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A New Evaluation of h/e by X-Rays*

J. A. BEARDEN, F. T. JOHNSON, AND H. M. WATTS
Johns Hopkins University, Baltimore, Maryland

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In previous evaluations of h/e by x-rays the correction for the work function of the cathode has been the principal source of error. New experiments have been performed with a technique which eliminates this error and proves conclusively that in the usual x-ray method a correction for the cathode work function must be made. It is also shown that the separation of the fine structure peaks from the cut off point of the high frequency limit is a function of the voltage applied to the x-ray tube. The value of h/e computed with the new velocity of light is $(1.37928\pm0.00004)\times10^{-17}$ erg sec esu^{-1}.

I. INTRODUCTION

IN a recent paper,[1] the fundamental ratio h/e has been re-evaluated by the x-ray method. In that work, the principal factors which prevented a more precise evaluation of h/e were the indefiniteness of the proper work function that should be assumed for the particular oxide cathode used, and a small error which arose in locating the exact limit of the continuous spectrum. The sharpness of the fine structure observed with some targets, notably tungsten, suggested that both of the above difficulties could be eliminated by measuring the wavelength separation of the fine structure peaks for two widely separated voltages. This was found to be impossible, but h/e was measured at two very different frequencies using a unipotential tungsten emitter and a tungsten target, thus eliminating the uncertainty due to the cathode work function.

II. EXPERIMENTAL PROCEDURE

The apparatus and the experimental procedure used in the present work were the same as described by Bearden and Schwarz[1] with only two modifications. Instead of plotting the high frequency limits with a fixed x-ray wavelength and varying the voltage applied to the x-ray tube, we have maintained a constant potential and varied the x-ray wavelength by rotation of the second crystal of the double crystal spectrometer. This method, which was described in the above-mentioned work, but used only to a limited extent, has the advantage of eliminating the use of a potentiometer and its associated inaccuracies. The second, and more important modification of the equipment has been the introduction of a technique used in thermionic emission work.[2] This technique permits the use of a pure tungsten filament as a unipotential emitter. The block diagram of the apparatus is shown in Fig. 1. The precision megohm resistor[3] (number 1427) was divided into ten 10^5 ohm sections, and by a proper choice of high voltage and the number of 10^5 ohm sections used, a constant voltage drop was maintained across the 100-ohm standard resistor[3] (number 649482) which was exactly balanced by the voltage of a standard cell[3] (number 968). A switching arrangement made it possible to keep the standard cell out of the circuit while preliminary adjustments were being made. The x-ray intensity near the high frequency limit dropped so rapidly with voltage that it was found to be impracticable to use much less than 6000 volts with the x-ray spectrometer in air. The resolving power of the perfect crystals was such that little is gained by the use of potentials in excess of 10,000 volts. Therefore these were the voltages used in all of the present work.

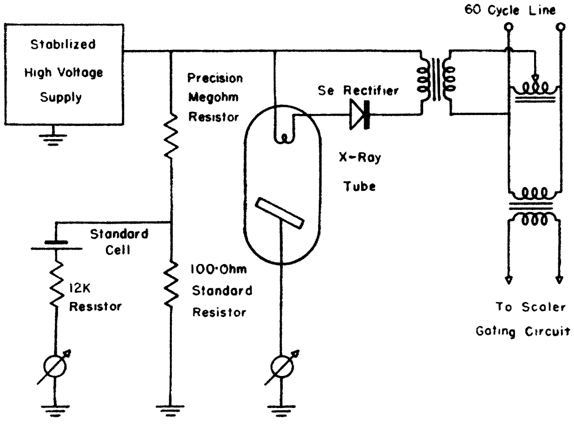

FIG. 1. Block diagram of apparatus.

In part of the present measurements, the unipotential cathode previously described[1] was used. In most of the work, however, a new technique was employed which permitted a pure tungsten filament to be used as a unipotential emitter. This was accomplished by heating the filament with half-wave rectified 60-cycle current as shown in Fig. 1 and applying a gate to the Geiger counter scaler from the same 60-cycle source, so that counts were registered only during the half-cycle when

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[1] J. A. Bearden and G. Schwarz, Phys. Rev. 79, 674 (1950). (The value of h/e quoted later from this paper has been corrected for the new velocity of light.)

[2] G. E. Moore and H. W. Allison, Phys. Rev. 77, 246 (1950).

[3] For National Bureau of Standards calibration of these resistors and standard cell, see reference 1. All of the present measurements have been made as described in the above reference. Correction for temperature of spectrometer crystals has also been made as above, and all auxiliary constants are the same except the velocity of light. We have adopted the value $C=299,790.0$ km/sec as derived in the following paper.

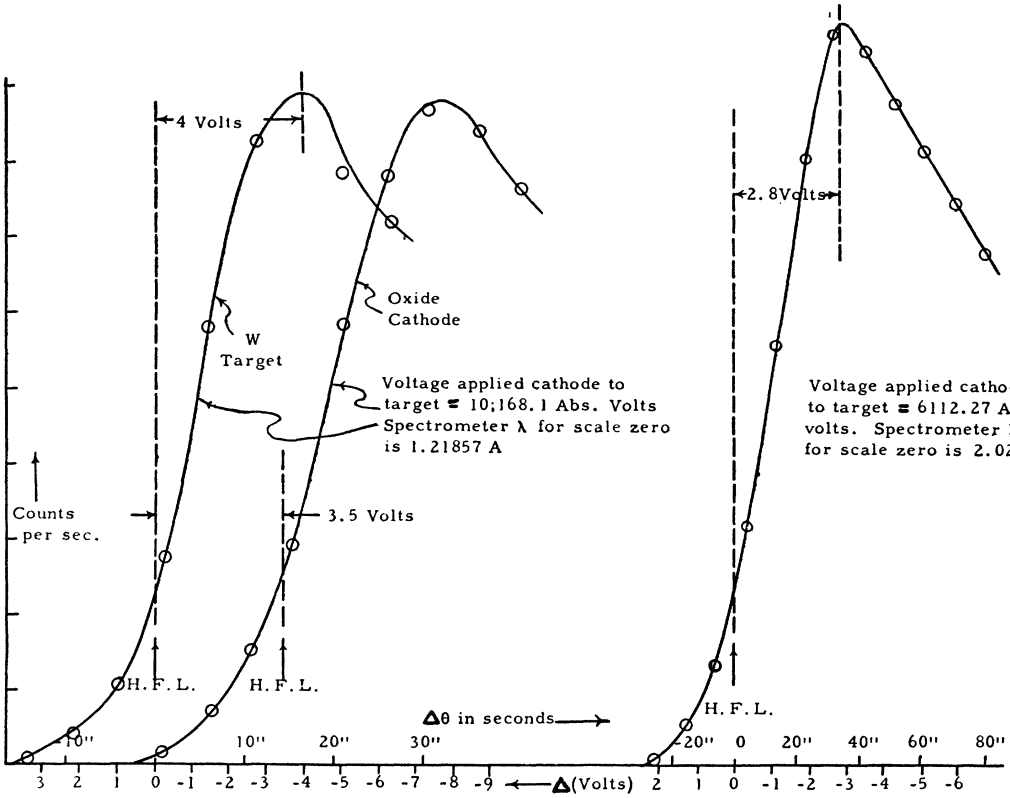

FIG. 2. Average intensity curves for three high frequency limits.

no heating current was flowing through the filament. Hence during the time the counting was taking place the filament was a unipotential surface. The x-ray tube current dropped about 20 percent during this half-cycle, but this introduced no difficulty, since the regulation of the power supply was sufficiently good to prevent the high voltage applied to the x-ray tube from changing during this current change. An oscilloscope study of the voltage variation across the tube occurring during the nonheating half of the cycle showed it to be less than 0.15 volt peak to peak, and over the entire cycle was less than 0.25 volt. The effect of the gating circuit on the scalar was tested by observing the counting rate for photons from a gamma-ray source with and without the gate at rates from 0.5 to 40 counts per second. The ratio of the counting rate with the gate to the counting rate without the gate was constant over this range, which included all the rates used in the x-ray measurements. This would not have been the case if the gate had introduced spurious counts.

III. RESULTS

The recording and averaging of the data was exactly the same as that in the previous work. Figure 2 shows the final average intensity curves for three high frequency limits taken with: (1) a tungsten target and tungsten cathode at 10 kv, (2) a tungsten target and a barium oxide on nickel cathode at 10 kv, and (3) a tungsten target and cathode at 6 kv.

The two curves taken at 10 kv were recorded under identical conditions except for the change in the x-ray tube cathode. The two limits are displaced from each other by 3.5 volts. This is exactly what we would expect[4] since the work function for tungsten is 4.52 electron volts, and a reasonable value for the oxide on nickel is one electron volt, which gives 3.5 electron volts as the

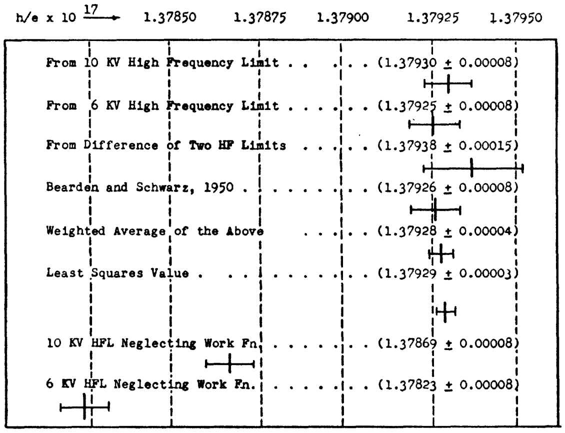

FIG. 3. Comparison of various values of h/e. *Note added in proof:* A correction to the least-squares work in the following paper yields $h/e = (1.379300 \pm 0.000016) \times 10^{-17}$ erg sec/esu.

difference in energy available for the production of x-rays. This is the most direct proof yet offered for the necessity of making the work function corrections. Additional evidence is shown in the lower part of Fig. 3, where it is to be noted that all of the values corrected for work function are consistent with each other, the least squares, and the difference value, the last of which is independent of whether or not the work function correction is made. The two values for which the work function correction is not made are inconsistent with each other, the least squares value, and the difference value. These results, together with the previous work, appear to disprove completely the contention of Ohlin[4] that the work function energy is not effective in shifting the position of the high frequency limit for the continuous x-ray spectrum.

An examination of the position of the first peak of the high frequency curves shows that its position with respect to the high frequency limit changes with the voltage applied to the x-ray tube. At 6 kv the peak is separated from the high frequency limit by 2.8 v, and at 10 kv by 4.0 v. This unexpected result prevents our using the voltages and wavelength separation of the fine structure peaks of the two high frequency limits as a method of evaluating h/e. Furthermore, it indicates that Nijboer's[5] theory of the fine structure is inadequate and a new theory must be sought.

Three new evaluations of h/e have been made from the curves in Fig. 2. Within the accuracy required, the present method of recording the high frequency limit does not prevent the use of the second derivative method for determining the cut-off position. These positions are indicated on the experimental curves. We have evaluated h/e for the two limits obtained with a pure tungsten cathode at 6 and 10 kv and in addition have evaluated h/e by the voltage and wavelength separation of the same limits. The latter evaluation completely eliminates any correction for work function. These values are indicated in the first part of Fig. 3. In the same figure we have shown the value of Bearden and Schwarz corrected for the new velocity of light, and an average value of h/e as derived from the experiments. This is compared with the least squares value found in the following paper. The last two values in Fig. 3 show the effect of neglecting to make a correction for the cathode work function.

The probable error indicated in Fig. 3 for the present measurements could be reduced to about two-thirds of that shown by a long and tedious recording of x-ray limits. Such an improvement would affect the weighted average only slightly, and the least squares value not at all. The agreement of the present measurements with those of Bearden and Schwarz[1] indicate that the selection of the work function for BaO on nickel in that work was correct. The agreement of these experiments on h/e with the least squares value gives complete confidence in accepting the latter as the best evaluation of this important atomic ratio.

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[4] P. Ohlin, Inaugural Dissertation, Uppsala (1941), Arkiv Mat. Astron. Fysik **27B**, No. 10; **29A**, No. 3; **29B**, No. 4; **31A**, No. 9; **33A**, No. 23.

[5] B. R. A. Nijboer, Physica **12**, 461 (1946).