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(affiliée à l'Organisation Internationale de Normalisation — ISO)
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(affiliated to the International Organization for Standardization — ISO)
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Spécification internationale d'un cuivre-type recuit

International standard of resistance for copper

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PREFACE TO FIRST EDITION.

The electrical industry has repeatedly felt the need of a resistance standard for copper. Until quite recently there has been a lack of uniformity in the values adopted in the different countries as the standard for annealed copper, arising in the main from the varying interpretation of Matthiessen's original work for the British Association Electrical Standards Committee in 1864, on which ultimately the various values were based. Although the differences have not been very great they have been sufficiently large to prevent the various national tables for copper wires being entirely comparable.

The idea of adopting an international standard for copper was first suggested at the Chicago Congress of 1893, but the proposal unfortunately fell to the ground. During 1911, however, on the initiative of the American Institute of Electrical Engineers, the Bureau of Standards, of Washington, undertook certain experimental work, the results of which are published in the Bulletin of the Bureau for 1911, Volume 7, No. 1*. On the conclusion of this experimental work the international aspect of the matter was considered by the various National Laboratories.

The National Committee of the United States of America also brought the subject to the notice of the I.E.C., and in May, 1912, certain definite propositions, based on the experiments carried out by the different National Laboratories, were considered by a Special Committee of the I.E.C. then sitting in Paris. These propositions were subsequently circulated to the various National Committees of the I.E.C., and at Zurich, in January, 1913, they were agreed to in principle, Dr. R. T. Glazebrook, C.B. (*Director of the National Physical Laboratory of London*) and Prof. Paul Janet (*Director of the Laboratoire central d'Electricité of Paris*) kindly undertaking to prepare the final wording of the different clauses in consultation with the Bureau of Standards, of Washington, and the Physikalisch-Technische Reichsanstalt, of Berlin.

At the Plenary Meeting of the I.E.C. held in Berlin in September, 1913, at which twenty-four nations were represented, the final recommendations, which were presented in person by Prof. Dr. E. Warburg (*President of the Physikalisch-Technische Reichsanstalt of Berlin*), were ratified.

LONDON, *March*, 1914.

PREFACE TO SECOND EDITION.

The purpose of this edition is not to change in any way the substance of the original recommendations but only to re-state them in a manner which renders them free from ambiguity or the possibility of misconstruction.

The recommendations as given in this report have been approved by the Directors of the National Laboratories of London, Paris and Washington. Through the good offices of the President of the Swiss Committee this revised report has been reviewed by Prof. Dr. E. Warburg.

LONDON, *March*, 1925.

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*J. H. Dellinger—"Temperature coefficient of the resistance of copper."
F. A. Wolff and J. H. Dellinger—"Electrical conductivity of commercial copper."

International Electrotechnical Commission.

International Standard of Resistance for Copper.

Definitions :—

(*a*) A metal being taken in the form of a wire of any length and of uniform section, the *volume resistivity* of this metal is the product of its resistance and its section divided by its length.

(*b*) The *mass resistivity* of this metal is the product of its resistance per unit length and its mass per unit length.

(*c*) The volume resistivity (ρ), mass resistivity (δ) and density (d) are interrelated by the formula: $\delta = \rho d$.

Units adopted :—

For this publication, where not otherwise specified, the gramme shall be taken as the unit of mass, the metre as the unit of length, the square millimetre as the unit of area, and the cubic centimetre as the unit of volume. Hence the unit of volume resistivity here used is the ohm square millimetre per metre $\left(\frac{\text{ohm mm}^2}{\text{m}}\right)$ and the unit of mass resistivity is the ohm gramme per metre per metre $\left(\frac{\text{ohm g}}{\text{m}^2}\right)$.

I. Standard Annealed Copper.

The following shall be taken as normal values for standard annealed copper :—

(1) At a temperature of 20° C. the volume resistivity of standard annealed copper is 1/58 = 0·017241... ohm square millimetre per metre $\left(\frac{\text{ohm mm}^2}{\text{m}}\right)$.

(2) At a temperature of 20° C. the density of standard annealed copper is 8·89 grammes per cubic centimetre $\left(\frac{\text{g}}{\text{cm}^3}\right)$.

(3) At a temperature of 20° C. the coefficient of linear expansion of standard annealed copper is 0·000017 per degree Centigrade.

(4) At a temperature of 20°C. the coefficient of variation of the resistance with temperature of standard annealed copper, measured between two potential points rigidly fixed to the wire, the metal being allowed to expand freely, is:

$$0{\cdot}00393 = \frac{1}{254{\cdot}45\ldots} \text{ per degree Centigrade.}$$

(5) As a consequence, it follows from (1) and (2) that at a temperature of 20° C. the mass resistivity of standard annealed copper is 1/58 × 8·89 = 0·15328... ohm gramme per metre per metre.

II. Commercial Copper.

(1) The conductivity of commercial annealed copper shall be expressed as a percentage, at 20° C., of that of standard annealed copper and given to approximately 0·1 per cent.

(2) The conductivity of commercial annealed copper is to be calculated on the following assumptions :—

(*a*) The temperature at which measurements are to be made shall not differ from 20° C. by more than ± 10° C.

(*b*) The volume resistivity of commercial copper increases by 0·000068 ohm square millimetre per metre per degree Centigrade.

(*c*) The mass resistivity of commercial copper increases by 0·00060 ohm gramme per metre per metre per degree Centigrade.

(*d*) The density of commercial annealed copper at a temperature of 20° C. is 8·89 grammes per cubic centimetre.

This value of the density shall be employed in calculating the percentage conductivity of commercial annealed copper.

From these assumptions it follows that, if at a temperature of t° C., R is the resistance, in ohms, of a wire "l" metres in length weighing "m" grammes, the volume resistivity of the same copper is :—

at t° C.......... $\frac{Rm}{l^2 \times 8{\cdot}89}$ ohm square millimetre per metre, and

at 20° C.......... $\frac{Rm}{l^2 \times 8{\cdot}89} + 0{\cdot}000068\,(20 - t)$ ohm square millimetre per metre.

The percentage conductivity of this copper is therefore :—

$$100 \times \frac{1/58}{\frac{Rm}{l^2 \times 8{\cdot}89} + 0{\cdot}000068\,(20 - t)}$$

And, similarly, the mass resistivity of a wire of the same copper is :—

at t° C.......... $\frac{Rm}{l^2}$ ohm gramme per metre per metre, and

at 20° C.......... $\frac{Rm}{l^2} + 0{\cdot}00060\,(20 - t)$ ohm gramme per metre per metre.

The percentage conductivity is therefore :—

$$100 \times \frac{0{\cdot}15328}{\frac{Rm}{l^2} + 0{\cdot}00060\,(20 - t)}$$

Note I. The standard values given above under (I.) are the mean values resulting from a large number of tests. Amongst various specimens of copper of standard conductivity the density may differ from the standard by 0·5 per cent., plus or minus, and the temperature coefficient of resistance may differ from the standard by 1 per cent., plus or minus ; but within the limits indicated in (II.) these differences will not affect the values of the resistance so long as the calculations are only carried to four significant figures.

Note II. The constants at 0°C. of standard annealed copper deduced from the values given above for 20°C. are the following:—

Density at 0°C. ... ... 8·90 $\frac{g}{cm^3}$.

Coefficient of linear expansion per degree Centigrade ... .. 0·000017

Volume resistivity at 0°C.... ... ... $1{\cdot}588_1$ microhm centimetres.

Coefficient at 0°C. of variation of volume resistivity $0{\cdot}00428_2$ per degree Centigrade.

Coefficient at 0°C. of variation of resistance (at constant mass and free expansion) measured between two potential points rigidly fixed to the wire ... ...

$$\frac{1}{234{\cdot}45} = 0{\cdot}00426_5 \text{ per degree Centigrade.}$$

Note III. Explanation of Temperature Coefficients.

1. *Coefficient of variation of resistance at constant mass and free expansion with the temperature.*

If R_1 and R_2 are the resistances measured at the temperatures t_1 and t_2 of a uniform wire, between two potential points rigidly fixed to the wire when the current flows parallel to the axis of the wire, the coefficient of variation of resistance at constant mass and free expansion for the temperature t_1, α_1 is defined by the formula:—

$$R_2 = R_1 \left[1 + \alpha_1 (t_2 - t_1)\right]$$

2. *Coefficient of variation of the volume resistivity with the temperature.*

If ρ represents the volume resistivity of the wire, *i.e.*, if the resistance R of the wire is equal to $\rho \frac{l}{S}$ (l = length of wire, S = section) and if, for the temperature t_1 the coefficient of variation of volume resistivity with the temperature is represented by β_1, the same notation being used as before, the following is obtained:—

$$\rho_2 = \rho_1 \left[1 + \beta_1 (t_2 - t_1)\right]$$

If γ represents the coefficient of linear expansion of the metal, the following is approximately correct:—

$$\beta_1 = \alpha_1 + \gamma$$

3. *Coefficient of variation of the mass resistivity with the temperature.*

If δ represents the mass resistivity, *i.e.*, if the resistance R of the wire is equal to $\delta \frac{l^2}{m}$, l being its length and m its mass, and if the coefficient of the variation of the mass resistivity with the temperature for the temperature t_1 is represented by β'_1, the following is obtained:—

$$\delta_2 = \delta_1 \left[1 + \beta'_1 (t_2 - t_1)\right]$$

giving the approximate formula:—

$$\beta_1 = \alpha_1 - 2\gamma$$