Resonance Ionization Spectroscopy: Inert Atom Detection

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1. Introduction

The central role of the atom in our concepts of matter creates a great need to count individual atoms in most of the scientific disciplines. The recent appearance of experimental techniques for the counting of atoms can be directly tied to the development of the pulsed laser.

Rutherford\(^\text{(1)}\) referred to "the counting of atoms" in an unpublished note. A form of "atom counting" or, more appropriately, "decay counting" has been an essential technique of nuclear physics (and its many applications) since 1908 when Rutherford and Geiger\(^\text{(2)}\) developed the first electrical counter. Furthermore, the mass spectrometer of J. J. Thomson\(^\text{(3)}\), when refined with modern particle detectors, can be used to count individual ions of atoms.

Recently the tunable laser has made possible resonance ionization spectroscopy (RIS), which is the basis for the counting of atoms in a more general way. Resonance ionization spectroscopy is a laser technique in which a single electron can be removed from each atom of a population...
of a given type of atom—and it is spectroscopically selective. These characteristics are in sharp contrast with the ionization of gases by the traditional methods, such as X rays or alpha particles, which are neither selective nor sensitive. Furthermore, with pulsed lasers, ionization can be created in a known volume at the time of choice of the observer. Combining RIS with the one ion-pair sensitivity of ionization detectors made it possible to count one atom with selectivity of the type of atom, with space resolution, and with time resolution.

One purpose of this article is to review RIS, especially recent developments which make possible the ionization of Ar, Kr, and Xe. Whereas RIS offers the potential for three fundamentally different ways of counting atoms, this article is limited to the “direct” method as shown in part (b) of Figure 1. A thorough discussion of this method is the second objective of this article. Finally, an analysis of applications of isotope selective noble gas atom counters in particle physics and weak interaction physics, and, more briefly, other areas of applications such as oceanography and ice cap dating is the third objective of this review.

2. Resonance Ionization Spectroscopy

It has been known since the discovery of X rays and of radioactivity that “ionization” can be measured in extremely sensitive as well as

![Figure 1](image_url)

**Figure 1.** A perspective on methods of counting atoms. The traditional method (a) is based on the radioactive decay of a nucleus. Resonance ionization spectroscopy (RIS) provides three additional methods as illustrated. The direct counting method (b) will be discussed in this article with concentration on the noble gases Ar, Kr, and Xe. The decay-daughter atom counting (c) offers the potential for counting facilities with very low backgrounds, and has been discussed elsewhere (Refs. 5–8). Direct counting of daughter atoms (d) accumulated on a surface could provide an alternative to decay counting for long-lived parent atoms (Ref. 4).