Measurement of effective lifetime of metastable excited atom Ne($^3P_2$)

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Measurement of the transient current after turning off the UV light in a Townsend discharge is carried out to determine the effective lifetime of the metastable excited atom Ne($^3P_2$). The diffusion coefficient of Ne($^3P_2$) in neon, the reflection coefficient of Ne($^3P_2$) at the electrode surface and the collisional quenching rate coefficient of Ne($^3P_2$) by Ne were determined from the observed effective lifetime of Ne($^3P_2$). Furthermore, both the diffusion coefficient and the collisional quenching rate coefficient were compared with previously reported values in the literature. Our present values were consistent with reported values.

1. Introduction

In the previous studies, we derived the effective lifetime of the metastable excited molecule $N_2(A^3\Sigma_u^+)$ by waveform analysis of the transient ionization current in a Townsend discharge. The fundamental coefficients of $N_2(A^3\Sigma_u^+)$ were determined by curve fitting procedure to theoretical values which were obtained from the solution of the diffusion equation. That was solved using the third kind of boundary problem. As a result, we determined three fundamental coefficients of $N_2(A^3\Sigma_u^+)$ by 16 air pollutant gases [1]-[4].

In this paper, we report similar results for the metastable excited atom Ne($^3P_2$). Many studies on metastable excited atoms of Ne have been performed not only to investigate the excitation and ionization processes in an inert gas but also to develop various types of light source. For example, Tachibana and Phelps [5] obtained the excitation coefficient by combining laser-induced fluorometry and the laser absorption method, and evaluated the electron excitation cross sections of 1s5 (metastable level) and 1s4 (resonance level). Biondi [6], Dixon and Grant [7] and Molnar [8, 9] determined the diffusion coefficient of Ne($^3P_2$). Moreover, Molnar analyzed and observed the current waveform after turning off the UV light in a Townsend discharge and determined the diffusion coefficient of the metastable excited atom. We used the same method in the present study but with a different procedure and we solved the diffusion equation as a third kind of boundary problem.

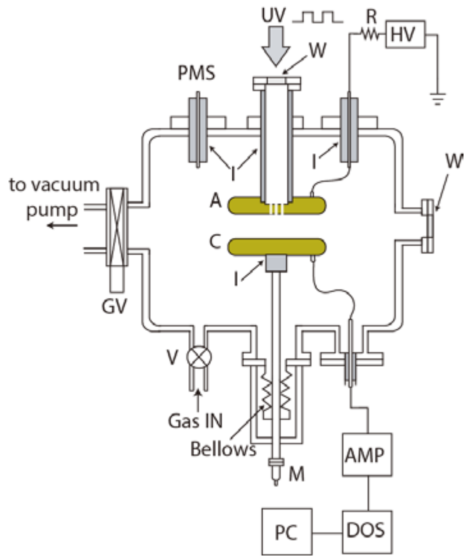
Here, we analyzed the effective lifetime of the metastable excited atom Ne($^3P_2$) taking into account the reflection on the electrode surface and we determined the diffusion coefficient, the reflection coefficient on the electrode surface and the collisional quenching rate coefficient of Ne($^3P_2$) by neon.

2. Metastable excited atom of Ne

It is well known that there are two metastable excited atoms Ne($^3P_2$) and Ne($^3P_0$) whose thresholds are 16.62 eV and 16.72 eV, respectively. Their lifetimes are both on the order of 1 s [10, 11]. Previously, we compared experimental results obtained from the luminous layers [12, 13] in Ne with the results of a Monte Carlo simulation. It was shown that the amount of Ne($^3P_2$) produced by electron impact in neon at a pressure of p_0=10 Torr and a reduced electric field of E/p_0=7.8 V/cmTorr was approximately five times the amount of Ne($^3P_0$) produced. It was concluded that this was due to differences in the electron collision cross section of Ne; the peak of the excitation cross section of Ne($^3P_2$) is about five times larger than that of Ne($^3P_0$) in the narrow electron energy region. Thus, in this paper, we assume that all of the metastable excited atoms are Ne($^3P_2$).

3. Experimental apparatus and method

A schematic of the experimental apparatus used in this study is shown in Fig. 1. A vacuum chamber was evacuated to a pressure of 10^{-8} Torr using a turbomolecular pumping system. A pair of gold-plated parallel plane electrodes were installed in the centers of the chamber. A stabilized DC high voltage was applied to the anode. UV light driven by a pulse lighting system with a period of about 0.4 Hz was irradiated onto the cathode through a quartz window and holes in the central part of the anode. The transient ionization current was observed using a fast current amplifier after turning off the UV light. A typical transient current waveform was observed as shown in Fig. 2. This waveform was monitored as averaging of 64 times of repeated measurements by a digital oscilloscope. An example of the waveform is shown in Fig. 2. After the turning off the UV light, an instantaneous decrease in the current I_p from the total current I was first observed. This component I_p is the product of the amplification factor by collisional ionization of electron in the gap and the sum of both emission currents from the cathode by the UV light and by positive ions and photons, the so-called fast γ-action. This was followed by a gradual decrease in the current $i_m(t)$ with initial amplitude I_m and time constant τ_m owing to the decay of electrons released by metastables striking the surface, the so-called γ_m process [14, 15]. Using both



AMP: High-speed current amplifier, DOS: Digital oscilloscope, PC: Personal computer, GV: Gate valve, HV: High voltage, PMS: Gas pressure measurement system, UV: UV light, M: Micrometer, V: Valve, W: Quartz window, A: Anode, C: Cathode, I: Insulator.

Fig. 1 A schematic of the experimental apparatus.

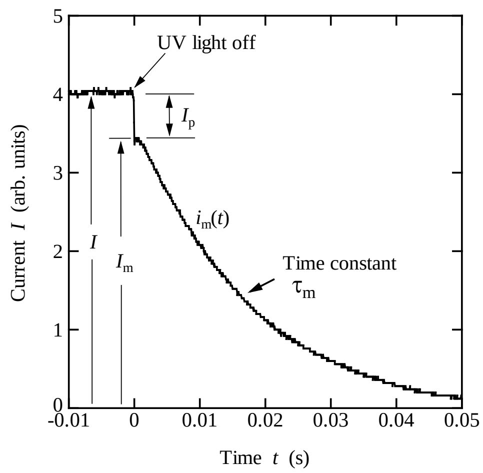


Fig. 2 Typical transient current waveform.

the observed currents I and I_m and τ_m, the effective lifetime τ_1 of $Ne(^3P_2)$ is given by

$$\tau_1 = \tau_m \left(1 - \frac{I_m}{I}\right). \quad (1)$$

τ_1 was calculated by analysis [15] in which the reflection of $Ne(^3P_2)$ on the surface of the electrode was considered. The expression used to calculate τ_1 consists of a diffusion term and a term representing collisional quenching by Ne as follows:

$$\frac{1}{\tau_1} = D_{m1}\frac{\mu_1^2}{d^2}\frac{1}{p_0} + kN_1 p_0 . \quad (2)$$

Here, D_{m1} $(=D_m \cdot p_0/p_1)$ (cm^2/s) is the diffusion coefficient of $(^3P_2)$ at 0℃ under a pressure of p_1 Torr, k cm^3 (1/s) is the collisional quenching rate coefficient of $Ne(^3P_2)$ by Ne, N_1 $(1/cm^3)$ is the density of gas molecules at 0℃ under a pressure of p_1 (Torr), d (cm) is the gap length, p_0 is the reduced gas pressure at 0℃ and p_1 is taken to be 1 Torr. μ_1 is a first-order constant that describes the density function of the metastables, that is, the first root of the Fourier radiation series given by the reflection coefficient R of metastable neon atoms at the surface of the electrode [1, 2].

4. Experimental results and discussion

4.1 Current-voltage characteristics

Figure 3 shows the observed current - E/p_0 curves in Ne at gas pressures from 1 to 10 Torr. The initial current induced by photoemission was 2×10^{-12} A after adjusting the intensity of the ultraviolet light at the reduced electric field of E/p_0=10 V/cmTorr. At a

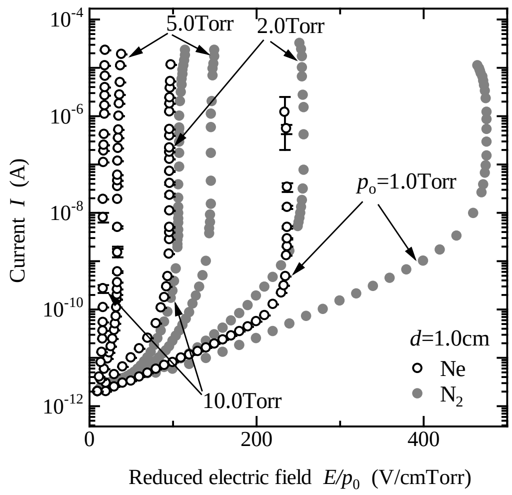


Fig. 3 Characteristic of current-voltage in Ne.

pressure of 1 Torr, the current increases gradually with increasing in E/p_0. At E/p_0≒230 V/cmTorr, the current - E/p_0 curves vertically increase when the current reaches approximately 1×10^{-10}A and the current increases to 10^{-9} A order. In the range of current, the current is not stable with time under a constant voltage. For comparison, the current - E/p_0 characteristic in N_2 is shown as filled circles in Fig. 3. The ionization current in N_2 increases gradually up to 10^{-9} - 10^{-8} A order over a wide range of E/p_0 then increases more slowly with a smooth curve, i.e., start of the self-sustaining discharge. These differences in the ionization growth of the current are caused by differences in the electron collision cross section. In the case of N_2, many inelastic collisions, i.e., energy loss process of electron by rotational excitation (however, this is not shown in Fig. 4), vibrational and electronic excitations in front of the ionization cross section. In contrast, in the case of Ne, no rotational and vibrational excitation collisions occure up to the threshold of the lowest electronic excitation Ne($^3P_2$) as shown in Fig. 5. Moreover, the difference in the threshold between the lowest electronic excitation (16.62 eV) and ionization (21.56 eV) is only 5 eV.

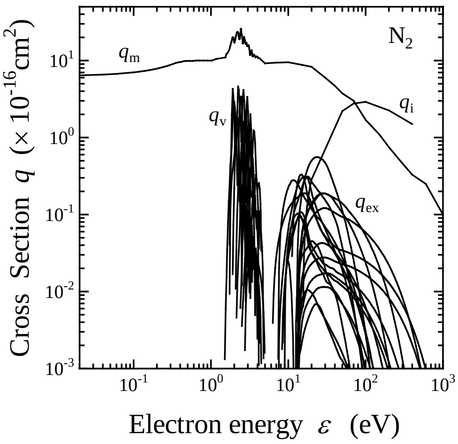


Fig. 4 Electron collision cross section of N_2 [16].

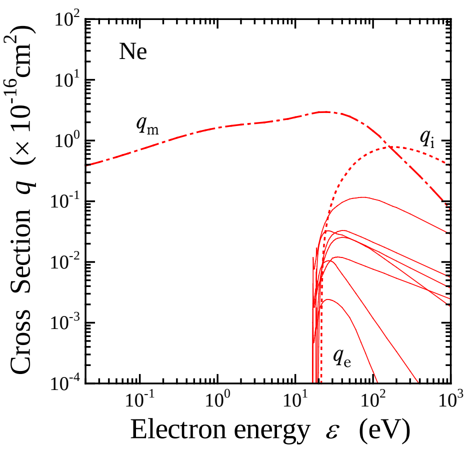


Fig. 5 Electron collision cross section of Ne [16].

Furthermore, we have many electronic excitation levels, however, we classified them seven into kind of excitation cross sections [16] in the narrow energy region. Thus, the current - E/p_0 curves for Ne suddenly increase near a current of 1×10^{-10}A as shown in Fig. 3.

4.2 Observation of transient current waveform and determination of three coefficients

Figure 6 shows the observed transient current waveform on the semi-logarithmic scale at a pressure of 10 Torr in Ne. We determined the effective lifetime τ_m of Ne($^3P_2$) from the slope and the initial value I_m of the decaying transient current component $i_m(t)$ using the eq. (1).

Curves showing the obtained effective lifetime τ_1 plotted against the gas pressure for different gap lenghs are plotted on a log-log scale in Fig. 7 with error bars representing the standard deviation. These plots were fitted using eq. (2), and the diffusion coefficient D_{m1}, the collisional quenching rate coefficient k of Ne($^3P_2$) by Ne and the reflection coefficient R of Ne($^3P_2$) at the electrode were determined as 177±17 cm^2/s, $(3.2\pm0.4)\times10^{-16}$ cm^3/s

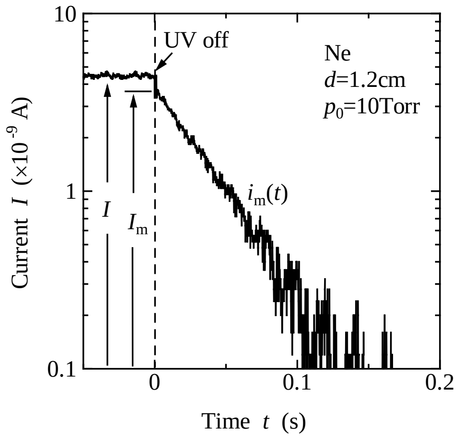


Fig. 6 Actual transient current waveforms at gas pressure of 10 Torr in Ne.

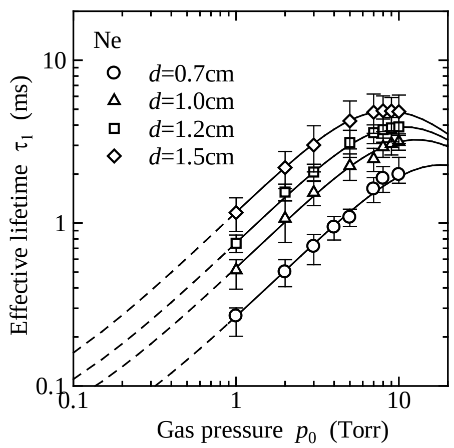


Fig. 7 Effective lifetime Ne metastable atoms in Ne.

and 0.10±0.04, respectively.

4.3 Diffusion coefficient of Ne($^3P_2$)

Table 1 lists the diffusion coefficient of the metastable excited atom Ne($^3P_2$) obtained in this study (177±17 cm^2/s) and previously reported values. Biondi [6] and Dixon and Grant [7] obtained their values experimentally by the pulse afterglow method. The value reported by Biondi was 200±20 cm^2/s. Dixon and Grant separated two Ne metastable excited atoms $^3P_2(1s_5)$ and $^3P_0(1s_3)$ obtained a value of 170±10 cm^2/s for both of them. Furthermore, Molnar [8, 9] analyzed the transient current waveform in the Townsend discharge region and obtained a value of 120±10 cm^2/s from the effective lifetime.

Table. 1 Reported values of diffusion coefficients of Ne($^3P_2$) in Ne.

Diffusion coefficient D_{m1} (cm^2/s)	Exp.	References
177±17	T.D.	Present
200±20	P.AF.	Biondi [6]
170±10	P.AF.	Dixon [7]
120±10	T.D.	Molnar [9]

4.4 Reaction rate coefficient of Ne($^3P_2$)

Table 2 lists the rate coefficients of Ne($^3P_2$) in the present and previous studies [17]-[19]. We measured the collisional quenching rate coefficient of Ne($^3P_2$) by Ne($^1S_0$) and obtained a value of (3.2±0.4)×10^{-16} cm^3/s from the secondary electron emission current of the γ-action by metastable excited Ne($^3P_2$) at the cathode. Collisional quenching rate coefficients of Ne($^3P_2$) by Ne($^1S_0$) have not been previously obtained by this procedure to the best of the authors' knowledge.

Table. 2 Reported values of rate coefficients.

Rate coefficient k (cm^3/s)	Temperature (K)	References
(4.4±0.6)×10^{-16}	300	Present
(2.08±0.8)×10^{-15}	300	Sierra et al [17]
3.4×10^{-15}	300	Phelps [18]
5×10^{-15}	300	Leichner et al [19]

5. Conclusion

We determined three fundamental coefficients for Ne($^3P_2$), i.e., the diffusion coefficient, the reflection coefficient on the electrode surface and the collisional quenching rate coefficient.

6. Acknowledgment

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7. References

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