MEP 2003

IODINE ($\lambda \approx 612$ nm)

Absorbing molecule $^{127}I_2$, a_7 component, R(47) 9-2 transition (1)

1. CIPM recommended values

The values $f = 489\ 880\ 354.9$ MHz
$\lambda = 611\ 970\ 770.0$ fm
with a relative standard uncertainty of 3×10^{-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 ± 2) °C (2).

2. Source data

Adopted value	$f = 489\ 880\ 354.93\ (15)$ MHz	$u_c/y = 3.0 \times 10^{-10}$
	for which:	
	$\lambda = 611\ 970\ 769.97\ (18)$ fm	$u_c/y = 3.0 \times 10^{-10}$

calculated from

f / kHz	u_c/y	source data
489 880 354 979	1×10^{-10}	2.1
489 880 354 728	2.1×10^{-10}	2.2
489 880 355 026	8.3×10^{-11}	2.3
489 880 355 062	3.0×10^{-10}	2.4
489 880 358 850	8.5×10^{-11}	2.5
Unweighted mean:	$f = 489\ 880\ 354\ 929$ kHz	

Other available values having relative uncertainties higher than 3.0×10^{-10} have not been used. The relative standard uncertainty calculated from the dispersion of the six values is 2.8×10^{-10}, which the CCL preferred to round up to 3.0×10^{-10}.

Source data

2.1 Reference [1] gives $f_{a7} / f_i = 1.034\ 349\ 072\ 43$ $u_c/y = 1 \times 10^{-10}$.

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 $f_{a7} = 489\ 880\ 354\ 979$ kHz $u_c/y = 1 \times 10^{-10}$.

---

(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.

2.2 Reference [2] gives $f_{a7} / f_i = 1.034\ 349\ 071\ 90$ $u_c/y = 2.1 \times 10^{-10}$.

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 $f_{a7} = 489\ 880\ 354\ 728$ kHz $u_c/y = 2.1 \times 10^{-10}$.

2.3 Bönsch et al. [3] give $\lambda_{b15}/\lambda_i = 0.966\ 791\ 921\ 43$ $u_c/y = 8 \times 10^{-11}$.

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 $u_c/y = 2.2 \times 10^{-11}$,

one calculates $f_{b15} = 489\ 880\ 194\ 708$ kHz $u_c/y = 8.3 \times 10^{-11}$.

From the measured value (see Table 40 below) $f_{b15} - f_{a7} = -160\ 318$ kHz $u_c = 3$ kHz

one calculates $f_{a7} = 489\ 880\ 355\ 026$ kHz $u_c/y = 8.3 \times 10^{-11}$.

2.4 Vitushkin et al. [4] give $\lambda_d / \lambda_{a7} = 1.034\ 348\ 712$ $u_c/y = 3 \times 10^{-10}$.

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

$f_d = 473\ 612\ 379\ 828$ kHz $u_c/y = 2.2 \times 10^{-11}$,

one calculates $f_{a7} = 489\ 880\ 355\ 062$ kHz $u_c/y = 3.0 \times 10^{-10}$.

2.5 Himbert et al. [5] give $f_{a13} = 489\ 880\ 604\ 541$ kHz $u_c = 88$ kHz.

This value is a result of the frequency ratio f_{a13}/f_e, to which the recommended value adopted by the CIPM in 1983 [6, 7] was applied, i.e. $f_i = 473\ 612\ 214.8$ MHz. (see iodine at $\lambda \approx 633$ nm and frequency differences listed in corresponding Table 1)

$f_e - f_i = 152\ 255$ kHz $u_c = 5$ kHz,

one obtains $f_e = 473\ 612\ 367\ 055$ kHz,

and hence $f_{a13} / f_e = 1.034\ 349\ 267$ $u_c/y = 8 \times 10^{-11}$.

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

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

one calculates $f_{a13} = 489\ 880\ 604\ 450$ $u_c/y = 8.3 \times 10^{-11}$.

Knowing the frequency difference (see Table 1) $f_{a7} - f_{a13} = -249\ 600$ kHz $u_c = 10$ kHz,

one obtains $f_{a7} = 489\ 880\ 354\ 850$ $u_c/y = 8.5 \times 10^{-11}$.

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**, 184-187 and Metrologia, 2003, **40**, 127-128.

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

$\lambda \approx 612$ nm $^{127}I_2$ R(47) 9-2

a_n	x	$[f(a_n) - f(a_7)]$/MHz	u_c/MHz	a_n	x	$[f(a_n) - f(a_7)]$/MHz	u_c/MHz
a_1	u	–357.16	0.02	a_{12}	j	219.602	0.006
a_2	t	–333.97	0.01	a_{13}	i	249.60	0.01
a_3	s	–312.46	0.02	a_{14}	h	284.30	0.01
a_4	r	–86.168	0.007	a_{15}	g	358.37	0.03
a_5	q	–47.274	0.004	a_{16}	f	384.66	0.01
a_6	p	–36.773	0.003	a_{17}	e	403.76	0.02
a_7	o	0	—	a_{18}	d	429.99	0.02
a_8	n	81.452	0.003	a_{19}	c	527.16	0.02
a_9	m	99.103	0.003	a_{20}	b	539.22	0.02
a_{10}	l	107.463	0.005	a_{21}	a	555.09	0.02
a_{11}	k	119.045	0.006				

Frequency referenced to a_7, R(47) 9-2, $^{127}I_2$: $f = 489\,880\,354.9$ MHz [8]

Ref. [9, 10-14]

Table 2

$\lambda \approx 612$ nm $^{127}I_2$ P(48) 11-3

b_n	$[f(b_n) - f(a_7)]$/MHz	u_c/MHz	b_n	$[f(b_n) - f(a_7)]$/MHz	u_c/MHz
b_1	–1034.75	0.07	b_9	–579.91	0.01
b_2	–755.86	0.05	b_{10}	–452.163	0.005
b_3	–748.28	0.03	b_{11}	–316.6	0.4
b_4	–738.35	0.04	b_{12}	–315.8	0.4
b_5	–731.396	0.006	b_{13}	–297.42	0.03
b_6	–616.01	0.03	b_{14}	–294.72	0.03
b_7	–602.42	0.03	b_{15}	–160.318	0.003
b_8	–593.98	0.01			

Frequency referenced to a_7, R(47) 9-2, $^{127}I_2$: $f = 489\,880\,354.9$ MHz [8]

Ref. [9, 10, 12-15]

Table 3

$\lambda \approx 612$ nm $^{127}I_2$ R(48) 15-5

c_n	$[f(c_n) - f(a_7)]$/MHz	u_c/MHz	c_n	$[f(c_n) - f(a_7)]$/MHz	u_c/MHz
c_1	–513.83	0.03	c_5	–209.96	0.03
c_2	–237.40	0.03	c_6	–97.74	0.03
c_3	–228.08	0.03	c_8	–73.92	0.03
c_4	–218.78	0.03	c_9	–59.30	0.03

Frequency referenced to a_7, R(47) 9-2, $^{127}I_2$: $f = 489\,880\,354.9$ MHz [8]

Ref. [10]

Table 4

$\lambda \approx 612$ nm $^{129}I_2$ P(110) 10-2

a_n	x	$[f(a_n) - f(a_7\{^{127}I_2\})]$/MHz	u_c/MHz	a_n	x	$[f(a_n) - f(a_7\{^{127}I_2\})]$/MHz	u_c/MHz
a_1	b′	–376.29	0.05	a_{15}	n	1.61	0.20
a_2	a′	–244.76	0.10	a_{16}	m	10.63	0.15
a_3	z	–230.79	0.20	a_{17}	l	15.82	0.20
a_4	y	–229.40	0.20	a_{18}	k	25.32	0.10
a_5	x	–216.10	0.05	a_{19}	j	49.44	0.15
a_6	w	–149.37	0.10	a_{20}	i	54.66	0.20
a_7	v	–134.68	0.10	a_{21}	h	69.02	0.10
a_8	u	–130.98	0.10	a_{22}	g	74.47	0.15
a_9	t	–116.67	0.05	a_{23}	f	110.60	0.10
a_{10}	s	–96.26	0.20	a_{24}	e	153.09	0.20
a_{11}	r	–90.70	0.20	a_{25}	d	154.70	0.20
a_{12}	q	–84.12	0.20	a_{26}	c	163.98	0.20
a_{13}	p	–77.79	0.20	a_{27}	b	166.22	0.20
a_{14}	o	–72.70	0.20	a_{28}	a	208.29	0.10

Frequency referenced to a_7, R(47) 9-2, $^{127}I_2$: $f = 489\ 880\ 354.9$ MHz [8]

Ref. [16–18]

Table 5

$\lambda \approx 612$ nm $^{129}I_2$ R(113) 14-4

b_n	x	$[f(b_n) - f(a_7\{^{127}I_2\})]$/MHz	u_c/MHz	b_n	x	$[f(b_n) - f(a_7\{^{127}I_2\})]$/MHz	u_c/MHz
b_{19}	r	–410.4	0.3	b_{28}	i	–289.4	0.5
b_{20}	q	–390.0	0.3	b_{29}	h	–273.1	0.3
b_{21}	p	–383.9	0.5	b_{30}	g	–255.7	0.5
b_{22}	o	–362.8	0.3	b_{31}	f	–247	5
b_{23}	n	–352.9	0.3	b_{32}	e	–237	5
b_{24}	m	–346.4	0.3	b_{33}	d	–223	5
b_{25}	l	–330.0	0.3	b_{34}	c	–198.6	0.3
b_{26}	k	–324.9	0.3	b_{35}	b	–193.1	0.3
b_{27}	j	–304.7	0.3	b_{36}	a	–187.0	0.3

Frequency referenced to a_7, R(47) 9-2, $^{127}I_2$: $f = 489\ 880\ 354.9$ MHz [8]

Ref. [17, 18]

4. References

[1] CCDM/82-34, NPL, Laser wavelength Measurements, May 1982.

[2] CCDM/82-19a, BIPM, Réponse au questionnaire CCDM/82-3.

[3] Bönsch G., Gläser M., Spieweck F., Bestimmung der Wellenlängenverhältnisse von drei $^{127}I_2$-stabilisierten Lasern bei 515 nm, 612 nm und 633 nm, *PTB Jahresbericht*, 1986, 161.

[4] Vitushkin L. F., Zakharenko Yu. G., Yvanov I. V., Leibengardt G. I., Shur V. L., Measurements of Wavelength of High-Stabilized He-Ne/I_2 Laser at 612 nm, *Opt. Spectr.*, 1990, **68**, 705-707.

[5] Himbert M., Bouchareine P., Hachour A., Juncar P., Millerioux Y., Razet A., Measurements of Optical Wavelength Ratios Using a Compensated Field Sigmameter, *IEEE Trans. Instrum. Meas.*, 1991, **40**, 200-203.

[6] *BIPM, Proc. Verb. Com. Int. Poids et Mesures*, 1983, **51**.

[7] Documents Concerning the New Definition of the Metre, *Metrologia*, 1984, **19**, 163-178.

[8] 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).

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

[10] Razet A., Millerioux Y., Juncar P., Hyperfine Structure of the 47R(9-2), 48P(11-3) and 48R(15-5) Lines of $^{127}I_2$ at 612 nm as Secondary Standards of Optical Frequency, *Metrologia*, 1991, **28**, 309-316.

[11] Cérez P., Bennett S. J., Helium-neon laser stabilized by saturated absorption in iodine at 612 nm, *Appl. Opt.*,1979, **18**, 1079-1083.

[12] Gläser M., Properties of a He-Ne Laser at $\lambda \approx 612$ nm, Stabilized by Means of an External Iodine Absorption Cell, *IEEE Trans. Instrum. Meas.*, 1987, **IM-36**, 604-608.

[13] 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.

[14] Robertsson L., Iodine-stabilized He-Ne lasers at $\lambda = 612$ nm using internal and external cells, *BIPM Proc.-Verb. Com. Int. Poids et Mesures*, 1992, **60**, 160-162.

[15] Bertinetto F., Cordiale P., Picotto G. B., Chartier J.-M., Felder R., Gläser M., Comparison Between the $^{127}I_2$ Stabilized He-Ne Lasers at 633 nm and at 612 nm of the BIPM and the IMGC, *IEEE Trans. Instrum. Meas.*, 1983, **IM-32**, 72-76.

[16] Kegung D., Gläser M., Helmcke J., I_2 Stabilized He-Ne Lasers at 612 nm, *IEEE Trans. Instrum. Meas.*, 1980, **IM-29**, 354-357.

[17] Ciddor P. E., Brown N., Hyperfine Spectra in Iodine-129 at 612 nm, *Opt. Commun.*, 1980, **34**, 53-56.

[18] Gläser M., Kegung D., Foth H. J., Hyperfine Structure and Fluorescence Analysis of Enriched $^{129}I_2$ at the 612 nm Wavelength of the He-Ne Laser, *Opt. Commun.*, 1981, **38**, 119-123.