Efficient Method for Cold Muonium Negative Ion Production

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The **muonium atom** is made up of an antimuon and an electron and is given the chemical symbol Mu. A second electron with binding energy or electron affinity of 0.75 eV makes the Mu- ion, which is in many ways almost identical to the H- ion that is used for charge-exchange injection into most proton particle.

The work described below represents continued interest by the Industrial Community, often supported in the past by SBIR and STTR grants [1], to develop new ideas for intense, cooled muon beams that are useful for colliders, neutrino factories, energy and intensity frontier experiments, as well as commercial applications such as a muon microscopy, muon spin spectroscopy, cargo scanning and tomography.

INTRODUCTION

Muonium negative ions were observed in 1987 [2] by interaction of muons with a foil. Using the foil charge-exchange approach, the efficiency of transformation of muons to negative muonium ions has been very low $\sim 10^{-4}$. However, by using a hot tungsten or palladium single crystal foil treated by cesium deposition, the production efficiency can be improved up to 50%.

The process proposed here has surface muons focused onto a tungsten or palladium single crystal foil (that can be heated up to 2000 Celsius) and partially covered by a cesium layer up to minimal work function. The negative muon ions can be extracted by a DC electric field and further accelerated by a linac and stripped in a thin foil.

Our proposed new approach avoids the use of a complex laser by taking advantage of adding cesium to the foil and offers the prospect of increased production efficiency. Improvement estimates are made with comparisons to H- and positronium negative ion production. We then describe conceptually how the system would work. Finally, we discuss possible locations and uses for testing the proposed approach.

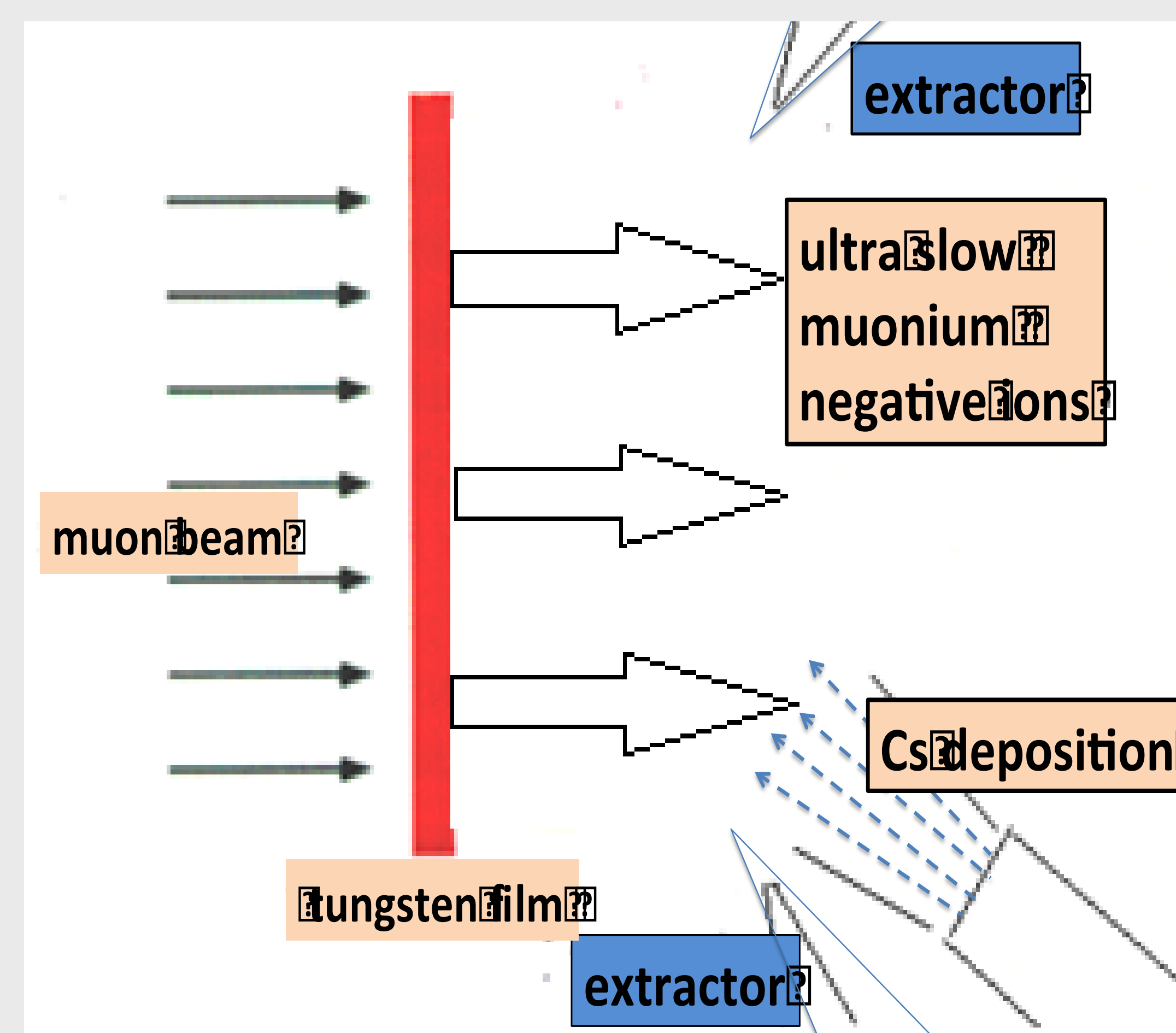## NEW METHOD OF COLD MUONIUM NEGATIVE ION PRODUCTION

Ultra-slow muons up to now have been generated by resonant ionization of thermal muonium atoms (Mu) generated from the surface of a hot tungsten foil placed at the end of an intense surface muon beam line. In order to efficiently ionize the Mu near the W surface, a resonant ionization scheme via the 1s-2p unbound transition has been used.. A complex laser system has been used to efficiently ionize the Mu near the W surface This is described in the literature [3]**.**

Cesiation is the addition of a small admixture of cesium to a gas discharge, increasing negative ion emission and decreasing electron emission below that of the negative ions. Cesiation decreases the surface work function and increases the probability for back scattered and sputtered particles to escape as negative ions. It is difficult to control the surface work function during the discharge, so photoelectron measurements are used to regulate the deposition process [4].

A proposed location for this system is at **the J-PARC U-Line** . Compared to the conventional beamlines, the large acceptance of the front-end solenoid will allow for the capture of more than 10 times intensity pulsed muons [5].

NEW MUONIUM PRODUCTION SYSTEM

A schematic of our proposed system for production of slow muonium negative ions is shown in Fig. 1, below. The principle component of this system is a single crystal of tungsten or palladium with deposition of cesium and extraction system. This eliminates the need for a laser system. The work function can be controlled by photoelectric effect measurements to calibrate the cesium deposition.

Schematic diagram of ultraslow muonium negative ion production.

POSSIBLE COLD MUONIUM NEGATIVE ION PRODUCTION TEST BEAM

For production of muonium negative ions, a proton (deuteron) beam is first injected into a primary pion production target made of 20-30 mm thick, disc-shaped, isotropic graphite. About 5% of the proton beam is consumed in the target. Most positive muon beams are generated from pions stopped at the inner surface layer of the primary production target and decaying at rest, hence the common name, surface muons. The muon is emitted isotropically from the pion with momentum 29.8 MeV/c and kinetic energy 4.119 MeV (in the rest frame of the pion). The **extraction** angle of two beam transport lines is 60 degrees relative to the proton beamline (forward) direction.

The intensity of the surface muon beam can be estimated from the number of pions stopped near to the surface. There, it is possible to collect surface muons with a large acceptance of 400 mSr. The large acceptance of the **J-PARC U-Line** front-end solenoid will allow for the capture of more than 10 times intensity pulsed muons [5]. With a muon capture of 5×10^8/s surface muons, can be collected 2×10^8/s surface muons on the W target in the Mu chamber, with an approximate transport efficiency of 40%. The focused beam spot size at the foil is required to be less than 4 cm in diameter. Achieving the smallest beam spot size increases the slow muon beam intensity.

CALCULATIONS FROM H- ION PRODUCTION

Kishinevskii [6,7], calculated the probability of sputtered and reflected particles escaping as H-. For a realistic work function $\varphi > 1.7$ eV, the probability, β^-, of a negative ion forming on the metal surface is proportional to the ion escape velocity v (transverse to the surface) and inversely proportional to the surface work function (less the affinity) for low velocities; at larger velocities, it saturates (Fig. 2 below).
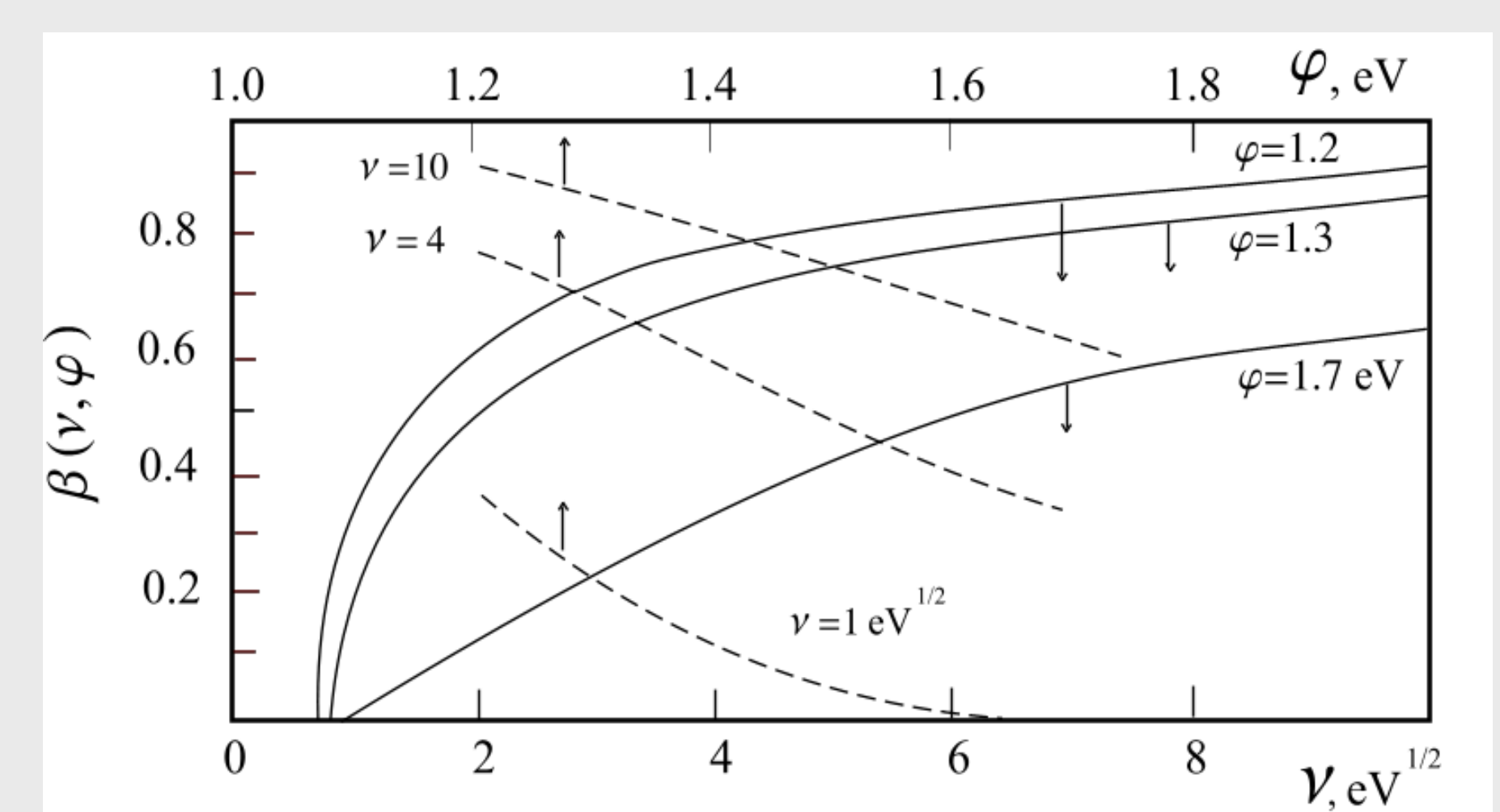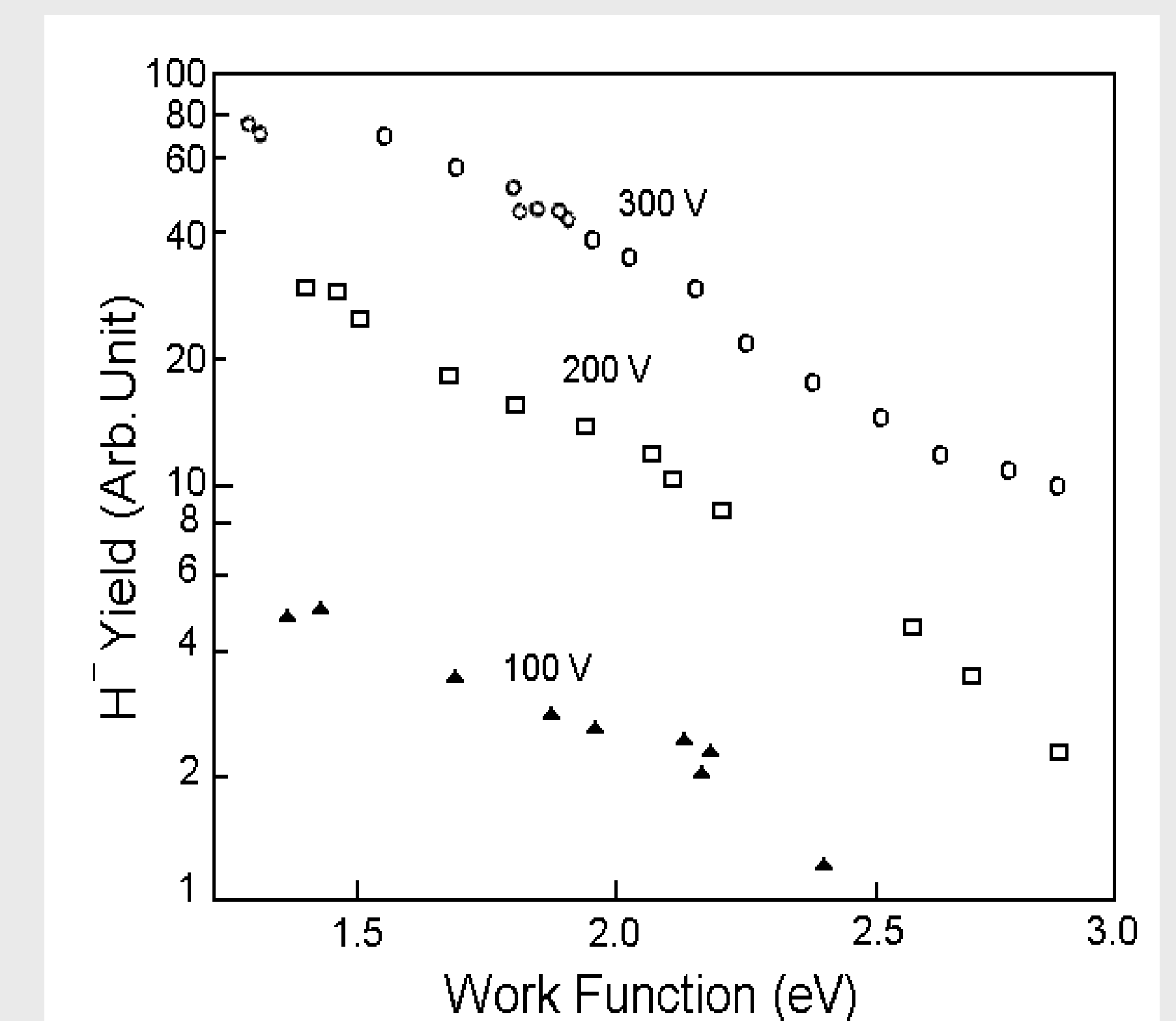

Fig. 3 shows the dependence of the H- production on the work function of the Mo surface in cesiated hydrogen discharge for different bias voltages (escape velocities) [5], as shown in Fig 2.

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