THE CLOCK VAULT OF THE U. S. NAVAL OBSERVAVORY.

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The clock vault of the U. S. Naval Observatory was designed and built in January and February, 1901, by Professor Milton Updegraff under the direction of Professor S. J. Brown, then astronomical director. It is located in the basement of the west observer's room near the six-inch transit circle and consequently is limited in size by this basement. The ground plan of this vault is shown in Figure *A*.

The vault is of a doubled walled construction having a so-called outer and inner vault; the walls being separated by an air space of about one foot. The outer vault is inclosed by brick walls nine inches thick, has a floor of concrete eight inches thick, while the ceiling is composed of six inches of mineral wool. The inner vault is built of wood and is about eight feet square with a height of seven feet. There is a door entering the outer vault from the basement and a set of double doors, forming an air-lock, lead from the outer to the inner vault. The three doors are never all opened at the same time.

The inner vault contains three substantial brick piers embedded in a footing of concrete upon which are mounted Riefler clocks Nos. 60, 70, and 151. There is also a low brick pier for auxilliary apparatus which is used at present for a very sensitive Richard thermograph; this thermograph has a scale value of 10 mm. per degree centigrade and a sensitiveness of about 0°.01 is claimed for it by the makers. In each clock case is ; n accurate thermometer graduated to one-fifth of a degree Centigrade which is placed at the mean elevation of the pendulum, also each case contains the usual Riefler clock barometers. Max-

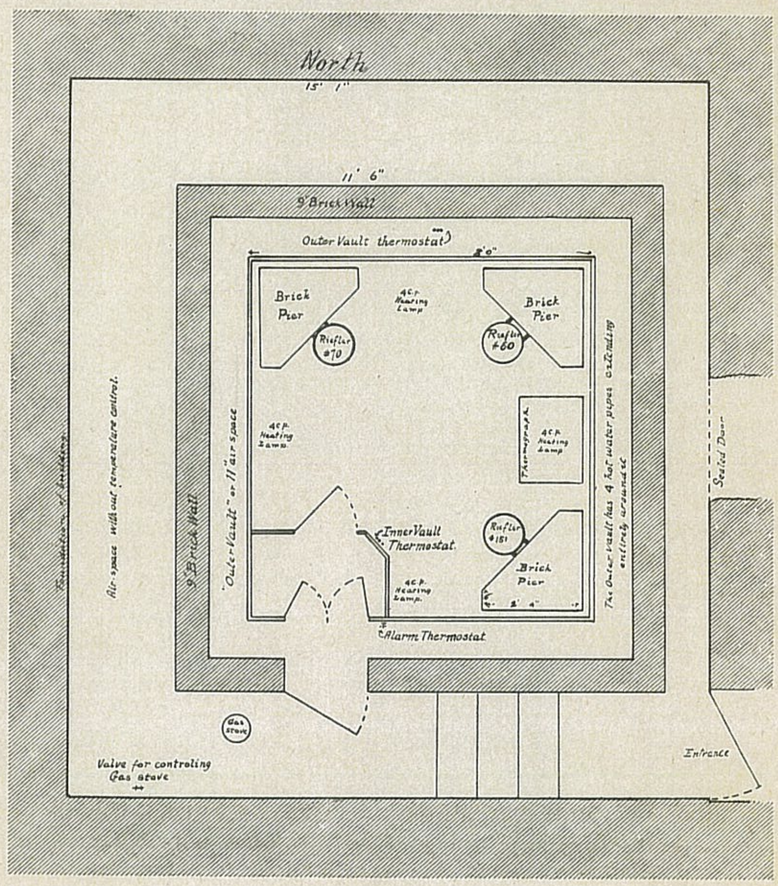

FIGURE A.—Plan of Vault.

imum-minum thermometers are mounted ¦ both in the inner and outer vaults.

The outer vault is heated by four hot water pipes running almost completely around it in the air space between the two vaults, and supplied from a gas water heater. The original gas stoves were used until December, 1908, when a new copper tube gas water heater of better and more economical design was installed; and later there was provided efficient means of carrying off the waste products of combustion. The supply of gas is regulated by an electrically operated valve and thermostat placed in the air space between the inner and outer vaults and symmetrically situated with respect to the heating pipes. Before December, 1908, the thermostat used was of the well-known compound bar type which is designed and successfully used for commerical purposes, but is not of the proper type where accurate control of temperature is required.

During the latter part of 1908 a study was made of various forms of thermostats with a view to eliminating any appreciable changes for considerable periods of time. After investigating several forms and receiving valuable advice from Dr. Wolf of the Bureau of Standards, the type illustrated was designed.

The principle of this thermostat is the use of a liquid having a reasonably high coefficient of cubical expansion, to move a column of mercury into or away from contact with a platinum point. At first the liquid used was methyl alcohol because of its large expansion coefficient, but this was almost at once discarded on account of the apparent impossibility of preventing a leakage either through or around the inclosing column of mercury. At the suggestion of Dr. Wolf a purified kerosene was substituted and proved satisfactory in an experimental thermostat constructed of glass tubing sealed with melted shellac.

The construction of these thermostats shown in Figure B is very simple and needs no description except for a few practical points. The kerosene reservoir should be of sufficient size; in this case it is blown from glass tubing 16 mm. bore and 750 mm. long. The contact tube must not be too small, preferably not much under one millimeter bore, in thermostat No. 1 it is $0.^{mm}8$ and in No. 2 it is $3.^{mm}0$. The tube containing the kerosene must be completely filled in order to avoid any error due to varying barometric pressure. The mercury used was carefully cleaned with nitric acid and afterwards shaken together with ordinary kerosene for five minutes at intervals of a few hours for several days. A black sediment which is formed during this process can be allowed to settle or removed by filtration. It was thought best to have the tube for the kerosene sealed by the glass blower and the thermostats were filled by alternately heating and cooling, each time drawing in more kerosene. The column of mercury in the contact tube was set lower than the mercury-kerosene surface in order to prevent creepage of kerosene

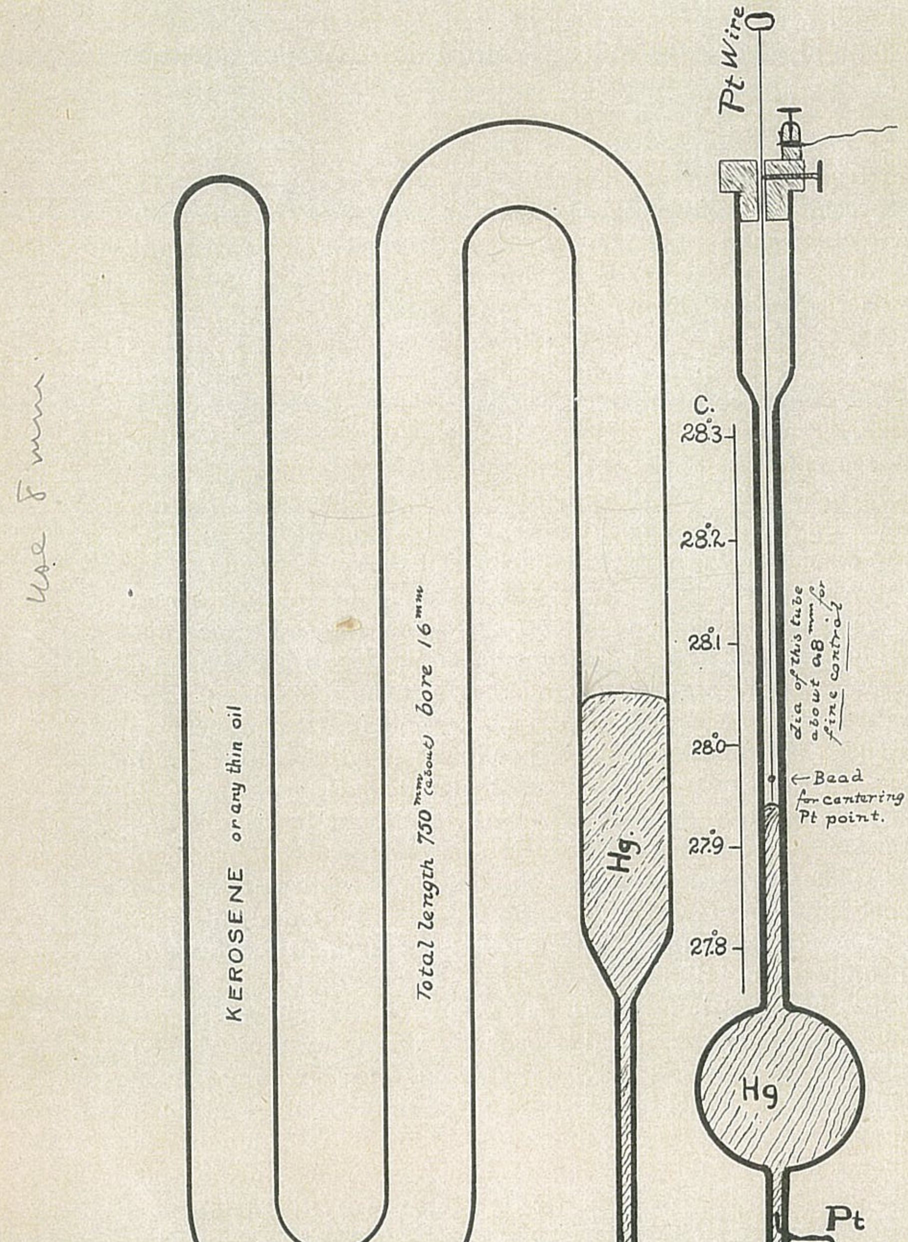

FIGURE B.—Plan of Thermostat.

between the mercury and the glass which otherwise is apt to occur for some days after the thermostat is set up.

On December 3, 1908, thermostat No. 1 was substituted for the compound bar thermostat in the outer vault. Some interesting results were obtained with this single control. A well marked heating and cooling period was shown on the thermograph records, amounting approximately to a tenth of a degree centigrade and with a period of between one and two hours corresponding to the period of heating by the gas water heater. Another temperature error was observed whenever there was a cold north wind blowing which seemed to relatively cool the thermostat with respect to the rest of the vault and thus raise the clock temperatures by about a tenth of a degree. During the spring months there was a slow and uniform rise in the clock cases of about one half degree. The records showed that the errors were due to a lag in the hot water heating system and to a varying distribution of the heat when the outside weather conditions varied.

It was deemed advisable to install a secondary or inner temperature control, with a sensitive and quick acting source of heat, and by this means to raise the temperature of the inner vault between ½° and 1° Centigrade. With this in view, four electric lights of four candle power each were placed in a symmetrical manner on the ceiling of the inner vault and provided with deep conical, metallic reflectors, throwing the radient heat toward the floor and shielding the clocks from direct radiation.

In May, 1908, thermostat No. 2 was substituted for No. 1 in the outer vault and the latter mounted in the inner vault at the mean elevation of the pendulums from the floor and thermally insulated from the walls so that it would have as nearly as possible the same temperature as the clock pendulums. Across the terminals of this thermostat is bridged an 800 ohm non-inductive resistance. The controlling current is supplied by four Gordon cells, grouped two in series, and operates a standard 150 ohm relay with heavy platinum contact points. The heating lamps are on the regular 110 volt alternating current lighting circuit of the observatory. This thermostat and relay operate between one and two thousand times a day, and the freedom from trouble at the contacts is very satisfactory; the platinum points on the relay showed scarcely a trace of wear at the end of six months, while the monthly cleaning of the mercury platinum contact appears almost unnecessary, probably because of the relatively low non-inductive resistance and the high resistance of the relay. The mercury of the contact surface is cleaned by taking a few fine cotton covered wires, twisting them together, and running them down the contact tube into the mercury two or three times. This does not appreciably change the point of control, as in thermostat No. 1 two millimeters of mercury would have to be removed to change the point of control by a hundredth of a degree.

The old compound bar thermostat was placed in the outer vault and connected with an alarm on the watchman's desk in the main building. One contact was set a little above the highest and the other a little below the lowest normal temperature of the outer vault. This thermostat is to give warning when any part of the outer vault heating system gives out. In the west observer's room over the vault is placed a two candle power electric light connected on the same circuit as the heating lamps so that this pilot lamp operates in unison with them; in this way we can easily see the period of heating and cooling which varies from a few seconds to almost two minutes and is a valuable criterion of the temperatures. A much smaller disturbance than will affect either the thermometers or thermograph will stop the working of the pilot lamp. A person entering the vault in hot weather will turn off the heating lights in a few seconds, but in cold weather the lights, if off, are almost instantly turned on and may remain on for some time if much cold air has been carried in the vault on one's clothes.

When the secondary control was installed it was thought that probably an electric fan would be required to keep a uniform distribution of the heat in the vault. There does not seem to be much doubt that a fan would keep the air in motion and help to equalize the temperature in different parts of the vault and perhaps would be almost a necessity in some cases, particularly where the temperatures surrounding the vault varied considerably, but in this vault there has been no evidence in the past six months that fans are necessary. If it were desired to keep a very close temperature control for the use of uncompensated pendulums made of a pure unalloyed metal, a fan would probably be necessary or at least useful.

Since the installation of the secondary control, the temperatures have remained pratically constant; when no work is being done in the vault, the thermograph records from week to week appear to be straight lines, and the indices of the maximum-minum thermometer are not moved away from contact with the mercury column; the errors for periods of many weeks probably being only a few hundredths of a degree. Therefore it seems that no temperature terms can be used in the clock rates except upon the rare occasions when work is being done in the vault. It is thus hoped to reduce the errors of the clocks to the actual defects in the form and materials of which they are constructed or to causes unknown at present.

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