Measurement of the variations in the reception of solar ultra-violet radiation at the earths surface
by Nathaniel J Kutzman

A THESIS Submitted to the Graduate Committee in partial fulfullment of the requirements for the degree of Master of Science in Engineering Physics
Montana State University

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Approved:

[illegible] M Johnson
In Charge of Major Work

[illegible] M Johnson
Chairman, Examining Committee

J A Nelson
Dean, Graduate Division

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[redacted]

TABLE OF CONTENTS

ABSTRACT Page 3

PURPOSE OF THESIS 4

PREVIOUS MEASUREMENTS 7

SELECTION OF PHOTOTUBE 9

PROBLEM OF AMPLIFICATION 10

CURRENT INTEGRATING CIRCUIT 12

DESCRIPTION AND OPERATION OF COMPLETE APPARATUS 13

RESULTS 17

FIGURES 20

ACKNOWLEDGEMENTS 27

LITERATURE CITED AND SONSULTED 28

ABSTRACT

An instrument is constructed to give a reading proportional to the intensity of the ultra-violet component of the sun's radiation as the latter is incident to the earth's surface.

Poultry raisers are interested in ultra-violet radiation. This radiation is essential to the production of vitamin-D by chickens. Without an adequate supply of the vitamin, the chicken is unable to produce satisfactory eggs. The eggs have fragile and porous shells and are undersize.

A study of the amount of ultra-violet radiation received at the earth's surface will enable the poultry raiser to better regulate the supplementary feeding and irradiation of his flock.

Ultra-violet energy is converted to electrical energy in an electron-multiplier type of phototube. The resultant energy is integrated by a parallel capacitor-resistor combination and "counted" by the firing of a thyratron. The counts are recorded by a mechanical counter activated by the thyratron.

Data have been obtained and graphed to show the relative intensity of the radiation at different hours of the day and during different days over an extended period of time. Data will be obtained for days at different times of the year.

PURPOSE OF THESIS

The problem of the measurement of the variations in the reception of solar ultra-violet radiation at the earth's surface was undertaken, primarily, because of the interest of poultry raisers in the causes of the production of soft-shelled eggs. A deficiency of vitamin-D in the diet of hens affects the thickness of egg shells and their ability to resist breakage according to Ewing[4a]. Ewing[4b] also states that the lack of vitamin-D is a contributing factor to high porosity in shells with a resultant poor hatchability, to retarded egg production, and to reduction in egg size.

Vitamin-D is necessary for a proper conversion of the calcium fed to the chicken to a form suitable for egg shell production. If the vitamin is not forthcoming, the chicken will rob its bones of the minerals necessary. Then, when the vitamin is again present in sufficient quantity, the skeletal structure must have this loss rebuilt before egg production can be resumed. Ewing[4c] says that hens coming from open range feeding in the fall have sufficient stored vitamin-D to produce normal eggs for several months without any considerable feeding of vitamins.

The poultry raiser is, of course, interested in maintaining a sufficient supply of the vitamin-D in his chickens all during the laying season. He attempts to do this by two means. One is the feeding of supplemental foods; while the second is the irradiation of his flock by ultra-violet lamps. Hughes, Payne, and Latshaw[4d] found in 1925 that irradiation of confined hens increased shell weight 44 percent. A study at the

Kentucky Experiment Station was conducted with three groups of hens treated as follows: group 1 confined and receiving sunlight through window glass, group 2 confined and irradiated for 30 minutes daily, group 3 allowed free range. The study showed that the third group had the heaviest shells at all times[40]. Numerous other researches have shown that exposure to sunlight is the most beneficial.

The efficacy of the sunlight is directly proportional to the amount of ultra-violet energy present. The antirachitic or vitamin-D producing effects of sunlight were shown by Coblentz[1] to lie entirely below 3150 Angstrom units. Unfortunately, the quantity of ultra-violet energy falls to a minimum during the long winter laying season. This is during the months when the sun is low in the southern sky and makes its appearance for only eight or ten hours a day. The increased atmospheric path for the rays during this time greatly decreases the ultra-violet energy received at the earth's surface. As the sun's elevation decreases the ultra-violet intensity will eventually reach a level below which it is not adequate to maintain the production of sufficient vitamin-D within the chicken. Then supplemental feeding and irradiation must be practiced.

The long range program of this research is to find the time of year at which the ultra-violet energy reception falls below this necessary minimum. This knowledge would result in savings to the poultry raiser through better and more economical production. The research will also determine the time in the spring when the corrective measures of feeding and irradiation may be terminated.

In order to measure the energy reception in the ultra-violet range, use was made of a photo-electric tube sensitive in this region. The output of photo-electrons for a given emitter and a given wave length is directly proportional to the intensity of the light[5]. Thus the phototube's output current will be directly proportional to the intensity of the ultra-violet components of the sun's radiation. This current could be sent through a recording ammeter and the area under the resultant curve integrated (planimetered) to give an indication of the amount of energy received during a period of time. To eliminate the trouble of integrating, a circuit was devised to accomplish this purpose. This circuit gives a "count", the firing of a thyratron, every time a fixed quantity of charge is delivered from the phototube. These counts are recorded by a relay circuit. The number of counts per hour or per day is then proportional to the energy received during that time. The value of the proportionality factor was not determined during the work covered by this thesis. All data are left in the proportional form and thus show the relative amounts of radiation received at different times.

Graphs are presented that show the variations of the ultra-violet energy received during different hours of the day and during different days. This work will be extended later until a complete picture of the seasonal variation can be given and used to advise the poultryman as to the times to begin and to end the supplemental feedings of vitamin-D.

PREVIOUS MEASUREMENTS

In 1934, W. W. Coblentz and R. Stair[3] published a description of a portable ultra-violet intensity meter. The construction of their apparatus was complicated by the necessity of securing nearly identical tubes for the operation of a balanced amplifier. The output from the amplifier was fed into a micro-ammeter. Thus the instrument gave a reading proportional to the intensity of radiation received but had no provision for integrating the energy received.

G. W. Kenrick and H. Ortiz[5], working in Puerto Rico, developed a recorder in 1938. They used a circuit similar in many respects to that described later in this paper.

In 1940, W. W. Coblentz and R. J. Cashman[2] worked on the relation between ultra-violet intensity and the biological response. This work, as well as that of the first paragraph above, was performed at the Bureau of Standards in Washington, D. C.

The preceding measurements of radiation intensities are not applicable to Montana. It is necessary to add that observations made at any particular place in this state will have little value elsewhere in such a large area. Of the many factors that can influence the rate of ultra-violet reception, two will be especially noticeable here. As the intensity falls off with increase in the length of the path through the atmosphere, both the altitude and the latitude of the station at which the readings are taken must be considered. As the altitude is increased the distance the light must travel through air is decreased and the intensity is increased. As latitude is increased the angle of elevation of the sun at any given date is decreased and the air path becomes greater reducing the intensity. A third factor of importance is the changes in the air mass that the light must traverse. Such changes are caused by variations in barometric pressure. A fourth factor, whose importance has been noted from a comparison of intensities with weather conditions, is the total water vapor content of the air above the observation point.

SELECTION OF PHOTOTUBE

The first problem met in constructing an instrument to measure the relative intensities of ultra-violet radiation was that concerning the appearance of the ultra-violet light as only a small portion of the sun's total radiation. The integrated radiation of wave lengths less than 3132 Angstrom units is only about 75 parts in 100,000 of the total solar intensity, according to W. W. Coblentz[1]. 3132 Angstrom units is considered the long wave end of antirachitic action.

Figure 1 shows a graph by W. W. Coblentz[1] giving the relation between the antirachitic response and the incident radiation. The antirachitic response is the transforming of unactivated 7-dehydrocholesterol into vitamin-D_3, the form best used by the chicken. An inspection of the graph shows the maximum response at 2950 Angstroms. The phototube selected, the RCA 1P28, has a maximum at 3400 Angstroms and a response of eighty-eight percent of maximum at 2950 Angstroms[6a]. (Figure 2.) This tube comes the closest of all tubes investigated to having its maximum response coincide with the maximum antirachitic response.

A disadvantage to the use of the 1P28 is its response to visible light. A light filter, Central Scientific Company No. 87308A, was obtained to remove all radiations above 4100 Angstroms. As this work is carried forward an attempt will be made to obtain a filter with a lower upper cut-off. The dashed vertical line on Figure 2 shows the upper limit of wave length passed by the filter.

PROBLEM OF AMPLIFICATION

The second problem presented in converting the energy in ultra-violet light into an electric current was that of amplification. The relatively few photons in the sun's radiation possessing wave lengths below 4100 Angstroms will liberate a correspondingly few photo-electrons from the photosensitive surface. These few electrons will constitute an electric current of the order of 10^{-8} amperes. The current would be difficult to record on a commercial ammeter. The operation of a counting circuit, to be described later, would entail even greater difficulties. Hence, the feeble current must be amplified.

Amplification by conventional electronic amplifiers was deemed impractical because of the number of stages required. Normally, an amplification factor of a few hundred is considered good. The achievement of linearity in a series of amplifiers is difficult to obtain. Linearity is absolutely necessary if the output current is to be directly proportional to the first power of the light intensity.

The above-mentioned difficulties were overcome by the use of an RCA 1P28 phototube. This tube is an example of the electrostatic electron multiplier discussed on page 50 of the book "Applied Electronics" by the Electrical Engineering Staff of M. I. T. The RCA 1P28 consists of a cathode, nine dynodes, and an anode.

The photo-electrons liberated by the ultra-violet light are accelerated by an electric field between the cathode and the first dynode. When the electron strikes the dynode, secondary emission occurs. The amount of secondary emission, is a function of the energy of the striking electron. The energy possessed by the electron will depend upon the difference in potential between the two electrodes. The liberated secondary electrons then proceed to the second dynode whose potential is maintained above that of the first. Secondary emission again takes place with a multiplication of the number of electrons in the stream. This continues at each of the nine dynodes of the tube. The resultant stream may contain more than one hundred thousand times the number of electrons freed at the cathode. The overall voltage maintained across the tube was 320 volts. This gives 32 volts per dynode and an estimated amplification of the photo-electric current of 700 times.

When the energy content of the incident light rises to a high value (summer months) the output current of the tube would rise to a relatively high value. This would have two disadvantages. The first is the excessive drain on the tube. The second is a too rapid counting rate. The latter would lead to overheating of elements in the counting and recording circuits as well as confusion in recording the number of counts. The recorder has a maximum count of ten thousand. To reduce the size of the output current a calibrated shutter was placed in front of the tube.

CURRENT INTEGRATING CIRCUIT

The third problem to be solved was the construction of a circuit capable of integrating the current from the phototube to give the relative energies received during different periods. This is the counting circuit. It consists of three components: a condenser, a resistor, and a thyratron, arranged as shown in Figure 5.

As the electrons flow from the plate of the phototube they have two paths of return to the power supply. One path, that through R2, presents a very high resistance. Consequently, they will first flow onto the condenser, C2. This will establish a potential difference between the plates, making the upper positive and the lower negative. As this potential difference increases, more electrons will be forced to select the resistor path. This increasing current will make the upper end of the resistor become more positive with respect to the lower end. Thus the negative 22½ volt bias of the thyratron grid becomes less. Soon the bias becomes small enough that the 110 volt A. C. voltage on the plate fires the tube, producing a "count". The tube is turned off by the negative swing of the alternating current. The condenser is discharged before the plate is again brought to 110 volts positive. This prevents continuous firing of the tube. The circuit is now ready to "count" the current from the phototube again.

The rate at which counts occur was regulated by the selection of the sizes of the capacitor, the resistor, and the fixed grid bias. The values of these are given later.

DESCRIPTION AND OPERATION OF COMPLETE APPARATUS

The power supply for the circuits of the instrument is shown in Figure 3. Incoming 110 volt A. C. is fed into three branches. One branch goes to the thyratron cathode and the relay coil. Its purpose there will be discussed under the counter and relay circuits. The other two branches go to the primaries of a power and a filament transformer.

The filament transformer supplies 2.5 volt A. C. to the heater of the rectifier tube, 2X2 879, in the power supply and 6 volt A. C. to the heater of the thyratron in the counter circuit.

The output of the power transformer, at 710 volts A. C., is rectified by the 2X2 tube. Filtering of ripple is done by the inductance-capacitor combination. The capacitor, C1, has a rating of 2 micro-farads and 1500 volts. The output from the filter goes to the phototube at 520 volts D. C.

Figure 4 gives the details of the phototube circuit. The incoming 520 volts from the power supply is dropped to 320 volts by R1 and R2 which total 90,000 ohms. This was done in order to prevent too heavy a drain on the tube. The nine dynodes and the plate of the tube are maintained at successively higher potentials by means of the bleeder resistance. This resistance, consisting of ten equal parts, is 150,000 ohms. The upper end (positive) of the bleeder was grounded as is customary in circuits of this type[6b].

The counter circuit, shown in Figure 5, uses a grounded grid. C2 is a 52 micro-farad condenser. R2 is 20 megohms. The 22½ volt B battery gives the grid of the thyratron a negative bias and hold the tube in the "off" condition. As current builds up in R2, this bias is reduced until the tube "fires". 110 volt A. C. is placed on the plate of the thyratron through the coil of the relay and R3.

The thyratron, operating on A. C., is ready to fire every sixtieth of a second. The fact that it is in a non-operating condition meanwhile will not affect the accuracy of the measurements more than one part in one hundred and twenty as the minimum period between counts is kept at about two seconds by use of the shutter mentioned later.

R3, 400 ohms, was placed in the plate circuit so that its resistance will keep the current through the tube below the allowable maximu. Due to the intermittent action, it is possible to operate the tube at a current value above the recommended average current.

The relay circuits are shown in Figure 6. The current that is allowed to pass when the thyratron fires closes contacts 1, 2, and 3 simultaneously. The charging of C3, with the passage of the current, serves to hold the relay closed when the thyratron shuts off.

The closing of contact 2 places 22½ volts D. C. across R4 and the relay coil. This holds the relay closed until the recorder is operated. R4 is 40 ohms and is used to limit the current through the relay when this holding circuit is in operation.

The closing of contact 3 operates the counter by means of the current from the 1.5 volt dry cell.

When the armature of the recorder moves forward and completes the turning of the number dial, it closes contact 4. This shunts the current of the holding circuit away from the relay coil, allowing the relay to open. R5, of 5 ohms, is introduced to limit the current across the points of contact 4 and prevent their fusing.

Contact 1 places a short across C2 in the counter circuit. This discharges the condenser and makes it ready to integrate for a new count.

The inter-relationships of the parts of the complete instrument are shown in Figure 7. The arrows on the lines between the blocks are placed to indicate lines of action. The direct current produced in the power supply goes only to the phototube. A. C. from the power supply passes through the counter (thyratron) and thence to the coil of the relay. The two arrows returning from the relay indicate the discharging of the integrating condenser by the relay. The double set of arrows between the relay and the holding circuit show the relay activating the holding circuit and then the latter holding the relay closed while the count is recorded. The lines from the recorder to the holding circuit are for the purpose of shorting the latter when the count has been recorded.

In order to keep the photo-sensitive surface of the 1P25 always at the same angle to the sun's rays, a heliostat was constructed. It was patterned after Strong[6]. The motion to follow was developed by a worm and gear driven by a clock. The worm was placed on the shaft of the minute hand. Thus the worm made one complete revolution per hour. The gear has twenty-four teeth, and would turn the phototube mounting through one twenty-fourth of a circle each hour.

By raising or lowering the northern end of the heliostat it is possible to keep the device perpendicular to the sun's light as the elevation of the sun above the southern horizon changes with the seasons.

A calibrated shutter, placed before the filter admitting light to the phototube, permits reducing the counting rate when the incident energy is large. The calibration was done by exposing the tube to an ultra violet source (Dallon's Laboratory lamp) and noting the counting rate at each position of the shutter. A comparison of counting rates for the other positions with that for the full open position gave multiplication factors. When the shutter is at full open, Position 5, the factor is 1; for Position 4, 1.3; for Position 3, 2.9; for Position 2, 5.2; and for Position 1, 10.4.

For an example of the use of the multiplication factors, consider: With the shutter in Position 3 (on a day of moderate energy incidence) the instrument records 10 counts in one minute. Using Position 5 as standard, the number of counts should be: 2.9 x 10 or 29 per minute.

The 1P28 in use in the instrument is checked periodically against a 1P28 held as a standard. If it shows signs of decreasing response it will be discarded. All tubes to be used are calibrated in a manner similar to that above in terms of the standard. The tubes vary in response and multiplying factors must be applied to readings when a new tube is installed.

RESULTS

Figure 8 shows the relative intensities of the received ultra-violet radiation throughout the day of April 18, 1949. This curve is typical of the date received on an average day. The shape should, in general, resemble that of a normal distribution curve with the apex at high noon. The values here, however, are a little less in the afternoon than at a corresponding hour in the forenoon. During the morning hours the sky was very clear and the values obtained should be typical for this time of year. By one o'clock in the afternoon thunderheads were beginning to form on the southern and western horizons. The counts during the afternoon were probably decreased by the presence of considerable moisture in the air. During the late afternoon, from three o'clock on, light scattered clouds occasionally passed before the sun.

Figure 9 is for the date taken on the following day, April 19. The intensity at eight-thirty A. M. is approximately fifty percent less that at the same time on the eighteenth. Such a decided drop in intensity might be caused by an increase in the absolute humidity. The rapid increase in clouds during the next three hours would tend to bear this out. The great decrease occuring immediately after noon coincided with the presence of a heavy overcast. By one P. M. the sun's position in the sky could not be determined by the eye. From three to four P. M. the sky cleared. Readings after four P. M. were taken while the sky was nearly cloudless and compare well with typical readings.

Figure 10 shows the relative intensities on various days of March

April during 1949. Ten minute runs were taken on the days indicated at three o'clock in the afternoon. Dashed portions of the graph indicate periods when the equipment was not in operation due to repairs or to rainy weather which prohibited exposure of the photo-cell. The graph shows the gradual seasonal increase in counts with the increase in the sun's elevation. Between March 26 and April 4 two cycles can be seen that coincided well with two weather cycles at the same times. The "lows" occurred on, or just prior to, days of heavy clouds. The "high" came on clear days. On April 15 another such cycle began that coincided with a period of cloudy weather.

A consideration of the facts presented in the preceeding paragraphs leads to the suggestion that the instrument might have another use. The readings taken over the period April 2 to 4 indicate that it might be used to measure the total moisture content of the air between the observing station and the sun.

April 2 and 3 were days of equal brightness and clearness as nearly as could be determined by the unaided eye. However, the second of these two days gave a reading four counts per minute less than the first. By April 4 a slight haze was apparent in the sky. April 5 was so stormy that the apparatus could not be safely placed outside. The sky was entirely covered with heavy clouds.

However, such factors as barometric pressure, smoke, and possible solar disturbances (sun spots) would cause variations and would have to be taken into consideration. It might be possible to establish a relationship between the amount of moisture in an air sample and the drop in ultra-violet energy of light passing through the sample. Such a relationship could then be used to determine how much above or below a norm was the total moisture content of the air mass lying between the sun and the exposed area of the phototube. It is thought that such information could be of assistance in the prediction of weather at "downwind" points.

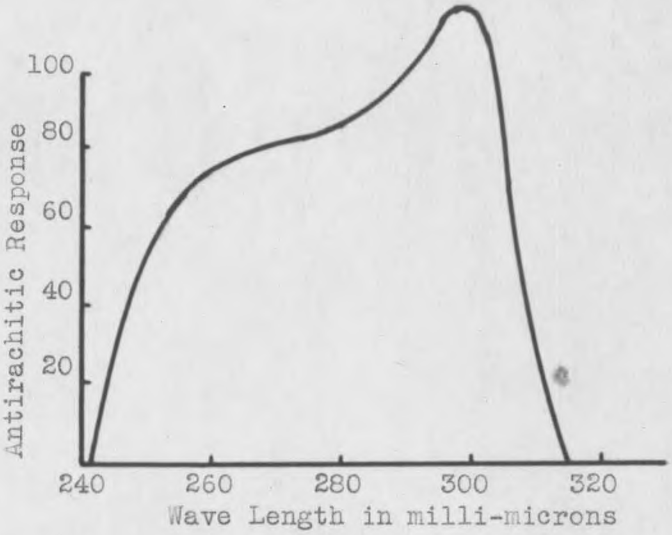

Figure 1. Relation between antirachitic response and wave length of light.

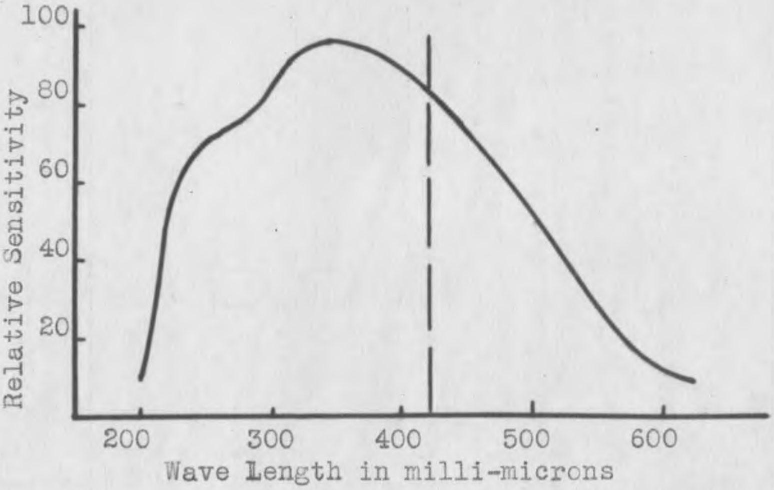

Figure 2. Relative sensitivity of 1P28 to different wave lengths. The dashed line is the cut-off for the filter.

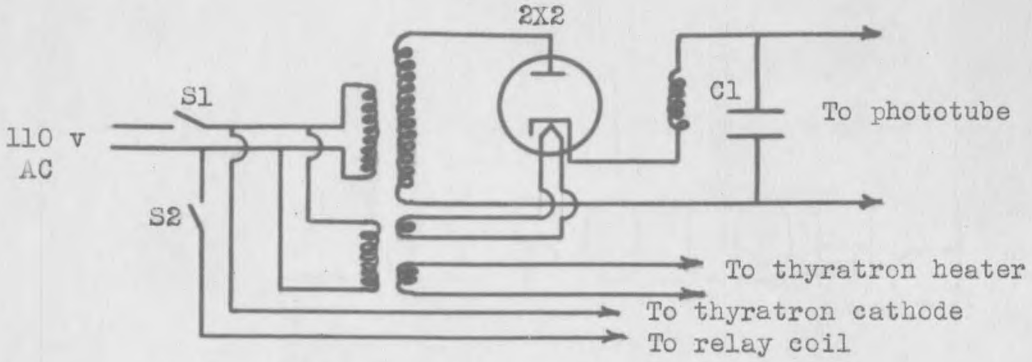

Figure 3. Power supply circuit

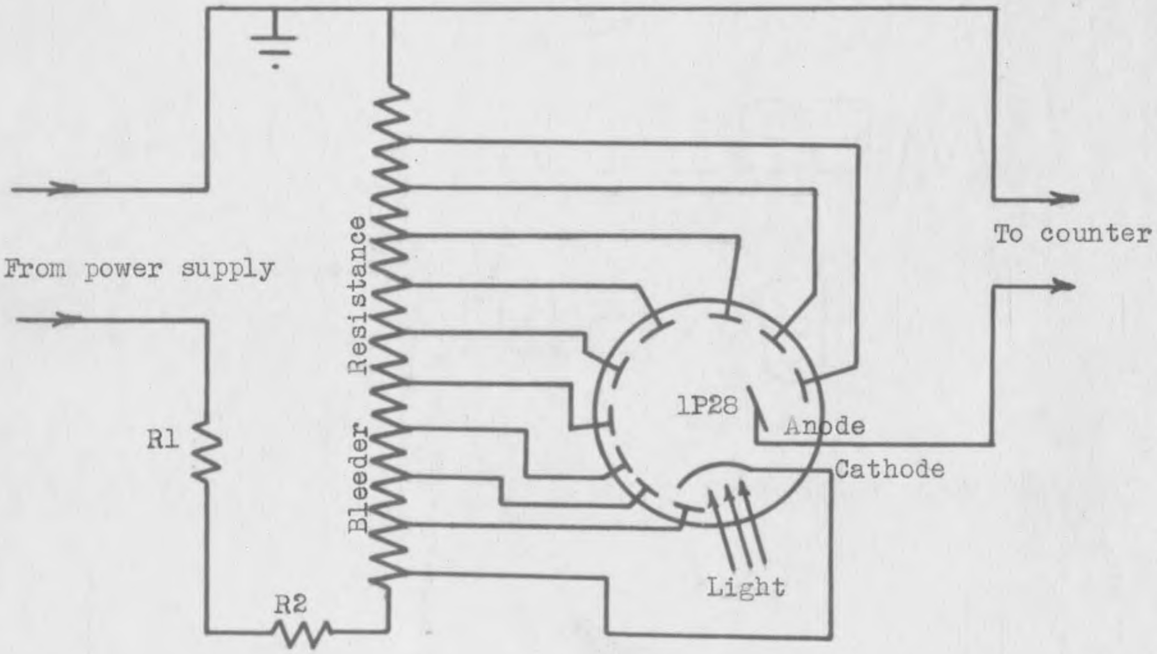

Figure 4. Phototube circuit

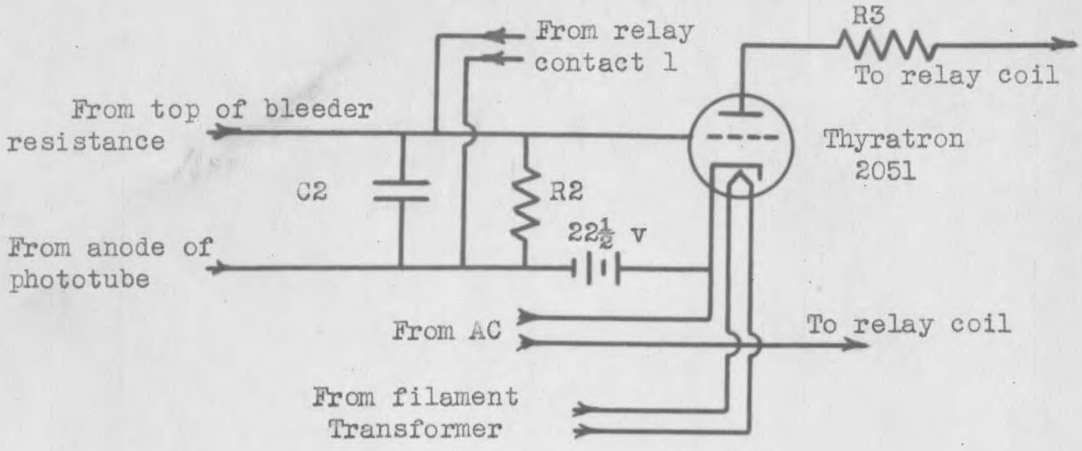

Figure 5. Counter circuit

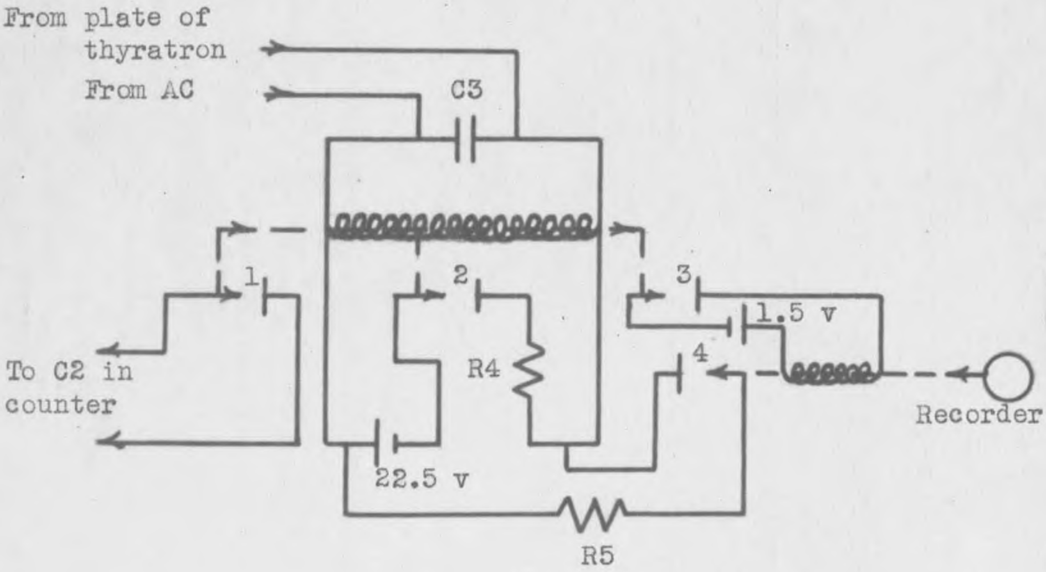

Figure 6. Relay circuits

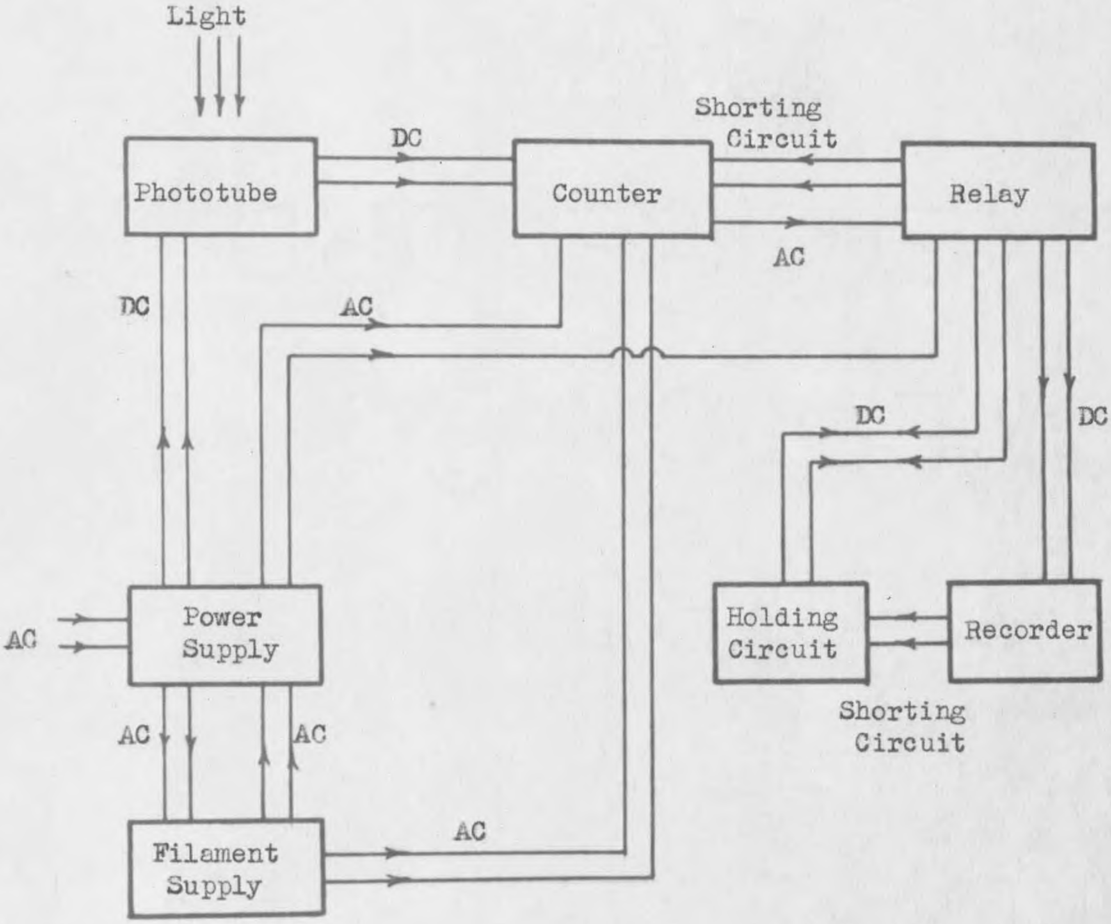

Figure 7. Block diagram of component circuits. Arrows indicate direction of action between the parts.

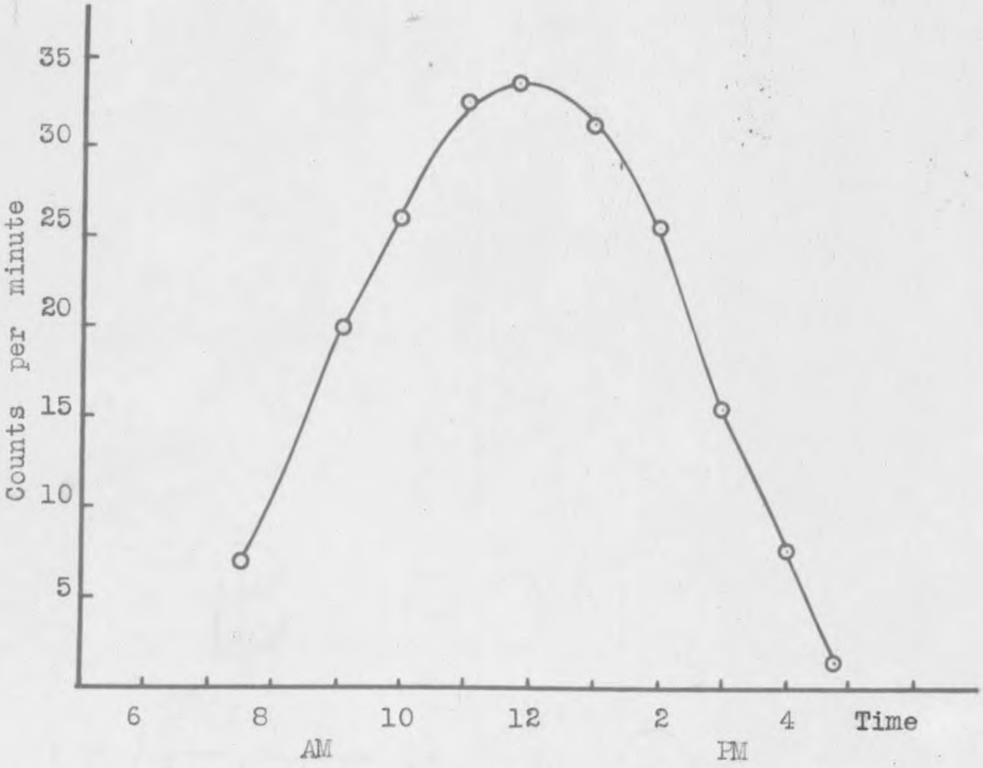

Figure 8. Relative Ultra-Violet Radiation Intensities vs. Time

April 18, 1949

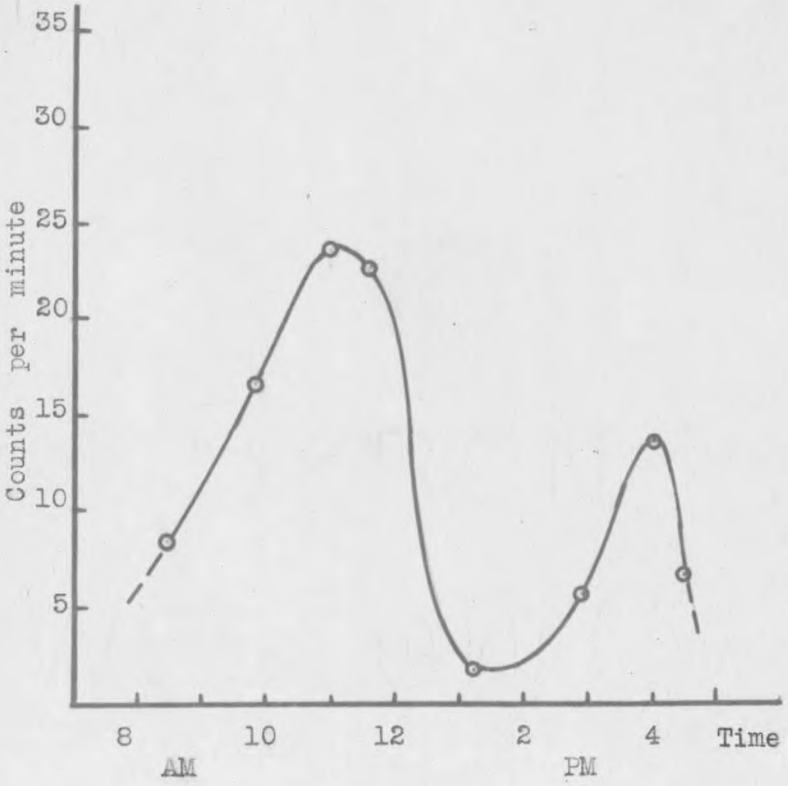

Figure 9. Relative Ultra-Violet Radiation Intensities vs. Time

April 19, 1949

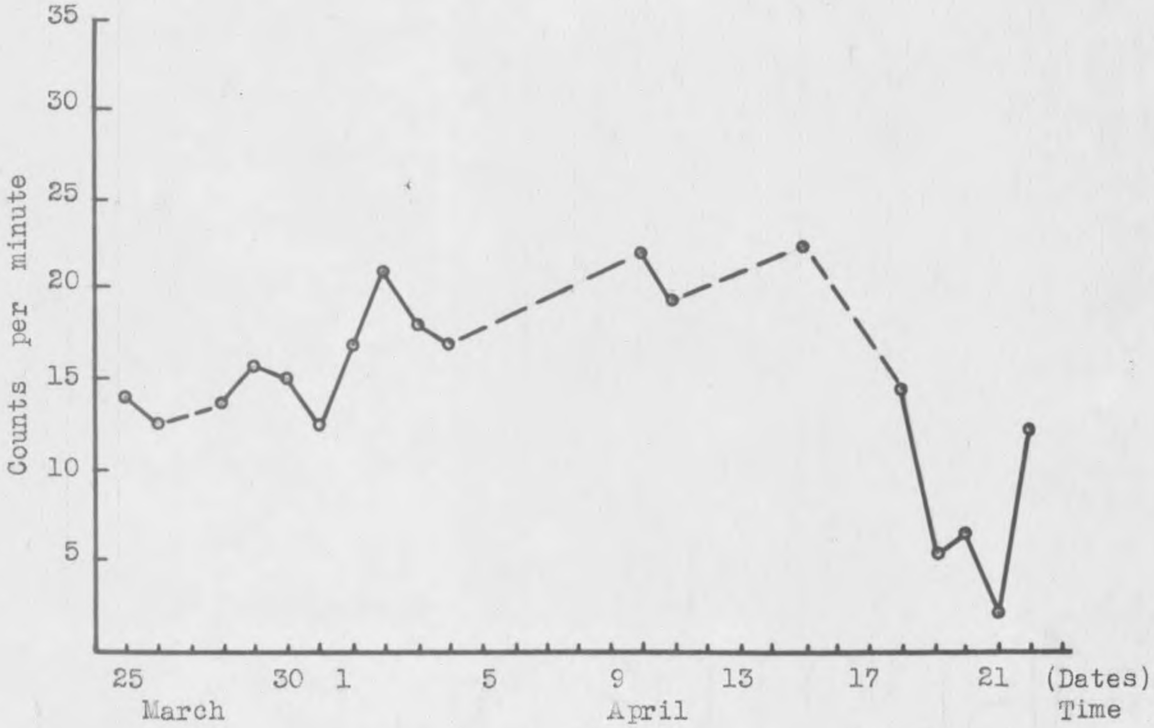

Figure 10. Relative Intensities at 3:00 P. M. during

March and April, 1949

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Prof. Fred Homann, of the Mechanical Engineering Department, for the design and construction of the gears to drive the heliostat.

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