A study of a sodium photocell with sensitivity dependent on the potential difference across the collecting anode
by Otto B Van Horn Jr

A THESIS Submitted to the Graduate Committee in partial fulfillment of the requirements for the Degree of Master of Science in Engineering Physics at Montana State College
Montana State University

Abstract:
no abstract found in this volume

A STUDY OF A SODIUM PHOTOCELL WITH SENSITIVITY DEPENDENT ON THE POTENTIAL DIFFERENCE ACROSS THE COLLECTING ANODE

by

OTTO B. VAN HORN JR.

A THESIS

Submitted to the Graduate Committee in partial fulfillment of the requirements for the Degree of Master of Science in Engineering Physics at Montana State College

Approved:

In Charge of Major Work

Chairman Examining Committee

Chairman Graduate Committee

Bozeman, Montana
June, 1935

TABLE OF CONTENTS

INTRODUCTION

In May of 1933 an unexpectedly large variation in the sensitivity of a photocell constructed from an ordinary light bulb was observed. The photocell was insensitive to the radiation from a carbon arc unless the anode (tungsten filament) was heated by a minimum potential drop of thirty volts. At higher filament potential drops large currents (plus or minus) flowed from the cathode to the anode; the only illumination of the surface being from the hot filament. Illumination of the cell by the carbon arc at these higher filament potential drops increased the current flowing from the cathode to the anode by amounts that were much larger than the current due to illumination by the carbon arc at the minimum potential.

Investigation of this phenomenon was undertaken as a project for a Masters' Thesis in Engineering Physics at Montana State College.

DESCRIPTION OF PHOTOCELL

Construction

The photocell was constructed from a 60 watt, inside frosted, gas filled, second grade, G.E. light bulb. A platinum wire was sealed through the wall of the cell to make contact with the photoelectric surface. An approximate cross section of the cell is shown in Fig. 1. The glass was partially cleared for about 0.75 centimeter around the platinum wire due to the sealing process.

Atmospheric gases were admitted to the cell during the insertion of the platinum lead. Although 0.32 gram of magnesium ribbon was introduced into the cell for use as a getter of residual gases it was not found feasible to flash the magnesium.

The vacuum assembly consisted of a glass condensation pump using butyl pthallate, backed by a motor driven Cenco oil pump. The cell was connected to the pumps for twenty four hours. During this time the walls of the cell were heated to just below the melting point by the direct application of the blue flame of a Bunsen burner for 4 fifteen minute intervals, in an attempt to free the walls of the cell of occluded gasses.

Both before and after sealing off, the application of a 75,000 volt potential from a Cenco spark coil failed to produce a visible discharge through the cell. This indicated the pressure within the cell to be not higher than the order of 10^{-4}

millimeters of mercury.7

The introduction of the metallic surface into the cell was accomplished by electrolysis through the glass walls. A molten mixture of half sodium and half potassium nitrates was used as the electrolyte. The metallic layer deposited around the platinum contact wire was quite transparent to daylight.

Visual spectroscopic inspection of the flame spectrum of the deposited metal showed it to be sodium. The spectroscope used had sufficient power to show clearly the red lines of calcium in a flame spectrum produced from a 1% calcium nitrate solution. It was not felt that this was entirely satisfactory but served to give one reason to feel that very little potassium or magnesium was present in the metal of the cathode.

Treatment After Completion

As mentioned under "Construction" the pressure in the newly evacuated cell was estimated to be not higher than 10^{-4} millimeters of mercury. After about 50 hours of experimental use the application of a 50,000 volt potential from the spark coil caused a dim blue discharge through the cell thus indicating a pressure in the cell estimated to be of the order of 10^{-3} millimeters of mercury.7

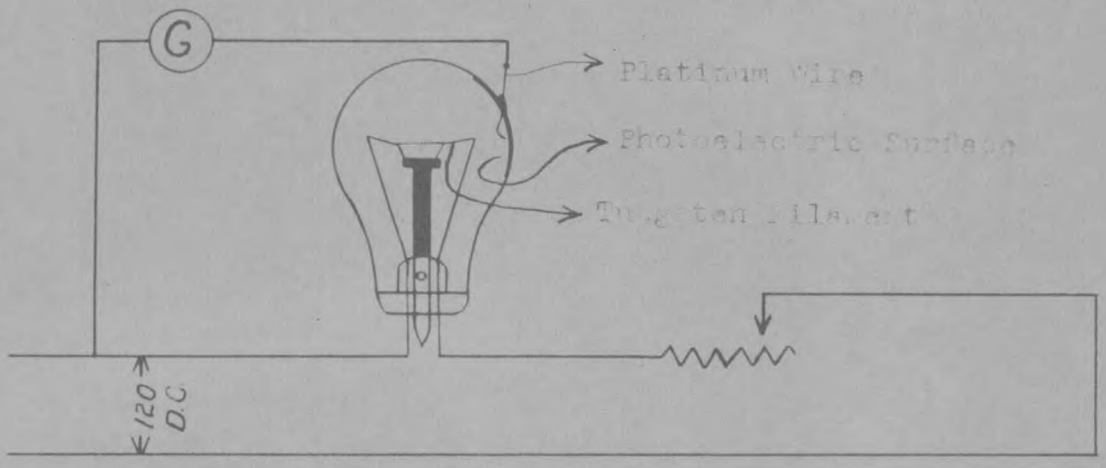


Figure 1. Electrical connections used in the original study of the phenomenon.

EXPERIMENTAL METHODS

Early in the course of the experimental work it became apparent that the photoelectric sensitivity of the cell was somewhat dependent on the immediate usage of the cell prior to the taking of data. Apparently the passage of a thermionic current (electrons from filament to sensitive surface) decreased the sensitivity of the cell, the passage of photoelectric current produced the opposite effect. This effect was small compared with the effect of filament potential drop upon the sensitivity.

In order to check these minor variations in the sensitivity and if possible to connect the cause of them with the major dependence of the sensitivity on the filament potential drop, attempts were made to regulate the sensitivity of the cell by varying the conditions of cell operation before and during the taking of data. This was done by arranging the passage of small thermionic or large photoelectric currents through the cell before starting to take a set of data and maintaining these conditions of operation between the taking of successive data.

A study was also made of the variation of the current through the cell with potentials of varying sign applied to the cathode. The electrical connections used in obtaining current data are shown in Figure 2.

The arc used was formed between the tips of plain, $\frac{1}{2}$ inch,

carbon sticks, and drew a current of 12 amperes. A tungsten filament lamp operating at 110 volts, burning magnesium, and a flashlight were all tried as light sources for illuminating the cell but proved to be ineffective.

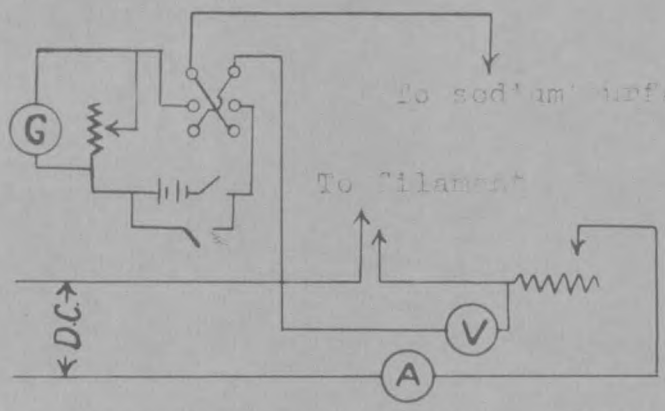


Figure 3. Electrical connections used for cell current measurements.

EXPERIMENTAL DATA

A study of the photoelectric sensitivity of the photocell as a function of the filament potential drop is shown by the data plotted in Fig. 3. In obtaining the data for Fig. 3 an attempt was made to determine the effect of passing small currents of the order of 10^{-9} ampere through the cell between the taking of successive data. Experimental data taken in this manner were obtained in the interval between taking the data for curve 2 and later the data for curve 1.

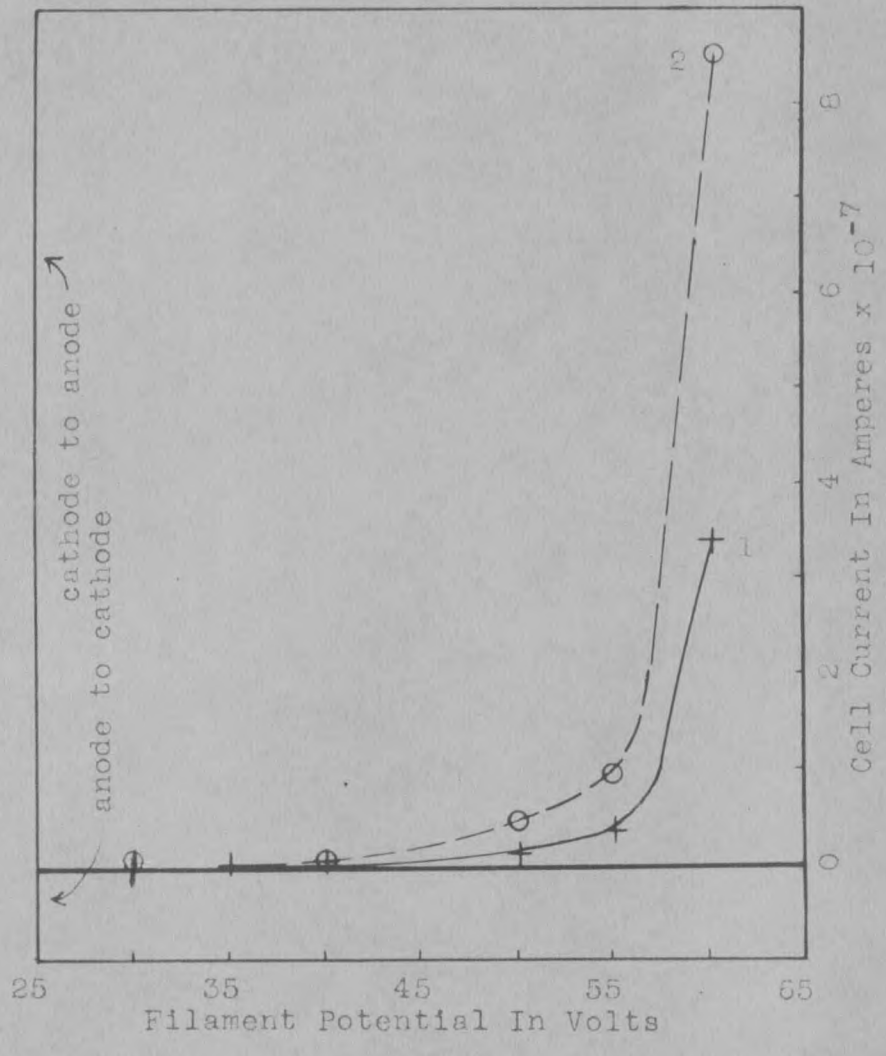
For a given filament potential drop the sensitivity of the cell was less in the set of data shown in curve 1 than for curve 2. At a 60 volt filament potential drop the ratio of the currents I_2/I_1 was 2.5/1.

A study of the photoelectric sensitivity of the cell as a function of the filament potential drop with different potentials applied to the cathode is shown by the data plotted in Fig. 4. In obtaining the data for Fig. 4 an attempt was made to determine the effect of passing large currents averaging 5×10^{-7} ampere through the cell between the taking of successive data.

The data for curves 1 and 2 were obtained in this manner at the beginning of the run, then after several sets of data were taken in a similar manner the data for curves 3 and 4 were obtained. Finally the cell was again operated under conditions corresponding to those for curve 1.

The effect of applying plus 6.25 volts to the cathode in obtaining the data for curves 3 and 4 was to cause the passage of current from anode to cathode until a filament potential drop of 59 volts was reached. The current reversed at this value of the filament potential drop and at the maximum filament potential drop of 65 volts the current values for curves, 3 and 4 were about half the values for curves 1 and 2. Curve 5 was not of the same shape as curve 1 but the current values for corresponding filament potential drops were closely the same indicating that the sensitivity of the cell had been maintained.

In obtaining the data for Figure 4' potentials of opposite sign were applied to the cathode while running the cell as before in an attempt to determine the effect of an electrostatic field on the passage of current through the cell. Curve 1 shows data taken with -48.3 volts applied to the cathode. The current was small until a filament potential drop of 59 volts was reached then it very rapidly rose to values that were nearly 50 times the current through the cell without any applied electrostatic field. (See curve 2,Fig. 3 and curve 1, Fig. 4). Reversing the applied electrostatic field also had the effect of reversing the current at all values of the filament potential drop used. The current flow from anode to cathode in this case did not rise abruptly as in curve 1 but more nearly approached a



1,———,0 volts to cathode,arc off.10:40-10:50
2,— —,0 volts to cathode,arc off. 9:18-9:25

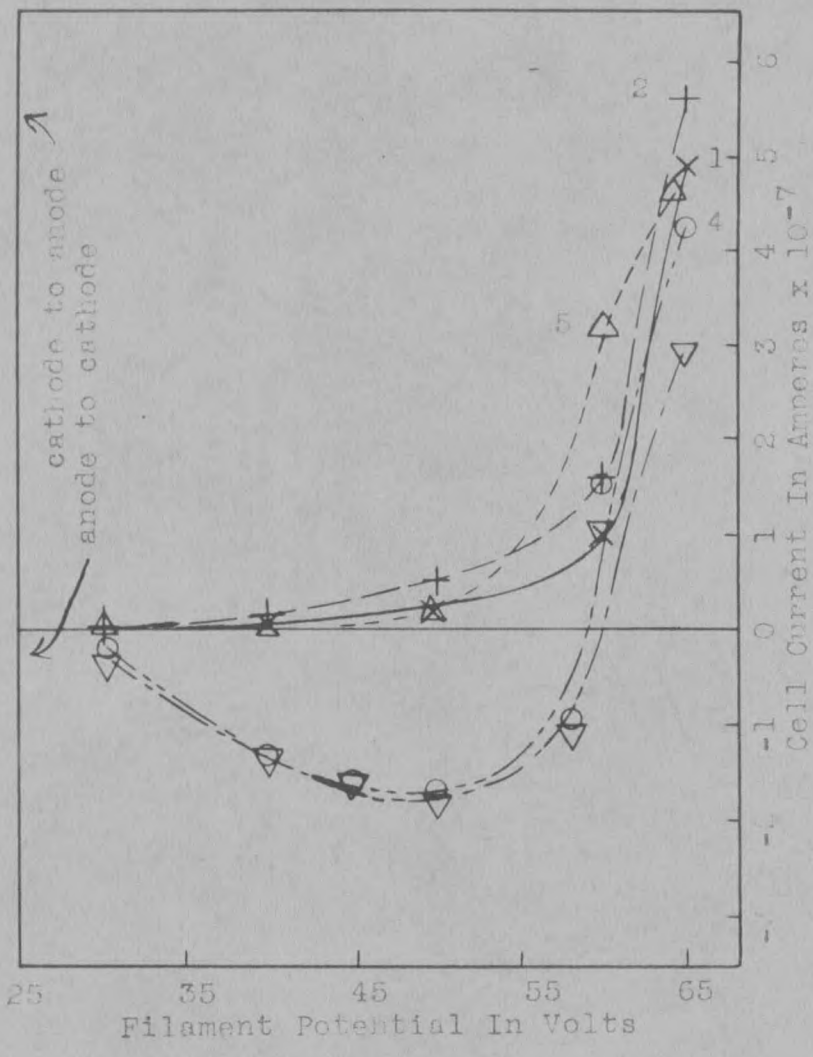
Figure 3. Decrease of photoelectric sensitivity with the passage of small currents.

TABLE I

January 28, 1934

Cell Current - Filament Potential Data for Fig. 3.

Filament Potential In Volts	Cell Current In Amperes x 10^{-7}
0	0.00
30	0.00
40	0.06
50	0.45
55	0.96
60	8.50
0 volts to cathode. Arc off. 9:18-9:25	
0	0.00
30	- 0.06
35	- 0.06
40	0.00
50	0.12
55	0.32
60	3.40
0 volts to cathode. Arc off. 10:40-10:50	



1, ×, ———, 0volts to cathode, arc off. 3:30-3:37
2, +, — —, 0volts to cathode, arc on. 3:37-3:50
3, ▽, — - —, +[illegible].25 volts to cathode, arc off. 4:50-5:25
4, ○, — - - —, +[illegible].25 volts to cathode, arc on. 4:50-5:25
5, △, - - - - -, 0volts to cathode, arc off. 5:25-5:45

Figure 4. Variation of cell current with filament [illegible] applied cathode potentials.

Table II.
February 4, 1934
Cell Current - Filament Potential Data For Fig. 4.

Filament Potential In Volts	In Amperes x 10^{-7} Cell Current
65	4.85
60	0.94
50	0.27
40	0.07
35	- 0.07
30	- 0.02
0	0.00
0 volts to cathode.	Arc off. 3:30-3:37
65	5.60
60	1.55
50	0.47
40	0.10
30	0.03
0	0.00
0 volts to cathode.	Arc on. 3:37-3:50
65	2.94
60	1.01
58	- 1.08
50	- 1.69
45	- 1.55
40	- 1.35
30	- 0.27
0	0.00
+ 6.250 volts to cathode.	Arc off. 4:50-5:25
65	4.19
60	1.55
58	- 0.94
50	- 1.62
45	- 1.55
40	- 1.35
30	- 0.20
0	- 0.00
+ 6.250 volts to cathode.	Arc on . 4:50-5:25

Table II Continued

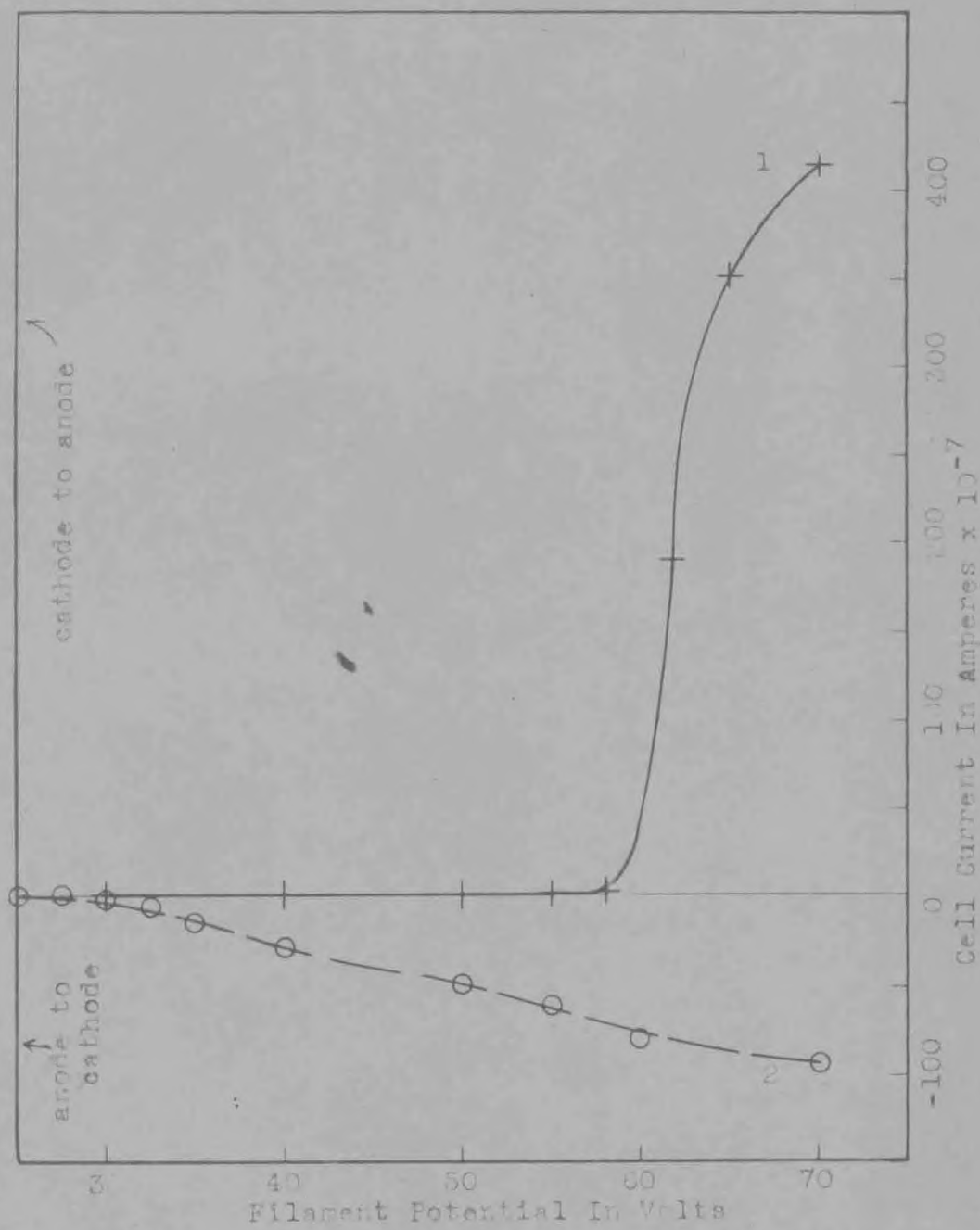
Filament Potential I In Volts	Cell Current In Amperes x 10^{-7}
65	4.72
60	3.17
50	0.20
40	0.07
30	0.07
0	0.00
0 volts to cathode	Arc off. 5:25-5:45

linear dependence on the filament potential drop. The maximum current value reached was slightly less than $\frac{1}{4}$ the corresponding current value for curve 1.

The resistances of the lamp filament at various filament potential drops were utilized to calculate the temperature of the filament for any given voltage drop in the range used.[6] The plotted curve of filament potential drop against filament temperature may be found in the appendix. The temperatures corresponding to the working range of voltage (30-60 volts) ran from 1350°K to 1880°K.

The sodium in the photocell had at room temperature a vapor pressure of 6.8×10^{-8} millimeters of mercury.[4] By use of Langmuirs modification of the Saha equation, the temperature at which the tungsten filament would ionize every sodium atom that fell upon it was calculated to be 940°K.[2] This meant that any enhancement of the electron emission due to a thin layer of sodium on the tungsten surface would occur only at temperatures which were at least 400°C below the minimum working temperature.[1] Accordingly the thermionic emission from the filament throughout the working range of temperatures was that characteristic of tungsten.

It should be noted here that even with minus 90 volts applied to the cathode, there was no detectable current (with the instrument used) passing from the cathode to the anode, when



1, ————,-48.3 volts to cathode, arc off.4:15-4:30
2, — — —,-48.3 volts to cathode, arc off.4:35-4:47

Figure 4'. Variation of cell current with filament and applied cathode potentials.