A NEW FORM OF AIR THERMOMETER FOR TECHNICAL PURPOSES.

A comparison of several ordinary thermometers in use in a varnish factory showed, as was anticipated, considerable differences in reading under similar circumstances, these differences amounting to as much as 50° F. at a temperature of 500° F. or thereabout. A part of these differences could be ascribed to age, one of the instruments being about fifteen years old; but only a small part of the differences were due to any such cause. Inquiry of parties who make a business of correcting thermometers disclosed the fact that very little had been done in the way of correcting thermometers for high temperatures, and the conclusions finally reached were as follows:

It appears to be customary to assume the expansion of mercury to be uniform; but this is said not to be the case when we approach its boiling point, and I have not found any statement as to its expansion at high temperatures under pressure, as in the nitrogen filled instruments.

It is customary to assume the expansion of glass to be uniform; but this is not true when we approach the softening point, and in any given instrument it is impossible to tell how much of an error is thus occasioned.

In graduating a thermometer it is customary to assume that all that part of the instrument which at the time is full of mercury is immersed in the fluid which is under examination; and the error from this cause is stated by an expert to be probably as much as 80° F. at temperatures approaching the boiling point of mercury.

The improved method for graduating instruments for use at high temperature appears to be by the use of substances of high boiling point, such as naphthaline and benzophenone. But different observers find different boiling points, even for a simple substance like mercury, and to get even approximate accuracy the experimenter would be obliged to determine with an air thermometer the boiling point of each substance he used, under the conditions of use.

Finally, the conclusion appears to be inevitable that the thermometer must be standardized under conditions essentially or absolutely similar to those under which it is to be used.

The conditions in the particular case in which I am interested are as follows: The thermometer tube is about three feet long, the graduation being confined to the upper one-third, and is inclosed in a tubular case, which terminates at the bottom in a steel cylinder which surrounds the bulb and is partly filled with mercury. This instrument is put in a copper kettle about two feet deep and has about a foot of the lower part of the instrument immersed in hot oil. Now any reading based on the ordinary graduation will under these circumstances be so erroneous as to be of no absolute value, and in fact, varnish makers do not go by degrees, but put arbitrary marks on their instruments and heat up to the mark, these marks not being at the same scale points of different thermometers.

I desired to make a thermometer which would give a reading within 5° F. of absolute accuracy, and the means I employ are as follows :

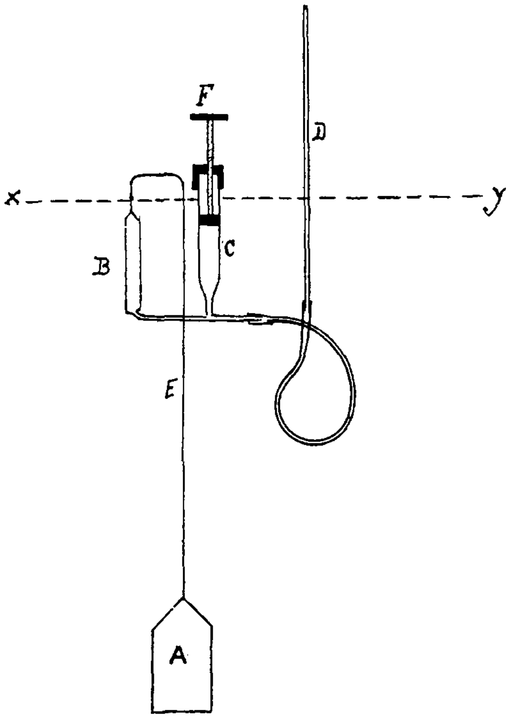

Fig. 1.

DESCRIPTION OF THE DIAGRAM.

A.....Bulb.
B.....Safety chamber for air and mercury.
C.....Mercury cylinder.
D.....Air pressure gauge.
E.....Capillary tube.
F.....Piston with screw to force mercury from C.
x y...Horizontal line showing level of mercury in capillary tube and gauge glass.

To avoid the irregular expansion of glass heated to near its softening point I use a bulb of metal, iron being selected; all the experiments which have been made tend to show that the rate of expansion of iron at temperatures not exceeding 800° F. is very uniform, and on general principles we should expect this to be the case, since such temperatures are far from its softening point. A bulb of cast iron containing about 160 c.c. is fitted by an asbestos-packed joint to a capillary glass tube; the capacity of the bulb is of no consequence except that it should be large enough to make the capacity of the capillary tube insignificant. This glass tube is of any convenient length, say $3\frac{1}{2}$ feet, and after bending downward is connected with a chamber to prevent the escape of air, as shown in the accompanying diagram. This safety chamber is normally filled with mercury, which is forced into it by a piston which is screwed into a cylinder filled with mercury which communicates with this safety chamber, and by this means the thermometer is made a constant volume one. This mercury also connects with a suitable pressure gauge; the form which I use is a closed tube containing air which is connected by a rubber tube with the safety chamber. Owing to the flexibility of the connection the gauge tube can always be placed so that the mercury in it shall be at the level of the mercury in the capillary tube and thus any correction on that account is avoided, and the whole apparatus being closed no correction for barometric pressure is needed. Of course an open mercury gauge tube could be used just as well if desired. What occurs when the bulb is heated is this: The expansion of the air is exactly counterbalanced by the operator who screws down the piston of the mercury cylinder so as to keep the mercury at the same point in the capillary tube; the only effect then of the heat is to increase the pressure on the mercury. The mercury transmits the pressure to the air in the gauge glass, which is compressed, and from the amount of this compression the temperature is calculated.

The calculation was made in the following manner: The expansion of air is $\frac{1}{273}$ of its 0° C. volume for each degree C. it is heated; or $\frac{1}{491.4}$ its 32° F. volume for each degree F. it is heated. $\frac{1}{491.4} =$ .002035, and 1 volume air at 32° F. becomes 1.07733 vol. at 70° F. Since 70° F. is the lowest ordinary temperature in the places where I am likely to use this instrument, for reasons which are obvious, I have selected 70° F. as my normal temperature. Other observers of course would calculate other tables. Now if we assume 70° F. as normal, what will be the expansion of a given volume of air? The given volume will fill the space which would be occupied by 1.07733 volumes if the temperature were 32° and therefore consists of $\frac{100000}{107733} = .9282$ of the amount of 32° air which it would take to fill the space; and as its expansion is calculated on 32° air, it will expand .9282 of .002035 = .00188 . . . . of its own 70° F. volume for each degree F. it is raised in temperature.

If air at 70° tends to expand .00188 . . . of its volume when heated 1° and is prevented from doing so by being enclosed in a rigid vessel, the pressure is equivalent to that produced by pumping in .001888 of the original volume and keeping the temperature at 70°. In that case we should have 1.001888 vol. condensed to 1.0000 vol.; and the original 1 volume would be condensed to .998113 as found by the proportion 1.001888 : 1 : : 1 : .998113; and so on. Thus a rise of 10° F., that is, to 80° F., would produce a condensation found by this proportion : 1.01888 : 1 : : 1 : .9814 and the space occupied by the condensing agent, which is the mercury in the gauge glass, is .0186 of the normal volume of the gauge, for *this* interval of 10° F. To get the volume at each successive interval of 10° F., multiply .0188 . . . by one, two, three, and so on, and add the product to unity for the first member of the proportion, whence we get a table, which does not, however, allow for the expansion of the iron bulb, nor for a change of temperature in the air of the gauge glass.

The cubical expansion of cast iron is .0000336 for 1° C. If the shell be heated to 800° F., from 70° F., which is equal to 405.6° C., it will expand $.0000336 \times 405.6 = .01363$ of the original volume of the bulb. At 800° F. the volume of the air in the gauge is .4203 of its normal volume; and $.4203 \times .01363 = .00573$, this latter fraction being the part of the normal volume of the gauge which the air in it will expand on account of the increase of the size of the iron bulb at 800° F. This makes a difference in reading such as would be caused by a difference of about 16.8° in temperature. Actually the volume of the air in the gauge is .4203+.00573= .42603 of its normal volume, when the bulb is heated to 800° F.

In this manner a corrected table may be derived from the table already calculated, and this corrected table will show the absolute temperature of the air in the bulb, when the air in the gauge glass is at 70° F.

At 200° F. the volume of the air in the gauge glass if at 70°, is .8047 of its normal volume. Now if the original volume were raised to 80° F. it would have the volume 1.01888, and if this volume were subjected to sufficient pressure to compress it to .8047 of its bulk it would occupy .8047×1.01888=.8762. This exceeds the 70° volume by .0715, since .8762—.8047=.0715; and the difference for 10° in the bulb at this temperature (200° F.) is .0119 : and $\frac{.0715}{.0119}=6.01$: hence an elevation of 10° in the gauge air temperature makes a difference of 10×6.01=60.1° in the reading and this amount should be added to the observed temperature under such conditions; and this ratio of 6.01 : 1 is true not only of the temperature of ten degrees in excess of 70° in the gauge glass, but also of all temperatures in excess of 70° when the bulb temperature is 200° F. In this way a table of corrections may be calculated for the various bulb temperatures to be observed. The ratio increases as the temperature rises. The air gauge of the instrument should contain a small thermometer, and a sliding scale can be arranged if desired.