamb dip because the higher power laser (pump) saturates the ground state population.
2. Transverse Doppler Effect:
   According to special relativity, time dilation occurs when an atom moves fast. The magnitude of shift of transition frequency can be calculated by Lorentz transformation.

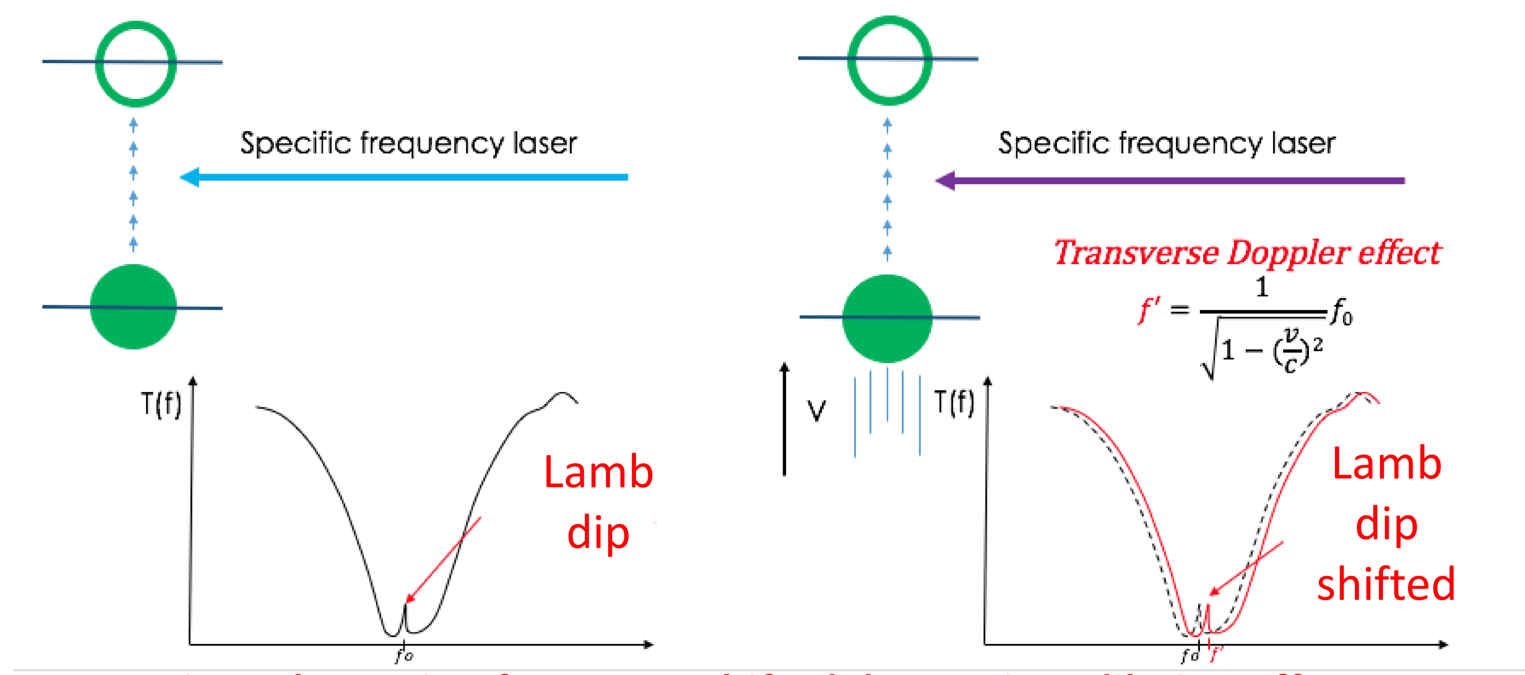

Fig.1 Absorption frequency shifted due to time dilation effect

EXPERIMENT SETUP

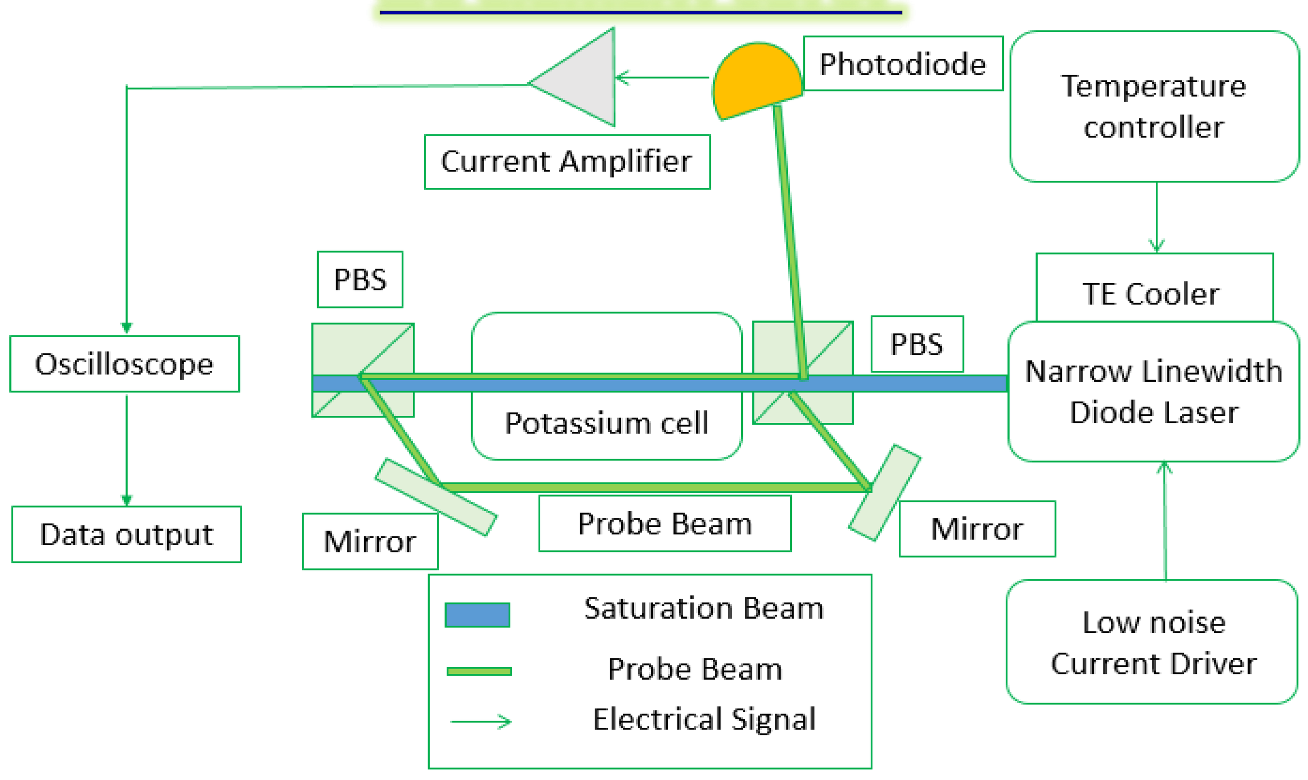

Fig.2 Block diagram of experiment

1. Home made potassium vapor cell:
   [Fig.4] The transition wavelength for potassium from 4s to 5p state is about 405nm.[1] [Fig.5] The cell was made by reducing the air pressure to 10^{-5} $torr$. The temperature of the cell is kept at 403K while conducting our experiment.
2. External cavity diode laser (ECDL) [Fig.6]:
   Made with 405nm laser diode and 1200 g/mm blazed grating
3. Low noise current driver:
   Low noise current driver maintains a stable current to the laser diode and therefore increasing the stability of lasing wavelength. The circuit of the driver is referred to [3]. The output current drift is about 700 nA/hr
4. TE cooler with PID control:
   TE cooler is used to adjust the temperature of laser diode.

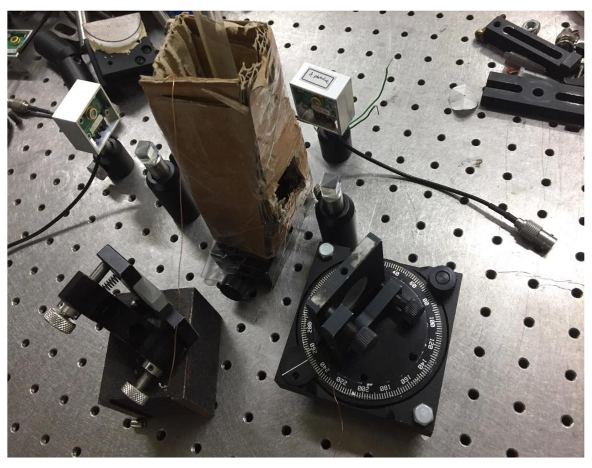

Fig.3 Experimental setup

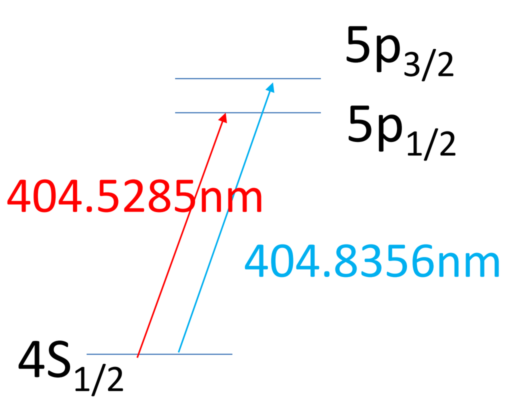

Fig.4 Potassium 4s to 5p transitions

Fig.5 Potassium cell

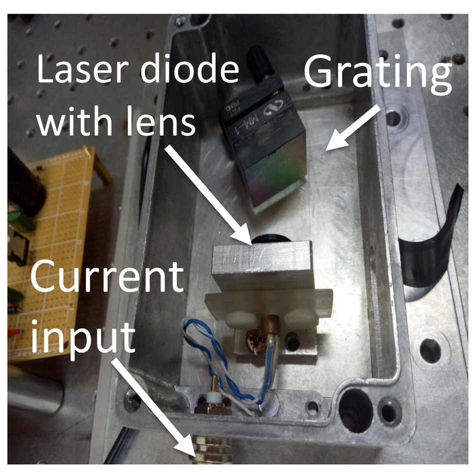

Fig.6 ECDL

EXPERIMENTAL METHOD

- The lasing wavelength depends on temperature. Our way to scan the spectroscopy is to heat up the laser diode to a certain temperature then turn off heating power to make the temperature of laser being cooled down naturally while photodiode detecting the intensity of probe beam passing through the cell.
- The temperature changes of laser diode measured by thermistor with time are recorded and plotted. [Fig.7]
- Linearly proportional relationship between them is found near the range of absorption spectrum. Hence, for each temperature corresponds to a wavelength, the relationship between lasing wavelength and time can be claimed to be linearly proportional.

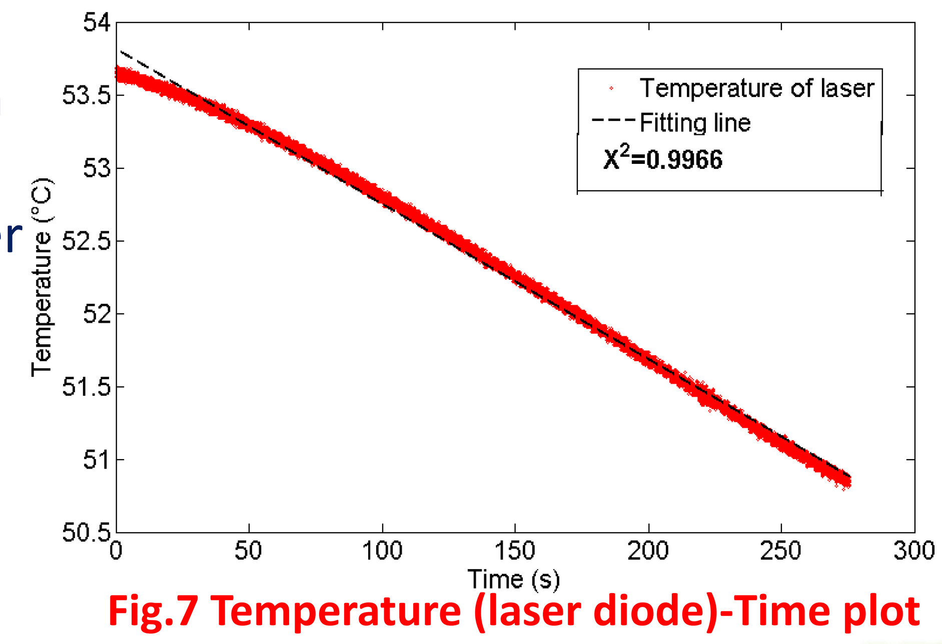

Fig.7 Temperature (laser diode)-Time plot

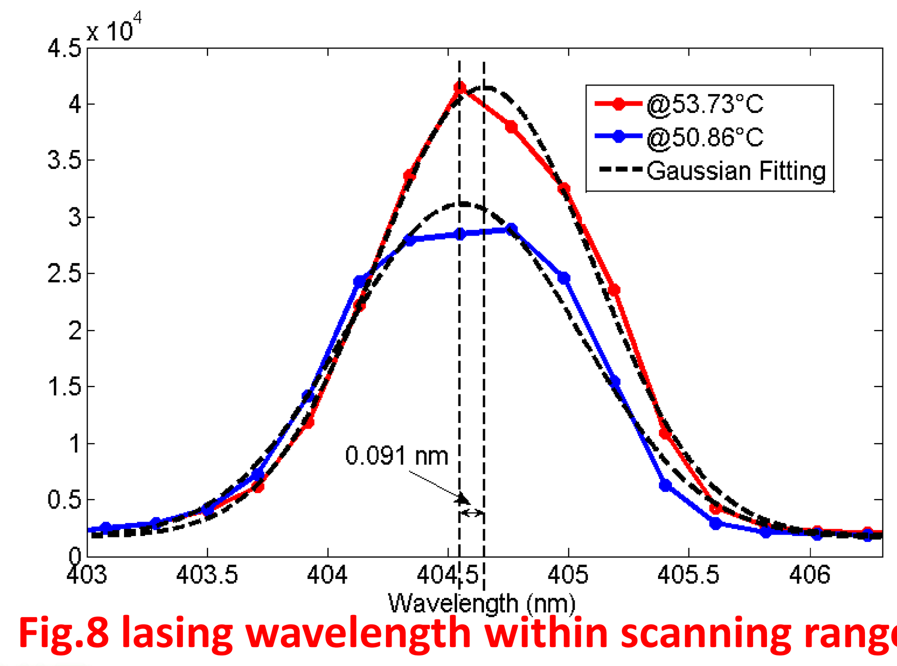

Fig.8 lasing wavelength within scanning range

RESULT

Data of absorption spectroscopy has been taken average of every four points. The time full width of half maximum (FWHM) is estimated by the Gaussian fitting of the data of spectroscopy. As a result, we can use the range of wavelength change within a recorded time to deduce the bandwidth of spectrum representing by wavelength.

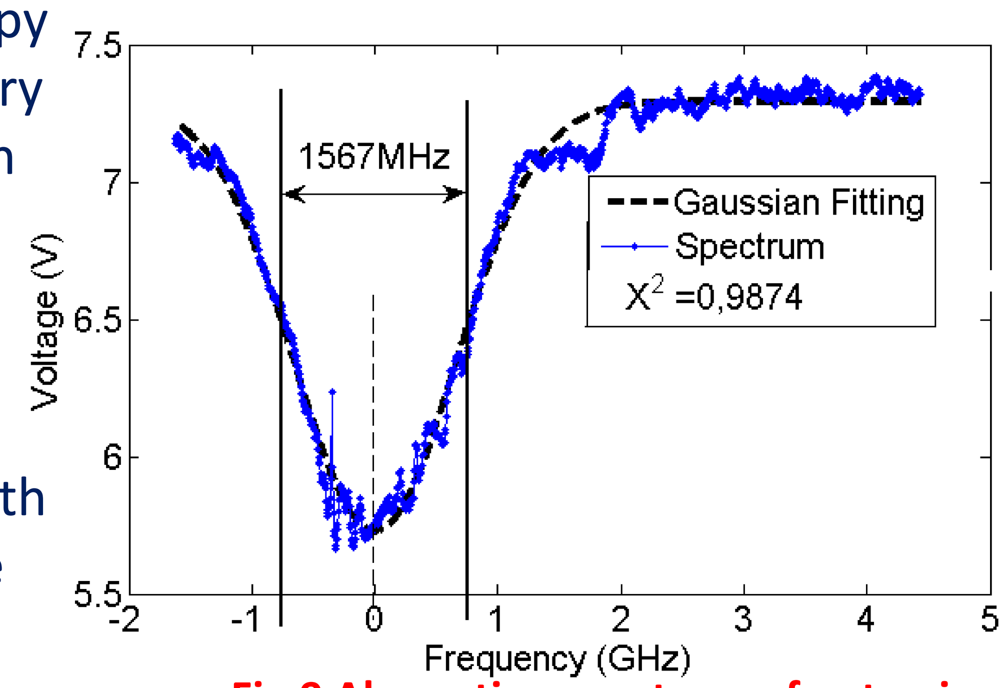

Fig.9 Absorption spectrum of potassium and Gaussian fitting curve

DISCUSSION

1. The noise of the signal from photodiode is too large to observe the Lamb dip. It maybe a result from the unsteady performance of heating system when laser diode is in a relatively high temperature state.
2. The thermal velocity distribution is given by Maxwell–Boltzmann distribution, so the Doppler broadened spectral bandwidth can be described as

$$\Delta f_{FWHM} = \sqrt{\frac{8kT\ ln2}{mc^2}} f_0$$

Comparing with the Doppler broadening from our experiment. We can get the Boltzmann constant of 1.170×10^{-23}J/K with an error of 15.3%($1.38064852 \times 10^{-23}$J/K).

CONCLUSION

1. Doppler broadening of the absorption spectroscopy of potassium has been observed.
2. The measured Boltzmann constant is about 1.170×10^{-23}J/K.
3. Thermal motion is characterized.

REFERENCE

[1] David Mckay(2009), Potassium 5p Line Data
[2] 卓至原(2015), D1 Line Spectrum Of Rubidium Atoms
[3] K. G. Libbrecht & J. L. Hall(1993), A low-noise high- speed diode laser current controlled.

Acknowledgement

We thank Yung-Fu Chen(陳永富) and Po-Han Chen(陳柏瀚), Low Temperature Physics Laboratory for vacuum pumps ; Jyhpyng Wang (汪治平), Hsu-hsin Chu(朱旭新)and Ya-Po Yang(楊雅博), High-Field Physics and Ultrafast Technology Laboratory for PBS ; Wang-Yau Cheng(鄭王曜) and Ya-Po Yang(楊雅博) ,Laboratory for comb laser based spectroscopy for project design.