Lifetime of the 3^1P State of Helium*

R. G. FOWLER, T. M. HOLZBERLEIN,† AND C. H. JACOBSON
Samuel Roberts Noble Laboratory of Electron Physics, University of Oklahoma, Norman, Oklahoma
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The pressure dependence of the lifetime of the helium transition 3^1P-2^1S has been measured over a wide range of pressure, ranging from free escape to complete blockading. The values of lifetimes so obtained are in good agreement with theory. At pressures beyond 1 mm Hg, quenching is observed corresponding to a probable molecular formation.

IN another place[1] we have described a new absolute method for obtaining radiative lifetimes of atoms, and given a number of our earlier results for helium.[2] We have recently completed a study of the crossing over of the 3^1P state of helium with increasing density from radiating jointly via 3^1P-1^1S and 3^1P-2^1S to radiating solely via the 3^1P-2^1S transition as the ground-state radiation becomes impeded by absorption in the gas. The results are compared in Fig. 1 with the "maximum" and "minimum" theories of escape advanced by Phelps.[3] It is seen that rather than bounding the experimental data, these curves both lie below the majority of points measured.

We have also plotted the variation of the relative intensity of the 5016-Å line as observed by St. John *et al.*[4] in a beam apparatus. For the purpose of the plot, these data were fitted to the theoretical value of lifetime at very small pressures, and then allowed to follow their natural course at higher pressures. They would be expected to deviate at high pressures because of the drastically differing geometric factors for the two situations. It is evident from this relative-intensity curve that the lifetime apparatus is giving reliable numbers even at gas densities as low as 3×10^{-3} atoms/cc, and times as short as 3 nsec. Insofar as possible, systematic error has been avoided by the use of several operators, two different styles of experimental tubes, and two quite different oscilloscopes.

The ability to measure these short lifetimes with either a triode configuration for the experimental tube in which the cutoff voltage was applied between two grids, or a diode configuration in which it was applied

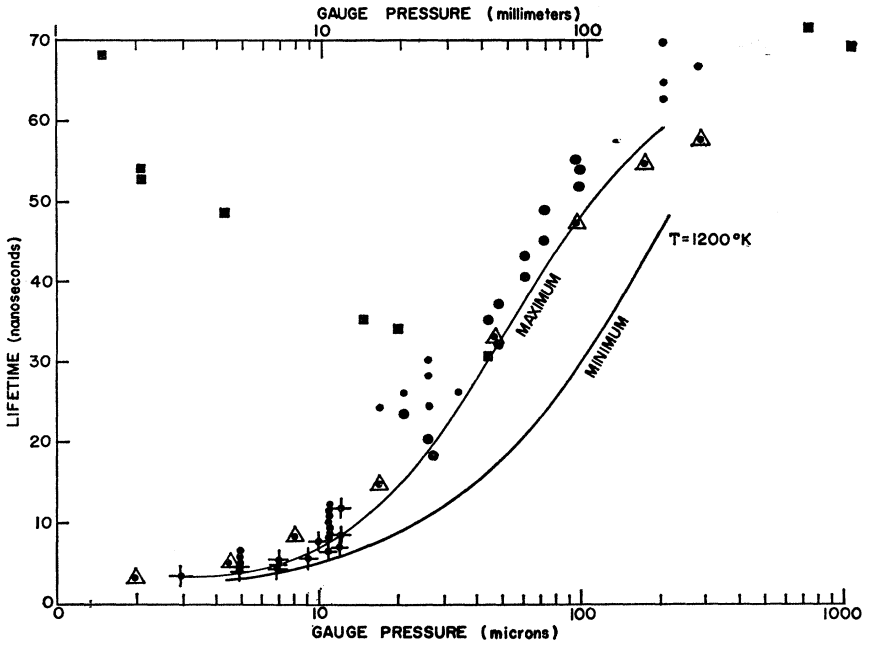

FIG. 1. Lifetime of 5016 Å helium transition. Various operators and conditions. Dots = Holzberlein, triode, 555 Tektronix, August 1964; dot-circles = Jacobson, triode, 555 Tektronix, May 1964; crosses = Holzberlein, diode, 519 Tektronix, August 1964; hollow squares = Holzberlein, diode, 555 Tektronix, February 1964; solid squares = same as hollow squares except pressure scale is in mm Hg rather than μ Hg; triangles = St. John *et al.* intensity data normalized at lower end. Curves are from Phelps' theory.

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† Permanent address: Principia College, Elsah, Illinois.
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between grid and cathode was gratifying since it served to validate the longer lifetimes reported previously[2] using only the triode. Such a reinforcement in confidence in the triode is desirable since it is so much more flexible a device, and we expect to use it solely in future work.

Above the saturation state expected when full blockading of the 3^1P-1^1S transition sets in, a decline from saturation occurs as density is further increased. This may perhaps be explained by the hypothetical process of molecular formation in collisions between 1^1S states and the 3^1P states.

The cross section for this process would have needed to be 2.0×10^{-16} cm^2 for formation from the 3^1P state compared with 2.7×10^{-16} cm^2 as found by Fowler and Duffendack[5] (their Table II contains a computational error) and with a value of 2.0×10^{-16} deducible from Hornbeck's measurements[6] on the assumption that the formation cross section is the same for all states.

In the course of these measurements, additional high-pressure data were obtained on two other transitions: 3^3D-2^3P at 5876 Å and 4^1D-2^1P at 4921 Å. At 20 mm Hg these lifetimes were 56 nsec and 42 nsec, respectively, and at 44 mm Hg they were 46 nsec and 34 nsec. The 5876 Å is down considerably from the 200-nsec value obtained at low pressures, but the 4921-Å lifetime is within the experimental error of the 35-nsec value observed in a low pressure.

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Stimulated Emission of Radiation in a Single Mode

F. W. CUMMINGS
University of California, Riverside, California
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Recently Glauber has described the properties of coherent radiation fields, and has constructed the density matrix of the field in two simple cases: (1) The radiating system is a classical radiator and no reaction is considered; (2) the central-limit theorem applies to a collection of radiators. This paper investigates other simple "almost" exactly soluble problems, in which a quantum-mechanical two-level system interacts with a quantized electromagnetic field originally in a pure coherent state in a single mode. The first-order correlation function $G^{(1)}=\langle E^-E^+\rangle$ is compared with $\langle E^-\rangle\langle E^+\rangle$ at resonance when the stimulating field is initially a pure coherent state and the two-level system is initially in its excited state. The corresponding quantities are also computed for a field whose initial density matrix is a Gaussian superposition of coherent states (e.g., blackbody radiation), as well as for a field which is initially described as having a given number of photons.

I. INTRODUCTION

THE concept of coherence of an electromagnetic field has been introduced by Glauber[1] in terms of an nth-order correlation function

$$G_{\mu_1\cdots\mu_{2n}}{}^{(n)}=\langle E_{\mu_1}{}^-(x_1)E_{\mu_2}{}^-(x_2)\cdots E_{\mu_n}{}^-(x_n) \times E_{\mu_{n+1}}{}^+(x_{n+1})\cdots E_{\mu_{2n}}{}^+(x_{2n})\rangle, \quad \text{(I1)}$$

where $\langle(\ )\rangle$ stands for trace $\rho(\ )$, $x_n\equiv(\mathbf{x}_n,t_n)$, and the μ's denote the polarization. The electric field operator E is written as a sum of positive- and negative-frequency parts, $E=E^+{+}E^-$. A "pure coherent" state is one for which $G^{(n)}$ factors into the product

$$G_{\mu_1\cdots\mu_{2n}}{}^{(n)}=\mathcal{E}_{\mu_1}{}^*(x_1)\mathcal{E}_{\mu_2}{}^*(x_2)\cdots\mathcal{E}_{\mu_n}{}^*(x_n) \times\mathcal{E}_{\mu_{n+1}}(x_{n+1})\cdots\mathcal{E}_{\mu_{2n}}(x_{2n}) \quad \text{(I2)}$$

for all n. We are led to a definition of "nth-order coherence" as factorization through order n of $G^{(n)}$. This definition is the quantum-mechanical generalization of previous ones[2] and includes nonstationary processes, an example of which is investigated in this paper. In two elegant papers,[1,3] Glauber defines nth-order coherence and describes the properties of coherent states of the electromagnetic (e.m.) field. Two examples are given, one in which the field is produced by a classical radiator (which always produces pure coherent states) and in the other by a chaotic source (e.g., discharge lamp) for which the density matrix of the field is seen from the central-limit theorem to be a Gaussian superposition of coherent density operators in each normal mode. The problem which we shall investigate here is the following: An atom (molecule, spin) is initially in an excited state at $t=0$, at which time it comes into interaction with a quantum-e.m. field in a pure coherent state in a single mode at the resonance frequency of the two-level system (TLS).[4] The question arises: "To what extent will the field produced by stimulation also be coherent?" It is also interesting to compare the resulting field, in which the stimulating

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