of a standard at several temperatures, preferably in a resistance furnace of the Heræus type. This second method of calibration is usually less accurate than the first. Methods of realizing experimentally the sulphur point and other fixed temperatures will be described in Chapter XI on Standardization.

The platinum thermometer may be, and should be, for technical work, so constructed as to read directly in platinum degrees, or still better in degrees of temperature. This method saves much time and chance of mistake. The calibration curve, once made for an instrument, serves indefinitely, with occasional checking up if used at high temperatures; so that in spite of the appearance of complications in this method of measuring temperatures, actually in practical use the determination of a temperature on the normal scale by the platinum thermometer is the affair of a few seconds only.

Reduction Tables. — In the Appendix are given tables for the reduction of platinum temperatures to centigrade temperatures for wires of pure platinum, correction tables for wires of impure platinum, and other auxiliary tables.

Some Results Obtained. — There is a remarkable agreement among the fixed points obtained by several observers using the platinum thermometer, for observations extending over twenty years, as shown in the following tables, in which all the observations were obtained by calibrating the platinum thermometer in ice, steam, and sulphur vapor, the temperature of this last being here taken as 444.70 on the constant-volume nitrogen scale, the value best representing the work of these observers except Holborn and Henning.

SCALE OF RESISTANCE THERMOMETER.

	Boiling Points.	
	Naphthaline.	Benzophenone.
Callendar and Griffiths (1891)	217.97°	305.89°
Travers and Gwyer (1905)	218.07	305.87
Holborn and Henning (1908 and 1911)*	217.96	305.89
Waidner and Burgess (1910)	217.98	306.02

* S.B.P. = 444.5_1 C. at constant volume.

SCALE OF RESISTANCE THERMOMETER (*Continued*)

	Freezing Points.			
	Sn	Cd	Pb	Zn
Callendar and Griffiths (1891)	231.9	320.8	327.8	419.0
Heycock and Neville (1897)	231.9	.....	.....	419.4
Waidner and Burgess (1909)	231.9	321.0	327.4	419.4
Holborn and Henning (1911)†	231.8_3	320.9_2	.....	419.4_0

	Freezing Points.				
	Sb	Al	Ag	Au	Cu
Heycock and Neville	630.0	656*	961.9	1063.5	1082
Waidner and Burgess	630.7	658	960.9	.....	1083

* Containing 0.5 per cent impurities. † S.B.P. = 444.5_1 C. at constant volume.

Use as a Standard. — In 1899, Callendar, at a meeting of the British Association for the Advancement of Science, in view of the relative ease and great precision of resistance measurements and the great difficulties in the use of the gas thermometer, suggested that the platinum thermometer be adopted as a secondary standard, reducing its readings as above indicated, and assuming as calibration points, 0°, 100°, 444.5°, the last being the sulphur boiling point on the constant-pressure scale. All platinum thermometers could then be compared with one selected as standard and calibrated as above indicated. He also pointed out that as regards portability and ease of reproduction, it is sufficient to send a few grams of the standard wire in an ordinary letter, to reproduce the scale with the utmost accuracy in any part of the world.

The work done in platinum and gas thermometry since 1899 abundantly justifies Callendar's suggestion of using the platinum thermometer as a secondary standard, since, as has been shown in preceding paragraphs, a resistance thermometer of pure platinum calibrated at three temperatures reproduces the gas scale with the greatest exactness to as high temperatures as the platinum thermometer can be used conveniently. It is not necessary, however, to compare a platinum thermometer with another taken as standard, if means are at hand for an independent calibration, since the characteristic constants of pure platinum are now known, and this metal can easily be had of sufficient purity to satisfy them. It is perhaps better to take the sulphur boiling temperature on the constant-volume scale, as most of the recent work in the determination of fixed points has been in terms of this scale.

For a platinum-resistance thermometer to serve as a secondary standard, therefore, provided its construction and use are otherwise correct, it is necessary and sufficient that its value of $\delta = 1.50$ (or 1.49 according to Holborn and Henning's scale) and of $C = 0.0039$, when calibrated in ice, steam, and sulphur vapor. (See chapter on Standardization.)

Sources of Error in Accurate Work. — *Heating by the Measuring Current.* — It is evident that if a too large current is sent through an electrical resistance thermometer, the heating thus occasioned will cause the indicated temperatures to be high. The limiting value of the current Callendar has shown to be about 0.01 ampere per 0.01 degree with an average platinum thermometer of wire 0.15 mm. in diameter. If a galvanometer of sufficient sensibility is used this effect is negligible, and when a greater current has to be used on account of lack of galvanometer sensibility, the heating effect may be maintained nearly constant by keeping the current constant by means of a rheostat in the battery circuit, since the resistance of the thermometer increases very nearly as fast as the rate of cooling, or a little faster than the temperature. Callendar also indicates that the heating effect is readily measured by using as current source two storage cells, connected first in parallel and then in series, the current heating correction being given by subtracting from the first reading one-third of the difference between the two readings.

Waidner and Burgess have also studied the heating effect of the measuring current and find that although this current may heat the coil to more than 1° C. above its surroundings, the value of the fundamental interval of the thermometer remains the same as when a current one-fifth as great is used.

The effect of using different measuring currents with a thermometer of $R_0 = 3.48\ \omega$ is shown below:

HEATING EFFECT OF MEASURING CURRENT.

Amperes.	R_0	F.I.	$R_{444 \cdot 33}$	$pt_{S.B.P.}$	δ
$2.5 \cdot 10^{-3}$	3.48160	1.34115	9.13220	421.33	1.503
$10.0 \cdot 10^{-3}$	3.48174	1.34113	9.13213	421.31	1.505
$50.0 \cdot 10^{-3}$	3.48705	1.34114	9.13608	421.21	1.511
$100.0 \cdot 10^{-3}$	3.50373	1.34173	9.14832	420.69	1.545

HEATING OF PT COIL ABOVE SURROUNDING TEMPERATURE.

Amperes.	ΔT_0	ΔT_{100}	$\Delta T_{S.B.P.}$
$2.5 \cdot 10^{-3}$	0.001°	0.001°	....
$10.0 \cdot 10^{-3}$	.011	.010	....
$50.0 \cdot 10^{-3}$	.41	.41	.29
$100.0 \cdot 10^{-3}$	1.65	1.69	1.20

For a given small excess in temperature of the platinum coil above the temperature of its surroundings, the energy radiated in steam is 3.7 and in sulphur 52 times that radiated at 0° C., assuming that the radiation from platinum is proportional to the fifth power of the absolute temperature. For constant measuring current, the energy supplied to the coil at the S.B.P. is only 2.6 times the energy supplied at 0° C. It follows that the greater part of the energy loss is by convection and conduction rather than by radiation.

Lag of the Platinum Thermometer. — Inclosed as it necessarily is for most work in a sheath of porcelain, and possessing besides considerable mass, the platinum thermometer does not immediately assume the temperature of its surroundings. Put into a sulphur bath, it assumes an equilibrium condition in ten minutes. For small changes of temperature this effect is hardly perceptible and may be neglected in most practical work.

Inclosed in a thin flat-sided metal case (see Fig. 66), the temperature lag is practically nothing.

Insulation. — Defective insulation due to moisture condensed in the tubes is sometimes a source of error in accurate work at the ice point and lower temperatures with thermometers of high resistance if the tubes are not sealed. This may be readily done, if the containing sheath is of glass, by sealing the platinum leads into the glass so that they terminate in cups. When the containing sheath is of porcelain, as for high-temperature work, this sealing is not necessary, nor is it convenient; but running the leads into metal cups containing a fusible alloy still offers the readiest method of securing a good contact with the rest of the circuit.

Compensation for Resistance of the Leads. — It is necessary, in order to avoid thermal currents at the junctions with the thermometer proper and also evaporation and consequent change of resistance, to employ platinum leads from the thermometer to a point in the circuit at a constant temperature. Even if these leads are of relatively large diameter, there will still remain an error due to the varying resistance of these leads with change in temperature and with varying depth of immersion. It becomes necessary either to apply a "stem correction," which is troublesome and uncertain, or compensate for this effect as described under methods of measurement. Nowadays most platinum thermometers sold for industrial and scientific purposes are compensated. Uncompensated thermometers with gold leads are also to be found. They are not to be recommended for work of high accuracy. Silver leads are to be avoided.

The copper leads from the thermometer head to the measuring apparatus may be of appreciable resistance, and to render them flexible they are often stranded, when their resistance may vary somewhat. Thus Mr. F. W. Smith has found copper leads of $\frac{1}{40}\,\omega$ resistance to vary 1 or 2 per cent, giving 0.003° C. uncertainty at 0° C. In work of high accuracy it is evidently as important to keep the copper leads as constant as the platinum. It is now possible to obtain stranded wire in which each strand is enameled, and so eliminate the slip resistance.

In addition to the potential lead method, there have been bridge methods devised for the complete experimental elimination of all leads to the thermometer which is required in work of the highest accuracy, as it is extremely difficult, if not impossible, to make the compensation absolutely exact by adjustment in construction. These methods require, for the most part, rather elaborate experimental arrangements, for descriptions of which the reader is referred to the papers of Edwards, W. Jaeger, and F. W. Smith. In brief, such methods depend either upon devices for alternately throwing the thermometer leads in the two sides of the bridge, measuring these leads, or eliminating them by use of the Kelvin double bridge or some modification.

Conduction along the Leads. — The thermometer leads may be the seat of another source of error, which increases in importance with the diameter of the leads, their length immersed, and the temperature gradient, namely, the effect of heat conduction along the leads influencing the resistance of the thermometer coil. This effect is especially to be looked for in four-lead bridge thermometers, where all four leads are of relatively heavy platinum. The best way to eliminate this source of error is to so design the instrument that it is negligible. Its presence may be recognized and corrected for by varying the depth of immersion of the thermometer in a bath at constant temperature.

Use of Impure Platinum. — The value of the constant δ in the Callendar formula (2), page 201, is a measure of the purity of the metal. For the purest platinum the value of δ is 1.500, assuming the S.B.P. = 444.70, and for impure platinum the value of δ increases with the impurity. Heycock and Neville made a study of the effect on the temperature scale obtained by using platinum of different degrees of purity, and concluded, erroneously it now appears, due to an incorrect method of calculation, that thermometers having different values of δ would give the same temperature scale when reduced by the parabolic formula of Callendar.

It has been shown since that impure platinum does not obey the same resistance-temperature law as the pure metal, and Waidner and Burgess have indicated the corrections to be applied to temperatures obtained by the Callendar method, using impure platinum to reduce to the usual temperature scale. They find, for platinum of varying degrees of purity as indicated by the values of δ, the following values for fixed points, using the Callendar equation in all cases for computing the temperatures:

FREEZING POINTS FOR VALUES OF δ INDICATED BELOW.

$\delta =$	1.505	1.570	1.803
Tin.........	231.90	231.82	......
Zinc........	419.37	419.32	......
Antimony...	630.70	631.25	632.65
Ag_3-Cu_2....	779.2	......	784.6
Silver......	960.9	966.2	975.3
Copper.....	1083.0	1092.0	1106.0

In Table VIII of the Appendix are indicated the corrections to be applied when using thermometers of impure platinum. Wires with a large δ are more liable to change with use, so that, although correct results may be obtained with them if properly reduced and checked up occasionally, it is preferable to use the purest platinum.

Changes in the Constants. — If platinum thermometers are repeatedly heated to temperatures in the neighborhood of 1000° C., or are kept for very considerable periods of time at even lower temperatures, changes in the value of the constants R_0, R_{100}, and δ will develop, necessitating frequent recalibration in work of high accuracy. Pyrometers for use at high temperatures should not be inclosed in inglazed porcelain even if the glaze does not touch the metal, as deterioration of the latter will otherwise ensue. The mica supports undergo distortion on cooling from high temperatures, increasing in size, tending to stretch the wire and increase its resistance. For this reason it is probably better to use the constants determined before a measurement at high temperature, rather than those determined afterwards. Again, if the wire of the thermometer has not been well annealed at a temperature higher than it is to be used, irregular changes will occur, which are the most marked for the first few heatings.

Waidner and Burgess find that for thermometers of pure platinum, the changes in their constants after the wires have been annealed are very much less than for those of impure platinum; thus, as shown in the accompanying table, which is typical, R_0 changes only by a few tenths of a degree for pure platinum, but by several degrees for impure. These changes are

CHANGES IN ZERO OF PLATINUM THERMOMETERS.

Thermometer of pure platinum.		Thermometer of impure platinum.	
$R_0=3.47971$ at start; $\delta=1.503$. $R_0=3.48164$ at end; diam. = .15 mm.		$R_0=21.3476$ at start; $\delta=1.570$. $R_0=21.0617$ at end; diam. = .10 mm.	
Changes in zero. °C.	History of thermometer previously annealed at 1200°.	Changes in zero. °C.	History of thermometer previously annealed at 1200°.
−0.005	After Zn F.P. 3 times.	−0.18	After Zn F.P. 10 times.
− .001	After Sb F.P. 1 time.	− .29	After Sb F.P. 7 times.
+ .007	After Sb F.P. 2 times.	−2.27	After 2 hrs. at 1100°+ C.
− .002	After 2 hrs. at 1100°+ C.	−3.94	After Cu F.P. 1 time.
− .050	After Cu F.P. 1 time.	−4.66	After Cu F.P. 1 time.
+ .013	After Cu F.P. 2 times.	−5.99	After Cu F.P. 2 times.
+ .138	After Cu F.P. 5 times.	−6.20	After Ag F.P. 2 times.
+ .144	After Ag−Cu F.P. 5 times.	−6.46	After Ag−Cu F.P. 4 times.

least for pure platinum wire of large diameter and suspended free from strains. For impure platinum wire, the effect of high temperatures is to decrease R_0 and to increase the fundamental coefficient, c; that is, the effect is as if the wire became purer, possibly because of the evaporation of impurities, for example, iridium. If the platinum is pure, the slight changes indicate a contamination of the wire and the effect of strains, as is evidenced by decrease in c and increase in R_0. The total change observed is the resultant of the effects of strains, of annealing, and of contamination and purification.

Use of Metals other than Platinum. — Holborn and Wien found that with palladium the absorption of hydrogen at low temperatures, giving the hydride, increases the resistance by 60 per cent; besides, the same effect of alteration as with platinum is noticed if the palladium is placed in hydrogen in the presence of silica. Palladium wound on mica and inclosed in porcelain has been shown by Waidner and Burgess to behave in a very similar manner as platinum to above 1000° C.; the law of the change of resistance of palladium with temperature is, however, very different from the Callendar equation, and is an equation of the fourth degree between 0° and 1100° C. for a precision better than 0.5° C., although up to 600° the Callendar equation is nearly satisfied.

No very definite conclusion is to be drawn from the work of Holborn and Wien with iridium and rhodium, except that these metals assume their normal resistance only after being heated several times to a high temperature. Iridium evaporates so much more readily than the others that it would seem the least best adapted for temperature measurement by means of the metals of this group, and platinum is evidently to be preferred.

Nickel is sometimes used in resistance thermometers, but it is not to be recommended for temperatures above 300° C., due to the change in the resistance-temperature relation as the transition temperature of nickel is approached and to oxidation at higher temperatures. Marvin has shown that for pure nickel the equation $\log R = a + mt$ holds approximately in the above limited range 0° to 300° C.

Conditions of Use. — The electrical resistance pyrometer of platinum seems, by reason of the great precision of the measurements which it allows, to be especially serviceable for laboratory investigations. It seems, on the other hand, to be too fragile for many of the industrial applications when there is rough handling, although it is very convenient in permanent installations when properly protected, and when it is desired to eliminate completely the often troublesome correction necessary for the temperature of the cold junction of the thermocouple.

The relation between the platinum-thermometer scale and the gas scale is well established to 1100° C., which is beyond the limit above which it is not safe to use the platinum-resistance pyrometer without frequent checking of its calibration.

The resistance pyrometer is the best instrument for differential work and for detecting small temperature changes as well as for controlling a constant temperature. It is also particularly adapted for use with recording instruments. Great care has to be taken that the platinum does not become contaminated.

Industrial Installations and Checking. — We have already called attention to the fragility of the fire end of a resistance

thermometer and the necessity for protection of the coil from contact with furnace gases. In industrial installations it is preferable to so mount the pyrometer that it may not readily be damaged by the furnace operations or by the handling of the pyrometer when necessary to withdraw it. This can usually be done by a suitable arrangement of the pyrometer within the furnace and by providing a convenient mechanism for withdrawing and holding the pyrometer free of the furnace. A design of bracket by Leeds and Northrup is shown for use with a small oil- or gas-burning furnace in Fig. 83. A sliding and slotted collar L carries the pyrometer on the arm N; the whole may be raised, caught, and

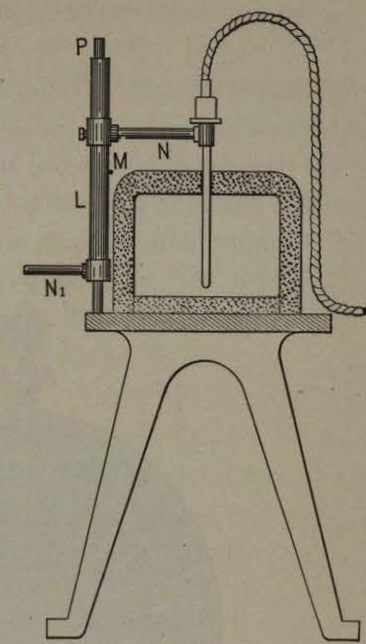

Fig. 83. Bracket Mounting.

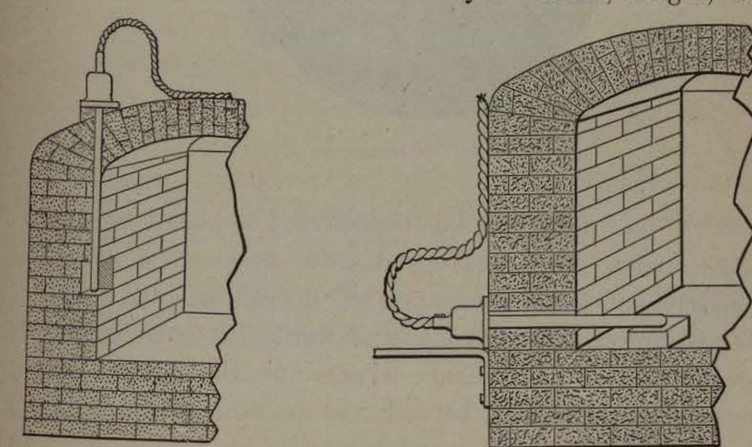

Fig. 84. Mountings in Oven.

turned on the pin M, permitting the removal of the pyrometer without shock and providing a resting place without handling or fear of breakage. Proper designs for mounting pyrometers in furnaces, kilns and duct pipes are shown in Figs. 83, 84, and 85. If the pyrometer tube be inserted horizontally supported only at one end, there is danger of bending and breaking even when the outer sheath is of metal.

The resistance pyrometer and its electrical circuit may be tested in place and the calibration verified without removal. An industrial installation should always be tested for proper insula-

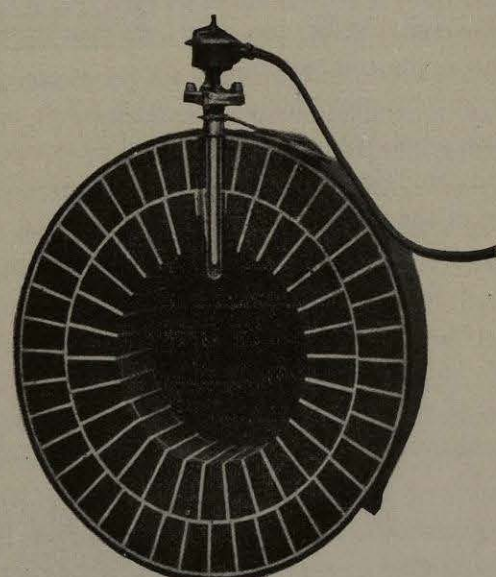

Fig. 85. Mounting in Duct.

tion, not only when new but periodically, or when irregular behavior occurs. The actual operations of checking out the insulation, lead, and contact resistances will depend upon the design of the instrument and the voltage for which it is intended. It is safe to say that the resistance between any wire and the ground or thermometer case, or between two disconnected wires of the system, should be over 1 megohm per 100 volts.

Some of the manufacturers provide outfits for the automatic checking of thermometer indicators and coils. Thus, Leeds and Northrup furnish an equipment consisting of a series of coils cor-

responding to definite temperatures on the indicator, and another coil equal to the resistance of the thermometer at room temperature. The Cambridge Company also furnish "ice bobbins" by means of which the thermometer resistance may be checked at 0° C. The use of the resistance pyrometer industrially is also greatly facilitated by the practice that is becoming general among makers of constructing the instruments and all parts so that they are interchangeable. This is particularly necessary for multiple circuits using the same indicator or when using a single automatic recorder in connection with a number of indicators. These questions are considered in Chapter X.