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An elementary theory for determination of precise and reliable work function via photon energy and photoelectric yield

Liu Changshi [a,*], Liu Wen Li [b]

[a] Nan Hu College, Jiaxing University, Zhejiang, 314001, PR China
[b] College of Mathematics, Physics and Information Engineering, Jiaxing University, Zhejiang, 314001, PR China

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ABSTRACT

An elementary theory of using the definition of work function in photoelectric effect to determine precise and reliable work function by contributing frequency to optical-electric yield is investigated in this paper. On account of the theory of Fermi-Dirac distribution as well as the definition of work function proposed by Einstein in photoelectric effect, a representative mathematical approach is applied to analyze the frequency-based optical-electric yield in quantitatively terms. Supplementing applications to In_{14} cluster and three kinds of metals, the simulations agree well with the observed spectra (photoelectric yield-frequency). At the same time, the threshold frequency of light-dependent the work function is theoretically explained successfully via one equation so that the work function can be predicted precisely and reliably. The consequences provide that the formalism pursed in this paper, which is straight forward and practical, could play a significant role in studying metal cluster spectroscopy. The experimental results in this paper may hopefully promote overall analysis on theoretical basis. They may further analyze the usability of bulk-derived models to cluster photo-ionization activity, and the conversion of molecular or atomic form into surface photoemission form.

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1. Introduction

Light not only can produce photoelectric effect on bulk metal surfaces [1–5], but also can created photoelectric effect in metal cluster [6]. Based on the explanation on photoelectric effect of Einstein [7], the work function can be detected after the curve of frequency-depend stopping potential is fitted. Work function is one key to metal cluster ionization potentiality as one of the significant features in the "artificial atoms." However, a difficulty in this method is that the equivalent of the stopping potential is not sharp: As a decelerating method to stop potential, the anode current tends to be a fixed value. Partly it is due to distribution of heat energy by electrons within photocathode which enhances the operation function. Hence, the stopping potential is detected by extrapolating with geometry feature so that the reliability of the stopping potential is compromised. Another of the most widely applied method of determining work function was established which is the thermic emission of electrons from the surface of cathode presently known as the Richardson-Dushman equation [8]. But it should be noted that the Richardson-Dushman equation was developed via classical statistics named Maxwell-Boltzmann

* Corresponding author.
E-mail address: lcswlx@163.com (L. Changshi).

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instead of quantum statistics, so the reliability of the Richardson-Dushman equation is not the highest. Although there has been Fowler's theory of photoelectric emission or Fowler formula [9], Fowler formula was concerned with values of photon energy, $h\nu$, near the work function and at very low temperature [9].

The interest in work function is growing in the context of metal clusters [6], new metal, new electrode and new alloy [10–19]. Studying functional metal requires the most accuracy knowledge of the physical principle of metal. In view of this requirement, an attempt is made to predict the metal physical function more precise and more reliable via natural path in this paper. Direct experience convinces people that specified function against lab values may specify a physical experience leads people to believe that specification function on experimental results defines a distinctive practical problem though it exists in empiric functional form. In order to obtain the work function more precisely and reliably, in the light of the distributing theory of Fermi-Dirac and optical-electric equation by Einstein, a natural path and formulation is suggested in this paper. This method may be the most precise determination of work function.

2. Methodologies

Since electron exists in fermions, the distribution of Fermi-Dirac should work with electron. Hence, Fermi-Dirac distribution can describe the photoelectrons in an external electronic field [8,9], The probable state of an electron with total energy E being occupied is rendered by the distribution of Fermi-Dirac (F-D)

$$f(E) = \frac{1}{1 + \exp((E - E_f)/kT)} \tag{1}$$

where f(E) the particle is most likely to possess energy E, E_f represents Fermi energy, T presents absolute temperature, k presents Boltzmann constant and its value is $k = 1.38 \times 10^{-23}$ in SI unit.

The maximum energy of motion in the photoelectron is $eV + h\nu - h\nu_0 - e\delta$ after releasing from the metal (due to exterior optical-electric effect), it then enters the exterior electronic field with V. In this field e = electron charge = 1.602×10^{-19}, $h\nu_0$ is the metal working function. $h\nu_0$ is the necessary energy for the electron at Fermi level to liberate itself from the metal and to become a free electron. In case an electron is below Fermi level, it needs more energy than $h\nu_0$ to escape; δ is an extra potential contact since the surface of the anode and the cathode are not the same. After absorbing a photon, the electron then gain the maximum optical-electric kinetic energy $eV + h\nu - h\nu_0 - e\delta$. Consequently, the possibility for an electron to gain the maximum photoelectron kinetic energy $eV + h\nu - h\nu_0 - e\delta$ is

$$f(E) = \frac{1}{1 + \exp((eV + h\nu - h\nu_0 - e\delta)\frac{1}{kT})} \tag{2}$$

A change of Eq. (2) variable to ν yields

$$f(E) = \frac{1}{1 + \exp((\nu - \nu_1)/\nu_2)} \tag{3}$$

where ν_1 is $\frac{1}{h}(h\nu_0 + e\delta - eV)$ and ν_2 is $\frac{kT}{h}$. One natural conclusion is optical-electric yield, Y(ν), defined as photo-current by per unit light intensity, is proportional to the possibility, f(E), which an electron may gain energy $eV + h\nu - h\nu_0 - e\delta$, in numerical terms:

$$f(E) = \frac{Y_2}{1 + \exp((\nu - \nu_1)/\nu_2)} \tag{4}$$

However, the numerical result is listed as below:

$$\frac{1}{1 + \exp((\nu - \nu_1)/\nu_2)} | \nu \to \infty = 0 \tag{5}$$

Data-based results of optical-electric effect shows that with the frequency of incident light approaching enough high, the anode yield, Y(ν), tends to be a fixed value known as the maximum yield, Y_{max}:

$$Y(\nu) | \nu \to \infty = Y_{max} \tag{6}$$

Critical condition (6) anticipates that the optical-electric yield and the frequency of incident light should be related as:

$$Y(\nu) = Y_1 + \frac{Y_2}{1 + \exp((\nu - \nu_1)/\nu_2)} \tag{7}$$

Combining Eqs. (5)–(7) yields

$$Y_1 = Y_{max} \tag{8}$$

Substitution of Eqs. (8) into (7) leads to following expressions:

$$Y(\nu) = Y_{max} + \frac{Y_2}{1 + \exp((\nu - \nu_1)/\nu_2)} \tag{9}$$

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