5. Experimental contents

1) Understand the collision rule of electrons with atoms and learn how to measure atomic scattering cross section.
2) Measure scattering probability of low-energy electrons collided with gas atoms versus the speed of electrons.
3) Calculate the effective elastic scattering cross section of gas atoms versus the speed of electrons and measure the energy of electrons at the minimum scattering probability or scattering cross section.
4) Verify Ramsauer-Townsend effect and explain it with quantum mechanics.

6. Experimental Procedure

A. <u>AC measurement</u>

The schematic of AC measurement is seen in Figure 7 while the wire connection diagram of the apparatus is shown in Figure 8.

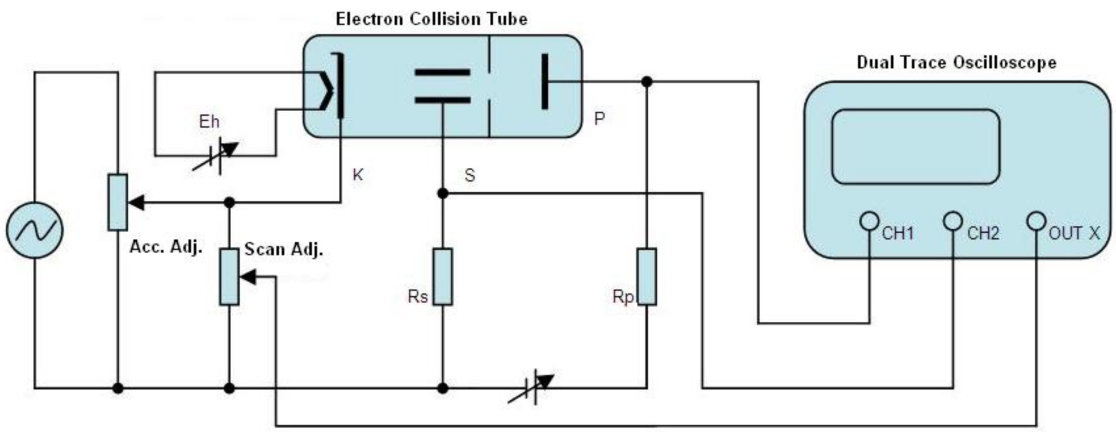

Figure 7 Schematic diagram of AC measurement

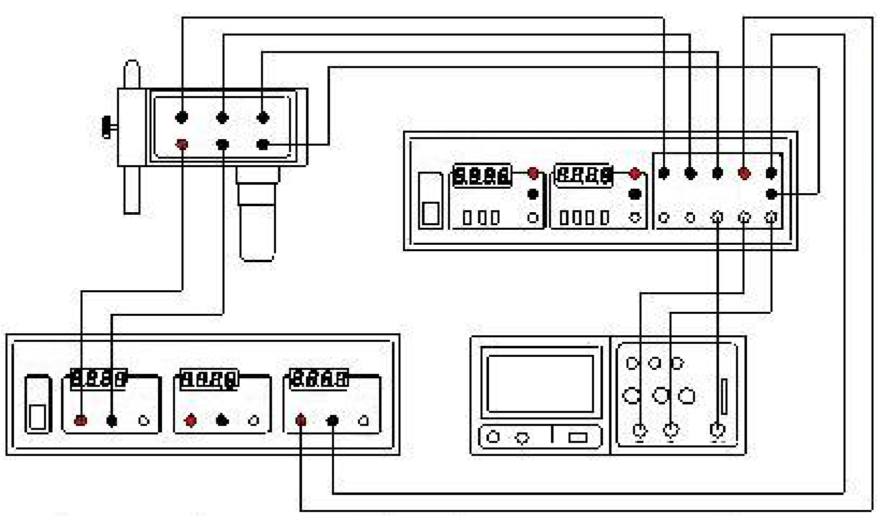

Figure 8 Wire connection diagram of apparatus

1) Connect wires per Figure 8 and ensure all connections are correct.
2) Turn on the two electric units and the oscilloscope. Set the filament voltage "E_h" to approximately "2 V" and the compensation voltage "E_c " to "0 V".
3) Set the oscilloscope: trigger source as "External", trigger coupling mode as "AC", and mode as "Dual Channel". Select "AC" coupling and "50 mV" or "100 mV" per division for both CH1 and CH2.
4) Adjust potentiometers "Acc. Adj" and "Scan Adj" to change the amplitude of the AC acceleration voltage and the scan range of the oscilloscope *X*-axis, respectively. Now, the qualitative relationship between acceleration voltage and currents I_p and I_s can be observed on the oscilloscope.
5) **Note:** do not apply excessive acceleration voltage, as otherwise the gas atoms could be ionized causing a sharp increase in tube current. Acceleration voltage should be reduced below the ionization voltage of the gas atoms (Xenon ionization potential is ~ 12.13 V).
6) Pure liquid Nitrogen into the flask slowly, then immerse the lower half portion of the collision tube into liquid Nitrogen (**Note:** the electron collision tube should be slowly immersed into liquid Nitrogen to avoid sudden cooling of the tube for the prevention of the tube from bursting). In the meanwhile, observe change of currents I_p and I_s on the oscilloscope, and compare this curve with the curve at room temperature.
7) Under low temperature, adjust E_c until both I_c and I_p appear. Write down the value of E_c.

B. DC measurement

The schematic diagram of DC measurement is seen in Figure 9 while the wire connection diagram of the apparatus is shown in Figure 10.

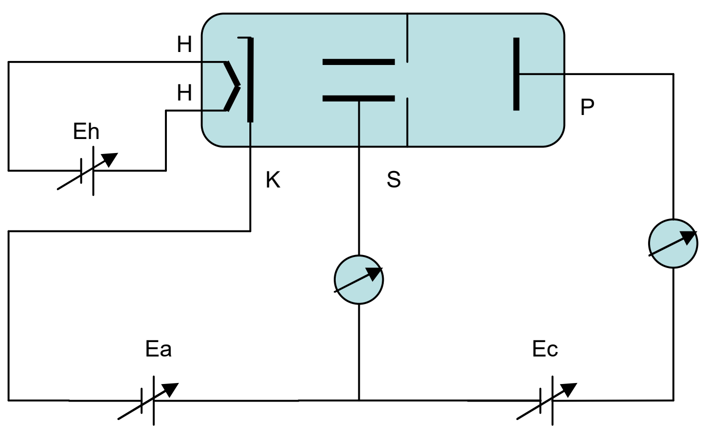

Figure 9 Schematic diagram of DC measurement

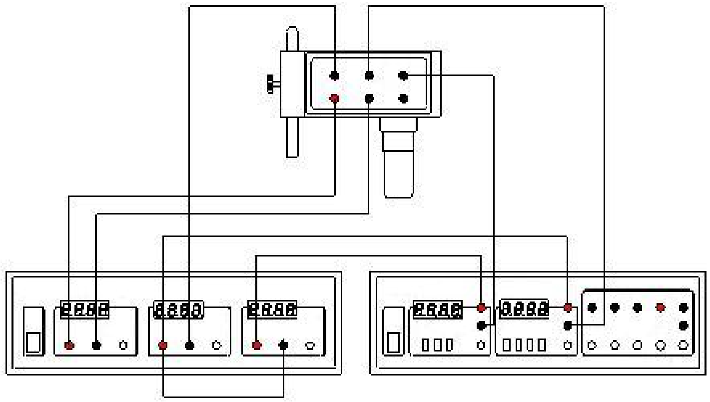

Figure 10 Wire connection diagram of apparatus

1) Based on the AC measurement experiment, Connect wires per Figure 10.
2) Turn on the measurement unit, set the minimum current scales of I_p and I_s at "2 μA" and "20 μA", respectively, while zeroing both currents.
3) Turn on the power supply unit. Adjust filament voltage "E_h" to "2.000 V" while setting both DC acceleration voltage "E_a" and compensation voltage "E_c" to "0.000 V".
4) Turn off the power supply unit, and wait till the two current meters on the measurement unit displaying "0.000". Now immerse the lower half portion of the collision tube into liquid Nitrogen (**Note**: the electron collision tube should be slowly immersed into liquid Nitrogen to avoid sudden cooling of the tube for the prevention of the tube from bursting). Slowly adjust acceleration voltage E_a from -1 V to 1 V while observing the two current meters. If no current is displayed, appropriately change the compensation voltage "E_c" until both current meters display non-zero values. Record the "E_c" value and the initial "E_a" value when non-zero current is displayed.
5) Under low temperature at 77 K by keeping the lower half portion of the collision tube immersed in liquid Nitrogen, slowly increase "E_a" from the value recorded in step 4) at a step size of 0.1 V (E_a<2 V), or 0.2 V (2 V<E_a<3 V), and then 0.5 V, while recording currents I_p^* and I_s^* of each step in a table.
6) Remove the electron collision tube from liquid Nitrogen, and pure the remaining liquid Nitrogen from the container to the original Dewar. Wait the electron collision tube to recover to room temperature and then set acceleration voltage to zero. To maintain a constant cathode temperature, adjust filament voltage E_h until $I_p+I_s=I_p^*+I_s^*$ is achieved when E_a is set at 1 V.
7) Gradually increase acceleration voltage in steps while recording currents I_p and I_s at each step. Based on equation (14), plot $\ln[\frac{I_P^*(I_S+I_P)}{I_P(I_S^*+I_P^*)}] \sim V_a$ curve, or P_s~V_a curve, from which the scattering probability P_s of low-energy electrons collided with gas atom can be acquired with a function of the energy of electrons.

7. An Example for Data Record and Processing

Note: Data is only for reference purpose, not the criteria for apparatus performance.

A. <u>AC measurement</u> (E_h=3.33 V, E_c=1.51 V)

Curves observed on the oscilloscope are shown in Figures 11 and 12.

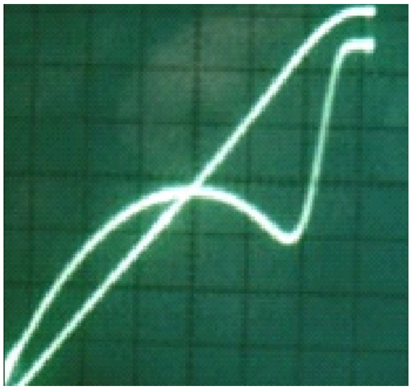

Figure 11 Under room temperature

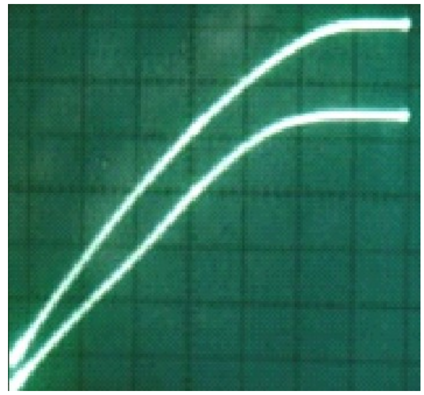

Figure 12 Under low temperature

B. DC measurement (E_h=2.31 V at room temperature, E_h=2.00 V at low temperature of 77 K, E_c=0.42 V, initial E_a=-0.34 V)

Table 1 Measured data of plate current, grid current and acceleration voltage

E_a (V)	I_p^* (μA)	I_s^* (μA)	I_p (μA)	I_s (μA)	$\sqrt{Ea - Ea_0}$	P_s	QL
-0.20	0.003	0.04	0.002	0.08	0.374	0.650	1.051
-0.10	0.009	0.14	0.006	0.22	0.490	0.560	0.822
0	0.024	0.42	0.013	0.49	0.583	0.522	0.738
0.10	0.042	0.90	0.026	1.03	0.663	0.448	0.594
0.20	0.067	1.71	0.045	1.84	0.735	0.367	0.457
0.30	0.100	2.73	0.072	2.90	0.800	0.314	0.377
0.40	0.151	4.20	0.112	4.30	0.860	0.269	0.313
0.50	0.205	5.87	0.159	6.02	0.917	0.237	0.271
0.60	0.275	8.00	0.218	8.16	0.970	0.217	0.245
0.70	0.356	10.44	0.285	10.66	1.020	0.210	0.236
0.80	0.454	13.39	0.369	13.85	1.068	0.209	0.234
0.90	0.568	16.93	0.457	17.50	1.114	0.216	0.243
1.00	0.672	21.1	0.540	21.8	1.158	0.217	0.244
1.10	0.785	25.2	0.627	26.3	1.200	0.229	0.260
1.20	0.915	30.0	0.712	31.0	1.241	0.241	0.276
1.30	1.045	35.0	0.799	36.5	1.281	0.261	0.303
1.40	1.184	40.3	0.872	41.7	1.320	0.282	0.332
1.50	1.327	45.8	0.941	47.8	1.356	0.314	0.377
1.60	1.478	51.5	1.001	54.3	1.393	0.351	0.433
1.70	1.629	57.8	1.046	60.6	1.428	0.381	0.480
1.80	1.780	63.8	1.083	66.8	1.463	0.412	0.531
1.90	1.937	70.4	1.107	74.2	1.497	0.451	0.600
2.00	2.09	76.8	1.124	80.7	1.530	0.481	0.657
2.20	2.39	89.7	1.138	95.2	1.594	0.545	0.787
2.40	2.73	103.8	1.136	110.0	1.655	0.601	0.919
2.60	3.06	117.5	1.125	125.0	1.715	0.649	1.046

2.80	3.40	131.3	1.108	139.6	1.772	0.688	1.165
3.00	3.76	146.0	1.090	154.9	1.830	0.722	1.279
3.50	4.63	181.5	1.052	190.6	1.960	0.779	1.511
4.00	5.53	216	1.028	223	2.083	0.816	1.694
4.50	6.40	253	1.019	258	2.200	0.841	1.836
5.00	7.24	290	1.030	291	2.311	0.855	1.932
6.00	9.00	365	1.124	357	2.518	0.870	2.037
7.00	10.55	430	1.302	424	2.711	0.872	2.056
8.00	11.66	476	1.564	493	2.888	0.868	2.023
9.00	12.10	500	1.926	565	3.056	0.856	1.939
10.00	11.68	504	2.42	647	3.216	0.835	1.805

In the above table, I_p and I_s are the measured plate current and grid current at room temperature, respectively, while I_p^* and I_s^* are the measured plate current and grid current at liquid Nitrogen temperature, respectively. The relationship between acceleration voltage and plate current is plotted in Figure 13, in which I_p is multiplied by a factor of 10 in order to better compare the curves under room temperature and low temperature.

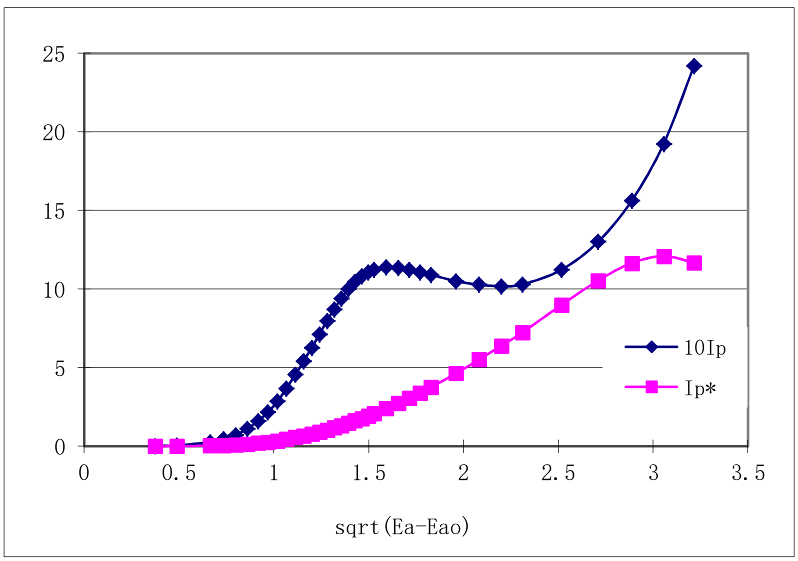

Figure 13 Relationship of plate currents I_p and I_p^* with acceleration voltage

The relationship between the total effective scattering cross section QL (L is a constant) and the square root of acceleration voltage $(E_a\text{-}E_{a0})^{1/2}$ (related to the speed of electrons) is plotted in Figure 14, while the relationship between the electron scattering probability and the square root of acceleration voltage is plotted in Figure 15.

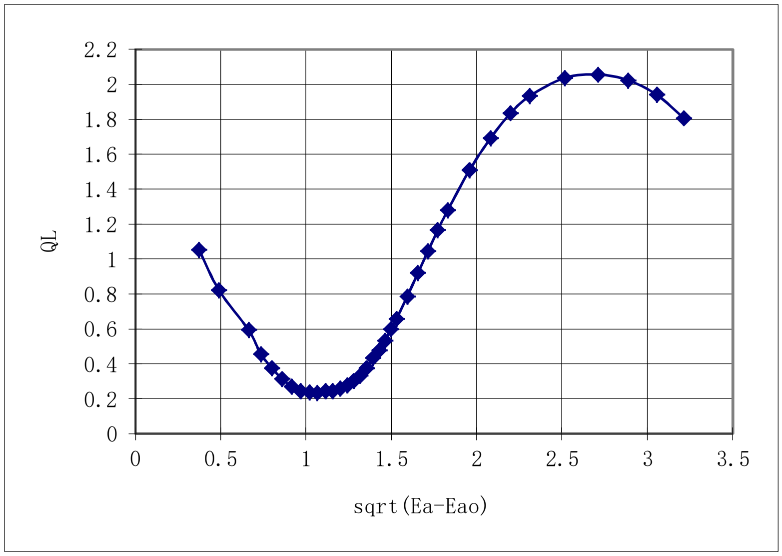

Figure 14 Relationship between the total effective scattering cross section and the square root of acceleration voltage

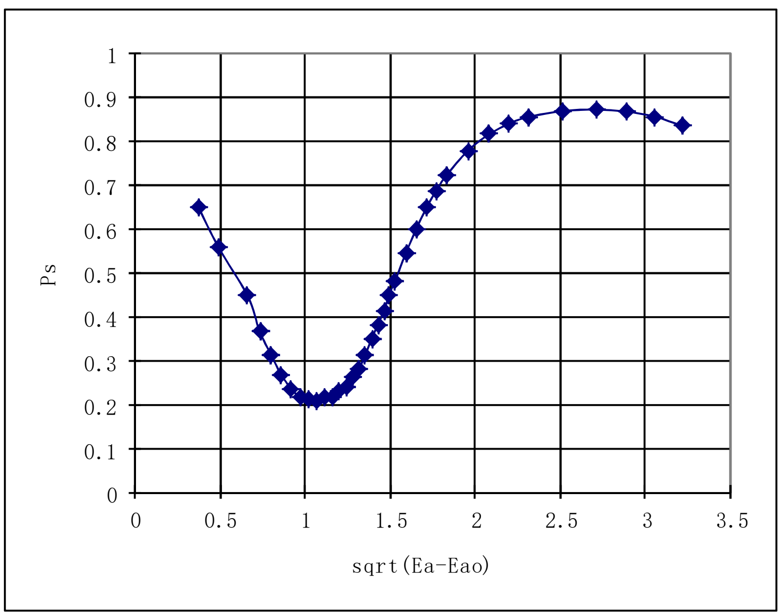

Figure 15 Relationship between the electron scattering probability and the square root of acceleration voltage

It is apparent from Figures 14 and 15 that the electron scattering probability and total effective scattering section are both closely related to the speed of electrons. When electron energy is reduced to about 6 eV, scattering section reaches a maximum value; when electron energy is further reduced, scattering section decreases rapidly and eventually reaches a minimum value when electron energy is reduced to ~1 eV. Under such condition, gas atoms show the so-called “transparent” phenomenon, as electrons that pass through atomic gas undertake no collision with gas atoms. When electron energy is further reduced, the scattering cross section increases again.