Rapport BIPM-89/7

BUREAU INTERNATIONAL DES POIDS ET MESURES

Projected Changes in National Reference Standards of Electromotive Force and Resistance

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Abstract

Results are reported from a survey of national standards laboratories concerning the application on 1 January 1990 of new reference standards of electromotive force and resistance. Values of the changes with respect to present standards are tabulated.

Introduction.

In October 1988 the Comité International des Poids et Mesures (CIPM) voted Recommendations 1 (CI-1988) and 2 (CI-1988) proposing conventional values of the Josephson constant, K_J, and the von Klitzing constant, R_K, to be used in conjunction with the Josephson effect and the quantum Hall effect for the purpose of maintaining reference standards of electromotive force and electrical resistance. The recommendations are the result of a detailed study by the Comité Consultatif d'Electricité (CCE) since 1986 and are based on the conclusions of the CCE's Working Group on the Josephson Effect and Working Group on the Quantum Hall Effect.

Recommendation 1 (CI-1988) concerns standards of electromotive force and is meant to establish international uniformity in reference standards based on the Josephson effect. It proposes a new value of the Josephson constant, designated K_{J-90}, to be used in all standards laboratories. The recommended numerical value of K_{J-90} follows from a number of the most recent measurements. It is believed to agree to within 4 parts in 10^7 with the true numerical value of K_J in SI units and it is meant to replace the four different values of K_J now in use. Not only do the four presently used values disagree among themselves by as much as 5.7 parts in 10^6 but also they all disagree with K_{J-90} by up to 9.3 parts in 10^6. Recommendation 1 (CI-1988) requests laboratories that do not carry out Josephson effect measurements themselves to adjust the values of their standards to be consistant with K_{J-90}.

Recommendation 2 (CI-1988) concerns standards of resistance and is meant to establish international uniformity in reference standards based on the quantum Hall effect. It proposes a value of the von Klitzing constant, designated R_{K-90}, to be used in all standards laboratories. The recommended numerical value of R_{K-90} follows from a number of recent measurements. It is believed to agree to within 2 parts in 10^7 with the true numerical value of R_K in SI units and, in conjunction with accurate measurements of the quantized Hall resistance, is meant to replace reference standards based on wirewound resistors. Not only are the latter subject to slow changes with time, they also disagree among themselves by as much as 3.7 parts in 10^6 and typically disagree with the ohm by 0 to 2 parts in 10^6. Recommendation 2 (CI-1988) requests laboratories that do not carry out quantum Hall effect measurements themselves to adjust the values of their standards to be consistant with R_{K-90}.

Survey of Reference Standards of Electromotive Force and Resistance.

Because K_{J-90} differs significantly from all of the values previously used for the Josephson constant by various national laboratories and because reference standards of resistance maintained by the laboratories also differ among themselves by small but significant amounts, manufacturers and users of precise electrical measurement equipment requested the drafting of tables of the projected changes in the electrical reference standards in the national laboratories. These requests were forwarded to the Bureau International des Poids et Mesures (BIPM) since one of its most important tasks is to aid the coordination of basic standards among the national laboratories.

To gather the required information, the BIPM prepared and distributed a questionnaire consisting of eight questions. A copy is included in the Appendix of this report. Questionnaires were sent to the national standards laboratories in all 47 member countries of the Convention du Mètre.

Results and Comments.

When considering the replies to the questionnaire, it should be borne in mind that some laboratories are now working on establishing or refining their measurements of the Josephson effect or of the quantum Hall effect and others are verifying the values of their reference resistors or standard cells with respect to the BIPM. Consequently the values reported here are projected *estimates* made six months before the changes take place. Later data may lead to some modifications. In order to take this possibility into account and to help the CCE in its intended review of progress in adopting the new reference standards, on 1 April 1990 the BIPM will prepare an updated version of the tables of changes in the reference standards in the national laboratories based on data available after 1 January 1990.

Table I. Summary of policies and procedures related to the metrology of electromotive force and electrical potential difference at the BIPM and in national standards laboratories beginning 1 January, 1990. $\{E_{new}\}$ is the numerical value ascribed to an ideal transfer standard based on the new reference standard and $\{E_{old}\}$ is that based on the laboratory's old standard.

country	laboratory	follow Recommendation 1 (CI-1988)	$[(\{E\}_{new} - \{E\}_{old})/\{E\}_{old}] \times 10^6$	basis of ref. standard of emf	intends to implement ITS-90 in emf meas.
—	Bureau International des Poids et Mesures	yes	-8.06	Josephson ef.	yes
Argentina	Instituo Nacional de Tecnologia Industrial	yes	-8.06	cells in oil	yes
Australia	CSIRO National Measurement Laboratory	yes	-8.06	Josephson ef.	yes
Austria	Bundesamt für Eich- und Vermessungswesen	yes	-8.06	cells in oil/encl.	yes
Belgium	Inspection Générale de la Métrologie	yes	-8.06	Josephson ef.	yes
Canada	Laboratory for Basic Standards, Nat'l Research Council	yes	-8.06	Josephson ef.	yes
China (People's Republic of)	National Institute of Metrology	yes	-8.97	Josephson ef.	yes
Czechoslovakia	CSMU (Czechoslovak Institute of Metrology)	yes	-8.06	cells in oil	yes
Denmark	Danish Institute of Fundamental Metrology	yes	-8.06	Josephson ef.	undecided
Finland	Technical Research Centre of Finland	yes	-8.06	Josephson ef.	yes
France	Laboratoire Central des Industries Electriques	yes	-6.741	Josephson ef.	yes
German Democratic Republic	Amt für Standardisierung, Messwesen und Warenprüfung	yes	-8.06	Josephson ef.	yes
Germany(Federal Rep. of)	Physikalisch-Technische Bundesanstalt	yes	-8.06	Josephson ef.	yes
Hungary	Orszagos Meresugyi Hivatal	yes	-8.	cells in oil	yes
Italy	Istituto Elettrotecnico Nazionale Galileo Ferraris	yes	-8.06	Josephson ef.	yes
Japan	Electrotechnical Laboratory	yes	-8.06	Josephson ef.	yes
Korea (Rep. of)	Korea Standards Research Institute	yes	-9.8	Josephson ef.	no
Netherlands	Van Swinden Laboratory	yes	-8.06	Josephson ef.	yes
Norway	National Measurement Service	yes	-8.06	Josephson ef.	yes
Romania	National Institite of Metrology	yes	-8.06	cells in oil	yes
South Africa	CSIR Division of Production Technology	yes	-8.4	cells in oil	yes
Sweden	Statens Provningsanstalt	yes	-7.3	Josephson ef.	yes
Switzerland	Swiss Federal Office of Metrology	yes	-8.06	Josephson ef.	yes
Thailand	Thailand Institute of Scientific and Technological Research	yes	-8.00	cells in oil	yes
Turkey	Marmara Scientific and Industrial Research Institute	no	—	cells in encl.	—
Union of Soviet Socialist Republics	Institute of Metrology D. I. Mendeleyev	yes	-3.565	Josephson ef.	yes
United Kingdom	National Physical Laboratory	yes	-8.06	Josephson ef.	yes
United States of America	National Institute of Standards and Technology	yes	-9.264	Josephson ef.	yes
Yugoslavia	Federal Bureau of Measures and Precious Metals	yes	—	cells in oil	yes

Table I summarizes the responses given to questions 1 to 4 dealing with standards of electromotive force. As indicated in column 3, of the 29 laboratories (including the BIPM) that responded, all but one now intend to follow CIPM Recommendation 1 (CI-1988). Column 4 lists the relative difference in parts in 10^6 between the numerical value, $\{E_{new}\}$, ascribed to an ideal transfer standard based on the new reference standard of emf and $\{E_{old}\}$, that based on the laboratory's old standard. Many laboratories, including the BIPM, issue calibration certificates giving the value of a travelling standard in terms of their representations of the volt. For example, $V_{76\text{-BI}}$ is defined by

$$K_{J\text{-}72} = 483\ 594\ \text{GHz}/V_{76\text{-BI}}.$$

From the recommended value of $K_{J\text{-}90}$, namely,

$$K_{J\text{-}90} = 483\ 597.9\ \text{GHz/V}$$

it follows that

$$V_{76\text{-BI}} = 1\ \text{V} - 8.06\ \mu\text{V}.$$

Since the BIPM representation of the volt will *increase* by 8.06 µV, the numerical value assigned to a measured source of emf on the basis of the new representation will *decrease* by 8.06 parts in 10^6.

The laboratories reporting a value of -8.06×10^{-6} in column 4 are those that maintained their reference standards to be consistant with $K_{J\text{-}72}$. Of the laboratories responding, there is now a total of 20 which will use the Josephson effect directly as a reference standard.

Column 6 indicates that nearly all laboratories plan to apply the new temperature scale, ITS-90. The Comité Consultatif de Thermométrie will meet on 12-14 September 1989 to decide on the final details and when these become available the BIPM will communicate them to the national laboratories.

Table II summarizes the responses to questions 5 to 8 dealing with standards of resistance. Of 29 respondants, all but two intend to follow CIPM Recommendation 2 (CI-1988). Column 4 gives the relative difference in parts in 10^6 between the numerical value, $\{R_{new}\}$, ascribed to an ideal resistor based on the new reference standard of resistance and $\{R_{old}\}$, that based on the laboratory's old standard. Again, many laboratories, including the BIPM, issue calibration certificates giving the value of a travelling standard in terms of their representations of the ohm. For example, $\Omega_{69\text{-BI}}$ is defined by the mean value of six wirewound resistors. Quantized Hall resistance measurements carried out at the BIPM allow extrapolation of the value of $\Omega_{69\text{-BI}}$, which drifts slowly with time, to 1 January, 1990. This gives

$$\Omega_{69\text{-BI}} = 1\ \Omega - 1.90\ \mu\Omega, \text{ on 1 Jan. 1990.}$$

Table II. Summary of policies and procedures related to the metrology of electrical resistance at the BIPM and in national standards laboratories beginning 1 January, 1990. $\{R_{new}\}$ is the numerical value ascribed to an ideal resistor based on the new reference standard and $\{R_{old}\}$ is that based on the laboratory's old standard.

country	laboratory	follow Recommendation 2 (CI-1988)	$[(\{R\}_{new} - \{R\}_{old}) / \{R\}_{old}] \times 10^6$	basis of ref. standard of resistance	intends to implement ITS-90 in resistance meas.
—	Bureau International des Poids et Mesures	yes	-1.90	quantum Hall ef.	yes
Argentina	Instituo Nacional de Tecnologia Industrial	yes	-0.56	standard resistors	yes
Australia	CSIRO National Measurement Laboratory	yes	-0.09	quantum Hall ef.	yes
Austria	Bundesamt für Eich- und Vermessungswesen	yes	-1.9	standard resistors	yes
Belgium	Inspection Générale de la Métrologie	yes	-1.90	standard resistors	yes
Canada	Laboratory for Basic Standards, Nat'l Research Council	yes	-3.4	quantum Hall ef.	yes
China (People's Republic of)	National Institute of Metrology	yes	-1.50	quantum Hall ef.	yes
Czechoslovakia	CSMU (Czechoslovak Institute of Metrology)	yes	-1.90	standard resistors	yes
Denmark	Danish Institute of Fundamental Metrology	yes	—	none at present	yes
Finland	Technical Research Centre of Finland	yes	0	quantum Hall ef. (since 1 Feb., 1988)	yes
France	Laboratoire Central des Industries Electriques	yes	-0.66	quantum Hall ef.	yes
German Democratic Republic	Amt für Standardisierung, Messwesen und Warenprüfung	yes	-1.80	quantum Hall ef.	yes
Germany(Federal Rep. of)	Physikalisch-Technische Bundesanstalt	yes	-0.56	quantum Hall ef.	yes
Hungary	Orszagos Meresugyi Hivatal	yes	-1.9	standard resistors	yes
Italy	Istituto Elettrotecnico Nazionale Galileo Ferraris	yes	+0.3	quantum Hall ef.	yes
Japan	Electrotechnical Laboratory	yes	—	quantum Hall ef.	yes
Korea (Rep. of)	Korea Standards Research Institute	yes	-0.7	quantum Hall ef.	yes
Netherlands	Van Swinden Laboratory	yes	-1.20	quantum Hall ef.	yes
Norway	National Measurement Service	yes	-1.60	standard resistors	yes
Romania	National Institite of Metrology	yes	-1.90	standard resistors	yes
South Africa	CSIR Division of Production Technology	yes	-1.4	standard resistors	yes
Sweden	Statens Provningsanstalt	yes	-1.7	standard resistors	yes
Switzerland	Swiss Federal Office of Metrology	yes	-1.54	quantum Hall ef.	yes
Thailand	Thailand Institute of Scientific and Technological Research	yes	-2.00	standard resistors	yes
Turkey	Marmara Scientific and Industrial Research Institute	no	—	—	—
Union of Soviet Socialist Republics	Institute of Metrology D. I. Mendeleyev	yes	-0.02	quantum Hall ef.	yes
United Kingdom	National Physical Laboratory	yes	-1.61	quantum Hall ef.	yes
United States of America	National Institute of Standards and Technology	yes	-1.69	quantum Hall ef.	yes
Yugoslavia	Federal Bureau of Measures and Precious Metals	no	—	standard resistors	yes

Since the BIPM representation of the ohm will *increase* by 1.90 parts in 10^6, the numerical value assigned to a resistor on the basis of the new representation will *decrease* by 1.90 parts in 10^6. Finally, it should be noted that laboratories reporting values close to -1.90×10^{-6} in column 4 are those which endeavor to maintain resistance standards consistant with $\Omega_{69\text{-}BI}$.

Of the laboratories responding, there are 16 which will use the quantum Hall effect directly as a reference standard. The rapid development of this technique attests to the great importance laboratories have placed on maintaining stable and precise electrical standards.

Column 6 shows that nearly all laboratories intend to apply the new temperature scale, ITS-90, in the calibration of standard resistors.

Conclusion.

The results of the questionnaire show that practically all laboratories intend to apply CIPM Recommendations 1 (CI-1988) and 2 (CI-1988). This indicates that an important goal, worldwide uniformity and constancy in national representations of the electrical units, is about to be achieved.

Annotated Bibliography.

A summary of the CCEs 18th meeting including a description of the proposed electrical reference standards and the texts of the CIPM Recommendations is given in the following, a copy of which was sent to all laboratories along with the questionnaire.

- T. J. Quinn, *News from the BIPM*, Metrologia, 26, pp. 69-74, 1989.

The formal report of the CCEs 18th meeting including the minutes, the reports of the Working Groups and the Guidelines for Reliable Measurements of the Quantized Hall Resistance will be available in about August, 1989 in:

- BIPM Com. Cons. Electricité, 18, (1988), in press.

A combined version of the reports of the two Working Groups emphasizing details of the selection of values of $K_{J\text{-}90}$ and $R_{K\text{-}90}$ appears in:

- B. N. Taylor and T. J. Witt, *New international electrical reference standards based on the Josephson and quantum Hall effects*, Metrologia, 26, pp. 47-62, 1989.

A report by the Working Group on the Quantum Hall Effect on the precautions and tests to apply for accurate measurements of the quantized Hall resistance appears in:

• F. Delahaye, *Technical Guidelines for Reliable Measurements of the Quantized Hall Resistance*, Metrologia, 26, pp. 63-68, 1989.

Sèvres, 12 July, 1989.

Appendix.

For completeness, a copy of the original questionnaire is reproduced below.

BIPM questionnaire on changes of national reference standards of emf and resistance

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Name of laboratory:

Question 1. Does your laboratory intend to change its reference standard of emf on 1 January 1990 according to Recommendation 1 (CI-1988), that is, to be in agreement with the Josephson constant $K_{J\text{-}90}$ = 483 597.9 GHz/V? (Place an "X" beside the response corresponding to your choice).

Yes ___ No ___

Question 2. Please indicate into which of the following categories your laboratory falls.

• A. A laboratory that now uses or will use the Josephson effect directly to maintain a reference standard of emf.

• B1. A laboratory that uses standard cells or Zener diodes in thermoregulated enclosures whose temperature is constant but not measured exactly, as in the case of commercial thermoregulated enclosures, to maintain a reference standard of emf; the value of the reference standard is determined by comparisons with a laboratory which uses the Josephson effect.

• B2. A laboratory that uses standard cells in a thermoregulated bath at a fixed temperature such as t_{68} = 20 °C (or 25 °C or 30 °C), as is usually the case for cells in an oil bath, to maintain a reference standard of emf; the value of the reference standard is determined by comparisons with a laboratory which uses the Josephson effect. Note that in this case the change in the value of the reference temperature is equivalent to a change in the definition of your standard.

A ___ B1 _____ B2 _____

Question 3. If on 1 January 1990 your laboratory calibrates an ideal, perfectly stable standard of emf having a negligible temperature coefficient, what is your present predicted value of the relative difference

$$(\{E\}_{new} - \{E\}_{old})/\{E\}_{old}$$

where $\{E\}_{new}$ is the numerical value of the emf referred to your new reference standard and $\{E\}_{old}$ is that referred to your old reference standard of emf?

$$(\{E\}_{new} - \{E\}_{old})/\{E\}_{old} = \_\_\_\_\_\_\_\_\_\_.$$

Question 4. On 1 January 1990 the present temperature scale IPTS-68 will be replaced by ITS-90 and the temperature t_{90} will differ from temperature t_{68} (see enclosed *News from the BIPM*, pp. 69-71) as, for example, $(t_{90} - t_{68})_{20°C} = -5$ mK. The use of ITS-90 will have an effect on the values assigned to reference standards based on standard cells at a defined temperature. There are two alternatives, either you increase the physical temperature of a standard cell maintained at, for example, $t_{68} = 20$ °C to $t_{90} = 20$ °C, changing the emf by approximately -0.2 μV or you maintain the same physical temperature, $t_{90} = 19.995$ °C. This remark applies equally to cells used to maintain a reference standard (as in category B2) and to cells being calibrated.

Does your laboratory intend to implement ITS-90 as of 1 January, 1990 in the calibration of standard cells?

Yes _____ No _____ Undecided _____

Question 5. Does your laboratory intend to change its reference standard of resistance on 1 January 1990 according to Recommendation 2 (CI-1988), that is, to be in agreement with $R_{K-90} = 25\ 812.807\ \Omega$ for the value of the von Klitzing constant?

Yes ___ No ___

Question 6. Please indicate into which of the following categories your laboratory falls.

- C. A laboratory that will use the quantum Hall effect directly to maintain a reference standard of resistance.
- D. A laboratory that will continue to use standard resistors in a thermoregulated bath at a fixed temperature such as $t_{68} = 20$ °C (or 25 °C); the value of the reference standard will be determined by comparisons with a laboratory which uses the quantum Hall effect. Note that in this case the change in the value of the reference temperature is equivalent to a change in the definition of your standard.

C ___ D _____ neither C nor D _____

Question 7. If on 1 January 1990 your laboratory calibrates an ideal, perfectly stable standard resistor having a negligible temperature coefficient, what is your present predicted value of the relative difference

$$(\{R\}_{new} - \{R\}_{old})/\{R\}_{old}$$

where $\{R\}_{new}$ is the numerical value of the resistance referred to your new reference standard and $\{R\}_{old}$ is that referred to your old reference standard of resistance?

$$(\{R\}_{new} - \{R\}_{old})/\{R\}_{old} = \_\_\_\_\_\_\_\_\_\_.$$

Question 8. As described in question 4, use of ITS-90 will have a small effect on values assigned to standard resistors in calibrations. A one ohm standard resistor maintained at t_{68} = 20 °C, having a relative temperature coefficient of resistance of 1 x 10^{-5} and increased in temperature to t_{90} = 20 °C will change in resistance by approximately 0.05 μΩ. This remark applies equally to resistors used to maintain a reference standard (as in category D) and to resistors being calibrated.

Does your laboratory intend to implement ITS-90 as of 1 January, 1990 in the calibration of resistors?

Yes _____ No _____ Undecided _____

Name(s) of person(s) responding to this questionnaire:

Telephone number(s):

Telex number(s):

Telefax number(s):

Date: