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Experimental investigation of the repelling force from RF carpets

A. Hamaker [a,b], M. Brodeur [a,*], J.M. Kelly [a], J. Long [a], C. Nicoloff [a,c], S. Ryan [a], B.E. Schultz [a], P. Schury [d], M. Wada [d]

[a] University of Notre Dame, Department of Physics, Notre Dame, IN 46556, USA
[b] Hanover College, Department of Physics, Hanover, IN 47243, USA
[c] Department of Physics, Wellesley College, Wellesley, MA 02481 USA
[d] Wake Nuclear Science Center (WNSC)/RNB(Radioactive Nuclear Beam) Group, Institute of Particle and Nuclear Studies, High Energy Accelerator Research Organization, Wako, Saitama 351-0198, Japan

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ABSTRACT

The theoretical description for the ion motion above a radio-frequency carpet was proposed in [S. Schwarz, Int. J. Mass Spectrom. 299 (2011) 71], and using this description, the maximal repelling force created by the RF carpet that leads to stable ion motion can be determined. The predicted changes in the repelling force were experimentally tested for different RF amplitudes, helium gas pressures, and electric push field strength that the RF carpet is counteracting. We observed good overall agreement between the experimental and the theoretical descriptions.

1. Introduction

With the continued emergence of new radioactive ion beam facilities worldwide [1], there is a high potential for answering pressing questions ranging from the creation of heavy nuclei to the structure of exotic nuclei. Among the two major types of production methods [1], Isotope Separator On-Line (ISOL) and in-flight, the chemistry-independent nature of the latter method allows for the delivery of a broader range of elements. However, the high energy and momentum spread of the produced beams from the in-flight method seem to be at odds with the requirements for low energy experiments, such as high precision mass measurements and laser spectroscopy [2]. Fortunately, the development of gas cells [3] has bridged the gap. While these gas cells vary in design, a common feature of many of them is the use of so-called radio-frequency (RF) carpets [4]. The RF carpet can take various forms, from copper rings with a rigid or semi-rigid backing [5–7] to individual electrodes spaced by ceramic insulators [8,9]. However, these various configurations all serve the dual purpose of repelling the ions from the gas cell walls while transporting them towards an extraction orifice. Other than nuclear physics, RF carpets can be used in other areas of research, including analytical chemistry. For instance, it was recently shown that a combination of an RF carpet and a DC carpet can form a simple electrospray interface [10,11].

There are currently two methods of using RF carpets for transporting ions in gas volumes: the traditional method [4], for which a static electric potential of decreasing strength towards the extraction orifice is applied on the individual electrodes, and the ion surfing method [12], which replaces this static potential with a traveling wave. The common feature of both methods is the application of RF signals on the carpet electrodes to provide a repelling force. The ion motion above the carpet and the stability conditions for that motion were investigated, leading to a theoretical description of the maximal force on an ion that an RF carpet can balance [13]. The force being balanced can derive from such necessary sources, as the drag field that moves the ion along the carpet, or from detrimental sources, such as the induced ionization of the buffer gas.

In both situations, knowing how to maximize the repelling force is desirable for both the design and optimal operation of RF carpets. Hence, considering the growing use of RF carpet technology,

* Corresponding author. Tel.: +1 5746318204.
E-mail address: mbrodeur@nd.edu (M. Brodeur).

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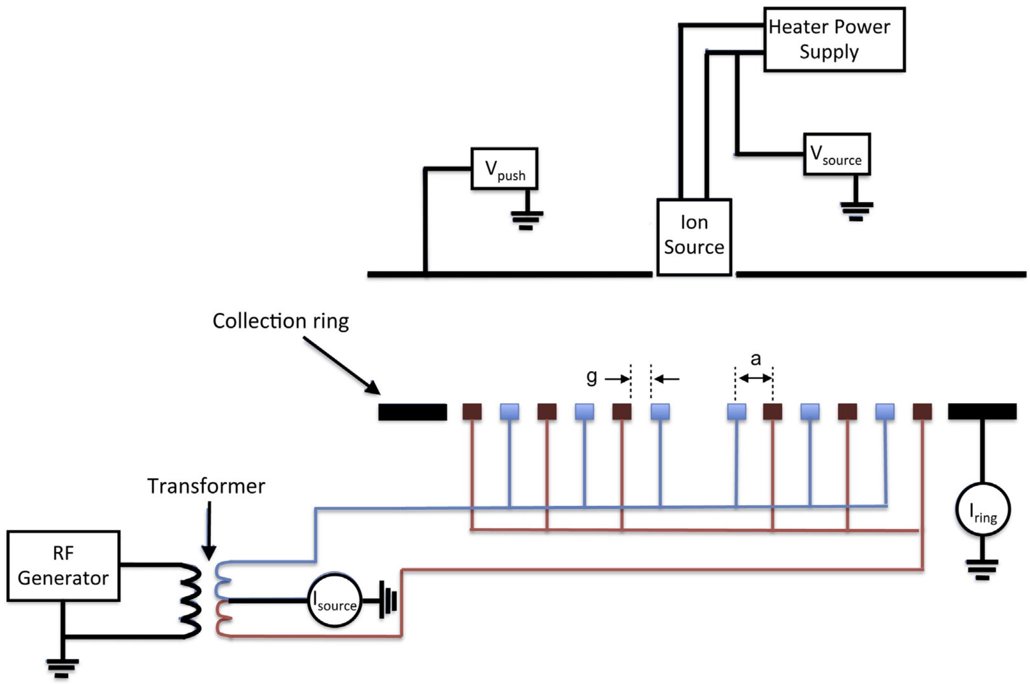

Fig. 1. Schematic view of experimental set-up. The dark red and light blue squares denote the alternating electrodes of opposite RF phase. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)

we have investigated experimentally the behavior of the repelling force as a function of various experimental parameters. In this paper, we report on the results for various values of the RF amplitude and the pressure inside the gas cell.

2. Theoretical description

An RF carpet is made of a series of closely spaced electrodes on which an alternating potential is applied with a 180° phase shift between adjacent electrodes (see Fig. 1). The resulting time-dependent electric field creates a repelling force above the electrodes. To keep the ions hovering just above the RF carpet, a "push" force is used to balance the repelling force from the RF. The push force can be created by applying a voltage to a metallic plate above the RF carpet surface.

Using the analytical expression for the electric field produced by an RF carpet [13], the equation of motion of an ion above the carpet can be written as [13]:

$$\frac{d^2 y_\pi}{d\xi^2} = E_d e^{-y_\pi} \cos(\xi) - E_{pr} - \kappa \frac{dy_\pi}{d\xi}, \quad (1)$$

where $\xi = 2\pi f$, $y_\pi = y\pi/a$, f is the RF frequency, a is the center-to-center distance between electrodes (also known as the carpet pitch), and y is the vertical distance from the carpet electrode surface. The dimensionless parameters E_d (RF amplitude-dependent), E_{pr} (push field-dependent) and κ (pressure-dependent) are defined as:

$$E_d = \frac{q}{m} \frac{2V_{RF}}{\gamma\pi^2 a^2 f^2} \sin\left(\frac{\pi\gamma}{2}\right) \quad (2)$$

$$E_{pr} = \frac{q}{m} \frac{1}{4\pi a f^2} E_p \quad (3)$$

$$\kappa = \frac{q}{m} \frac{1}{2\pi f K_0} \frac{p/p_0}{T/T_0} \quad (4)$$

where γ is the ratio of the gap g between adjacent electrodes to their pitch, V_{RF} is the zero-to-peak RF amplitude, E_p is the push field, m is the ion mass, p is the gas pressure, T is the gas temperature, with p_0 = 1013.25 mbar and T_0 = 273.15 K, q is the charge of the ion, and K_0 is the reduced ion mobility in the buffer gas.

As described in [13], Eq. (1) can be solved numerically to obtain the time-dependence of the distance of the ion above the RF carpet. The carpet's maximum sustainable push field as a function of either RF amplitude or pressure can be found from the value of E_{pr} in the case where the ion would just touch the carpet ($y_\pi \to 0$).

3. Experimental set-up

The experimental setup used to perform the measurements includes an RF carpet, a stainless steel plate to provide the push field, and an ion source (see Fig. 2), which are all placed inside the vacuum chamber as shown in Fig. 3. The circuitry used to produce the RF and the push field, the ion source power supply, the RF supplies, and instrumentation were placed outside the vacuum chamber.

The vacuum chamber was evacuated with an Edwards nXDS10i 11.4 m^3/h scroll pump and an Edwards STP301 300 L/s turbo molecular pump in order to minimize residual air contamination in the chamber. The system was pumped down to a base pressure in the 10^{-9} mbar range between measurements. During the measurements, Grade 5 ultra-pure helium was injected in the chamber. The gas pressure was monitored using three different gauges: a convection gauge when pumping down the system, a hot cathode gauge at ultra high vacuum conditions, and a baratron gauge for a precise, absolute pressure reading during the measurements. A thermocouple was also used to measure the temperature inside the chamber (see Fig. 2). In order to avoid RF discharges in the chamber, the RF amplitude was kept below 70 V.

The circuitry used to operate the RF carpet was constructed to maximize the RF frequency on the carpet and maintain a stable RF amplitude. In order to maximize the transfer of power from the generator to the carpet, the RF signal from a AC1020 175W low frequency amplifier from T&C Power Conversion was impedance matched using an air core impedance matching transformer (see Fig. 2). The transformer was made of a single turn of a 2 cm large