MEP 2003

IODINE ($\lambda \approx 640$ nm)

Absorbing molecule $^{127}I_2$, a_9 component, P(10) 8-5 transition [(1)]

1. CIPM recommended values

The values $f = 468\ 218\ 332.4$ MHz
$\lambda = 640\ 283\ 468.7$ fm
with a relative standard uncertainty of 4.5×10^{-10} apply to the radiation of a He-Ne laser stabilized with an internal iodine cell having a cold-finger temperature of (16 ± 1) °C [(2)] and a frequency modulation width, peak-to-peak, of (6 ± 1) MHz.

2. Source data

Adopted value	$f = 468\ 218\ 332.4\ (2)$ MHz	$u_c/y = 4.5 \times 10^{-10}$
	for which:	
	$\lambda = 640\ 283\ 468.7\ (3)$ fm	$u_c/y = 4.5 \times 10^{-10}$

calculated from

f / kHz	u_c/y	source data
468 218 332 419	1.0×10^{-10}	2. 1
468 218 332 310	1.2×10^{-10}	2. 2
468 218 332 069	4.6×10^{-10}	2. 3
Weighted mean:	$f = 468\ 218\ 332\ 366$ kHz	

Given the small number of determinations, the CCL considered it prudent to assume a relative standard uncertainty of 4.5×10^{-10}.

Source data

2.1 Bennet and Mills-Baker [1] give $\lambda_{a9} = 640.283\ 4686$ nm.
From this paper the ratio f_{a9}/f_i is calculated as $f_{a9}/f_i = 0.988\ 611\ 184\ 191$ $u_c/y = 1 \times 10^{-10}$.

Using the recommended value of the absorbing molecule $^{127}I_2$, a_{16} or f component, R(127) 11-5 transition (see iodine at $\lambda \approx 633$ nm and frequency differences listed in corresponding Table 1) one obtains
$f_i = 473\ 612\ 214\ 712$ kHz $u_c/y = 2.2 \times 10^{-11}$,

one calculates $f_{a9} = 468\ 218\ 332\ 434$ kHz $u_c/y = 1.0 \times 10^{-10}$

at a cold-finger temperature of 14.3 °C (iodine pressure = 16 Pa) and a modulation width of 7 MHz. For a reference temperature of 16 °C (iodine pressure = 18.9 Pa) and a modulation width of 6 MHz, corrections of –23 kHz and +8

---

(1) All transitions in I_2 refer to the $B^3\Pi\,0_u^+ - X^1\,\Sigma_g^+$ system.

(2) For the specification of operating conditions, such as temperature, modulation width and laser power, the symbols ± refer to a tolerance, not an uncertainty.

kHz has to be applied to this value assuming a pressure dependence of –7.8 kHz/Pa and a modulation dependence of –7.6 kHz/MHz, similar to that reported in [2], giving

f_{a9} = 468 218 332 419 kHz $\quad u_c/y = 1.0 \times 10^{-10}$.

2.2 Zhao et al. [2, 3] give λ_{a9} = 640.283 4688 nm $\quad 3 \times (u_c/y) = 1.1 \times 10^{-9}$.

Bönsch [4] gives λ_i/λ_{a9} = 0.988 611 183 8 $\quad u_c/y = 12 \times 10^{-11}$.

Using the recommended value of the absorbing molecule $^{127}I_2$, a_{16} or f component, R(127) 11-5 transition (see iodine at $\lambda \approx 633$ nm and frequency differences listed in corresponding Table 1) one obtains

f_i = 473 612 214 712 kHz $\quad u_c/y = 2.2 \times 10^{-11}$,

one calculates f_{a9} = 468 218 332 277 kHz $\quad u_c/y = 1.2 \times 10^{-10}$

at a cold-finger temperature of 18 °C (iodine pressure = 22.6 Pa) and a modulation width of 6.5 MHz. For a reference temperature of 16 °C (iodine pressure = 18.9 Pa) and a modulation width of 6 MHz, corrections of +29 kHz and +4 kHz have to be applied to this value knowing a pressure dependence of –7.8 kHz/Pa and a modulation dependence of –7.6 kHz/MHz, giving

f_{a9} = 468 218 332 310 kHz $\quad u_c/y = 1.2 \times 10^{-10}$.

2.3 Reference [5, 6] give λ_{a9}(17 °C) / λ_e (20 °C) = 1.011 520 341 04 $\quad u_c/y = 4.6 \times 10^{-10}$.

Using the recommended value of the absorbing molecule $^{127}I_2$, a_{16} or f component, R(127) 11-5 transition (see iodine at $\lambda \approx 633$ nm and frequency differences listed in corresponding Table 1) one obtains

f_e = 473 612 366 967 kHz $\quad u_c/y = 2.2 \times 10^{-11}$,

one calculates f_{a9} = 468 218 332 055 kHz $\quad u_c/y = 4.6 \times 10^{-10}$

at a cold-finger temperature of 17 °C (iodine pressure = 20.7 Pa). For a reference temperature of 16 °C (iodine pressure = 18.9 Pa), a correction of +14 kHz has to be applied to this value, assuming a pressure dependence of –7.8 kHz/Pa similar to that reported in [2], giving

f_{a9} = 468 218 332 069 kHz $\quad u_c/y = 4.6 \times 10^{-10}$.

3. Absolute frequency of the other transitions related to those adopted as recommended and frequency intervals between transitions and hyperfine components

These tables replace those published in BIPM Com. Cons. Long., 2001, **10**, 188 and Metrologia, 2003, **40**, 128.

The notation for the transitions and the components is that used in the source references. The values adopted for the frequency intervals are the weighted means of the values given in the references.

For the uncertainties, account has been taken of:

- the uncertainties given by the authors;
- the spread in the different determinations of a single component;
- the effect of any perturbing components;
- the difference between the calculated and the measured values.

In the tables, u_c represents the estimated combined standard uncertainty (1 σ).

All transitions in molecular iodine refer to the B-X system.

Table 1

$\lambda \approx 640$ nm $^{127}I_2$ P(10) 8-5					
a_n	$[f(a_n) - f(a_9)]$/MHz	u_c/MHz	a_n	$[f(a_n) - f(a_9)]$/MHz	u_c/MHz
a_1	–495.4	0.4	a_9	0	—
a_2	–241.5	0.7	a_{10}	77.84	0.03
a_3	–233.0	0.4	a_{11}	186.22	0.07
a_4	–177.8	1.3	a_{12}	199.51	0.07
a_5	–175.2	0.6	a_{13}	256.6	0.2
a_6	–130.8	0.1	a_{14}	272.75	0.07
a_7	–82.45	0.03	a_{15}	374.0	0.2
a_8	–61.85	0.14			
Frequency referenced to a_9, P(10) 8-5, $^{127}I_2$: f = 468 218 332.4 MHz [7]					
Ref. [8, 9, 10-15]					

Table 2

$\lambda \approx 640$ nm $^{127}I_2$ R(16) 8-5		
b_n	$[f(b_n) - f(a_9)]$/MHz	u_c/MHz
b_1	62.834	0.01
b_2	329.8	0.2
b_3	335.99	0.02
Frequency referenced to a_9, P(10) 8-5, $^{127}I_2$: f = 468 218 332.4 MHz [7]		
Ref. [8, 9, 10-15]		

4. References

[1] Bennett S. J., Mills-Baker P., Iodine Stabilized 640 nm Helium-Neon laser, *Opt. Commun.*,1984, **51**, 322-324.

[2] Zhao K. G., Blabla J., Helmcke J., $^{127}I_2$-Stabilized ^{3}He-^{22}Ne Laser at 640 nm Wavelength, *IEEE Trans. Instrum. Meas.*, 1985, **IM-34**, 252-256.

[3] CCDM/92-10a, NIM, Research findings in realizing the definition of the metre measurement/intercomparison of frequency (wavelength) and geometrical standard of length.

[4] Bönsch G., Simultaneous Wavelength Comparison of Iodine-Stabilized Lasers at 515 nm, 633 nm, and 640 nm, *IEEE Trans. Instrum. Meas.*, 1985, **IM-34**, 248-251.

[5] CCDM/92-20a, BIPM, Reply to the Questionnaire for the CCDM.

[6] CCDM/92-6a, IMGC, Reply to questionnaire CCDM/92-1, 5 June 1992.

[7] Recommendation CCL3 (*BIPM Com. Cons. Long.*, 10th Meeting, 2001) adopted by the Comité International des Poids et Mesures at its 91th Meeting as Recommendation 1 (CI-2002).

[8] Gläser M., Hyperfine Components of Iodine for Optical Frequency Standards *PTB-Bericht*, 1987, **PTB-Opt-25**.

[9] Bertinetto F., Cordiale P., Fontana S., Picotto G. B., Recent Progresses in He-Ne Lasers Stabilized to $^{127}I_2$, *IEEE Trans. Instrum. Meas.*, 1985, **IM-34**, 256-261.

[10] Bennett S. J., Cérez P., Hyperfine Structure in Iodine at the 612-nm and 640-nm Helium-Neon Laser Wavelengths, *Opt. Commun.*, 1978, **25**, 343-347.

[11] Kegung D., Xu J., Li C.-Y., Liu H.-T., Hyperfine Structure in Iodine Observed at the 612 nm and 640 nm ^{3}He-^{22}Ne Laser Wavelengths, *Acta Metrologica Sinica*, 1982, **3**, 322-323.

[12] Zhao K., Li H., Hyperfine structure of iodine at 640 nm ^{3}He-^{22}Ne laser wavelength and identification, *Acta Metrologica Sinica*, 1983, **3**, 673-677.

[13] Zhao K.-G., Li H., Analysis and Calculation of Hyperfine Lines of Iodine Molecule, *Acta Metrologica Sinica*, 1985, **6**, 83-88.0-2c.

[14] Gläser M., Identification of Hyperfine Structure Components of the Iodine Molecule at 640 nm Wavelength, *Opt. Commun.*, 1985, **54**, 335-342.

[15] Zhao K.-G., Li C.-Y., Li H., Xu J., Way H., Investigations of $^{127}I_2$-Stabilized He - Ne Laser at 640 nm, *Acta Metrologica Sinica*, 1987, **8**, 88-95.