A PHOTOEMISSIVE MONOENERGETIC ELECTRON SOURCE FOR CALIBRATING THE BETA–MAGNETIC SPECTROMETER*

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ABSTRACT

A new kind of electron source, the photoemissive monoenergetic electron source has been invented for calibrating the beta-magnetic spectrometer. It produces electrons in the form of simulating a radioactive monoenergetic electron source and can be made in any shape and size according to the demands of experiments. In this paper, the principles and basic constructions of the photoemissive monoenergetic electron source are described, the results of calibrating our $2^{1/2}\pi$ beta-magnetic spectrometer with a single strip arc shaped photoemissive monoenergetic electron source are listed, a new way for determining resolution function of experimental system in the research of neutrino rest mass has been posed and one of its actual applications is also given.

Keywords Photoemission, Monoenergetic electron sources, Beta-magnetic spectrometer, Resolution function, Neutrino rest mass

1 INTRODUCTION

It is very important to determine the resolution function of experimental system accurately in experiments on the base of tritium beta-decay for research of electron antineutrino rest mass.

Up till now, some radioactive monoenergetic electron sources have usually been adopted for calibrating the beta-magnetic spectrometer. However, varied corrections, *e.g.*, natural width, scatter and backward scatter in the radioactive source, shake-off and shake-up effect *etc.* must be done, thus the experimental method is quite complicated. In order to calibrate the beta-magnetic spectrometer and determine the resolution function of experimental system easily and simply, we have manufactured the photoemissive monoenergetic electron source.

2 THE PRINCIPLES AND BASIC CONSTRUCTIONS

In accordance with requirements of calibrating the beta-magnetic spectrometer and determining the resolution function of experimental system, the photoemissive monoenergetic electron source must be provided with some specific properties

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simultaneously: (1) emitting electrons, of which the energy spread is only a few eV; (2) can be easily made into any appropriate geometric shape and size to simulate the beta-source; (3) appropriate in intensity, stability and convenient to use etc. Fig.1 is a scheme which shows the principle of the photoemissive monoenergetic electron source.

In Fig.1 (a), the metal strip-anode and cathode resemble each other in shape and size, and are settled in a vacuum chamber. The anode is grounded and its surface is irregular, e.g. like a rope. The cathode is connected to negative high voltage V_a. When a bundle of monocolour light in the vicinity of position A shines on the cathode, it is possible that the approximate monoenergetic electrons are knocked out from the cathode. The electrons are accelerated by means of high voltage V_a and the monoenergetic electrons required can be obtained at the front of the anode, in the vicinity of position B.

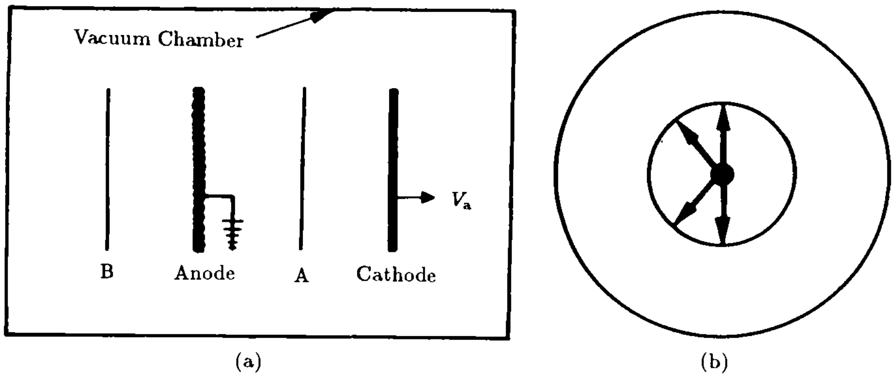

Fig.1 The scheme of the photoemissive monoenergetic electron source

It is already known that if an electrostatic voltage is applied between two parallel metal wires with smooth surface, the cross cut lines of the electrostatic equipotential surface surrounding the wires are the concentric circles showed in Fig.1 (b), in which, the dot in the centre shows the metal wire. When the electrons of which the initial energy is near zero travel in the electrostatic field, they move essentially along the electrolines. So, the emitting directions of the electrons closed to the surface of the anode are showed as the arrows in Fig.1 (b). Owing to obstruction of the grounded anode, no electron moving to the front is emitted.

Now, the surface of the anode in the photoemissive monoenergetic electron source is irregular, the shape of the equipotential surface near the surface of the anode is irregular too. So, the emitted electrons near the surface of the anode can simulate a radioactive source in emitting fashion and their energies are almost identical. Modulating the intensity of the light can change the intensity of monoenergetic electron source; Adjusting the accelerating high voltage can change the energy of monoenergetic eletron source; Altering the size and shape of the cathode and anode (especially to the anode) can make the monoenergetic electrons source into different geometric shape and size and can determine the space distribution of emitting electrons. For example, if the anode is a kind of metal wire of gauze, the cathode is irradiated uniformly by monocolour light, and the anode and cathode are approximately a pair of concentric sphere, then, the photoemissive monoenergetic electron source is almost one of emitting well-distributed electrons in 4π space.

3 MEASUREMENTS

For determining the characteristics, as an example, the calibration was carried out on a $2^{1/2}\pi$ beta-magnetic spectrometer with a flowing gas proportional counter.

3.1 The electron source

A single strip arc shaped photoemissive monoenergetic electron source was used. The parallel anode and cathode, which have the similar shape and size, was mounted vertically on a level thick organic glass plate. The light source may be placed by the side between the two poles, or in front of the anode. The anode, the effective size of which is about 0.5 mm in width, [illegible] mm in length and 166 mm in radius of curvature, is a fine and closely woven stainless steel wire gauze (118 holes per centimetre, the diameter of each hole is about 0.054 mm, and the wire of gauze is about 0.031 mm in diameter), which covers and sticks on the arc shaped hole of an aluminium supporter. The cathode is a tantalum foil. The reasons of using the tantalum foil as cathode material are: Tests have showed that the emitting of electron of tantalum is stable; no exoelectron is observed; and the metal tantalum is sensitive to incandescence and ultraviolet light. So it is convenient to use. The filament of the incandescence light is a fine tungsten wire of about 5 cm in length; The source of ultraviolet ray is a low pressure mercury lamp with quartz glass in disk shape. The dominant wave length of the ultraviolet radiation is 253.7 nm. The fraction energy of the dominat ultraviolet radiation in whole ultraviolet radiation is more than 90%.

3.2 Results

a. The resolution function: The incandescence was used as a light source. The electron spectrum was measured by using magnetic scanning with constant accelerating high voltage. Corresponding to each adjusted position of the proportional counter, one electron spectrum is obtained. When the excellent electron spectrum is obtained, completion of modulation of the beta-magnetic spectrometer is approved, and we can measure the electron spectrum i.e. the resolution function of experimental system under this state. Two typical electron spectra with accelerating high voltage of 13.7 kV and 23 kV are given in Fig.2(a) and Fig.2(b) respectively in which the signs I_H denotes the magnetic current and N indicates the counts. After correction of leakage current the energy of photoemissive monoenergetic electrons is 13.5 keV and 22.6 keV respectively. It is thus clear from the figures that the full width at the half maximum, FWHM is about 0.38 mA and 0.46 mA respectively, i.e. corresponding to the energy resolution, $\triangle E$ which can be suggested as biggest energy spread of the photoemissive

Table 1

The characteristics of the beta–magnetic spectrometer

Electron source	Electron energy/keV	Kind of results	Momentum resolution[1] $\triangle p \cdot p^{-1} / 10^{-4}$	Energy resolution $\triangle E$/eV
Photoemissive monoenergetic electron source	13.5	A group of spectra	5.82	15.5
	15.0		5.50	16.3
	18.5		5.34	19.4
	22.5		5.34	23.5
	22.6[2]	One spectrum	5.46	24.2
	22.9[3]		5.46	24.5
^{170}Tm single stripe[4]	22.9	Earlier results	≈5	≈22
Point electron gun	18.6		≈2	≈7

1) The significant figures for $\triangle E$, and $\triangle p/p$ obtained with photoemissive monoenergetic electron source experimentally are two digits. 2) Experimental point. 3) Extrapolated point. 4) A straight strip source, the length is about 6 cm, the width is about 0.5 mm

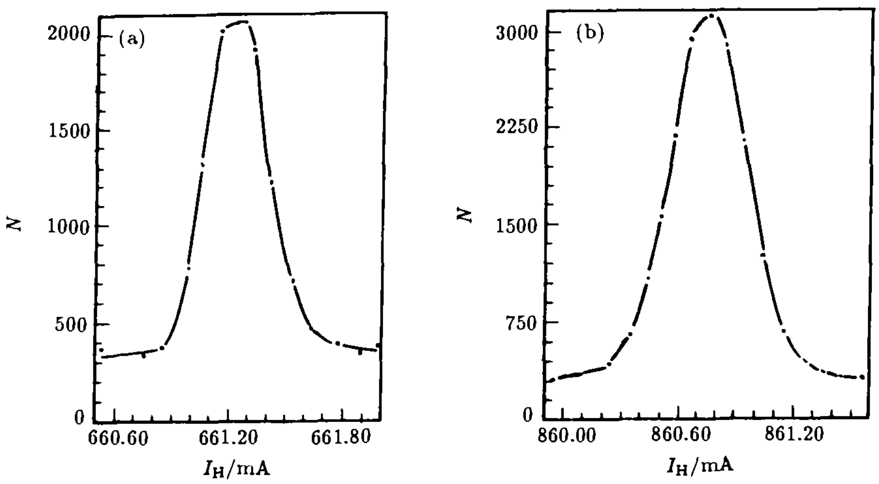

Fig.2 The electron spectra

monoenergetic electron source is about 15.5 eV and 24 eV respectively. While the momentum resolution of the beta-magnetic spectrometer is almost a constant, about 5×10^{-4}. The results listed in Table 1 are the characteristics of the beta-magnetic spectrometer. In order to compare obviously, the corresponding earlier data obtained with ^{170}Tm single stripe and a point electron gun[1] are also listed in the table together.

b. The stability and uniformity: The experiments showed that the stability of the intensity of electron of the photoemissive monoenergetic electron source relates to the material of the cathode, the intensity of photons, the accelerating voltage V_a, and the time duration of measurements. The stability of the spectrum shape of electron spectra relates mainly to the state of magnetic field (including magnetic currents), the environment in which the photoemissive monoenergetic electron source was placed, and electrons intensity.

The results obtained after continual measurements for fifteen electron spectra using ultraviolet light for irradiation in a duration of six hours are showed in Fig.3 in which N is expressing the counts of peak of electrons spectrum. From the figure, it is thus clear that there is a stable region of electrons intensity, denoted by C. In the stable region C, the great majority of the changes of peak counts of electron spectra is less than 3% in three hours, a tiny minority reaches about 5%.

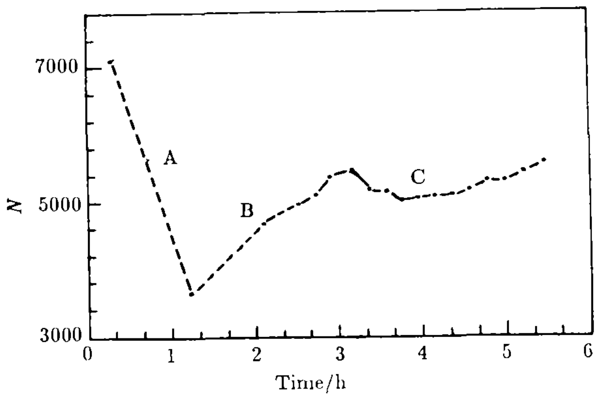

Fig.3 The stability of electron intensity

Table 2

The stability of the shape of electron spectra

Ordinal number of group	Ordinal number of spectrum	Peak counts	Position of peak / mA	ΔI_H (FWHM) / mA	ΔE* / eV	Average value, $\overline{\Delta E}$ / eV
1	1	1077	860.20	0.45	23.6	24.7 ±2.0%
	2	1161	860.07	0.46	24.2	
	3	1228	860.10	0.46	24.2	
	4	1331	860.05	0.47	24.7	
	5	1343	859.98	0.51	26.8	
	6	1438	860.01	0.47	24.7	
2	1	1044	860.47	0.44	23.1	25.7 ±3.0%
	2	1109	860.40	0.47	24.7	
	3	1259	860.38	0.48	25.2	
	4	1288	860.37	0.52	27.3	
	5	1389	860.36	0.51	26.8	
	6	1440	860.27	0.52	27.3	

* The energy of electrons is 22.6 keV; In fact, the significant figures for ΔE are two digits

The material of the cathode has a quite notable impact on the stability of the electron source. If the intensity of electron is too large, e.g. reached to about 10^4 cps in our measuring system, the tested photocathode made mainly of copper may engender fatigued effect rapidly, can not even obtained an evident electron spectrum; while the photocathode made mainly of silver or tantalum has not emerged obvious fatigued effect, nevertheless too high intensity of electron may raise the effect of space charge which is unfavourable to experiments.

The influence to the shape of spectrum comes mainly from the change of magnetic state under normal working conditions. The alteration of the magnetic current I_H is under 0.01%, instantaneous change is below $\pm$ 0.05 mA. At selected moment the change of I_H is $\pm$0.03m A which is the most stable condition and then start to count. Then the change of energy resolution $\triangle E$ indicating the quality of spectrum shape also reaches about $\pm$10%.

Table 3

The repeatability of the characteristics of photoemissive monoenergetic electron source

Ordinal numbers of spectrum	Light source	Peak counts	Position of peak / mA	$\triangle I_H$ (FWHM) / mA	$\triangle E^*$ / eV	Average value, $\overline{\triangle E}$ / eV
1	icd	1799	861.72	0.51	26.8	
2	icd	3140	860.75	0.46	24.2	
3	icd	1620	860.57	0.44	23.1	
4	utv	1207	860.30	0.43	22.6	24.8
5	icd	1331	860.05	0.47	24.7	$\pm$3.5%
6	icd	1288	860.37	0.52	27.3	

icd: incandescence light; utv: ultraviolet light

* The energy of electrons is 22.6 keV; The actual significant figures for $\triangle E$ are two digits

After two primary adjustments of working state of the beta-magnetic spectrometer, the two groups of the results measuring six spectra of electron continually in two hours in unstable region B showed in Fig.3 are listed in Table 2. Comparing the results from Fig.3 to Table 2, it is known that although the change of peak counts ascends regularly, the energy resolution expressing the alteration of the spectrum shape is irregular and its difference is about under 10% and the deviation of its average value is under 3.0%. Cut out the magnetic current, use the incandescence or ultraviolet light placed by the side between the anode and cathode or at front of the anode with the distance of about 20 or 30 cm between the light source and cathode, readjust the magnet field and the position of counter, do tests of repeatability, six independent typic results of electron spectrum under different irradiating conditions of light on different date are listed in Table 3. The disparity of energy resolutions $\triangle E$ obtained from six independent experiments has been displayed by it and is under 10%, the deviation of the average value of the energy resolution $\triangle E$ is under 3.5%. Comparing with the results listed in Table 3 and 2, we can find although there are the differences in irradiating conditions of light, positions of counter and states of the magnetic field etc, yet at the same energy point the energy resolution $\triangle E$ maintains no change within uncertainty. So we can conclude that each surface element on the photoemissive monoenergetic electron source emits uniformly all over the entrance aperture of the spectrometer, *i.e.* favour emission of electrons is negligible. Moreover, the fact that the momentum resolution $\triangle p/p$ at different energy points listed in Table 1 is almost a constant provides a further support to the conclusion.

4 APPLICATIONS

The photoemissive monoenergetic electron source emits electrons simulating radioactive source, and can be made in any shape and size to satisfy demands of diffrent situations. Obviously, these advantages are not possessed by the electron gun. In the electron spectrum measured with the photoemissive monoenergetic electron source, there is no natural width, no shake-off and shake-up effect, no self-absorption and no backscatter background. These advantages are not possessed by the radioactive monoenergetic electron source. So, this kind of photoemissive monoenergetic electron source is very useful in calibrating beta-magnetic spectrometer and determining resolution function of experimental system, especially in the research of neutrino rest mass. After simple design according with actual situation of the tritium source, the determination of the experimental system's resolution function has a new kind of way.

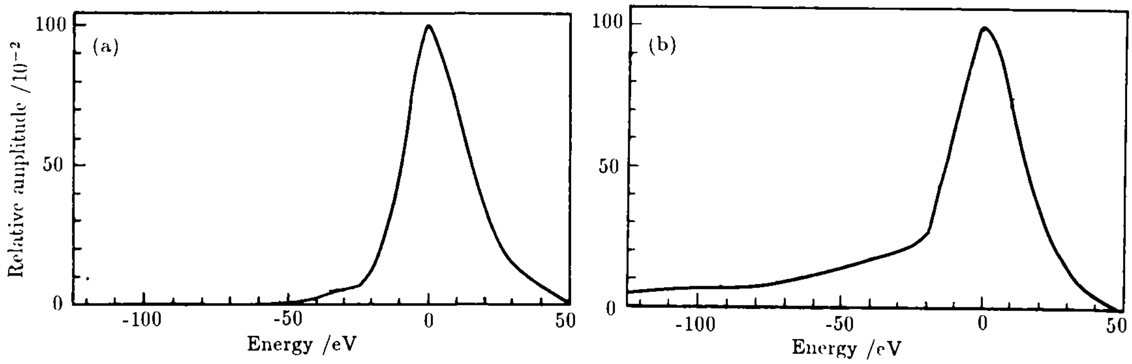

Fig.4 The experimental system's resolution function

The single strip photoemissive monoenergetic electron source can directly simulate the tritium source without compensating the electric potential. But, for determining the resolution function of experimental system corresponding to the large area tritium source with compensation of electric potential, there are two kinds of way to use the photoemissive monoenergetic electron source.

In our research of neutrino rest mass, we measured electron spectra simulating the large area tritium source with compensation of electric potential using arc shaped radioactive monoenergetic electron source of five strips without and with compensating electric potential. The middle peak of electron spectra corresponding to the single strip source placed in the central position and merged one had been gotten. Now, we have also measured the electron spectra of a single strip arc shaped photoemissive monoenergetic electron source placed in the central position. Utilizing these spectra and adopting the deconvolution procedures, corresponding to the large area tritium source with compensating electric potential, we have established the resolution function of experimental system, and an example of which is showed in Fig.4(a). After correction of natural width, scatter and backward scatter in the radioactive source, shake-off and shake-up effect etc. to merged electron spectrum of multistrip radioactive monoenergetic electron source, the corresponding curve is also gotten and is given in Fig.4(b).

In fact, for simulating the large area tritium source with compensating electric potential, for example, we can use a tristrips photoemissive monoenergetic electron source on which the focusing electric potential is applied. The anode and cathode are stretched the geometric dimension as the large area tritium source respectively. The anode is grounded and constructed with tristrips metal wire gauzes, each one of which is similar to the anode of the single strip arc shaped photoemissive monoenergetic electron source. The cathode is connected to a negative high voltage V_a and may be constructed with tristrips tantalum foils fixed parallelly on an insulator backing plate in equal distance. Corresponding to the tristrips anode, we can obtain three peaks of an electron spectrum *i.e.* three voltage values using electric field scanning with constant magnetic current. To get an excellent merged spectrum, i.e. the resolution function of experimental system corresponding to the large area tritium source with compensating electric potential, we can apply the three voltages to the tristrips cathode at the same time using three negative supplies, or fix the cathode as shown in Fig.5 in which R denotes the resistance; V_c^+ and V_c^- denote positive and negative compensation voltage respectively. After fine modulation of

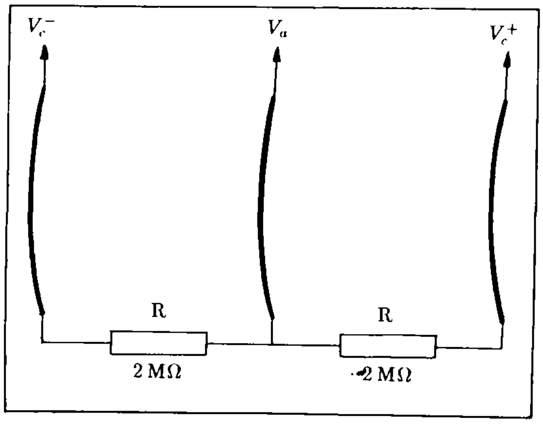

Fig.5 The tristrips cathode of photoemissive monoenergetic electron source

voltage V_a, V_c^+ and V_c^-, the excellent merged spectrum may be obtained too.

5 CONCLUSIONS

The photoemissive monoenergetic electron source can simulate a radioactive monoenergetic electron source in the form of emitting electrons and can be made in any shape and size. The results of calibrating $2^{1/2}\pi$ beta-magnetic spectrometer with the single strip arc shaped photoemissive monoenergetic electron source show that the intensity, monochromaticity, stability and uniformity of the emitted electrons can satisfy the demands of the research of neutrino rest mass at present.

In research of neutrino rest mass, after simple design according with actual situation, it is effective that to determine the resolution function of experimental system with the photoemissive monoenergetic electron source.

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