# A Parametric Comparison Between the Behavio $^1S_0$ and $^3S_1$ of Helium and the Excited S-States o in Helium Neon laser

*Parekhan.M.Abdulrahman*

*Department of Physics ,College of Science , University of Sulaimani,Kurdistan Region / Iraq*

***Abstract***

*Gas-discharges have a wide range of spectroscopic parameters including the after-glow excitations. If a fixed mixture of He and Ne is operated as a traditional discharge phenomenon, then the important parameters could be measured spectroscopically.*

*This project aims to parametric comparison between the situation of both metastables of He states and the excited S-states of Ne in terms of different collision cross-sections, life-time considerations, spectral notations and many other resonant transfer parameters. The results were expected to be favorable and suitable for our purposes and they were optimum for a mixture of He and Ne in low power gas lasers.*

***Keyword*** : Meta-stable states, spectroscopy of inert gases, laser physics

## *Introduction*

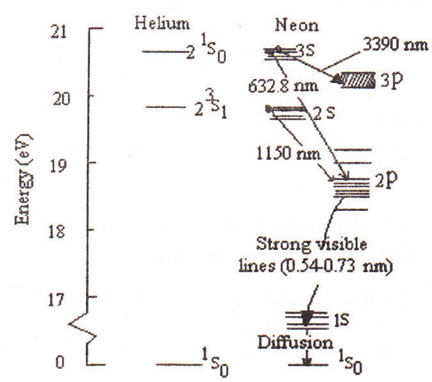
The He-Ne lasers active medium is an excellent example to be studied on the behavior of the process of exciting the $^1S_0$,$^3S_1$ of helium and 2S, 3S of neon.

All inert gases, He,Ne, Ar, Kr,and Xe possess at least one metastable state for which no selection rule, in both J-J and L-S coupling schemes, will be obeyed. The reason of this is that the atoms or molecules situated in these levels stay as much as they can and after this period they will de-excite to the lower state either by collision with the container wall or with neighboring atom. The optimum life time for these states range from few micro seconds to ~ 10 ms. Life time consideration will be of great importance in this work and the tendency will be toward the mechanism of excitation transfer at resonance, i.e. the net number of absorptions per unit time is the same as the net number of emissions per unit time also.

The factors responsible for this resonance were studied in detail and theoretical calculations were done to compare them with experimental one. The expotion of a mixture of helium and neon as the active medium in gas laser was analyzed to identify ideal requisites to operate this laser.

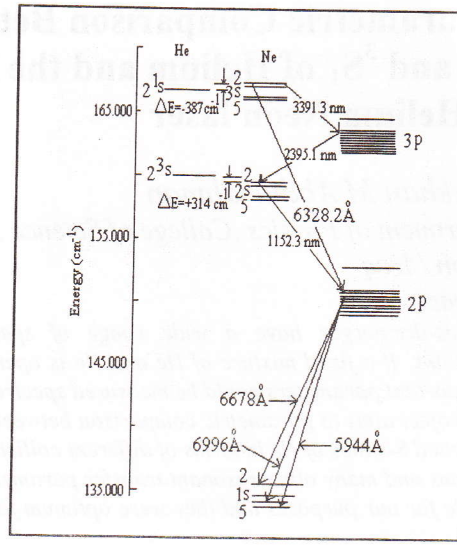
## *Theory*

Gas lasers [1] were generally employed a mixture of non- reacting gases to act as an active medium with specified ratios, for instance in $CO_2$ lasers the ratio of $CO_2$ : $N_2$ : He is 1:2:3




in volume proportion.

Partial atomic energy level diagram of helium and neon is shown in fig.1



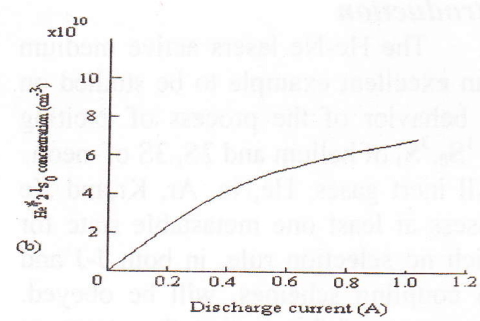

In fig.(1) both $^1S_0$ and $^3S_1$ in helium are metastables there life time estimated to be about **8** μs and 125 μs respectively, So the chance of $^1S_0$ to collide with neighboring atoms is much less than that of $^3S_1$, that stays for much longer time rather than $^1S_0$. The metastable of neon is represented by the 1s state where there is no lower states below it, thus the atoms in this state cool down through collision. Spectroscopic differences between metastables of helium and ( s ) states of neon are shown in fig.(2) In this figure, the spectroscopic equations governing the excitation transfer between the levels are reduced by two reactions :

He ($2^1S$)+Ne(G)+387cm$^{-1}$→ He(1S)+Ne(3S)

He ($2^3S$)+Ne(G)–314cm$^{-1}$→ He(1S)+Ne(2S)

Fig.(2) Spectroscopic details between meta-stables of helium and( s )states of neone This means that 3S state of neon lays above $^1S_0$ of helium by 387 cm$^{-1}$ ~ (0.048 eV) and 2S below $^3S_1$ of He by 314 cm$^{-1}$ (0.039 eV).

The collision excitation transfer in such mixtures are very complex we shall focuse only on those which occur at resonance.




**Fig(2)spectrospic details between meta-stnbles of hbelium and (5)states of neon.**

## *Transfer mechanisms*

Verdyen et al [2] have suggested that the number of variables in such transfers should be reduced by four processes. Fig.3 shows detail of these resonance transfers between the metastable ( $^1S_0$ , $^3S_1$) of helium and (3s ,2s) of neon.

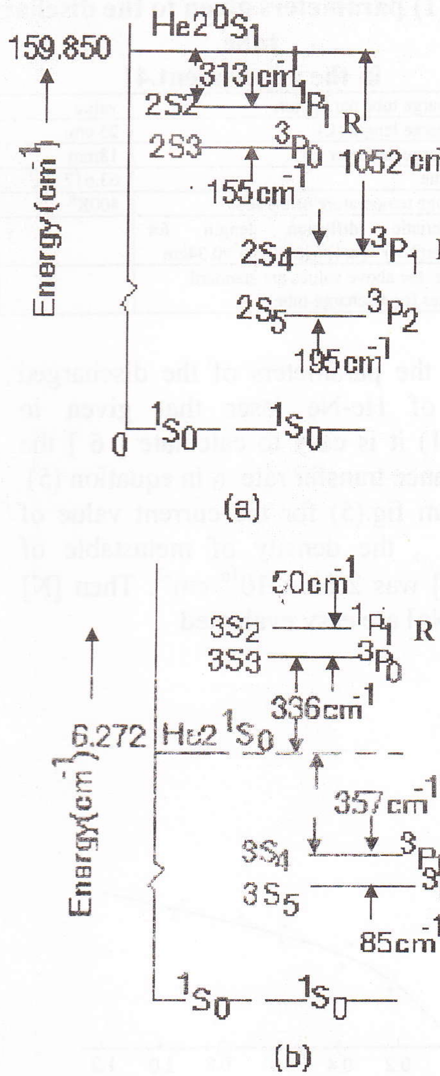



Fig.(3) The resonance transfer levels between :a- $^3S_1$ and 2s .b- $^1S_0$ and 3s
* R : refer to resonance state

Investigations by Phelps and his colleages [3]shows that for a simplified model of He-Ne laser the current of the discharge for all levels varies with densities of states semi-exponentially, i.e. for $N_0,N_1,N_2$, which are the meta-stables 1S,2S and 3S of Ne respectively and M is the meta-stable of He ($N_0,N_1,N_2$ and M are density numbers of excited atoms).The main equations for these states are :

$$d[M]/dt = n_{e\,m}v_e\,[He]-M/\tau_m- r_t[M][Ne]-n_e' v_e[M]......(1)$$

$$d[N_2]/dt = r_t[M][Ne]-A_2[N_2].....(2)$$

$$d[N_1]/dt = n_{ei}v_e\,[Ne]+n_{e10}\,v_e\,[N_0]-A_1[N_1]....(3)$$

$$d[N_0]/dt = n_{e\,0}v_e\,[Ne]+A_1[N_1]-n_{e\,0}\,v_e\,[N_0]+A_2N_2-[N_0]/\tau_0-n_{e\,3}\,v_e\,[N_0] ......(4)$$

Here: 1-All quantities in brackets refer to densities (number of excited atoms per unit volume) where:

$v_e$=the electron velocity calculated from $V_e=\sqrt{2T/M}$ where T is the kinetic energy of the electron and m is its mass.

$n_e$=the density of the state.

´ = the cross-section of the transition.

$\tau$ = the state life time

$r_t$ = the transition rate.

2-The products of ( ´)s i.e ($_{m,\ i,\ 3......}$) ,(N) and ($n_e$) represented the collision frequency of any process and multiplied by the proper density of the state.

Jeffery and Dalgarno [4], have shown algebraic analysis for these equations and used the Rapnsden-Newton iteration of the following values for the density of states, they were obtained by :

$M=n_{e}{}_{m}\acute{}Ne[He]/\ \tau_m{}^{-1}+r_t[Ne]+n_{e}{}_{i}\acute{}Ne$..(5)

$N_0=n_e[{}_0\acute{}Ne+{}_1\acute{}Ne][Ne]/\ \tau_0{}^{-1}+n_e\ {}_3\acute{}Ne$.(6)

$N_1=n_e\ {}_1\acute{}Ne[Ne]+n_e\ {}_{01}\acute{}Ne[Ne]$........(7)

$N_2=r_t[Ne][M]/\ \tau_2{}^{-1}$......................(8

If these equations hold for an optimum discharge current and voltage then we would be in a position to calculate the transfer rate ($r_t$) [5] for both absorption and emission transfers.

## *Experimentaldetails*

The apparatus arranged in fig.(4) was used to obtain the experimental part of this work. A He-Ne laser of 20mW [out put] connected with two digital multi-meters one in series and the other in parallel with the output of the step-up transformer of the laser cavity

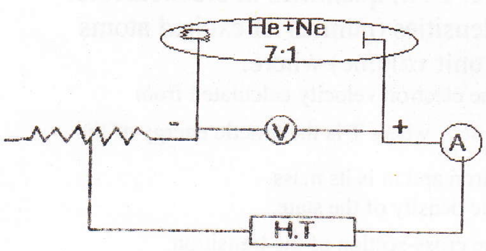



**Fig.(4) Experimental arrangement of the He-Ne discharge tube**

When the step-up was established against any mechanical shock, then through the rheostat the current was varied through 0.05A and the voltmeters reading was observed.

A repetitive set of readings were taken then after lengthly observation for the optimum temperature of the gas discharges the current was stabilized at 0.44A and at potential difference of 1100V the power consumption obtained was.

$P = V*I = 1100*0.44 = 484$ Watts..(9)

If the volume of the discharge is known then the density of metastables of He [ M ] and (No) of Ne are calculated.

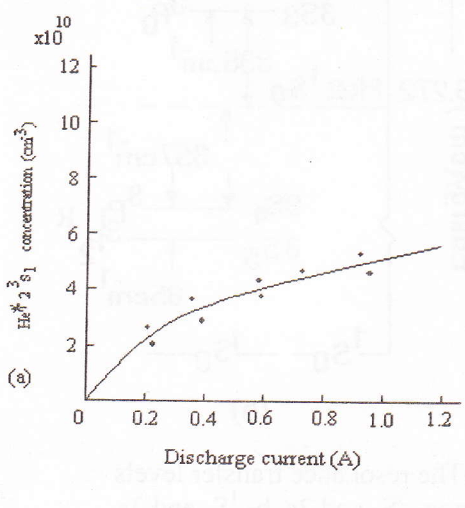
The results and tabulated in table No 2

**Table (1) parameters given to the discharge tube in the experiment.41**

| Discharge tube parameters | value |
|---|---|
| Discharge length (L) | 25 cm. |
| Discharge diameter (2r) | 18mm. |
| Volume | 63.617 $cm^3$ |
| Average temperature of the tube | $400K^0$ |
| Characteristic diffusion length for cylinder$(1/\wedge)^2=(\pi/4)^2+(2.405/r)^2=0.34$cm | |
| Note :the above values are standard values for discharge tube | |

From the parameters of the discharged tube of He-Ne laser that given in table(1) it is easy to calculate [ 6 ] the resonance transfer rate $r_t$ in equation (5)

From fig.(5) for the current value of 0.44A , the density of metastable of He[M] was $2.11 \times 10^{16}$ $cm^{-3}$. Then [N] and [No] are easy evaluated




State electron densitiees of metastables with discharge current.

## Results and Discussion

From equations (5) to (8) the discharge current is stabilized, then the relation between [Ne] and the decay rate $r_t \times 10^6 sec^{-1}$ is plotted as shown in fig.(6)

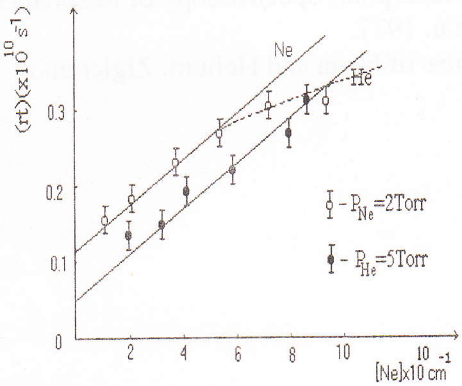



*Fig.(6)Decay rate of meta-stable rate($r_t$) wth densty of Ne*

It is clear from fig.(6) that for low [Ne] densities the transfer rate between metastables of He and 3S of Ne is low, and increases exponentially at about $6.85\times10^{10} cm^{-3}$ for [Ne].Then we alculate the rate coefficient of He at resonance for both metastablestates

Once Boltzmann distribution [6] is used to calculate the atomic densities for 2S and 3S in Ne without discharge by using eq.(9) and the standard values of the discharge tube in table(1) the ionization cross-section for both states are used to find the electron velocities at $^1S_0$ and $^3S_1$ for He. The results are arranged in table (2).

**Table(2Theoretical calculation for collision process between 1So →3S and 3S1→2S in resonance tube**

| Parameter | $^1S_0$ | $^3S_1$ |
|---|---|---|
| $\sigma_i$ ($cm^2$) ionization cross section | $0.28\times10^{-16}$ | $4.1\times10^{-18}$ |
| $v_e$ $cm\ s^{-1}$ the electron velocity | $2.639\times10^{8}$ | $2.692\times10^{8}$ |
| $n_e$ $cm^{-3}$ the density of state | $4.1\times10^{13}$ | $0.42\times10^{11}$ |
| $r_e$ emission rate | 3.4x1011 $cm^{-3}\ s^{-1}$ | 3.7x1011 $cm^{-3}\ s^{-1}$ |
| $r_a$ absorption rate | $6.46\times10^{11}\ cm^{-3}\ s^{-1}$ | $3.85\times10^{11}\ cm^{-3}\ s^{-1}$ |

## Conclusion

From the result of calculations it is obvious that there are few spectroscopic differences between the two meta-stables of He. The important conclusion regarding these states are :

1. The total number of collision per unit time [collisional frequencies] in $^1S_0$ is much less than that of $^3S_1$, the reason for this is that the latter has a better chance to collide with atoms of 2S in Ne rather than with 3S
2. The absorption and emission transition rates [$r_a$,$r_e$] are characteristics of collision cross-section at resonance between meta-stable states of [He] and (S) states of Ne.

This means that they are independent of the discharge parameters like tube length, cross-section, temperature or densities but they are functions of excitation and ionization cross-sections only.

3. In this project the important parameters of the discharge can not be measured classically. But when the equations of state (eq.1 → eq.4) are used then the microscopic views of the discharge could be studied in terms of the concentrations.

## References

[1] Laser electronics,Joseph Verdyen Princton-Hall, New Jersey1988.
Verdyen et al, Resonant excitation transfer between [He] and [Ne] mixtures "Phy.
[2] Scientific instrumentation" 1995,**26**,415.
[3] Phelps.,A.V. Excitation collision cross-section in gas discharge mixture J.of Chemical physic, 1992,**57**,3175.
[4] Jeffery,A,and Palgarno,G,Matrix Element Operater for rate equation in Inert gases, J.of the Optical Society of America, 1998,**16**,266.
[5] P-Zenter,et al. Dynamics of Emission and Absorption Spectroscopy of Resonance discharge tube. Highly Ionized gas, Oxford p.u. 1977.
[6] Laser induced transition between meta-stables of Neon and Helium, Zigler and Zmara"J.J.P.S 1999,**16**,122.

# بەراوردی لە نێوان خۆمالیەکانی ئاستی$S_0$ $^1$و$S_1$ $^3$ ی هێلیۆم وئاستی بزوێنراوی $S$بەراورد ی نیۆن لە لەیزەری هێلیۆم نیۆن دا .

پەری خان محەمەد عبدالرحمن
فیزیك / كۆلێجی زانست/ زانكۆی سلێمانی / هەرێمی کوردستان- عێراق

## پوختە

ئاشكرایە كە كرداری خاڵی کردنەوەی کارەبا لە گازدا کاری گەرێکی فراوانی هەیە وگۆرانکاریەکی زۆر لە دوایی خاڵیکردنەوەکەدا روو ئەدا. وەك بزواندنی ناوەندەکەو گۆرانی ئاستی ووزە.

ئەگەر چەسپەرێژەیەك لە هێلیۆم و نیۆن تێکەڵ بکرێن لە نێو تیووبێکی خالیکەرەوەی کارەبایی دا ئەوا شەبەنگ کاری تیشکی بە دەست هێنراو زانیاریەکی زۆرمان ئەداتێ.

مەبەست لەم توێژینەوەیە بەراوردکردنی رۆڵی هەردوو ئاستی نینچەجێگیری هێلیۆم و ئاستە وروژاوەکانی جۆری$S$ لە گازی نیۆن دا یە بە هاوکاری چۆنیەتی گونجانی رووبەری بەریەك کەوتن, ئەگەری بەریەك کەوتن, تەمەنی ئاستەکان, هیمایی شەبەنگیەکان وگەلێ ڕواڵەت کاری تری زرنگە گواستنەوە.

ئە نجامەکان زۆر گونجاوبوون لە گەڵ هاوتاتیۆریەکانیان و توانرا نرخی لە باریان بۆ بدۆزرێتەوە لە لەیزەری هێلیۆم نیۆنی توانانزمەکاندا.

## الخلاصة

# دراسة مقارنة لسلوك المستويين والمستوي $S$للنيون في ليزر الهيليوم _نيون
# $^1S_0$ و $^3S_1$ للهيليوم

به ری خان محمد عبدالرحمن
قسم الفيزياء / كلية العلوم / جامعة السليمانية / اقليم كردستان - العراق

تعد عملية التفريغ الغازي وسيلة ملائمة لإنارة الأوساط الغازية ,فهناك تغيرات كثيرة تطرأ على الوسط الغازي بعد عملية التفريغ من ضمنها تغير مستوي طاقة مكونات الوسط الغازي.

عند دمج نسبة محددة من غازي الهيليوم والنيون في انبوبة التفريغ الغازية فان التحليل الطيفي للضوء المنبعث يعطي معلومات قيمة حول الموضوع.

الهدف من هذه الدراسة هي مقارنة المستويين الشبه المستقرين للهيليوم مع المستويات المثارة من نوعs للنيون بدلالة المقطع العرضي للتصادم ,مدى العمر ,الرموز الطيفية وغيرها من باراميترات الانتقال الرنيني.

نتائج الدراسة كانت مرضية ومناسبة لأغراضنا ومثالية في حالة ليزرات الهيليوم _نيون الغازية ذات القدرات الواطئة .

Received 6 /1/2002 .Accepted 22/1/2002. وەرگیرا لە٦/١/٢٠٠٢دا وەپەسەندکرا لە ٢٢/١٢/٢٠٠٢.