Differences Between the International Temperature Scales of 1948 and 1927

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Tables and a graph are presented showing differences that exist between temperatures expressed on the International Temperature Scale of 1927 and the recently adopted International Temperature Scale of 1948.

The experimental difficulties inherent in the measurement of temperature on the thermodynamic scale led to the adoption in 1927, by the Seventh General Conference on Weights and Measures, of a practical scale that was designated as the International Temperature Scale.[1] The first revision of this scale came with the adoption of the International Temperature Scale of 1948 [2] [2] by the Ninth General Conference on Weights and Measures. The revised scale was designed to conform as nearly as practicable to the thermodynamic centigrade (Celsius) scale as then known, while incorporating certain refinements, based on experience, to make the scale more uniform and reproducible than its predecessor.

In the following sections, tables, and a graph are presented showing differences that exist between temperatures expressed on the International Temperature Scales of 1948 and 1927.

Platinum resistance thermometer range (oxygen point to freezing point of antimony). The changes [3] adopted in this range have the effect of making the scale more definite and reproducible but cause little or no change in the numerical values of temperatures.

Standard thermocouple range (freezing point of antimony to the gold point). The change in the value for the silver point from 960.5° to 960.8° C changes the numerical values of temperatures measured with the standard thermocouple.[4] Because both the 1927 and 1948 scales provide for some variation of thermoelectric properties of standard thermocouples, the differences between the two scales in the thermocouple range cannot be stated explicitly. The differences have been calculated for the median standard thermocouple allowed by the International Temperature Scale of 1948, namely, $E_{Au} = 10,300$ microvolts, $E_{Ag} = 9,117$ microvolts, $E_{Sb} = 5,530$ microvolts, as follows.

The temperature, t, is defined by the formula,

$$E = a + bt + ct^2, \qquad (1)$$

where E is the electromotive force of a standard thermocouple of platinum and platinum-rhodium alloy when one junction is at 0° C and the other is at the temperature, t. The constants, a, b, and c, are to be calculated from measured values of E at the freezing point of antimony and at the silver and gold points. The fixed points will be referred to by subscripts 1, 2, and 3, respectively, in what follows. For a given set of values of E, it is desired to determine the effect upon calculated values of t of changing the value assigned to t_2. Differentiating eq 1 with respect to t_2 and setting $\partial E / \partial t_2$ equal to zero leads to the following equation:

$$\partial t / \partial t_2 = \frac{-\partial a / \partial t_2 - t \partial b / \partial t_2 - t^2 \partial c / \partial t_2}{b + 2ct},$$

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[1] G. K. Burgess, The International Temperature Scale, BS J. Research **1**, 635 (1928) RP22.

[2] H. F. Stimson, The International Temperature Scale of 1948, J. Research NBS **42**, 209 (1949) RP1962.

[3] These changes are: (a) The termination of the scale at the oxygen point (−182.970° C) instead of at −190° C, (b) the division of the scale at the freezing point of antimony (about 630.5° C) instead of at 660° C, (c) the requirement for higher purity of the platinum of the standard resistance thermometer. In addition, a resolution was adopted that the zero of the thermodynamic centigrade scale should be defined as the temperature 0.0100 degree below that of the triple point of pure water.

[4] In addition there are changes of the type mentioned in footnote 3 that cause little or no change in the numerical values of temperatures. These include requirements for higher purity of the platinum of the standard thermocouple and for smaller permissible limits for the electromotive force of the standard thermocouple at the gold point.

where

$$a = \frac{E_1(t_2 t_3{}^2 - t_3 t_2{}^2) + E_2(t_3 t_1{}^2 - t_1 t_3{}^2) + E_3(t_1 t_2{}^2 - t_2 t_1{}^2)}{x}$$

$$b = \frac{E_1(t_2{}^2 - t_3{}^2) + E_2(t_3{}^2 - t_1{}^2) + E_3(t_1{}^2 - t_2{}^2)}{x}$$

$$c = \frac{E_1(t_3 - t_2) + E_2(t_1 - t_3) + E_3(t_2 - t_1)}{x}$$

$$x = t_2 t_3{}^2 - t_3 t_2{}^2 + t_3 t_1{}^2 - t_1 t_3{}^2 + t_1 t_2{}^2 - t_2 t_1{}^2$$

$$\frac{\partial a}{\partial t_2} = \frac{E_1(t_3{}^2 - 2t_3 t_2) - E_3(t_1{}^2 - 2t_1 t_2)}{x} - \frac{a}{x}\frac{\partial x}{\partial t_2}$$

$$\frac{\partial b}{\partial t_2} = \frac{2t_2(E_1 - E_3)}{x} - \frac{b}{x}\frac{\partial x}{\partial t_2}$$

$$\frac{\partial c}{\partial t_2} = \frac{E_3 - E_1}{x} - \frac{c}{x}\frac{\partial x}{\partial t_2}$$

$$\frac{\partial x}{\partial t_2} = t_3{}^2 + 2t_1 t_2 - t_1{}^2 - 2t_3 t_2.$$

Inserting the values

$$t_1 = 630.5 \qquad E_1 = 5,530$$
$$t_2 = 960.8 \qquad E_2 = 9,117$$
$$t_3 = 1,063 \qquad E_3 = 10,300$$

gives

$$\frac{\partial t}{\partial t_2} = \frac{-226.466 + 0.5722281t - 0.0003378967t^2}{8.227 + 0.003309t}.$$

Values of Δt obtained by multiplying values of $\partial t/\partial t_2$ by $\Delta t_{Ag} = 0.3$ deg are given in table 1 and figure 1.

Calculation indicates that the maximum variation in Δt from the values in table 1, due to the
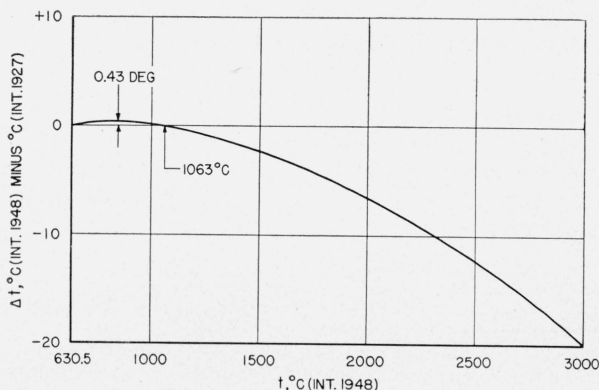
TABLE 1. *Differences between the International Temperature Scales of 1948 and 1927 in the standard thermocouple range*

t °C (Int. 1948)	Δt °C (Int. 1948) minus °C (Int. 1927)
630.5	0.00
650	+.08
700	.24
750	.35
800	.42
839.5	.43 (max)
850	.43
900	.40
950	.32
960.8	.30
1000	.20
1050	.05
1063	.00

variation in standard thermocouples permitted under the International Temperature Scale of 1948, is 0.002 deg. This is sufficient to change certain values of Δt by 0.01 deg upon rounding, which is not significant in comparison with the reproducibility of 0.1 deg C usually ascribed to standard thermocouples. The corresponding temperatures on the two scales between 630.5° and 1,063° C that appear in table 2 were calculated from table 1.

Radiation law range (above the gold point). The adoption of a different value for the radiation constant c_2 changes all temperatures above the gold point, while the use of the Planck radiation formula instead of the Wien formula affects the very high temperatures. The Planck formula is consistent with the thermodynamic scale and consequently removes the upper limit that was imposed by Wien's law in the 1927 scale.

Above the gold point the temperature, t, in degrees Centigrade (Int. 1948) is defined by the formula,

$$\frac{J_t}{J_{Au}} = \frac{e^{\frac{c_2}{\lambda(t_{Au} + T_0)}} - 1}{e^{\frac{c_2}{\lambda(t + T_0)}} - 1}, \tag{2}$$

in which J_t and J_{Au} are the radiant energies per unit wavelength interval at wavelength, λ, emitted per unit time by unit area of a black body at the

Degrees C (Int.)		Corresponding degrees F	
1948	1927	1948	1927
630. 50	630. 50	1166. 9	1166. 9
650	649. 92	1202	1201. 9
700	699. 76	1292	1291. 6
750	749. 65	1382	1381. 4
800	799. 58	1472	1471. 2
850	849. 57	1562	1561. 2
900	899. 60	1652	1651. 3
950	949. 68	1742	1741. 4
960. 80	960. 50	1761. 4	1760. 9
1000	999. 80	1832	1831. 6
1050	1049. 95	1922	1921. 9
1063. 00	1063. 00	1945. 4	1945. 4
1100	1100. 2	2012	2012
1200	1200. 6	2192	2193
1300	1301. 1	2372	2374
1400	1401. 7	2552	2555
1500	1502. 3	2732	2736
1600	1603. 0	2912	2917
1700	1703. 8	3092	3099
1800	1804. 6	3272	3280
1900	1905. 5	3452	3462
2000	2006. 4	3632	3644
2100	2107	3812	3825
2200	2208	3992	4007
2300	2310	4172	4189
2400	2411	4352	4372
2500	2512	4532	4554
2600	2613	4712	4736
2700	2715	4892	4919
2800	2816	5072	5102
2900	2918	5252	5285
3000	3020	5432	5468
3100	3122	5612	5651
3200	3223	5792	5834
3300	3325	5972	6018
3400	3428	6152	6202
3500	3530	6332	6386
3600	3632	6512	6570
3700	3735	6692	6754
3800	3837	6872	6939
3900	3940	7052	7124
4000	4043	7232	7309
4100	4146	7412	7495
4200	4249	7592	7681

temperature, t, and at the gold point, t_{Au}, respectively.

$c_2 = 1.438$ centimeter degrees.

T_0 = temperature of the ice point in degrees Kelvin.

λ = wavelength of the visible spectrum.

e = base of Naperian logarithms.

On the International Temperature Scale of 1927 the temperature, t', was defined by the formula

$$\log_e \frac{J_t}{J_{Au}} = \frac{c_2}{\lambda}\left[\frac{1}{1,336} - \frac{1}{(t'+273)}\right], \qquad (3)$$

where c_2 is taken as 1.432 cm degrees and J_t and J_{Au} have the same meanings as in eq 2. The equation is valid if $\lambda(t'+273)$ is less than 0.3 cm degree. Equating the logarithm of the right-hand side of eq 2 to the right-hand side of eq 3, one obtains the following formula relating t in degrees Centigrade (Int. 1948) and t' in degrees Centigrade (Int. 1927), in which t_{Au} is taken as 1,063 °C, T_0 is taken as 273.16 following the prevailing American usage and λ must be expressed in centimeters.

$$\log_e \frac{e^{\frac{1.438}{1336.16\lambda}}-1}{e^{\frac{1.438}{\lambda(t+273.16)}}-1} = \frac{1.432}{\lambda}\left[\frac{1}{1,336} - \frac{1}{(t'+273)}\right].$$

Corresponding values of t and t' have been calculated from this formula for temperatures above the gold point and for $\lambda = 0.65 \times 10^{-4}$ cm (which is approximately the effective wavelength of most optical pyrometers) and are given in table 2, together with corresponding temperatures below the gold point obtained as mentioned on p. 134. In figure 1, the difference, degrees Centigrade (Int. 1948) minus degrees Centigrade (Int. 1927), is plotted as a function of degrees Centigrade (Int. 1948). Values below 1,063° C are from table 1.

In the range above the gold point, the differences between the two scales cannot be stated explicitly due to the range of permissible values of λ. To indicate the possible variation of the differences due to variation of λ, table 3 has been prepared giving corresponding values of t and t' at $\lambda = 0.65 \times 10^{-4}$ cm and $\lambda = 0.4738 \times 10^{-4}$ cm. The latter wavelength occupies a position at the blue end of the visibility function of the human eye, which corresponds to the position of $\lambda = 0.65 \times 10^{-4}$ cm at the red end. It will be noted that the variation in difference due to variation of λ is in all cases much less than the accuracy of measurement of temperature with existing instruments.

International Temperature Scales

Tables 2 and 3 have not been carried above the maximum temperatures to which the International Temperature Scale of 1927 extends, namely, 4,342° C for $\lambda = 0.65 \times 10^{-4}$ cm and 6,059° C for $\lambda = 0.4738 \times 10^{-4}$ cm.

TABLE 3. *Corresponding temperatures on the International Temperature Scales of 1948 and 1927 at two wave lengths*

t ° C (Int. 1948)	t' ° C (Int. 1927)	
	($\lambda=0.65\times10^{-4}$ cm)	($\lambda=0.4738\times10^{-4}$ cm)
1063	1063	1063
1500	1502. 31	1502. 31
2000	2006. 41	2006. 39
2500	2512. 14	2512. 02
3000	3019. 76	3019. 22
3500	3529. 79	3528. 07
4000	4042. 99	4038. 72
5000	- - - - - - -	5066. 51

In determining temperatures with an optical pyrometer, the following approximate formula (based upon Wien's law),

$$\log_e \frac{J_t}{J_{Au}} = \frac{1.438}{\lambda} \left[\frac{1}{1,336} - \frac{1}{(t_w + 273)} \right], \qquad (4)$$

will usually yield values that are not significantly different from those yielded by eq 2. Corresponding values of t, degrees Centigrade (Int. 1948) and t_w are given in table 4.

TABLE 4.—*Corresponding temperatures on the International Temperature Scale of 1948 and from eq 4*

t ° C (Int. 1948)	t_w ° C
1063	1063. 0
1500	1499. 9
2000	1999. 7
2500	2499. 6
3000	2999. 8
3500	3500. 7
4000	4003. 2
4500	4508. 2
5000	5016. 8

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