

The Design and Construction of a System for Direct Measurement of Atomic Lifetimes

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Abstract

The project reported in this paper involved the design and construction of a system to directly measure atomic lifetimes, and follows the technique employed by Jules Klose of the National Bureau of Standards. A low energy 10 to 30 eV, 200 nsec-duration, 10 kHz square wave electron excitation pulse was used to excite a gas at a pressure of 1×10^{-4} Torr. The visible emission spectrum was observed by a photomultiplier through a grating spectrometer which permitted the selection of the desired spectral line or energy level transition. Employing delayed coincidence techniques familiar in nuclear physics, the square excitation pulse and the ensuing photomultiplier pulse were fed into a time-to-pulse height analyzer whose output would display the decay of the emission intensity as a function of the time for relaxation of the atomic systems. The project was completed to the construction of the time-to-pulse height converter and promises to be useful in obtaining data on atomic lifetimes.

Introduction

This project was the first study by the Department of Physics at Ball State University in the measurement of atomic lifetimes. For this initial work the project was divided into two segments. The theoretical computations and calculations comprised the M.S. thesis work by Mr. Danemar (4), while the actual design and construction of the system comprised the M.S. thesis work of Mr. Blanc (2). This paper is essentially a synopsis of the latter thesis.

The purpose of the project was to design and construct a system capable of measuring the rate of decay of excited atomic energy levels in neutral atoms. The atomic excitation was achieved by bombarding a gas with an electron beam of sufficiently low energy so as to obtain excitation of neutral atoms rather than ionization. A short square wave pulse of low energy electrons was used as the primary beam. The measurement of the decay time of the subsequent atomic relaxation after the pulse was made by observation of the decay time of the intensity of the invisible radiation emitted by the gas as detected by a grating spectrometer. The desired spectral line was selected from the spectrometer and the emitted photons received by a photomultiplier. By analysis of the delayed coincidence between the detected photomultiplier pulses and the primary electron pulses, the decay of the excited state could be determined.

History

The method of delayed coincidence in photomultiplier scintillation counting in nuclear physics was first applied to direct measurement of

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atomic lifetimes by Heron, McWhirter, and Rhoderick (6) about 1954 at the University of Glasgow. They sought to develop an accurate and direct method of measuring atomic lifetimes capable of determining whether or not the decay was of an exponential form. The technique was further developed by Bennett, Javan, and Ballik (1) in 1960 at the Bell Telephone Laboratories by using a multichannel pulse-height analyzer in conjunction with a pulse time-to-height converter. This method proved to be both enormously faster and stabler than the single-channel technique employed by Heron, et al (6). Later this technique was employed in 1964 by Holzberlein (7, 5) at the University of Oklahoma, as well as by Pendleton and Hughes (10) at the University of Arkansas, to measure the lifetime of helium. The same technique was employed by Klose (8, 9) at the National Bureau of Standards to study neon in 1965 and argon in 1967. Wolff and Davis (13) at the University of California used a laser excitation system to study cesium and sodium in 1967.

Project Rationale

The project was appealing to the authors for a number of reasons. First, up to the time of the initiation of the project there had been only five elements known to have been in some part studied—helium, neon, argon, cesium, and sodium. Thus there existed a need to extend knowledge to other elements and to attempt to expand the state of the art. Second, the field was relatively new and unpopulated. With the development of current electronics a successful technique had been acquired, but insofar as could be determined by the authors it had been success-

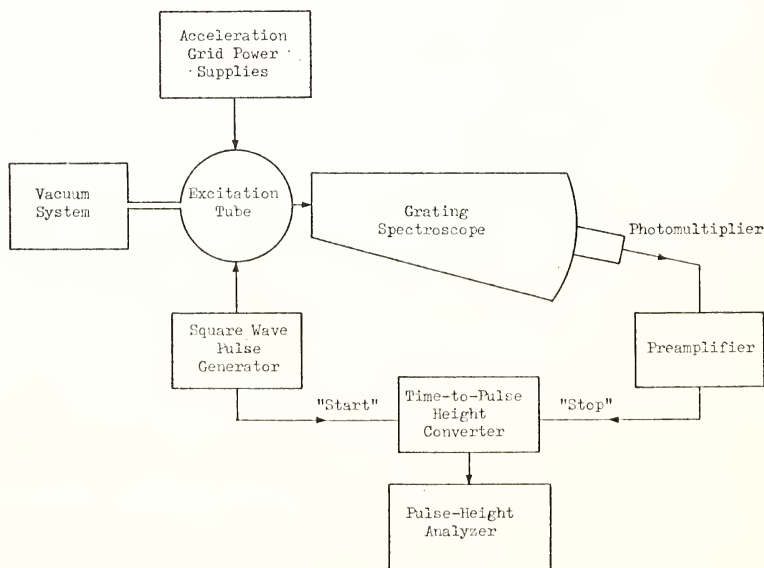


Figure 1. Block Diagram of Apparatus.

The vacuum or low pressure gas system was constructed entirely of glass, including a Delmar DS-7050-1 glass mercury diffusion pump which was fused directly into the system via a liquid nitrogen cold trap. The gas pressure in the excitation tube was operated at approximately 1×10^{-4} Torr or 0.1μ . Since the system was originally designed with a McLeod pressure gauge fused directly into the system and since the gauge was found to be a large source of mercury contamination, it was decided to study first the atomic lifetimes of mercury.

The spectograph system consisted merely of a slightly modified large Cenco Model 87102 grating spectograph with a dispersion of $16 \text{ \AA/mm}$.

The electronics system consisted of an HP-214A square wave pulse generator, an RCA-6655A photomultiplier and Victoreen PVS-C pre-amplifier, a time-to-pulse height converter (3), a Victoreen PIP-400A pulse-height analyzer, and an excitation tube control system. The last system, which is depicted diagrammatically in Figure 2, consisted of a series of meters and power supplies to enable the operator to have complete control and monitoring capabilities over the excitation tube.

Lastly, the excitation tube—the very heart of the project—proved to be one of the most difficult parts to design and construct. The excitation technique employed by Klose (8,9) was basically designed by Simpson and Kuyatt (12) at the National Bureau of Standards in which, by using a multistage device, electrons were first drawn from the cathode by a high potential of the order 300 V and then decelerated to obtain a beam of the desired energy range in the order of 10 to 30 eV. This design was successfully used by Klose in his studies but was found by the authors to be impractical to construct due to the lack of sufficiently sophisticated machining facilities. Thus it was decided to adapt a presently existing production TV electron gun to the above technique. A diagram of the authors' electron gun appears in Figure 3. The electron guns used in tele-

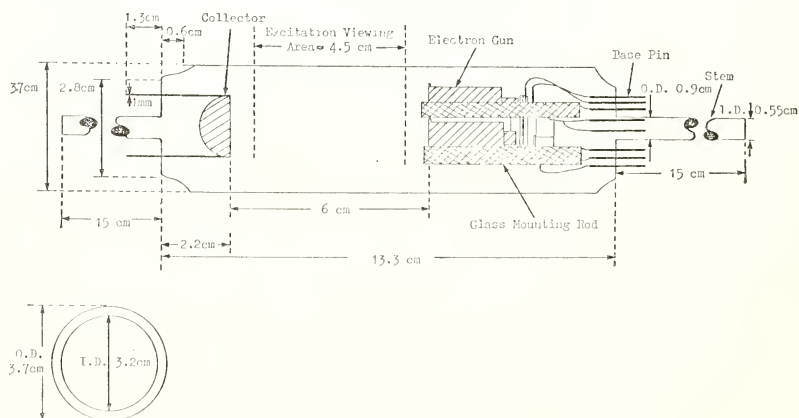


Figure 3. Diagram of Excitation Tube.

vision picture tubes are designed to operate at potentials of the order of 500 to 5000V. Use was made of an RCA 19GWP22 color television gun (11) in which the operating potentials on each of the gun elements were proportionately scaled down to produce an electron beam energy in the 10 to 30 eV range. This gun system had two advantages—it was designed to operate at comparatively low potentials and, since it was a color picture tube gun system, it actually consisted of three guns. Due to the fact that the gun was to be operated at relatively low potentials, the high potential grid 4 and magnetic shield were removed from the gun assembly leaving a three-grid electron gun. This had an advantage because the three guns could be operated singly, so that if one gun burned out it was possible to change to another gun by external switching without opening the tube. The collector was constructed out of stainless steel and formed into a "cup" shape to minimize the mechanical recoil of the low energy electrons back into the excitation viewing area.

The excitation tube functioned sufficiently well for obtaining some initial spectrograms, but was not as stable as desired because of the existence of a space charge in the viewing area arising from recoil electrons from the anode. A fine mesh suppressor grid at the anode potential should eliminate this annoyance and allow the tube to be used for atomic lifetime measurements.

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