remained unchanged during the testing period; therefore the instrument must have changed calibration before February 17, 1937.

The March and December calibration curves are shown in figure 4. If the data as transmitted (based on the December curve) are recomputed using the March calibration, results from the radio meteorograph show excellent agreement with those from the airplane instrument. On March 18 the airplane carried a different meteorograph; the results of that day, which are indicated in figure 5, show good agreement. No more comparisons could be made because the series was discontinued with that day. Additional tests were made by sending up the two meteorographs in the airplane; both showed good agreement. The record from the "questionable" meteorograph was evaluated twice; once with the calibration of March and again with that of December. With the latter calibration, the values were displaced from the March values in exactly the same manner as the radio meteorograph values were.

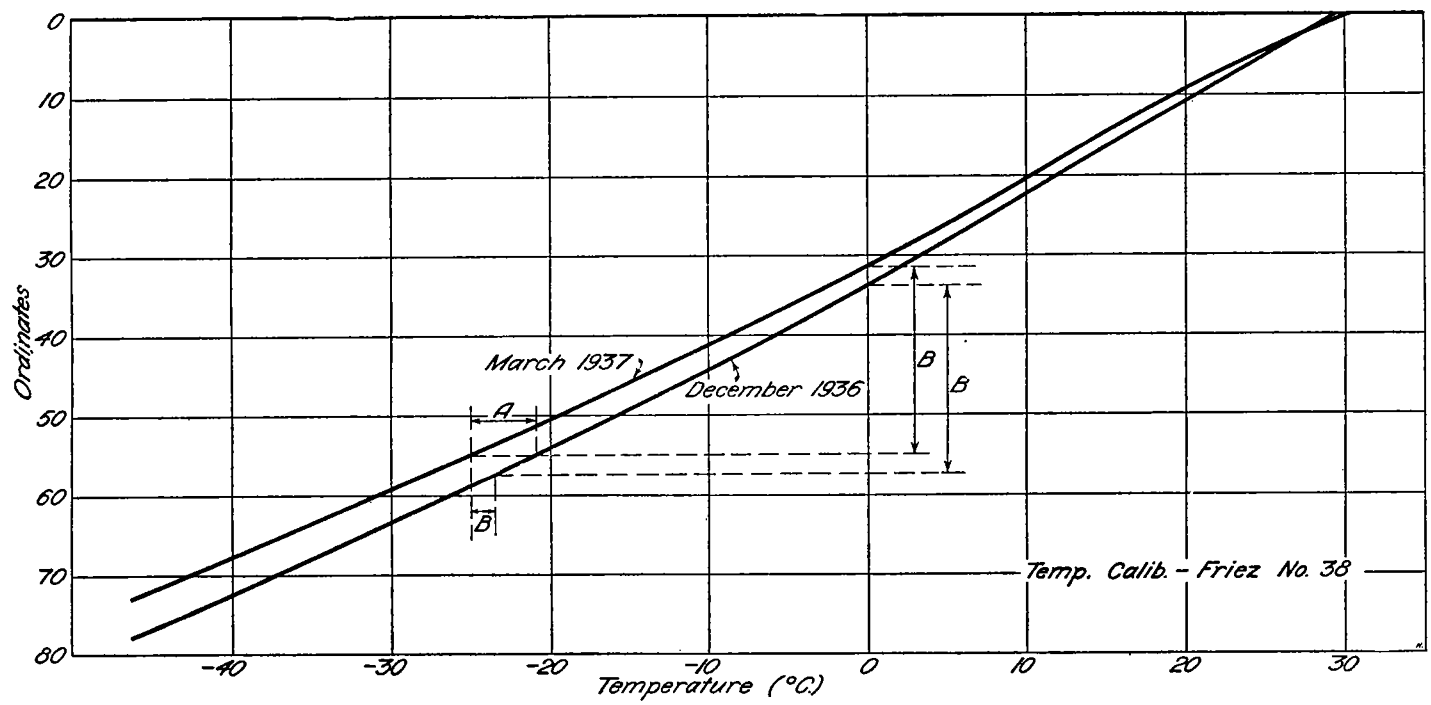

Figure 4.

Irrespective of the type of instrument used in making an aerological sounding, it is necessary to take check readings just before the ascent, and the reference line on the calibration curve should be established from them. A base reading made indoors, especially in winter, may lead to serious errors should the instrument be out of adjustment. By making settings at the outdoor temperature, instrument readings will be correct at the take-off and variations from true values at higher altitudes due to faulty calibration will be reduced considerably. The following example, referring to the calibration in figure 5, will make this clear: Assume a usual winter condition with a surface temperature of 0° C. and a minimum temperature of −25° C. If the base line were established from a room temperature reading (about 20° C.), the calibration curve will be used over a 45° range of temperature and the error due to faulty calibration would be 4° C. as shown at A. On the other hand, if the base line were established from zero degrees (the temperature at take off), the error would be only 1°— as indicated at B.

Although it is more difficult to establish a base from readings outdoors, it is necessary that this be done in order to reduce the magnitude of calibration errors. As an additional safeguard the instrument should be calibrated more frequently.

Furthermore, in plotting the adiabatic chart, the surface temperature should be that from the instrument and not the shelter reading. If the calibration curve is correct and the base line set from the shelter reading, both values will of course read the same. Otherwise, the initial lapse rates will be false, and depending on the error of calibration, nonexisting inversions or very steep lapse rates may be indicated.

With the exception of the additional trouble involved in the drawing of a separate calibration curve for each radio meteorograph, this instrument has certain advantages over the airplane meteorograph. Surface readings from the instrument are checked against those in the shelter. Then relative distances from all contacts are compared on the calibration curve, and any change of adjustment of the instrument will be apparent before it is released. Besides the advantage of obtaining higher altitudes than the airplane, the radio records can be evaluated with a considerable saving in time because they may be worked out simultaneously with the ascent.

NOTES ON TUBE AND BATTERY TESTS IN THE LABORATORY AND DURING FLIGHT

By D. P. Keily

In connection with the preparation and release of the Harvard radio-meteorographs used in this series of upper air soundings, a short study was made, under controlled laboratory conditions, of the operation of the tubes and batteries supplied with the radio portion of the instrument.

It was found that the average height of ascent could be consistently increased, except for instruments otherwise defective, by a better choice of the relative capacities of plate and filament batteries, without any increase in total battery weight.

Preliminary tests on a new type of radio tube, especially designed to be directly connected to a 1½-volt dry cell, indicated that, when substituted for the type used in the present meteorograph, it will probably not give equal results. However, it has inherent advantages which merit further tests and study, in order that it may be adapted to use in new radio-meteorographs.

Test for least battery voltages at which radio continues to transmit.—In actual flight the battery voltages are rapidly reduced as the instrument ascends, since the low temperatures stop the chemical action in the cells. Unless special precautions are taken to heat or insulate the batteries, the voltage will fall faster due to freezing than to the power drain of the radio transmitter.

ADIABATIC CHART

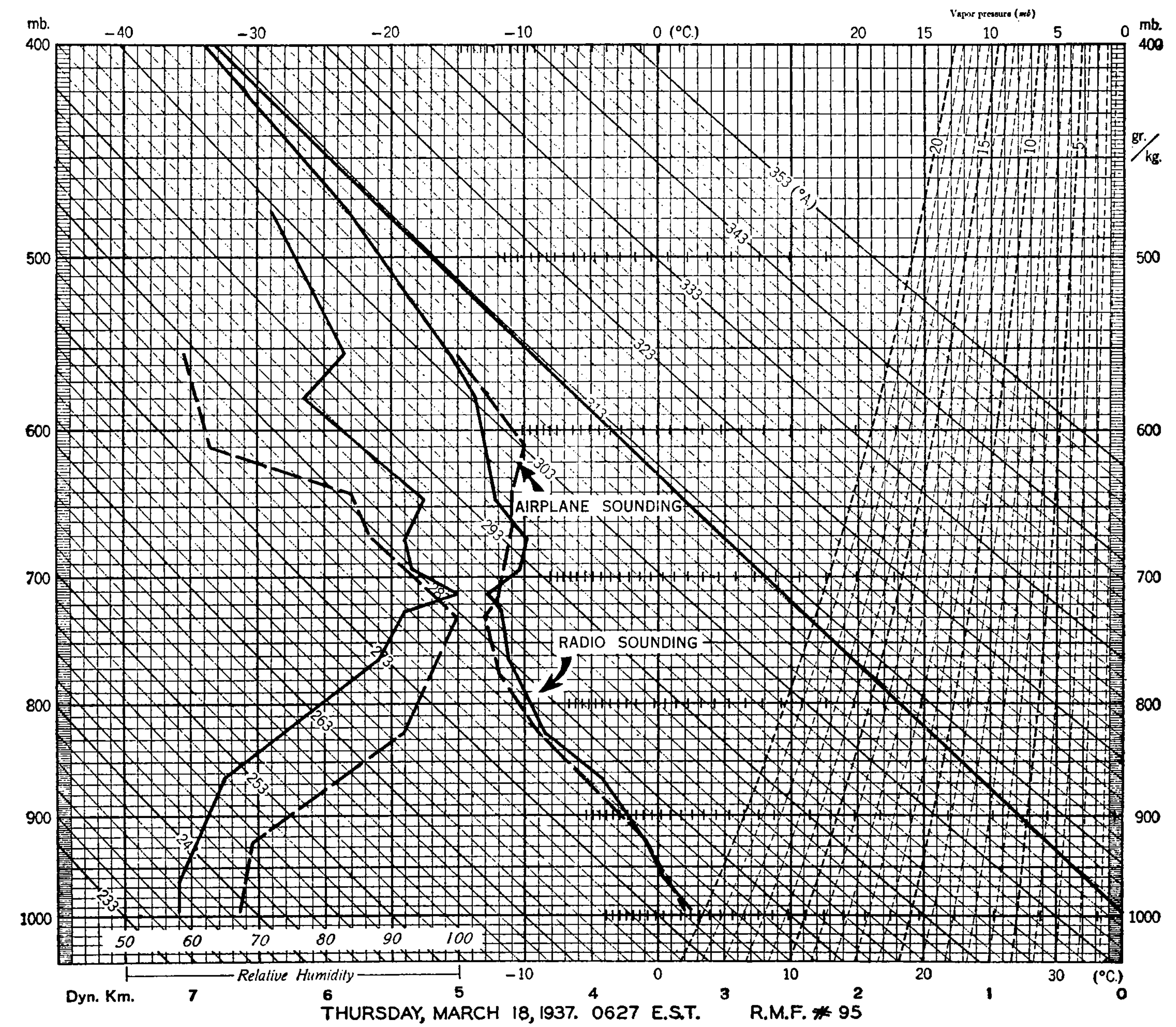

FIGURE 5.

The radio transmitter from a sample meteorograph was connected to sources of continuously varying power. The plate and filament potentials were reduced separately and together to determine the voltages at which the tubes ceased to oscillate. The normal filament voltage of two type 30 tubes, as used in the Harvard radiometeorograph, is 4 volts. A commercial unit battery of 4½ volts potential is supplied with the instrument. The filament cut-off voltage, at rated plate voltage, was found in this case to be 2.6 volts, which is 65 percent of rated voltage, or 58 percent of initial battery voltage. The usual plate voltage applied to this type of tube is 90 volts. The plate cut-off voltage, at rated filament voltage, was found to be 20 volts. The cut-off voltage at minimum filament voltage (2.6 volts) was found to be 22 volts. The latter value will hold in flight conditions, as the filament battery loses voltage more rapidly. 22/90 is 25 percent of initial battery voltage. Graphs of battery voltage at normal load plotted against temperature and time, show that both filament and plate batteries of the types supplied froze up and lost voltage at about the same rate, when under continuous load.

In flight, however, the filament load is continuous, while the plate load is applied only about one-sixth of the time, at fairly regular intervals corresponding to the emitted signals. Roughly, then, a six to one change in the present capacity relation of the batteries is indicated. The final selection of battery capacities, chosen after tests and observations during the last dozen ascents, stands in about this relation to the original sizes.

Battery life tests at varying temperatures.—The temperature of radiometeorograph batteries falls continuously during the ascent depending upon the rate of ascent, the lapse rate in the atmosphere, and the amount of heat insulation provided by the battery covering and the meteorograph case.

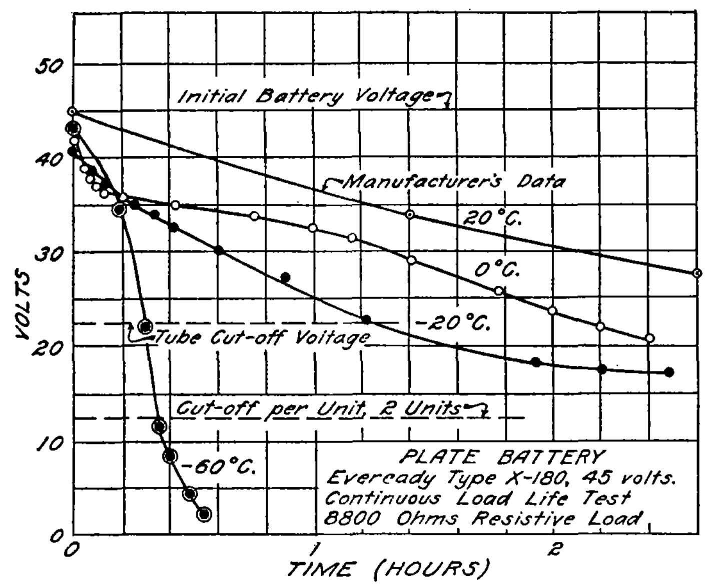

FIGURE 6.

In the laboratory tests, batteries were placed in the cold chamber and immediately put on load test. The batteries then reached a steady temperature at a more rapid rate than they would in an actual ascent. This procedure, however, is the nearest approach to flight conditions that could conveniently be made at the time. These tests were repeated with the same types of batteries at various temperatures from 0° C. to —60° C.

To find the actual temperature-time-voltage relation for any battery, it would be necessary to assume that the battery operated for a short period on successively lower temperatures, and study the time-voltage relation on several curves at different temperatures.

Results of the temperature tests are shown graphically in figures 6 and 7. It is important to note that although the nominal cut-off voltage for radio purposes is given as 34 volts per 45-volt unit, in this radio transmitter the cut-off voltages are much lower, and it is possible to obtain the extra life afforded by a slight leveling off of the otherwise steadily falling voltage characteristic in the neighborhood of 30 volts. Long battery life is important not only to permit of reaching great heights, but also to allow the use of a slow rate of ascent, in order that errors in measurement due to the varying lag of the different measuring elements may be minimized.

Flight tests with various battery combinations.—The first 6 instruments used one very small filament battery, type Burgess X-3-FL, and two small layerbuilt plate batteries, National Carbon type X-180. Previous experience with small batteries indicated that the short duration of these flights was due to a premature failure of the filament battery. A second battery of the same size was then connected in parallel with the single filament battery, doubling the capacity. The average height of flights increased over 50 percent during the next 10 days. The altitude reached by each sounding of the series is shown in daily sequence in Fig. 8. The addition of a third similar filament battery made a further slight increase in the average height of ascent. At the same time, the removal of one plate battery, thereby reducing the initial voltage to 45 volts, had no definite effect in either direction. It should increase the height, if anything, due to the considerable reduction in the weight of the instrument.

The average heights given here are obtained from values varying over a wide range. In most cases the impossibility of assigning failure of the signal to one of several possible reasons makes it difficult to know very exactly

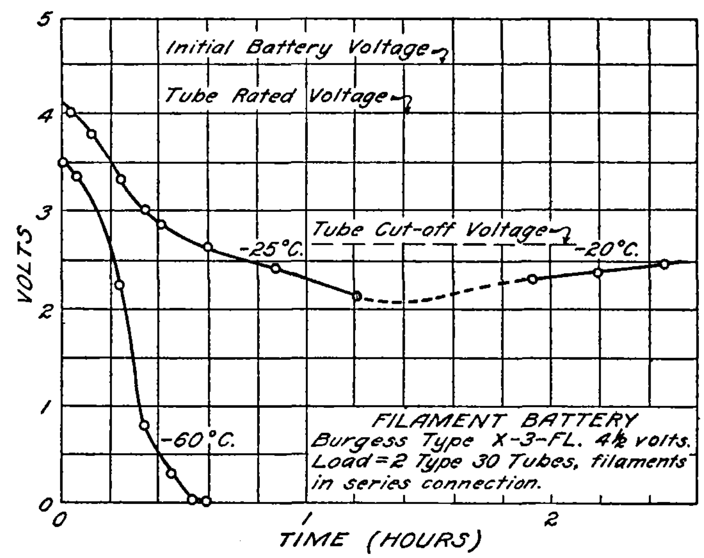

FIGURE 7.

the effect of particular changes in battery sizes. On the whole, however, it is justifiable to assign the considerably increased height of ascent to the increased filament battery capacity, since no other factor was varied in any definite and abrupt manner during the entire series.

Because of the expense and inconvenience of using several small filament batteries in parallel, a single battery of three small flashlight cells (1" dia.) was used in three of the last flights. The capacity was somewhat greater than that of three small batteries in parallel. The altitudes attained were 19.2, 18 and 18 kilometers, respectively. The average of these is higher by 2 kilometers than that for the flights with three special batteries in parallel. Also, there was again no noticeable difference in the use of one or two plate batteries.

Thus, by using larger filament cells and only one plate battery, the average altitude is more than doubled with a saving of about 5 percent of the total weight of the instrument.

Listening tests at various stations.—In an attempt to determine whether the signals were finally lost due to insensitivity of the receiver, insufficient range of the transmitter, failure of batteries, or other causes, arrangements were made to have two or more other stations from 10 to 20 miles apart listen to several ascents. In each of these tests, the signals faded rather abruptly at the Massachusetts Institute of Technology. This is indicative of battery failure while the instrument is still within normal range. In every case, the signals faded in the same manner at each of the other stations, and at about the same time, within 5 minutes, which was as close as the clocks could be checked. The other stations, of which there were three in one instance, had receivers as good as or better than that at the Massachusetts Institute of Technology. Their elevations were from 40 to 600 feet above sea level.

It is concluded that the loss of signal was generally due to failure of batteries, rather than to the instrument being carried out of range by high winds aloft, or to an insensitive local receiver. Also, since the batteries had been changed in capacity to run for more than an hour and up to 18 kilometers regularly, freezing rather than power drain is held to be the more probable cause of their failure.

1.5-volt tube (1 sample), 1.2 volts, or 80 percent of battery voltage. It appears, then, that for the same rate of voltage drop, the new type tube will operate for a less time before reaching cut-off voltage, than does the standard type tube. A 1.5 volt tube in which two-tube structures are enclosed in one glass bulb is also available, saving 50 percent of space requirements and about 30 grams weight over the present arrangements of two tubes.

No measurements were made of the power output of the new tubes, but the reduced filament power consumption of the new type indicates that the signal output will be somewhat lower than that of the older type.

One ascent was made with an instrument using one new type two-in-one tube. The altitude reached was 10.7 kilometers, in 58 minutes, when signals were lost due to other than radio faults. Laboratory tests showed the tubes quite capable of operating satisfactorily on the ultra short waves used (68 megacycles).

Use of the radio receiver.—The meteorograph transmitters as received from the maker are all tuned to within about three dial divisions of a fixed point on the receiver dial, when tested before release. As the signal could be

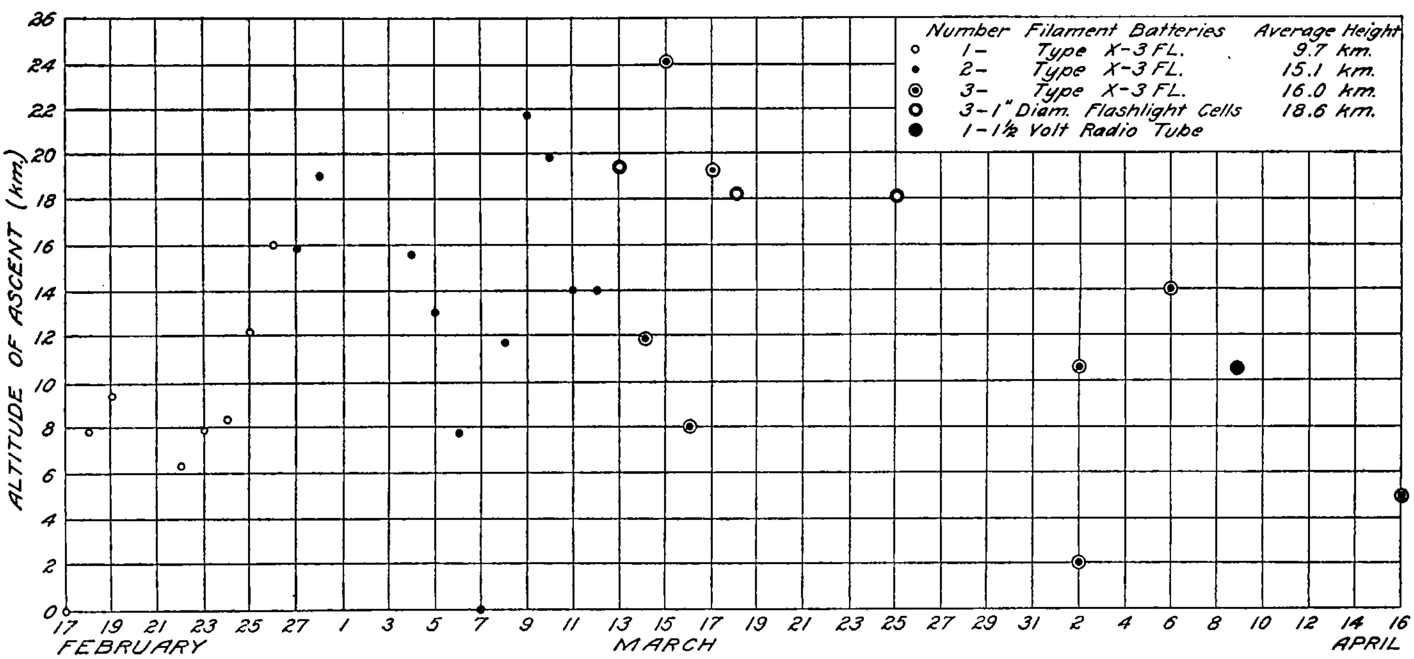

FIGURE 8.

Subsequent calculations have shown that the ceiling of the balloons is about 20 kilometers, so that further increase of battery capacity would be of little value with this size of balloon. Any slight increase in weight might better be used for insulating or heating the present batteries.

Tests of new type radio tubes—New tubes now being manufactured have a rated filament voltage of 1.5 volts, which is exactly the terminal voltage of a fresh dry cell. Use of a tube of this type would eliminate the danger of a burnout during flight, with loss of an instrument and record, and would avoid the expense and weight of resistors or series wiring arrangements to reduce the battery voltage.

Several experimental and production models of this 1.5 volt tube were tested in the laboratory and during ascent. Tests for filament cut-off voltage show: For standard 2-volt tubes: (*a*) 2.6 volts, or 58 percent of battery voltage; (*b*) 2.9 volts, or 65 percent of battery voltage. For new

heard over a distance of about six divisions of the dial, there was no difficulty in locating it on successive days with different instruments. Upon release, the signal frequency increased as the balloon rose the first few meters above the point of release. This shift was no more than a few dial divisions, and always in the direction of increased frequency. The change was not always noticeable because of the broadness of tuning of the signal when the instrument was close by.

As the instrument continued to rise, the signal weakened somewhat and the tuning sharpened, making it possible to locate the point of strongest signal more exactly. It was then necessary to readjust the tuning only occasionally, to compensate for the further slight increase in frequency caused by the effect of falling temperature on the transmitter.

In general, the sensitivity of the receiver should be adjusted so that only the signal is recorded, and not any interfering electrical disturbances or tube noises. Occasionally, when the signal weakens gradually but persists for a considerable time, it is possible to increase the sensitivity to the point where the recording relay is chattering continuously. If the instrument contacts are constant in length and regular in position, they may then be found among the random extraneous signals more or less readily, thereby increasing the duration of the flight considerably.

Conclusions and recommendations.—Considering maximum life and least weight, the most favorable combination of batteries for the present model of the Harvard meteorograph is believed to be a filament battery consisting of three 1-inch diameter flashlight cells in series and a plate battery consisting of one small 45-volt unit made of Burgess size V cells. Larger batteries or better heat insulation may become necessary when balloons reaching to higher altitudes are used, or when winds aloft have higher than normal velocities.

It is believed that the additional weight of a small amount of insulating material applied to the batteries would be more than compensated for by reduced weight of batteries required, or by much longer life of the present batteries.

Batteries should, in general, be used within a month of receipt from the factory. In no case should batteries of small special sizes be accepted from retailers or other indirect sources. Filament batteries can best be of standard flashlight cell sizes, obtainable fresh from large stores near the point of use, and used within a few days of purchase. Recent types of batteries with layer built cell construction were used during some of these soundings, and were found to lose voltage very rapidly within 2 weeks after their delivery with the instruments. Experience in these tests indicates that about 100 grams per 45-volt unit is the minimum safe weight of a dry battery as now constructed. Tests on batteries which failed on the shelf showed that their failure was probably due to a failure of a single cell, which made the whole battery useless. Improvement must presumably be in the direction of increased uniformity of chemical mixture and assembly technique.

The new 1.5 volt radio tubes are not considered satisfactory for immediate substitution in place of the present 2-volt tubes, due to their reduced power output and shorter period of operation before cut-off, but should be further investigated for possible use in a new design of the radiometeorograph.

FORMATION OF POLAR ANTICYCLONES

By H. WEXLER

[Weather Bureau, Washington, D. C., April 1937]

INTRODUCTION

Meteorologists have known for a long time that when air is cooled from below over a certain area for an extended length of time, an anticyclone forms. The explanation generally given is the following: Cooling of the air, when confined to a restricted area, lowers the isobaric surfaces and so causes a compensating inflow of air from adjacent regions which raises the surface pressure. However, the mechanism governing the compensating inflow and its distribution with height has not been studied carefully. This problem is the subject of the present paper.

Since the cooling over the area is accompanied by a lowering of the isobaric surfaces, that is, by a deepening of a cyclone situated at some level aloft, it seems natural to apply to the problem the Brunt-Douglas [1] theory of the isallobaric velocity component: When a pressure distribution changes with time, the actual wind is composed of two components, viz, the gradient wind, which prevails during stationary, nonfrictional conditions; and an isallobaric component, which blows into the central region of lowering pressure (isallobaric LOW), and is very nearly proportional to the isallobaric gradient. It will be shown that the transport of air across the isobars by the isallobaric component is sufficient to account for the growth of polar anticyclones that is actually observed on weather maps.

Before the isallobaric velocity component can be applied, it is necessary to adopt a cooling model for the atmosphere. In a recent paper by the author,[2] a cooling model was presented for a calm, cloudless, sunless atmosphere possessing, initially, a steep lapse rate and underlain by an unlimited snow surface. From the radiation exchange between the snow surface and the atmosphere, it was possible to determine a relation between the temperature of the snow surface and the maximum free-air temperature. For the snow surface temperature to fall below the value given by this relation, the maximum free-air temperature must decrease; and the cooling process will be one whereby the atmosphere loses energy to space mostly through the spectral band in the black-body radiation from the snow surface to which water vapor is transparent. As the cooling continues, the steep lapse rate decreases until, finally, the atmosphere becomes practically isothermal from above the shallow surface layer of cold air to a height dependent on the initial lapse rate (see fig. 1).

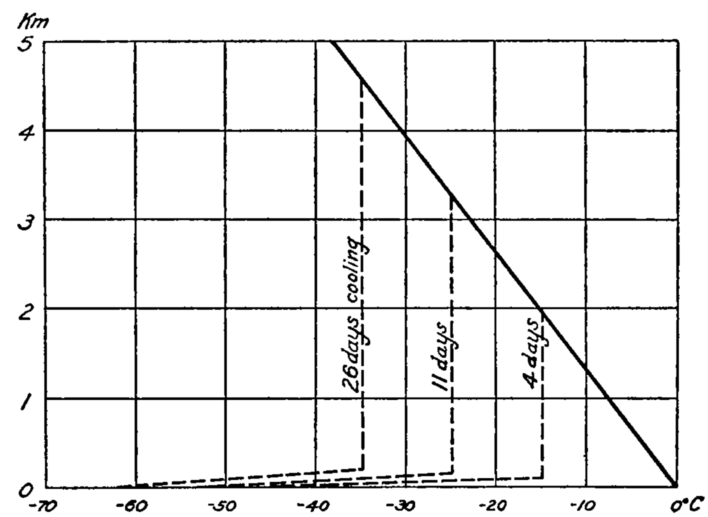

FIGURE 1.—Transformation of polar maritime air into polar continental air.

The cooled air mass is what may properly be called polar continental air, and is found over extensive land and frozen maritime areas in high latitudes during winter. The air above the cooled layer is still characterized by a steep lapse rate, and it also cools by means of radiation directly

[1] Mem. Roy. Met. Soc., Vol. III, No. 22, September 1928.
[2] Mo. WEA. REV., Vol. 64, p. 122, April 1936.