THE CALLENDAR SUNSHINE RECORDER AND SOME OF THE WORLD-WIDE PROBLEMS TO WHICH THIS INSTRUMENT CAN BE APPLIED.

Paper presented before the Second Pan American Scientific Congress, Washington, U. S. A., December 27, 1915–January 8, 1916.

By A. E. DOUGLASS,

Professor of Physics and Astronomy, University of Arizona, Tucson.

Since all mechanical energy has had its origin in the sun and has come to us in the form of radiation, and since this same radiation supplies the energy which keeps our atmosphere in constant motion, produces our winds, evaporates the ocean water for our rains, gives us our warm climate for orchard and field, its minute study and accurate record will present ever-increasing importance. Not only should we be able to gauge and measure the great source of our supply of energy, the sun, but we should learn something of its variations, which perhaps will give us a far deeper insight into weather and climatic variations and assist in their prediction—a matter of the utmost value. Whether, therefore, it is from an industrial or an agricultural point of view that we consider the future prosperity of our nations, long continued records of solar energy will perhaps in their final use be unsurpassed in value by any other form of record.

To get results of cosmic value these records should have a wide distribution in latitude, and therefore the present occasion, invoking cooperation between the Republics of the New World, whose interest in science is recognized by all, seems especially opportune for presenting practical experience with an instrument which will produce such records and some suggestions of the problems to which such an instrument can be applied.

THE PROBLEM INVOLVED IN THE PRESENT WORK.

The unusual excellence of the climate of Southern Arizona, both for astronomical work at night and for solar work by day, was long ago recognized by the writer. He also knew from living in Mexico and on the west coast of South America (Arequipa) the superb conditions prevailing over an immense extent of the western continents. During a long residence in Arizona he had devised and applied a plan for estimating some meteorological data from the growth of trees. There seemed to be a relation, not yet wholly worked out, between tree growth, some weather elements, and solar activity. It seemed, therefore, most desirable to institute in this location and continue some records of solar activity. But there were great restrictions in the matter of time which could be given to such work. The usual pyroheliometer method of testing for the transparency of the air and the intensity of solar radiation requires at least two observations on the sun at different altitudes and absorbs at least an hour or two of time per day. The problem, therefore, was to find at minimum cost of time and money a method of keeping a permanent record, whose reduction to tabular form could be done in some mechanical way by a clerk when subsequent opportunity offered and whose results would have a tangible value.

25807*e*–2—17

PURCHASE AND INSTALLATION.

In 1908 a fund of $10,000 was given to the University of Arizona by Dr. James Douglas, of New York City, the income from which was to be expended for instruments of precision for use in connection with the School of Mines. With the approval of the late Dr. W. P. Blake, who took great interest in this line of investigation, it was decided to purchase some instrument which would measure the energy of the sun, such data seeming to be especially desirable in an arid climate where the sunshine occupies a large part of the daylight hours. In 1910 the writer, traveling abroad, was unable to find just the instrument desired. Apparatus by which occasional measures could be made were available, such as the "Ångström pyrheliometer," and it was thought possible that this might serve the purpose, but in order to have the records continuous without constant attention from some assistant—conditions often involved in the use of research instruments at a university—it was deemed best to get some form of recording mechanism such as the Callendar Sunshine Receiver with its recorder. Acting, however, on the advice of those who had had experience with the Callendar recorder, it was decided to use a Leeds & Northrup recording galvanometer in place of the foreign instrument, because all instruments of this type require minute attention and often repairs which are more readily obtained from a near-by maker. In order to get other advantages out of this recording mechanism, it was decided to have its power of making a record include several different ranges of temperature, as well as the sunshine record, and to obtain with it a platinum resistance thermometer. These extras added to the price, but have not as yet been used.

The cost of the Sunshine receiver bulb was about $110. The cost of the recorder without its extra ranges and thermometer was about $250. Unfortunately, in transportation the bulb was broken and a long delay ensued before it could be replaced. It was, therefore, in the autumn of 1913 that the bulb was finally placed in its present position, and the recorder set up and the instrument put in operation. Instruments of this kind should always be carefully insured for transportation.

LOCATION.

The University of Arizona is located at Tucson, Ariz., at an altitude of 2,400 feet above the sea, in longitude 6 hours 23 minutes 50 seconds west and latitude 32 degrees 13 minutes north. The climate is arid, the average rainfall per year being between 12 and 13 inches. The mean temperature is high, giving extremely warm summers and very mild winters, with only rarely a trace of snow. The city is in a large flat valley, or "bolson," 30 or 40 miles across, and mostly limited by mountain ranges of 1,000 to 6,000 feet height above the valley bottom. The winds are slight, with very rarely a strong gale, which blows up the dust from the river bottom, about a mile distant.

The sensitive bulb is located on the top of the science building, about 55 feet from the ground. It is surrounded by a box whose open top is horizontal and exactly in line with the horizontal sensitive wires within the bulb. The sides of this box are about 10 inches away from the bulb. The purpose of this box is to make the background below the bulb as homogenous as possible under all conditions. It is realized that some radiation will reach the wires from below their surface. If this radiation comes from the ground it may be changed by vegetation, hence the unpainted wooden box has remained to supply this constant background since the instrument was mounted. If one sights across the edge of this box and the sensitive wires it is readily seen that all our horizon of mountains rises slightly above the true horizon of the Sunshine receiver.

The three wires from the bulb are carried through a lead pipe, then soldered to long wires that reach downstairs, which are carried first in a fiber tube and then in an iron pipe. Through a part of the tube an electric-light wire, carrying 110 volts, passes. However, tests of currents running through this wire have failed to produce any effect whatever upon the recorder, and as this wire is only rarely used it is not considered to interfere with the operation of the mechanism. The recorder itself is placed in the basement, in a room on the south side, but as far from the window as possible, and by thermograph records its temperature change has been found to be very slight indeed.

CHARACTER AND OPERATION OF INSTRUMENT.

The Callendar sunshine receiver consists of a glass bulb, 4 inches in diameter, with a vacuum inside. The top part is hemispherical and the lower part is an inverted cone. At the base of the hemisphere are four horizontal grids or squares of platinum wire, each 1 inch square, two of them at opposite corners being covered with white transparent varnish and the other two being covered with black varnish. The black varnish absorbs more heat from the sun than the white, and its temperature rises more than does the other. A neutral wire comes up from the recorder and is attached to both black and white wires. Two wires return down to the recorder—one from the black and the other from the white platinum wires. These are so joined at the recorder that the two sets, one of white wire and the other of black wire, form two branches of a Wheatstone bridge. When their temperatures are the same their resistances are the same. The radiant energy from the sun passes through and warms both wires; the blackened wire, however, absorbs more heat and rises more in temperature and disturbs the equilibrium of the bridge. This throws the galvanometer out of center. The galvanometer pointer is an aluminum needle, 2 inches long, extending out beneath two jaws, which close upon it at regular intervals of about four seconds. These two jaws, one on the right and one on the left, have a slight space between them, so that if the pointer is in the exact center the jaws are not affected. If, however, the pointer is to one side of the center, one or the other of these jaws is pushed out of place, and, by means of a system of levers, its displacement is communicated to a drum which carries the other two branches of the Wheatstone bridge and causes this drum to revolve in a direction which tends to restore the balance of the bridge. The motive power which keeps the jaws in motion and which moves the drum is supplied by a motor running on the lighting circuit. At the same time as doing these operations the motor moves the pen across the recording sheet, so that the position of the pen indicates the compensation resistance that has been placed in the two branches of the bridge in the recorder in order to equalize change of resistance in the grids of the receiving bulb upon the roof. The motion of the pen is proportional to differential temperatures in the receiver and may be perfectly calibrated.

DIFFICULTIES IN MANIPULATION.

Any recording galvanometer which automatically restores the balance of the Wheatstone bridge must necessarily be a complicated instrument and require considerable attention, especially when the variations in currents dealt with are as extremely small as in the present case. Add to that the fact that the instrument is working in a very dry climate, where all celluloid and hard rubber materials are liable to change shape through seasoning, and one is therefore not surprised that the first difficulty was sufficient change in shape of the drum carrying the resistance wires to throw the contact off the wire, nor that the second difficulty was the drying of ink at the point of the pen and stopping the record. An instrument of this sort should be supplied with a large ink reservoir, so that the pen will not require attention oftener than once a week. If the point is very small, so as to save the ink, it readily dries. This, therefore, is a feature which may need further experimentation. It was found that the holes along the margin of the record sheet did not always fit the pins at the end of the drum upon which the record sheet turns, and this was considered sometimes to be due to the drying out of the paper itself. Our current was found to be variable, probably unusually so, and on a few occasions it rose high enough to break the centrifugal governor which controls the speed of the machine, and even twice broke the suspension of the galvanometer. That, however, is a local condition which probably would not exist in a large city. It was not considered worth while to get a set of storage batteries to run this machine, because they would require so much extra attention and responsibility on their own account. Trouble was found in the wearing of the contact on the centrifugal governor, but this, so the makers assert, will be corrected in later models of the recorders, and it is probable that then one platinum point will outlast five or six in the present experience.

A more troublesome deterioration was the wearing of the motor. It is a very great tax on any motor to run continuously night and day. Even with considerable care in oiling, the motor was made to last a little less than two years, but for at least six months of that time it would have been better economy to purchase a new motor. Considering that the minimum time during which records of this kind should be obtained in any one locality is in the neighborhood of 12 years, so as to cover the possible variations of the sun-spot period, it would seem advisable at the outset to provide a mechanism with a large outside driving gear and a good pendulum regulator, and an automatic winding arrangement with large parts to the driving mechanism, which would not be likely to wear out from time to time and would be easier to get at for oiling and other purposes. Measures were made of the actual amount of power involved in turning this mechanism, in order to see how great an outside driving weight would be necessary. These tests were made of the maximum resistance that was introduced in large and rapid adjustments of the pen, and then this power was tripled. The final result was found to be only 200 foot-pounds per hour, or somewhat under 30 kilogram meters per hour.

Unexpected difficulty was encountered when the instrument was left in the hands of an assistant to be looked after for a few weeks. In putting on a dry cell to supply the current that goes through the receiving bulb the poles were reversed, and no amount of investigation by the assistants and by others called in at the time was able to find the difficulty, and some considerable time was lost. Other defects also deserve attention, namely, reflections of sunlight within the glass globe of the receiver and a possible effect due to orientation of the resistance wires within the receiver, making the daily record nonsymmetrical. Both of these features have been noted by Mr. E. R. Miller, of Madison, Wis., and published by him. ("Internal reflection as a source of error in the Callendar bolometric sunshine receiver, Monthly Weather Review, 43, 264, June, 1915.)

TIME SIGNALS.

During the long experience with this instrument the motor was found to run at irregular speeds when the current was variable or when the lubrication was imperfect, or, as in one case, when the spiral spring of the governor caught itself slightly, thus changing its tension. Furthermore, when an accident happened to the governor, or for any reason the current stopped, the time of this accident was sometimes hard to determine. The writer, therefore, added connections to a large clock in an adjoining room. These connecting wires short-circuited, one of them the black wires on the roof and the others the white wires on the roof, through resistance of about 2,000 ohms, on the even hour and the even half hour of the clock. The result of this was to displace the pen strongly for a few seconds upward on the even hour and downward on the even half hour. This method of introducing time signals gave a very satisfactory check upon the rate of the governor, but another effect of it was found to be of even greater importance than that, namely, in establishing a continuous record of the sensitiveness of the instrument. It was found that when the battery gets weak the recorder will not adapt itself to change of resistances as completely and as rapidly as before. A slight bending of the galvanometer pointer or a slight wearing of some of the eccentrics which move the jaws, above referred to, reduce the sensitiveness of the instrument also. Since these two time displacements act in opposite directions, the effort of the instrument to return to a center between them shows exactly how close to its true position the instrument can move the pen, which gives at once the accuracy of the record and the correction to the true place of the pen.

When this sensitiveness is not known it is evident that the noon displacement of the pen may not be as high as it should be, and the pen may not rise in the morning or descend in the afternoon as soon as it should. There may be, therefore, at midday a lessening of the recorded amount of insolation and a slight displacement of the maximum toward a postmeridian position; but with this method of showing the sensitiveness the curve throughout the day may be traced with great accuracy.

STANDARDIZING OR CALIBRATION OF CURVES.

For the purpose of standardizing the results obtained on the record sheets and for calibrating the different parts of the record, a Smithsonian silver disk pyrheliometer, standardized at the Smithsonian Astrophysical Observatory, was purchased; it is No. 16 on their list. (See Smithsonian Pyrheliometry Revised; Smiths. Misc. Coll. 60 No. 18, 1913.) Occasional observations with this instrument with the sun at high and low elevation serve to give a definite value to the curves obtained. In addition to this all resistences have been carefully measured at a known temperature and the bulb on the roof is watched with reference to any change in its external conditions.

ADMINISTRATIVE CONDITIONS.

The institution in which this recorder has been maintained is not a research institution, but an educational one. There is, therefore, no time for an assistant to examine and experiment with mechanism of this sort. The work of the instrument must be almost altogether automatic and require a minimum amount of attention. It is estimated that the expense of reductions will not take much time of a clerk, especially if it is found that the rate of the clockwork of the mechanism has remained constant. Nearly every university has some one who is taking meteorological records—usually one-half hour of his time per day, or, if the suggestions given herewith are followed out, perhaps one-half hour per week would be sufficient to keep the machine running.

RECOMMENDATIONS.

This recording machine was designed by the makers for scientific work when accurate high temperature records for short intervals were needed, and for industrial purpose in which there would be from time to time an opportunity for repairs. In the present case we are adapting it to continuous running night and day for 12 years at least. To get the best results we would be guided by the following recommendations in making another purchase:

1. Dispense with the motor and use an outside heavy driving gear, with automatic winding, regulated by a pendulum clock whose error may be noted. The accurate rate of the instrument is not so important for industrial purposes, but for meteorological purposes will vastly reduce the labor of reducing the records.

2. Introduce the time signals as above described in order to give the sensitiveness of the instrument.

3. Arrange, if possible, for a large reservoir pen and also for a holder for the pen in which the height of the ink may be seen at any time. Several extra pens should always be on hand.

4. If the paper has a tendency to cling to the drum, thus twisting sideways and lifting the pen off the paper, place a sheet of paper about the drum so as to raise the record sheet slightly.

5. If the motor and governor supplied with the recorder are used, it is advisable to keep an extra motor on hand, purchasing it at or near the outset. With this motor should be an extra worm gear also and extra contacts.

6. If lighting circuit is not available, storage batteries may be used to run the motor or a heavy weight could be arranged to be wound daily for running the mechanism.

7. The dry cell or storage cell, which sends a current through the receiver wires, should be attached to posts so labeled that no one will reverse the poles.

8. The pen can be filled, daily memoranda made, sheets changed, and work of that character done by an assistant or clerk, but there should be at hand someone skilled in electrical instruments for the detection of occasional difficulties. This makes the instrument especially well adapted for emplacement at educational institutions or in government central research stations such as weather bureaus. At the former, however, the summer vacation may offer a difficulty. The assistant's work can be obtained but the expert may not be there. This, however, can usually be anticipated in some way.

9. Besides the additional parts to the recorder do not omit a standardized pyrheliometer for correcting the results.

SIGNIFICANCE OF CURVES OBTAINED.

The curves obtained in this instrument give the amount of energy received on a horizontal surface of unit area in unit time. The character of the energy received is that absorbed by a black body in the form of heat. The instrument does not differentiate between the energy in different colors, and therefore if it is standardized in one condition of the atmosphere, in some other condition a slight error might be introduced due to the varying energies in different parts of the spectrum. Nor does this instrument give any measure of the actinic energy of the sun or the specialized form of energy which causes physiological changes in plants. The writer has outlined but not yet put into operation a photographic method of keeping continuous record of the actinic energy received on a flat surface. Dr. H. A. Spoehr, of the Desert Botanical Laboratory, Tucson, uses for his tests on the chemical energies of the sun's rays a mixture of oxalic acid and uranium acetate. After a certain number of hours' exposure the amount of unchanged oxalic acid may be measured. He is planning, however, to supersede this method by an improved process.

RECORDS OBTAINED AT TUCSON.

Continuous records began on October 6, 1913, and have continued to the present time with the exceptions noted below. In December, 1913, the motor needed repairs and was taken off for some time. Every day except one, however, the instrument was turned by hand, so that some records were obtained. In the summer of 1915, during the absence of the writer, the instrument was left in charge of an assistant, who, on leaving, placed it in charge of another. In this way 70 days were totally lost. Only three others have been lost out of the total of 756 from October 6, 1913, to October 31, 1915. Of the 683 days on which some records were obtained, 490 complete records have been obtained, or 72 per cent; 161 partly defective records, or 24 per cent; 32 days with only isolated settings by hand, or less than 5 per cent. During the same interval 327 days have been noted as clear or very nearly so, or 48 per cent; 300 half cloudy, or 44 per cent; and only 55 wholly cloudy or nearly so, or 8 per cent. Out of the 683 records it is estimated that 420, or 61.5 per cent, are likely to be available for determining the transparency of the air and therefore the approximate solar radiation. In considering this report it should be remembered that this use of the instrument is comparatively new, that no funds have been paid for the labor of keeping the instrument running, and that with the suggestions made above there is no necessity for any important loss of time.

PROBLEMS FOR WHICH THE RECORDS MAY BE USED.

1. *Industrial purposes.*—The daily curve may be read off in horsepower, per square yard or per square meter, per eight-hour day, which reaches a horizontal surface. This in turn may be interpreted in units of heat for running a motor or engine of any kind. It is true that this application looks far into the future, for at present no motor or engine using solar energy directly is in completely successful operation, but when genius or necessity gives us some method of conserving solar energy these solar records will have as great value as the records of flow of water in streams designed for water power. In order to give an idea of the enormous amounts of energy which are being received from the sun, it is only necessary to quote a brief calculation in regard to the five square miles covering the city of Tucson. The amount of energy received on this area on the average of an eight-hour day is so great that if it could be turned into electricity without loss and sold at the rate which we pay for electricity in our electric lights it would bring more than $1,000,000 per day.

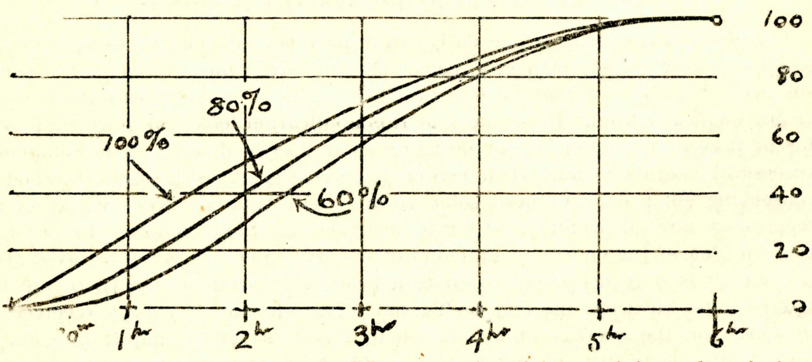
Many attempts have been made to make solar engines, of which the two most noteworthy are the movable and stationary mirror type. The movable mirror is usually made in the form of a paraboloid with the boiler in the center. This paraboloid is mounted on a equatorial axis which keeps the mirror facing the sun. Machines of this type have not been commercially successful because they require too much expert attention and are injured by the wind. The other form is stationary and consists usually of flat, shallow boilers arranged in tiers so that the hot water of one goes into another where the water is still hotter. This has been put in fairly successful operation by a Philadelphia company. It should be said also that solar heaters (manufactured by a Los Angeles company) are successfully used here in the Southwest where the hours of sunshine are very great. Reference should be made in this connection to the solar heater and cooker that is being constructed by Prof. C. G. Abbott, of the Smithsonian Astrophysical Observatory, at his house on Mount Wilson, Cal.

2. *Solar radiation and plant life.*—The number of heat units received on a flat surface is being investigated at the Desert Laboratory, Tucson. This work is being done by Dr. Spoehr, already mentioned in connection with his studies of the value of chemical energy. The actual number of energy units as derived from our records will be used by him in comparison with the development of plants.

3. *Light of the sky.*—The sunshine receiver here described, having a flat surface extending horizontally, receives heat not only from the sun itself but

from all the sky. No systematic attempt has here been made to differentiate between the two. For most agricultural purposes there is perhaps no need of differentiating between them. But in order to get the transmission of the atmosphere and estimates of the solar constant the actual energy received from the sky as apart from the sun should be known. Occasional tests of this have been made in a crude manner by using a screen on the end of a pole and shading the receiver from the sun. In every case the amount coming from the sky has proved very small and probably negligible. The great difference between the sun and the sky also is seen by us constantly on the records at the time of rising and setting of the sun. There is practically no difference in the curve at any time between night and the few minutes before the sun begins to rise, but as the sun's disk passes above the mountain top the pen of the recorder immediately rises and the day's record begins. It seems, therefore, that the amount of energy received from the sky, while deserving to be considered, practically has a very slight effect upon these curves.

4. *Atmospheric transmission.*—Atmospheric transmission is usually measured by some form of disk pyrheliometer with observations taken upon the sun



Insolation effect on a horizontal surface for different percentage of air transmission, as shown in shape of record curve above, noon heights of all curves being made equal.

at two different altitudes. It is believed that the sunshine curves obtained here in an arid climate are good enough to indicate the transmission of the atmosphere in a large percentage of days. Of course, the accuracy of such test will not be as great as with the regular pyrheliometer, but yet it is thought that the curve should do considerably better than within 5 per cent. In order to answer the question whether the curves are capable of doing this, a calculation was made of the relative amounts of insolation received from the sun while passing over the prime vertical for 100, 80, and 60 per cent transmission. This was done by the following formula:

$$I = E_0 \, a^{m-1} \cos z$$

in which I is the desired insolation; E_0 the solar constant taken as unity (in plotting these curves); (a) is the transmission; (m) is the air mass, the vertical being taken as unity; and (z) is zenith distance. If E_0 were constant, then (a) would be read off at once in height of the curve at noon. Probably for many purposes this would be sufficiently accurate, but in order to allow the subsequent determination of the value of E_0 we must get an idea of a from the shape of the curve alone, as is usual in pyrheliometer observations. So a^{m-1} in the formula brings the noon height of each curve to the same point in the plot, and the shape of the curve alone is left from which to judge (a). The curves so plotted are shown in the accompanying figure, in which abscissæ are the hours from zero to 6 as the sun rises from the eastern horizon to the zenith. The ordinates are proportional to the effect upon the horizontal surface with different percentages of transmission of the atmosphere. It is evident from a comparison of these curves that their maximum difference occurs at low elevations of the sun and that clear weather at such times of day will be important for the determination of transmission. In order to see whether variations of this magnitude in the curves already obtained here are available for determination of this transmission, the curve obtained here at the equinox shows by measurement a length of over 25 cm. for the hours from zero to 6. The elevation of the curve at noon is from 10 to 12 cm. At that time of the year the sun is 32° from the zenith at noon. It seems probable, therefore, that on this scale a fairly reliable transmission of the atmosphere will be obtained within 5 per cent or even less on a large number of days. Such records of atmospheric transmission if obtained constantly would form an interesting and valuable addition to the record of common meteorological elements.

5. *Solar constant.*—If the air transmission can be obtained from the pyrheliometer curves here considered within 5 per cent or less, then the solar constant can be determined with the same accuracy, and we shall have a check upon the constancy of our fundamental source of energy. During the last few years the work of C. G. Abbott and his colleagues at the Smithsonian Astrophysical Laboratory and others, has shown that the sun is not perfectly constant in the amount of heat transmitted to the earth. Changes often as great as 10 per cent have been found to occur within short periods of time. Variations of that proportionate value, and even variations of less than that, should be obtained or at least their occurrence should be checked by the recording mechanism here described.

For every meteorological purpose a knowledge of the solar constant would appear to be of the utmost value. In the variations of the sun will possibly be found some of the causes of weather change. To be sure, we need to learn the cause of solar variations, and many investigators are at work upon this problem, and of course we need to know why and how changes of insolation can produce unlike effects in different parts of the earth; but if we can securely forge one link in the chain of causes—namely, the physical relation between variation in the sun and climatic variations of the earth—we shall have done a work forever valuable for agricultural, industrial, and scientific purposes.

PRESENT OPPORTUNITY.

The cooperation of the western nations whose representatives are here gathered together gives a great opportunity for mutual help along scientific lines. In the present fundamental study of the heat received by the earth from the sun this cooperation offers a remarkable chance for finding the distribution of that insolation in latitude by the establishment of a number of recording stations throughout the immense extent of the Americas. By means of these stations also we would be able to trace the progress of heat distribution through the agency of our own atmosphere, and to understand the effect of mountain ranges or great changes in latitude, and by the combined results from a number of stations, properly distributed, a very accurate idea could be obtained of the transparency of our own atmosphere and a valuable check would result upon the variations of the sun and their relation to our weather. All countries, therefore, which could use a small fund for the purchase of such instrument and could supply a few minutes' time each day for the necessary attention and care required are urged to procure and install a recording mechanism of the type here described.

WASHINGTON : GOVERNMENT PRINTING OFFICE : 1917