Revision of the mise en pratique of the definition of the metre

RECOMMENDATION 3 (CI-1992)

The Comité International des Poids et Mesures,

recalling
— that in 1983 the 17th Conférence Générale des Poids et Mesures (CGPM) adopted a new definition of the metre;
— that in the same year the CGPM invited the Comité International des Poids et Mesures (CIPM)
  — to draw up instructions for the practical realization of the metre;
  — to choose radiations which can be recommended as standards of wavelength for the interferometric measurement of length and draw up instructions for their use;
  — to pursue studies undertaken to improve these standards and in due course to extend or revise these instructions;
— that in response to this invitation CIPM made a number of Recommendations in 1983 concerning the practical realization of the metre (the 'mise en pratique');

considering
— that science and technology continue to demand improved accuracy in the realization of the metre;
— that since 1983 work in national laboratories, BIPM and elsewhere has substantially improved the reproducibility of radiations which are suitable for the practical realization of the metre;
— that such work has also substantially reduced the uncertainty in the determined values of the frequencies and wavelengths of some of these radiations;

decides that the list of recommended radiations given by the CIPM in 1983 (Recommendation 1 (CI-1983)) be replaced by the list of recommended radiations given below.

LIST OF RECOMMENDED RADIATIONS, 1992


In this list, the values of the frequency $f$ and of the wavelength $\lambda$ should be related exactly by the relation $\lambda f = c$, with $c = 299 792 458$ m/s but the values of $\lambda$ are rounded.
The data and analysis used for the compilation of this list are set out in the associated Appendix: Source Data for the List of Recommended Radiations, 1992 and its Annotated Bibliography*.

It should be noted that for several of the listed radiations, few independent values are available, so that the estimated uncertainties may not, therefore, reflect all sources of variability.

Each of the listed radiations can be replaced, without degrading the accuracy, by a radiation corresponding to another component of the same transition or by another radiation, when the frequency difference is known with sufficient accuracy. It should be also noted that to achieve the uncertainties given here it is not sufficient just to meet the specifications for the listed parameters. In addition, it is necessary to follow the best good practice concerning methods of stabilization as described in numerous scientific and technical publications. References to appropriate articles, illustrating accepted good practice for a particular radiation, may be obtained by application to a member laboratory of the CCDM, or to the BIPM.

1. Radiations of Stabilized Lasers

1.1. Absorbing molecule CH₄, transition ν₃, P (7), component F₂(2).

1.1.1. The values \( f = 88376181600,18 \text{ kHz} \)
\[
\lambda = 3392231397,327 \text{ fm}
\]
with an estimated relative standard uncertainty of \( 3 \times 10^{-12} \) apply to the radiation of a He-Ne laser stabilized to the central component [(7-6) transition] of the resolved hyperfine-structure triplet, the mean of recoil splitting, for effectively stationary molecules, i.e. the values are corrected for second order Doppler shift.

1.1.2. The values \( f = 88376181600,5 \text{ kHz} \)
\[
\lambda = 3392231397,31 \text{ fm}
\]
with an estimated relative standard uncertainty of \( 2,3 \times 10^{-11} \) apply to the radiation of a He-Ne laser stabilized to the centre of the unresolved hyperfine structure of a room temperature methane cell, within or external to the laser, subject to the following conditions:
- methane pressure \( \leq 3 \text{ Pa} \)
- mean one-way axial intracavity surface power density* \( \leq 10^4 \text{ W m}^{-2} \)
- radius of wavefront curvature \( \geq 1 \text{ m} \)
- inequality of power between counter-propagating waves \( \leq 5 \% \)
- detector placed at the output facing the laser tube.

* The appendix referred to above is published in the Report of the 8th meeting of the CCDM (1992).
1.2. Absorbing atom $^{40}$Ca, transition $^3P_1 - ^1S_0$; $\Delta m_f = 0$.

The values

\[
\begin{align*}
 f &= 455 \, 986 \, 240,5 \text{ MHz} \\
 \lambda &= 657 \, 459 \, 439,3 \text{ fm}
\end{align*}
\]

with an estimated relative standard uncertainty of $4,5 \times 10^{-10}$ apply to the radiation of a laser stabilized with a thermal atomic beam.

1.3. Absorbing molecule $^{127}$I$_2$, transition 8-5, P(10), component $a_9$ (or g).

The values

\[
\begin{align*}
 f &= 468 \, 218 \, 332,4 \text{ MHz} \\
 \lambda &= 640 \, 283 \, 468,7 \text{ fm}
\end{align*}
\]

with an estimated relative standard uncertainty of $4,5 \times 10^{-10}$ apply to the radiation of a He-Ne laser stabilized with an internal iodine cell having a cold finger temperature of $(16 \pm 1) \, ^\circ\text{C}$ and a frequency modulation width, peak to peak, of $(6 \pm 1) \, \text{MHz}$.

1.4. Absorbing molecule $^{127}$I$_2$, transition 11-5, R(127), component $a_{13}$ (or i).

The values

\[
\begin{align*}
 f &= 473 \, 612 \, 214 \, 705 \text{ kHz} \\
 \lambda &= 632 \, 991 \, 398,22 \text{ fm}
\end{align*}
\]

with an estimated relative standard uncertainty of $2,5 \times 10^{-11}$ apply to the radiation of a He-Ne laser with an internal iodine cell, subject to the conditions:

- cell-wall temperature: $(25 \pm 5) \, ^\circ\text{C}$
- cold finger temperature: $(15 \pm 0,2) \, ^\circ\text{C}$
- frequency modulation width, peak to peak: $(6 \pm 0,3) \, \text{MHz}$
- one-way intracavity beam power$^+$: $(10 \pm 5) \, \text{mW}$, for an absolute value of the power shift coefficient $\leq 1,4 \, \text{kHz/mW}$.

These conditions are by themselves insufficient to ensure that the stated standard uncertainty will be achieved. It is also necessary for the optical and electronic control systems to be operating with the appropriate technical performance. The iodine cell may also be operated under relaxed conditions, leading to the larger uncertainty specified in Appendix M2 of the CCDM Report (1992).

1.5. Absorbing molecule $^{127}$I$_2$, transition 9-2, R(47), component $a_7$ (or o).

The values

\[
\begin{align*}
 f &= 489 \, 880 \, 354,9 \text{ MHz} \\
 \lambda &= 611 \, 970 \, 770,0 \text{ fm}
\end{align*}
\]

with an estimated relative standard uncertainty of $3 \times 10^{-10}$ apply to the radiation of a He-Ne laser stabilized with an iodine cell, within or external to the laser, having a cold finger temperature of $(5 \pm 2) \, ^\circ\text{C}$.
1.6. Absorbing molecule $^{127}$I$_2$, transition 17-1, P(62), component $a_1$.
The values 

\[ f = 520 206 808.4 \text{ MHz} \]
\[ \lambda = 576 294 760.4 \text{ fm} \]

with an estimated relative standard uncertainty of $4 \times 10^{-10}$ apply to the radiation of a dye laser (or frequency-doubled He-Ne laser) stabilized with an iodine cell, within or external to the laser, having a cold-finger temperature of $(6 \pm 2)$ °C.

1.7. Absorbing molecule $^{127}$I$_2$, transition 26-0, R(12), component $a_0$.
The values 

\[ f = 551 579 482.96 \text{ MHz} \]
\[ \lambda = 543 516 333.1 \text{ fm} \]

with an estimated relative standard uncertainty of $2.5 \times 10^{-10}$ apply to the radiation of a frequency stabilized He-Ne laser with an external iodine cell having a cold-finger temperature of $(0 \pm 2)$ °C.

1.8. Absorbing molecule $^{127}$I$_2$, transition 43-0, P(13), component $a_3$ (or s).
The values 

\[ f = 582 490 603.37 \text{ MHz} \]
\[ \lambda = 514 673 466.4 \text{ fm} \]

with an estimated relative standard uncertainty of $2.5 \times 10^{-10}$ apply to the radiation of an Ar$^+$ laser stabilized with an iodine cell external to the laser, having a cold-finger temperature of $(5 \pm 2)$ °C.

Note
* The one-way intracavity beam power is obtained by dividing the output power by the transmittance of the output mirror.

2. Radiations of Spectral Lamps

2.1. Radiation corresponding to the transition between the levels $2p_{10}$ and $5d_5$ of the atom of $^{86}$Kr.
The value 

\[ \lambda = 605 780 210.3 \text{ fm} \]

with an estimated overall relative uncertainty of $\pm 4 \times 10^{-9}$ [equivalent to three times the relative standard uncertainty of $1.3 \times 10^{-9}$] applies to the radiation emitted by a lamp operated under the conditions recommended by the CIPM (BIPM Proc.-Verb. Com. Int. Poids et Mesures, 1960, 28, 71-72 and BIPM Comptes Rendus 11e Conf. Gén. Poids et Mesures, 1960, 85]).