**The metal escape work experiment**

2022级 人工智能 ZYH

**Abstract**

There are a lot of free electrons in the metal, but the energy of electrons in the metal is lower than that in the outside. Therefore, when electrons escape from the metal, they need to provide a certain amount of energy for the electrons. This part of energy is called electron work function.

Work function is one of the basic properties of metal materials. Metal work function is an important parameter in the research or technology of electronic devices, such as light-emitting diodes (LEDs) and solar cells. Studying the physical properties of metal materials, such as work function, can not only improve the application effect of metal materials in electronic technology, but also deepen the understanding of the microscopic atomic structure, especially has an important significance for correcting the relevant atomic structure theory and calculation methods.

1. **Objectives**

1. Use Richardson straight line method to determine the electronic work function of tungsten

2. Learn the method of data processing.

1. **Experiment Equipment**

Electronic tube comprehensive experimental instrument

1. **Experiment Principles**

**The Basic Principle of Measuring Electron work function by Hot Electron Emission**

According to the metal electron theory in solid state physics, the conduction electrons in metals follow the Fermi Dirac distribution according to the energy distribution, namely:

In the equation, is called Fermi level.

At absolute zero, the energy distribution of electrons is shown in curve 1 of Figure 1. At this point, the maximum energy possessed by the electron is E\_ F. The energy distribution curve of electrons when the temperature increases is shown in Figure 1, Curve 2. Among them, a few electrons with higher energy have higher energy than E, and their number decreases exponentially with increasing energy. Usually, due to the presence of a potential barrier between the metal surface and the external environment (vacuum), electrons must have at least energy to escape from the metal surface. From the figure, it can be seen that at absolute zero, the minimum energy required for electrons to escape from the metal is:

(Or ) is called the work function of metal electrons, and its common unit is electron volt (). It represents the energy required for the electrons with the maximum energy in the metal at absolute zero to escape from the metal surface. It is called the escape potential, and its value is equal to the work function of the electron in electron volts.

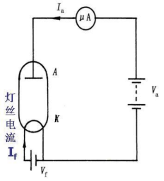


Figure 1

The cathode of the vacuum diode (made of the tested metal tungsten wire) is heated by an electric current to increase the electrode temperature. The increase in temperature changes the energy distribution of electrons inside the metal tungsten wire, increasing the number of electrons with kinetic energy greater than , resulting in kinetic energy greater than . The number of electrons reaches an observable size, resulting in a detectable number of hot electrons emitted from the metal surface. Therefore, when positive voltage is not applied to anode ( in the figure), thermal emission current (referred to as zero field current) will also be detected in the external circuit connecting the two electrodes. The zero-field current intensity I is determined by the Richardson-Dushmon formula, which includes:

Where, is the coefficient related to the chemical purity of the cathode surface (unit: ), is the effective emission area of the cathode (unit: ), is the absolute temperature of the cathode emitting hot electrons (unit: ), and is the Boltzmann constant. It is the basic principle formula of measuring electron work function by thermionic emission. This formula shows the electron work function (). It plays a decisive role in the strength of hot electron emission. Divide both sides of the equation by and take the logarithm to obtain:

This equation shows a linear relationship between and . If is taken as the ordinate and is taken as the abscissa, the escape potential of the electron can be calculated from the slope of the line. And electron work function ? This mathematical processing method is called the Richardson line method.

**Measurement of zero field current**

Space charges are formed during the continuous emission of hot electrons from the cathode towards the anode. The electric field of space charge hinders subsequent electrons from flying to the anode. This seriously affects the measurement of zero field current. In order to overcome the influence of space charge electric field and enable electrons to quickly fly to the anode once they escape, an acceleration field has to be added between the anode and cathode. However, will also produce the Schottky effect, causing the potential barrier decreases, the electron work function escapes decrease, and the emission current increases, so the measured current is the cathode surface emission current under the action of an accelerating electric field instead of zero field current . It can be proven that The relationship between the zero-field current and is:

Take the logarithm of the above equation, and after taking the straight curve, there is:

Usually, the cathode and anode are made into coaxial cylindrical shapes, ignoring the contact potential difference and other effects, and the accelerating electric field on the cathode surface can be expressed as:

Among them, and are the radii of the cathode and anode, is the anode voltage. Substituting into the above equation yields:

This formula is the basic formula for measuring zero level current. For diodes of a certain size, when the temperature of the cathode is constant, lgI\_ There is a linear relationship between and . If is used as the vertical axis and as the horizontal axis, with the extension lines of these lines intersect at , and the ordinate is . Then, by calculating its opposition number, the zero-field current at a certain temperature can be obtained.

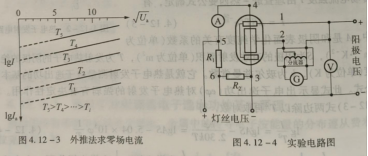


Figure 2

1. **Content Steps**

Connect the experimental circuit and turn on the power. Adjust the ideal diode filament current and measure it every 0.025A between 0.6 and 0.7A. For each filament current, preheat for 3-5 minutes, and the corresponding temperature should be (if the anode current is too small or too large, the filament currents can also be appropriately increased or decreased).

Corresponding to each filament current, apply 36V, 49V, 64V, 81V, 100V, 121V, 144V voltages to the anode in sequence, and measure a set of anode currents  and fill in the table.

Precautions:

1. When connecting the circuit before the experiment and unplugging the circuit after the experiment, do not touch the metal parts of the circuit to avoid high voltage causing harm to the body; Due to the possibility of being in a high-pressure state for a long time during the experimental process, the temperature of the chassis is relatively high. After the experimental data collection is completed, the pressure should be reduced or the tester should be turned off in a timely manner, while paying attention to cooling.
2. Due to production reasons, the performance of all electronic tubes in the experiment may not be completely consistent, so different electronic tubes have the same filament current.
3. **Data processing**

**Different filament currents**  **and anode voltage corresponding anode current (Unit: )**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
|  | 16V | 25V | 36V | 49V | 64V | 81V | 100V |
| 600mA | 52 | 56 | 59 | 62 | 64 | 66 | 68 |
| 625mA | 97 | 106 | 111 | 114 | 119 | 123 | 127 |
| 650mA | 175 | 190 | 199 | 206 | 213 | 219 | 227 |
| 675mA | 290 | 322 | 342 | 355 | 369 | 381 | 392 |
| 700mA | 460 | 513 | 561 | 595 | 618 | 639 | 658 |

After calculating and analyzing the data in the above figure, we have obtained the following figure :

Figure 3

Other process data is shown in the following figure:

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  |  |  |  |  |  |  |
| 0.600 | 1.6518 | 44.85388 | 1758.00 | 3090564 | 0.000568828 | -4.838237725 |
| 0.625 | 1.9272 | 84.56682 | 1793.75 | 3217539 | 0.000557491 | -4.58032382 |
| 0.650 | 2.1855 | 153.2851 | 1829.50 | 3347070 | 0.000546597 | -4.339164854 |
| 0.675 | 2.3993 | 250.7841 | 1865.25 | 3479157 | 0.000536121 | -4.142174029 |
| 0.700 | 2.5839 | 383.6189 | 1901.00 | 3613801 | 0.000526039 | -3.974064238 |

According to the data from table and can be obtained as follow relationship:

Figure 4

Observing the image shows the slope :

According to the formula:

Obtained:

According to the data, the expected electron work function is:

The relative experimental error is:

1. **Conclusion and analysis**

In the electronic work function experiment, if the final electronic work function calculation results differ greatly, it may be caused by the following reasons:

1. Measurement error: There may be measurement errors in the experiment, including instrument errors, environmental interference, or operational errors. These errors may have an impact on the experimental results, resulting in a large difference in the calculated values of electron work function.
2. Change of surface characteristics: calculation of electronic work function usually involves surface characteristics of materials, such as surface morphology, lattice structure or surface pollution. If the surface properties of materials change during the experiment, such as being affected by oxidation, pollution or structural change, the final calculated value of electronic work function will be inconsistent.
3. Material heterogeneity: if the studied materials have heterogeneity, that is, different regions have different physical or chemical properties, then the electronic work function of different regions may have significant differences. The heterogeneity of materials may not be fully considered in the experiment, resulting in significant differences in calculation results.
4. Change of experimental conditions: changes in the conditions during the experiment, such as changes in temperature, pressure or light intensity, may affect the measurement results of electronic work function. If these conditions differ significantly in different experiments, it will lead to inconsistent calculation results.

To reduce the differences in calculation results, the following measures can be taken:

1. Repeat experiments: conduct multiple experiments to obtain more data, thereby reducing the impact of measurement errors. Calibration of instruments: Ensure the accuracy and stability of the measuring instruments used, and perform instrument calibration to reduce system errors.
2. Control experimental conditions: Try to maintain the stability of experimental conditions and reduce the impact of environmental factors. Carefully handle the sample: carefully handle and analyze the surface characteristics and heterogeneity of the material to obtain more accurate calculation results of electronic work function.