Results from the regional APMP.L-K11 comparison hosted by NIM in November 2004.

J．QIAN, X. Y. LIU, C. Y. SHI, Z. Y. LIU, H. P. TAN, S. CAI,

NIM, 18, Bei san huan donglu, Bejing, China

T. K. Chan,

SCL, *36/F, Immigration Tower, 7 Gloucester Road, Wanchai, Hong Kong.*

Y-P. Lan,

CMS/ITRI， *321 Kuang Fu Road, Sec. 2, Hsinchu, Taiwan, Chinese Taipei*

J. Ishikawa,

AIST/NMIJ， *Tsukuba Central 3,1-1, Umezono-1, Tsukuba-shi, Ibaraki 305-8563, japan*

A. M Dahlan,

NML-SIRIM， *SIRIM Berhad,Lot PT 4803,Bandar Baru Salak, Tinggi 43900 Sepang, Selangor, Malaysia*

E. Howick,

MSLNZ，*Industrial Research, Gracefield Road, PO Box 31-310, Gracefield, Lower Hutt, New Zealand*

M. Louise,

CSIR-NML， *Dimensional Laboratory CSIR-NML, South Africa*

A. Tonmueanwai,

NIMT， *3/5 Moo 3, Klong 5, Klong Luang, Pathumthani, 12120 Thailand*

Abstract

Lasers from 8 national metrological institutes (NMIs) were brought to the NIM in Bejing in November 2004 for the APMP.L-K11 regional comparison. The frequency difference between the f components of the R(127) 11-5 transition was measured for these lasers following the Protocol for BIPM.L-K11. The absolute frequencies of three of the participating lasers have been measured with the comb technique either before or after the comparison. The absolute frequencies for the other lasers were then deduced using the three lasers as a link. The results of these measurements are compiled in the present paper. The comparison reports, as communicated by each participant, are included as Appendices.

Introduction

The BIPM.L-K10 (K10) key comparison was initiated in 1993 to provide a basis for demonstrating equivalence of national realizations of wavelength-standards used for the realization of the definition of the SI *metre* according to method (c) in the *Mise en Pratique* (MeP) [1]. The K10 took only the 633 nm He-Ne standards into consideration. Such a comparison seemed of particular importance since these lasers were most often used in the whole field of dimensional metrology to provide traceability to the *metre*. The measurand of the comparison was the difference between lasers of the *average* frequency of the components d, e, f, and g in the R(127) 11-5 line as obtained by matrix measurements [2]. The frequency of the reference laser BIPM-4 was used as the key comparison reference value.
During the last few years, the situation for realization of the *metre* has changed due to the introduction of new techniques for absolute frequency measurements. This has opened up the method (b) in the MeP for the realization of wavelength standards traceable to the *second*. The practical consequence of this development is that, at least, two methods are today being used for the realization of the *metre*, and several wavelengths, important for dimensional metrology applications, can now demonstrate traceability with relative ease. Considering these circumstances, the 11^{th} CCL meeting, held in October 2003, decided to close the K10 comparison and initiate a new key comparison named BIPM.L-K11 (K11) [3].

The K11 concerns those wavelengths present in the list of recommended radiations in the MeP, which are used in the field of dimensional metrology. Typical examples would be the 633 nm, 612 nm, 543 nm and 532 nm iodine-stabilized standards but others may also become appropriate to include. The CCL also proposed to include absolute frequency measurements, matrix measurements as well as direct frequency heterodyne measurements in which only the difference in frequency between two standards is measured. Besides being a key comparison, K11 will not only provide reduced uncertainties for the frequencies listed in the MeP but also extend the ways in which participants can claim traceability to the definition of the *metre* to comply with the MRA and the related ISO/IEC 17025 [4]. In connection to the ongoing BIPM.L-K11 comparison a RMO comparison APMP.L-K11 was organized in NIM in Beijing in October 2004. 8 national or regional labs took part in the measurement campaign. These institutes are listed in Table 1.

Measurements

The measurements carried out are compatible with the protocol of K11. For these laser standards, all working at 633 nm, the f-component of the 127(R) 11-5 transition in iodine was measured being the reference component recommended in the MeP.

Country	NMI	Contact person	Standard
China	NIM	J. Oian	NIM-D1 &NIM-C4
Hong Kong, PRC	SCL	T. K. Chan	SCL-1
Chinese Taipei	CMS/ITRI	Y-P. Lan	NML-04
Japan	AIST/NMIJ	J. Ishikawa	NRLM 03
Malaysia	NML-SIRIM	A. M Dahlan	NML-SIRIM-1
New Zealand	MSLNZ	E. Howick	MSL-1
South Africa	CSIR-NML	M. Louise	CSIR-4
Thailand	NIMT	A. Tonmueanwai	NIMT-1

Table 1. Participants

The measurements were made in two groups according to the division given in table 2. In this table are also the most important working parameters compiled.

Standard	Power[1] [μW]	I_2 temp.[2] [°C]	Modulation width[3] [MHz]	Appendix
NIM-D1	92 (2)	14.87(0.1)	6.0(0.1)	1
NML-SIRIM-1	93(2)	15.0(0.1)	6.0(0.1)	6
CSIR-4	92.2(2.0)	15.0(0.1)	6.0(0.25)	8
SCL-1	79(2)	15.0(0.1)	6.0(0.25)	3
NIMT-1	52(2)	15.0(0.1)	6.0(0.1)	9
NIM-D1	92 (2)	14.87(0.1)	6.0(0.1)	1
NRLM-3	60(1)	15.00 (0.03)	6.03(0.03)	5
NIM-C4	75(2)	15(0.1)	6.0(0.1)	2
MSL-1	85.0(2.1)	15.0(0.1)	6.0(0.1)	7
NML-04	92(2)	15.0(0.1)	6.0(0.1)	4

Table 2. Working parameter values for the standards with estimated standard uncertainty in parenthesis as given in the measurement reports included in Appendices 1-9.

The m3 method described in the Protocol for BIPM.L-K11 was used. An Acousto- Optic Modulator (AOM) employed to shift the frequency of one of two lasers, both locked to the f component of the 127(R) 11-5 transition. The frequency of the AOM was controlled by a signal generator (ROHDE & SCHWARZ 300.1000.53). The frequency was measured by a frequency counter and then used to correct the beat frequency.

Data reduction and results

The results of the difference frequency measurements are given in table 3. The frequencies given in column 3 are referenced to the mean value of all measurement results in each group.

Standard	N	Δf [kHz]	$s(f)$ [kHz]
NIM-D1	10	-7.82	1.05
NML-SIRIM-1	8	5.75	0.31
CSIR-4	10	-6.45	2.18
SCL-1	10	2.16	0.50
NIMT-1	10	6.39	0.91
NIM-D1	14	-7.68	0.83
NRLM-3	10	2.65	0.27
NIM-C4	10	3.50	1.44
MSL-1	8	1.38	0.26
NML-4	10	5.79	1.14

Table 3. The frequency difference measurement results. N – number of measurements, Δf – frequency difference, and $s(f)$ – the statistical fluctuations of the measured frequency difference given as one standard deviation of the mean.

[1] Output power when laser stabilised to the f component.
[2] Cold-finger temperature.
[3] Peak to peak modulation width.

Link to Absolute values.

3 of the lasers participating in the difference frequency measurements have been measured absolutely either before or after the comparison. These lasers are listed in table 4 together with their absolute frequency and estimated uncertainty. The frequency values are given relative to the frequency 473 612 353 000 kHz.

Standard	f [kHz]	$u_1(f)$ [kHz]	$u_2(f)$ [kHz]	$u_c(f)$ [kHz]	Power CW]	I_2 temp. [°C]	Modulation width [MHz]
NIM-D1[4]	**595.1**	0.1	1.9	**1.9**	92(2)	14.87(0.1)	6.0(0.1)
CSIR-4[5]	**599.0**	0.5	3.3	**3.3**	92.2(2.0)	15.0(0.1)	6.0(0.25)
NRLM-03[6]	**607.2**	0.7	5.3	**5.3**	60(0.9)	15.00(0.03)	6.03(0.03)

Table 4. Absolute frequency measurements on lasers that participated in the comparison that have been measured absolutely either before or after.

u_1 represents the uncertainty in the frequency determination while u_2 originates from the uncertainty in the parameter settings of the lasers. A weighted least squares minimisation approach is used to take both the absolute (table 4) and the difference measurements (table 3) into account and is exposed to a Birge ratio equal to a one condition. The weights are based on the uncertainties for each one of the three standards, column 5 table 4, combined with the uncertainties of each difference measurement, table 3 column 4. The resulting absolute frequency values of the lasers during APMP.L-K11 are given in table 5 for the three lasers, calculated at the working parameters given in table 2. Information about the frequency of these lasers is thus based on the direct absolute frequency measurements and the difference frequency measurements in Beijing.

Standard	f [kHz]	$u(f)$ [kHz]
NIM-D1	**595.5**	**0.6**
CSIR-4	**598.2**	**0.9**
NRLM-03	**606.5**	**1.3**

Table 5. Weighted average frequencies for the three absolutely measured lasers with their uncertainty.

Based on these values we can calculate the absolute frequencies of the remaining lasers using the difference frequency measurements, see table 6. The *uncertainty* of the determined frequency is composed of two parts, one from the frequency determination, u_1, and one from the uncertainty in the settings of the working parameters, u_2. The latter, the uncertainties related to the standard itself are to be estimated by each operator and are detailed in Appendices 1-9 and given in column 4 in table 6.

[4] Reported in CI-2004 under BIPM.L-K11 in the KCDB at www.BIPM.org
[5] Reported in CII-2004 under BIPM.L-K11 in the KCDB at www.BIPM.org
[6] Measurement made as part of the BIPM.L-K11. Report under preparation

Standard	f [kHz]	$u_1(f)$ [kHz]	$u_2(f)$ [kHz]	$u_c(f)$ [kHz]
NIM-D1	**595.5**	**0.7**	**1.9**	**2.0**
NRLM-03	**606.5**	**1.5**	**5.1**	**5.3**
CSIR-04	**598.2**	**1.0**	**3.3**	**3.4**
NML-SIRIM-1	**609.0**	**0.7**	**1.9**	**2.0**
SCL-1	**605.5**	**0.8**	**3.4**	**3.5**
NIMT-1	**609.7**	**1.1**	**2.0**	**2.3**
NIM-C4	**606.7**	**1.6**	**2.1**	**2.6**
MSL-1	**604.5**	**0.7**	**2.1**	**2.2**
NML-4	**608.9**	**1.3**	**1.9**	**2.3**

Table 6. The absolute frequencies of the 6 lasers only participating in the frequency difference measurements.

Here u_1 is taken as the root-sum-square (RSS) of the uncertainty of the NIM-D1 laser as obtained by the least squares adjustment within the group of the NIM-D1, the CSIR-4 and the NRLM-03 laser and the uncertainty of the difference frequency measurements as given in table 3.

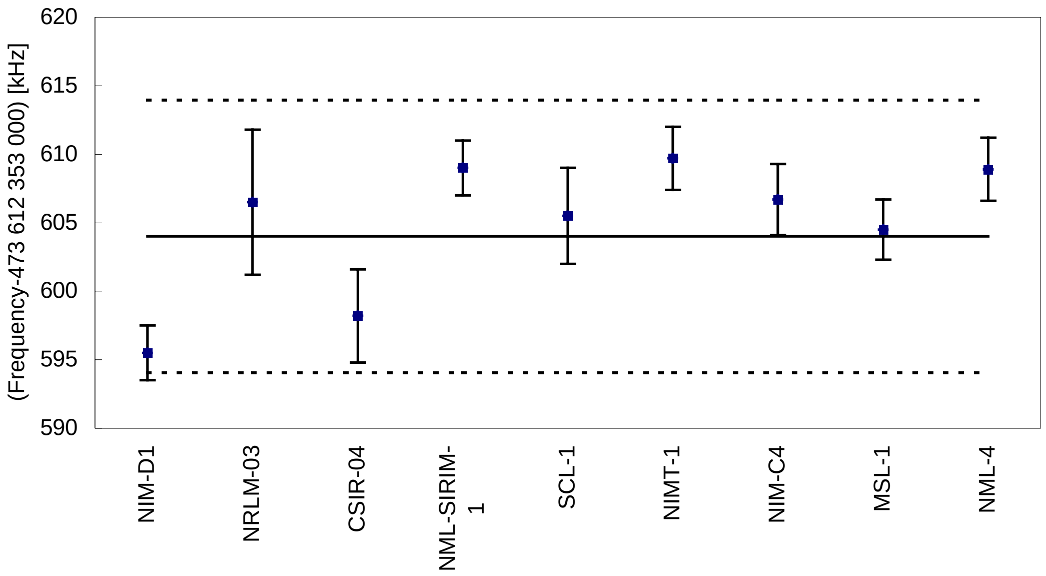

Figure 1. The final frequency values.

The final frequency values are depicted in figure 1 as given in column 2 in Table 6 for each laser with individual uncertainties given at a confidence level of 68% assuming a large number of degrees of freedom. The solid line represents the present recommended value for the 633 nm laser standard and the dotted lines its uncertainty [1].

Conclusion

Frequency measurements have been carried out on 9 primary wavelength standards. Good agreement between the lasers and also with the frequency value recommended in the MeP was found. The uncertainty of the laser frequencies is estimated to be of few kHz, which is considerably smaller than the uncertainty obtained by using the method (c) in the MeP, i.e. 10 kHz. The average frequency of the group is 604.9 kHz with a standard deviation of 4.9 kHz. This frequency value is in excellent agreement with the value recommended in the MeP giving further support to the validity of this recommendation.

References

[1] T. J. Quinn, "Practical realization of the definition of the metre, including recommended radiations of other optical frequency standards (2001)", *Metrologia*, vol. 40, pp. 103-133, 2003.

[2] Bayer-Melms F., Chartier J.-M., Helmcke J., Wallard A. J., *PTB-Bericht*, 1977, **PTP-ME 17**, 139-146.

[3] Proceedings from the 11th CCL meeting.

[4] International Organization of Standardization, ISO/IEC 17025, Geneva Switzerland.

<u>Appendix 1, NIM, NIM-D1.</u>
<u>Comparison report, APMP.L-K11.</u>

Add new lines in the tables as needed and modify names of sensitivity coefficients and operational parameters as relevant for the standard being compared.

D1. Host laboratory[7]

Lab. Name	*NIM*
Contact person	J. Qian
Address	NIM, 18, Bei san huan donglu, Bejing, China
Tel.	
e-mail	*qianjin@nim.ac.cn*

D2. Measurements[5]

Quantity compared	*The frequency of the output beam of the laser when this is stabilized to the f component of the 11-5, R(127) transition in* $^{127}I_2$ *contained in a glass tube.*
Period	*25/11 – 5/12 2004*
Describe measurements	*The frequency difference between lasers was measured using the heterodyn technique following the technical protocol for the method BIPM.L-K11 m3. A AOM was used to shift the frequency of one of the lasers to access direct frequency difference between same component.*
References and/or other documentation	

[7] To be filled in by the host laboratory

Detailed description of standard[8]

Give description of the standard, one page for each participating standard (here examples for 633 nm)

D3. Laboratory

Lab. Name	*NIM*
Operators	*LIU Xiuying*
Address	*18, BEISANDONGLU BEIJING, China*
Tel.	
e-mail	*qianjin@nim.ac.cn*

D4. Standard

Designation of laser standard	*NIM D1*
Standard last compared	*1997 in Beijing*
Modification on standard since	
Spectroscopy	*Intracavity saturation spectroscopy*
Modulation technique	*3rd harmonic*
Modulation frequency /kHz	*2.77*
Modulation width or index /	*6 MHz p.p Nominal*
Laser cavity length /cm	*33*
Mirror curvature R1 (tube side) /cm	*60*
Mirror curvature R2 (cell side) /cm	*120*
Mirror transmission T1 (tube side) / %	*0.8*
Mirror transmission T2 (cell side) / %	*0.3*
Output mirror, 1 or 2.	
Designation of iodine cell	*PTB 1987*
Cell length /Brewster /flat windows/origin	*10 cm / Brewster/PTB*

[8] To be filled in by the participating NMI.

D5. Description of measurements[5,6]

Give a brief description of the measurements made and the techniques used.

- Method: *The method described in the Protocol for BIPM.L-K11 method m3 was used. An Acousto-Optic Modulator (AOM) was used to shift the frequency of one of two lasers, both locked to the f component of the 127(R) 11-5 transition. The frequency of the AOM was controlled by a signal generator (ROHDE & SCHWARZ 300.1000.53). The frequency was measured by a frequency counter and then used to correct the beat frequency.*

D6. Sensitivity coefficients[6]

Parameter	**Sens. Coeff. Value**	**Uncertainty**	**Unit**	**Comments.**
Modulation width	*-11.1*	*1.1*	kHz/MHz	
Iodine pressure	*-7.9*	*0.4*	kHz/Pa	
Power (output)	*-0.155*	*0.028*	kHz/µW	
Cell wall temperature	*0.20*	*0.06*	kHz/ °C	*This parameter is not well known so the value 0.2 is proposed as default value . The uncertainty of 0.06 results from a tolerance of ± 0.1*

The list of parameters that influence the frequency of the standard might vary for different wavelengths and system. Some of the ones relevant for a typical 633 nm standard is included in the list.

D7. Measurements and parameter settings[6]

Parameter settings (different parameters can be important for different kind of standards)

Parameter	**value**	**Uncertainty**	**Unit**	**Comments**
Output power	*92*	*2*	µW	
Modulation width	*6.0*	*0.1*	MHz	
Iodine cell cold finger temperature	*14.87*	*0.1*	°C	
Cell wall temperature	*26*	*0.6*	°C	*Uncertainty from 2°C with a rectangular distribution*

Compilation of measurement and results

Two types of uncertainty can be identified in the measurements, the one that comes from the measurement of the standard, u_1, and the one that results from the uncertainty in the parameter setting for the standard, u_2.

D8. u_1.

Typical sources of uncertainty in the measurements could be[5.6]

source	**Value**	**unit**	**comments**
See in report			

D9. u_2.

Typical contributions to the uncertainty from the parameter settings[6]

Source	**Value**	**unit**	**comments**
Laser power	*0.32*	kHz	
Modulation width	*1.12*	kHz	
Iodine cold finger temperature	*1.26*	kHz	
Cell wall temp	*0.12*	kHz	
Electronic offset	*0.5*	kHz	
Alignment	*0.58*	kHz	
Total	*1.88*	kHz	

D10. Results:

See report

Appendix 2, NIM, NIM-C4.
Comparison report, APMP.L-K11.

Add new lines in the tables as needed and modify names of sensitivity coefficients and operational parameters as relevant for the standard being compared.

D1. Host laboratory[9]

Lab. Name	*NIM*
Contact person	*J. Qian*
Address	*NIM, 18, Bei san huan donglu, Bejing, China*
Tel.	
e-mail	*qianjin@nim.ac.cn*

D2. Measurements[5]

Quantity compared	*The frequency of the output beam of the laser when this is stabilized to the f component of the 11-5, R(127) transition in* $^{127}I_2$ *contained in a glass tube.*
Period	*25/11 – 5/12 2004*
Describe measurements	*The frequency difference between lasers was measured using the heterodyn technique following the technical protocol for the method BIPM.L-K11 m3. A AOM was used to shift the frequency of one of the lasers to access direct frequency difference between same component.*
References and/or other documentation	

[9] To be filled in by the host laboratory

<u>Detailed description of standard</u>[10]

Give description of the standard, one page for each participating standard (here examples for 633 nm)

D3. Laboratory

Lab. Name	*NIM*
Operators	*LIU Xiuying*
Address	*18, BEISANDONGLU BEIJING, China*
Tel.	
e-mail	*qianjin@nim.ac.cn*

D4. Standard

Designation of laser standard	*NIM C4 / Tube and laser from NIM*
Standard last compared	
Modification on standard since	
Spectroscopy	*Intracavity saturation spectroscopy*
Modulation technique	*3rd harmonic*
Modulation frequency /kHz	*1.04*
Modulation width or index /	*6 MHz p.p Nominal*
Laser cavity length /cm	*33*
Mirror curvature R1 (tube side) /cm	*60*
Mirror curvature R2 (cell side) /cm	*120*
Mirror transmission T1 (tube side) / %	*0.8*
Mirror transmission T2 (cell side) / %	*0.3*
Output mirror, 1 or 2.	
Designation of iodine cell	*NIM 1997*
Cell length /Brewster /flat windows/origin	*10 cm / Brewster/NIM*

[10] To be filled in by the participating NMI.

D5. Description of measurements[5,6]

Give a brief description of the measurements made and the techniques used.

- Method: *The method described in the Protocol for BIPM.L-K11 method m3 was used. An Acousto-Optic Modulator (AOM) was used to shift the frequency of one of two lasers, both locked to the f component of the 127(R) 11-5 transition. The frequency of the AOM was controlled by a signal generator (ROHDE & SCHWARZ 300.1000.53). The frequency was measured by a frequency counter and then used to correct the beat frequency.*

D6. Sensitivity coefficients[6]

Parameter	Sens. Coeff. Value	Uncertainty	Unit	Comments.
Modulation width	*-12.3*	*1.1*	kHz/MHz	
Iodine pressure	*-10.4*	*1*	kHz/Pa	
Power (output)	*-0.17*	*0.028*	kHz/μW	
Cell wall temperature	*0.5*		kHz/ °C	

The list of parameters that influence the frequency of the standard might vary for different wavelengths and system. Some of the ones relevant for a typical 633 nm standard is included in the list.

D7. Measurements and parameter settings[6]

Parameter settings (different parameters can be important for different kind of standards)

Parameter	value	Uncertainty	Unit	Comments
Output power	*75*	*2*	μW	
Modulation width	*6.0*	*0.1*	MHz	
Iodine cell cold finger temperature	*15*	*0.1*	°C	
Cell wall temperature	*26*	*0.6*	°C	*Uncertainty from 2°C with a rectangular distribution*

Compilation of measurement and results

Two types of uncertainty can be identified in the measurements, the one that comes from the measurement of the standard, u_1, and the one that results from the uncertainty in the parameter setting for the standard, u_2.

D8. u_1.

Typical sources of uncertainty in the measurements could be[5.6]

source	Value	unit	comments

See in report

D9. u_2.

Typical contributions to the uncertainty from the parameter settings[6]

Source	**Value**	**unit**	**comments**
Laser power	*0.34*	kHz	
Modulation width	*1.23*	kHz	
Iodine cold finger temperature	*1.67*	kHz	
Cell wall temp	*0.29*	kHz	
Electronic offset	*0*	kHz	
Alignment	*0*	kHz	
Total	*2.13*	kHz	

D10. Results:

See report

Appendix 3, SCL, SCL-1.
Comparison report, APMP.L-K11.

Add new lines in the tables as needed and modify names of sensitivity coefficients and operational parameters as relevant for the standard being compared.

D1. Host laboratory[11]

Lab. Name	*NIM*
Contact person	*J. Qian*
Address	*NIM, 18, Bei san huan donglu, Bejing, China*
Tel.	
e-mail	*qianjin@nim.ac.cn*

D2. Measurements[5]

Quantity compared	*The frequency of the output beam of the laser when this is stabilized to the f component of the 11-5, R(127) transition in* $^{127}I_2$ *contained in a glass tube.*
Period	*25/11 – 5/12 2004*
Describe measurements	*The frequency difference between lasers was measured using the heterodyne technique following the technical protocol for the method BIPM.L-K11 m3. A AOM was used to shift the frequency of one of the lasers to access direct frequency difference between same component.*
References and/or other documentation	

[11] To be filled in by the host laboratory

<u>Detailed description of standard[12]</u>

Give description of the standard, one page for each participating standard (here examples for 633 nm)

D3. Laboratory

Lab. Name	*The Government of the HKSAR Standards and Calibration Laboratory*
Operators	*T.K.Chan*
Address	*36/F, Immigration Tower, 7 Gloucester Road, Wanchai, Hong Kong.*
Tel.	*28294835*
e-mail	*tkchan@itc.gov.hk*

D4. Standard

Designation of laser standard	*SCL-1, REO, LTRP-0051-BW*
Standard last compared	*August 1998*
Modification on standard since	*Nil*
Spectroscopy	*Saturation spectroscopy*
Modulation technique	*Frequency modulation*
Modulation frequency /kHz	*1.172*
Modulation width or index /	*6 MHz peak-to-peak*
Laser cavity length /cm	*26*
Mirror curvature R1 (tube side) /cm	*30*
Mirror curvature R2 (cell side) /cm	$\propto$ *(plane mirror)*
Mirror transmission T1 (tube side) / %	*0.7*
Mirror transmission T2 (cell side) / %	*0.5*
Output mirror, 1 or 2.	*1*
Designation of iodine cell	*BIPM 235*
Cell length /Brewster /flat windows/origin	*10 cm, Brewster, BIPM*

[12] To be filled in by the participating NMI.

D5. Description of measurements[5,6]

Give a brief description of the measurements made and the techniques used.

- Method: *The method described in the Protocol for BIPM.L-K11 method m3 was used. An Acousto-Optic Modulator (AOM) was used to shift the frequency of one of two lasers, both locked to the f component of the 127(R) 11-5 transition. The frequency of the AOM was controlled by a signal generator (ROHDE & SCHWARZ 300.1000.53). The frequency was measured by a frequency counter and then used to correct the beat frequency. 24* **°C,** *24-48 %RH*

D6. Sensitivity coefficients[6]

Parameter	**Sens. Coeff. Value**	**Uncertainty**	**Unit**	**Comments.**
Modulation width	*-9.3*	*1*	kHz/MHz	
Iodine pressure	*-7.6*	*1*	kHz/Pa	
Power (output)	*-0.1*	*0.03*	kHz/μW	
Cell wall temperature	*1*	*0*	kHz/ °C	

The list of parameters that influence the frequency of the standard might vary for different wavelengths and system. Some of the ones relevant for a typical 633 nm standard is included in the list.

D7. Measurements and parameter settings[6]

Parameter settings (different parameters can be important for different kind of standards)

Parameter	**value**	**Uncertainty**	**Unit**	**Comments**
Output power	*79*	*2*	μW	
Modulation width	*6.0*	*0.25*	MHz	
Iodine cell cold finger temperature	*15.0*	*0.1*	°C	
Cell wall temperature	*25*	*0.3*	°C	*Uncertainty from 1*°C *with a rectangular distribution*

Compilation of measurement and results

Two types of uncertainty can be identified in the measurements, the one that comes from the measurement of the standard, u_1, and the one that results from the uncertainty in the parameter setting for the standard, u_2.

D8. u_1.

Typical sources of uncertainty in the measurements could be[5.6]

source	**Value**	**unit**	**comments**

See in report

D9. u_2.

Typical contributions to the uncertainty from the parameter settings[6]

Source	**Value**	**unit**	**comments**
Laser power	*0.21*	kHz	
Modulation width	*2.34*	kHz	
Iodine cold finger temperature	*1.23*	kHz	
Cell wall temp	*0.29*	kHz	
Electronic offset	*2.0*	kHz	
Alignment	*0.58*	kHz	
Total	*3.38*	kHz	

D10. Results:

See report

Appendix 4, CMS/ITRI, NML-04.
Comparison report, APMP.L-K11.

Add new lines in the tables as needed and modify names of sensitivity coefficients and operational parameters as relevant for the standard being compared.

D1. Host laboratory[13]

Lab. Name	*NIM*
Contact person	*J. Qian*
Address	*NIM, 18, Bei san huan donglu, Bejing, China*
Tel.	
e-mail	*qianjin@nim.ac.cn*

D2. Measurements[5]

Quantity compared	*The frequency of the output beam of the laser when this is stabilized to the f component of the 11-5, R(127) transition in* $^{127}I_2$ *contained in a glass tube.*
Period	*25/11 – 5/12 2004*
Describe measurements	*The frequency difference between lasers was measured using the heterodyne technique following the technical protocol for the method BIPM.L-K11 m3. A AOM was used to shift the frequency of one of the lasers to access direct frequency difference between same component.*
References and/or other documentation	

[13] To be filled in by the host laboratory

Detailed description of standard[14]

Give description of the standard, one page for each participating standard (here examples for 633 nm)

D3. Laboratory

Lab. Name	*CMS/ITRI*
Operators	*Yu-Ping Lan*
Address	*321 Kuang Fu Road, Sec. 2, Hsinchu, Taiwan, Chinese Taipei*
Tel.	
e-mail	*Yu-PingLan@itri.org.tw*

D4. Standard

Designation of laser standard	*NML-04 / REO,LTRP-0051-BW*
Standard last compared	
Modification on standard since	
Spectroscopy	*Saturation spectroscopy*
Modulation technique	*Frequency modulation*
Modulation frequency /kHz	*8.3*
Modulation width or index /	*6 MHz peak-to-peak*
Laser cavity length /cm	*26*
Mirror curvature R1 (tube side) /cm	*30*
Mirror curvature R2 (cell side) /cm	*∝ (plane mirror)*
Mirror transmission T1 (tube side) / %	*0.7*
Mirror transmission T2 (cell side) / %	*0.25*
Output mirror, 1 or 2.	
Designation of iodine cell	*BIPM 359*
Cell length /Brewster /flat windows/origin	*10 cm, Brewster, BIPM*

[14] To be filled in by the participating NMI.

D5. Description of measurements[5,6]

Give a brief description of the measurements made and the techniques used.

- Method: *The method described in the Protocol for BIPM.L-K11 method m3 was used. An Acousto-Optic Modulator (AOM) was used to shift the frequency of one of two lasers, both locked to the f component of the 127(R) 11-5 transition. The frequency of the AOM was controlled by a signal generator (ROHDE & SCHWARZ 300.1000.53). The frequency was measured by a frequency counter and then used to correct the beat frequency.*

D6. Sensitivity coefficients[6]

Parameter	Sens. Coeff. Value	Uncertainty	Unit	Comments.
Modulation width	*-9.3*	*1.1*	kHz/MHz	
Iodine pressure	*-8.3*	*1.0*	kHz/Pa	
Power (output)	*-0.02*	*0.04*	kHz/μW	
Cell wall temperature	*1*	*0*	kHz/ °C	

The list of parameters that influence the frequency of the standard might vary for different wavelengths and system. Some of the ones relevant for a typical 633 nm standard is included in the list.

D7. Measurements and parameter settings[6]

Parameter settings (different parameters can be important for different kind of standards)

Parameter	value	Uncertainty	Unit	Comments
Output power	*92*	*2*	μW	
Modulation width	*6.0*	*0.1*	MHz	
Iodine cell cold finger temperature	*15.0*	*0.1*	°C	
Cell wall temperature	*25*	*0.6*	°C	*Uncertainty from 2°C with a rectangular distribution*

Compilation of measurement and results

Two types of uncertainty can be identified in the measurements, the one that comes from the measurement of the standard, u_1, and the one that results from the uncertainty in the parameter setting for the standard, u_2.

D8. u_1.

Typical sources of uncertainty in the measurements could be[5.6]

source	Value	unit	comments

See in report

D9. u_2.

Typical contributions to the uncertainty from the parameter settings[6]

Source	**Value**	**unit**	**comments**
Laser power	*0.09*	kHz	
Modulation width	*0.94*	kHz	
Iodine cold finger temperature	*1.34*	kHz	
Cell wall temp	*0.58*	kHz	
Electronic offset	*0.5*	kHz	
Alignment	*0.58*	kHz	
Total	*1.89*	kHz	

D10. Results:

See report

Appendix 5, AIST/NMIJ, NRLM 03.
Comparison report, APMP.L-K11.

Add new lines in the tables as needed and modify names of sensitivity coefficients and operational parameters as relevant for the standard being compared.

D1. Host laboratory[15]

Lab. Name	*NIM*
Contact person	*J. Qian*
Address	*NIM, 18, Bei san huan donglu, Bejing, China*
Tel.	
e-mail	*qianjin@nim.ac.cn*

D2. Measurements[5]

Quantity compared	*The frequency of the output beam of the laser when this is stabilized to the f component of the 11-5, R(127) transition in* $^{127}I_2$ *contained in a glass tube.*
Period	*25/11 – 5/12 2004*
Describe measurements	*The frequency difference between lasers was measured using the heterodyne technique following the technical protocol for the method BIPM.L-K11 m3. A AOM was used to shift the frequency of one of the lasers to access direct frequency difference between same component.*
References and/or other documentation	

[15] To be filled in by the host laboratory

<u>Detailed description of standard[16]</u>

Give description of the standard, one page for each participating standard (here examples for 633 nm)

D3. Laboratory

Lab. Name	*AIST/NMIJ*
Operators	*Jun Ishikawa*
Address	*Tsukuba Central 3,1-1, Umezono-1, Tsukuba-shi, Ibaraki 305-8563, japan*
Tel.	
e-mail	*j.ishikawa@aist.go.jp*

D4. Standard

Designation of laser standard	*NRLM Open Laser (03)/ Neoark, HNC-92SI*
Standard last compared	*10/11/04 abs. freq. meas. in NMIJ*
Modification on standard since	
Spectroscopy	*Saturation spectroscopy*
Modulation technique	*Frequency modulation*
Modulation frequency /kHz	*3*
Modulation width or index /	*6 MHz peak-to-peak*
Laser cavity length /cm	*25*
Mirror curvature R1 (tube side) /cm	$\propto$ *(plane mirror)*
Mirror curvature R2 (cell side) /cm	*60*
Mirror transmission T1 (tube side) / %	*0.5*
Mirror transmission T2 (cell side) / %	*0.5*
Output mirror, 1 or 2.	
Designation of iodine cell	*AIST, 040925-1, 25/9/2004*
Cell length /Brewster /flat windows/origin	*7 cm, Brewster, AIST*

[16] To be filled in by the participating NMI.

D5. Description of measurements[5,6]

Give a brief description of the measurements made and the techniques used.

- Method: *The method described in the Protocol for BIPM.L-K11 method m3 was used. An Acousto-Optic Modulator (AOM) was used to shift the frequency of one of two lasers, both locked to the f component of the 127(R) 11-5 transition. The frequency of the AOM was controlled by a signal generator (ROHDE & SCHWARZ 300.1000.53). The frequency was measured by a frequency counter and then used to correct the beat frequency.*

D6. Sensitivity coefficients[6]

Parameter	Sens. Coeff. Value	Uncertainty	Unit	Comments.
Modulation width	*-9.8*	*1.1*	kHz/MHz	
Iodine pressure	*-8.6*	*1.0*	kHz/Pa	
Power (output)	*0.13*	*0.028*	kHz/μW	
Cell wall temperature	*0.5*		kHz/ °C	

The list of parameters that influence the frequency of the standard might vary for different wavelengths and system. Some of the ones relevant for a typical 633 nm standard is included in the list.

D7. Measurements and parameter settings[6]

Parameter settings (different parameters can be important for different kind of standards)

Parameter	**value**	**Uncertainty**	**Unit**	**Comments**
Output power	*60*	*0.9*	μW	
Modulation width	*6.03*	*0.03*	MHz	
Iodine cell cold finger temperature	*15.0*	*0.03*	°C	
Cell wall temperature	*24*	*0.3*	°C	*Uncertainty from 1°C with a rectangular distribution*

Compilation of measurement and results

Two types of uncertainty can be identified in the measurements, the one that comes from the measurement of the standard, u_1, and the one that results from the uncertainty in the parameter setting for the standard, u_2.

D8. u_1.
Typical sources of uncertainty in the measurements could be[5.6]

source	**Value**	**unit**	**comments**
See in report			

D9. u_2.
Typical contributions to the uncertainty from the parameter settings[6]

Source	**Value**	**unit**	**comments**
Laser power	*0.12*	kHz	
Modulation width	*0.28*	kHz	
Iodine cold finger temperature	*0.4*	kHz	
Cell wall temp	*0.14*	kHz	
Electronic offset	*0.5*	kHz	
Alignment	*5.0*	kHz	
Total	*5.05*	kHz	

D10. Results:
See report

Appendix 6, NML-SIRIM, NML-SIRIM-1.
Comparison report, APMP.L-K11.

Add new lines in the tables as needed and modify names of sensitivity coefficients and operational parameters as relevant for the standard being compared.

D1. Host laboratory[17]

Lab. Name	*NIM*
Contact person	*J. Qian*
Address	*NIM, 18, Bei san huan donglu, Bejing, China*
Tel.	
e-mail	*qianjin@nim.ac.cn*

D2. Measurements[5]

Quantity compared	*The frequency of the output beam of the laser when this is stabilized to the f component of the 11-5, R(127) transition in* $^{127}I_2$ *contained in a glass tube.*
Period	*25/11 – 5/12 2004*
Describe measurements	*The frequency difference between lasers was measured using the heterodyne technique following the technical protocol for the method BIPM.L-K11 m3. A AOM was used to shift the frequency of one of the lasers to access direct frequency difference between same component.*
References and/or other documentation	

[17] To be filled in by the host laboratory

Detailed description of standard[18]

Give description of the standard, one page for each participating standard (here examples for 633 nm)

D3. Laboratory

Lab. Name	*NML-SIRIM*
Operators	*Ahmad M Dahlan*
Address	*SIRIM Berhad,Lot PT 4803,Bandar Baru Salak, Tinggi 43900 Sepang, Selangor, Malaysia*
Tel.	
e-mail	*ahmadmd@sirim.my*

D4. Standard

Designation of laser standard	*NML-SIRIM-1, REO,LTRP-0051-BW*
Standard last compared	*24/11/2000 at the BIPM*
Modification on standard since	
Spectroscopy	*Saturation spectroscopy*
Modulation technique	*Frequency modulation*
Modulation frequency /kHz	*8.33*
Modulation width or index /	*6 MHz peak-to-peak*
Laser cavity length /cm	*26*
Mirror curvature R1 (tube side) /cm	*30*
Mirror curvature R2 (cell side) /cm	$\propto$ *(plane mirror)*
Mirror transmission T1 (tube side) / %	*0.7*
Mirror transmission T2 (cell side) / %	*0.25*
Output mirror, 1 or 2.	
Designation of iodine cell	*BIPM #336S*
Cell length /Brewster /flat windows/origin	*10 cm, Brewster, BIPM*

[18] To be filled in by the participating NMI.

D5. Description of measurements[5,6]

Give a brief description of the measurements made and the techniques used.

- Method: *The method described in the Protocol for BIPM.L-K11 method m3 was used. An Acousto-Optic Modulator (AOM) was used to shift the frequency of one of two lasers, both locked to the f component of the 127(R) 11-5 transition. The frequency of the AOM was controlled by a signal generator (ROHDE & SCHWARZ 300.1000.53). The frequency was measured by a frequency counter and then used to correct the beat frequency.*

D6. Sensitivity coefficients[6]

Parameter	Sens. Coeff. Value	Uncertainty	Unit	Comments.
Modulation width	*-5.5*	*1.1*	kHz/MHz	
Iodine pressure	*-8.3*	*1.0*	kHz/Pa	
Power (output)	*-0.02*	*0.04*	kHz/μW	
Cell wall temperature	*0.2*	*0.06*	kHz/ °C	

The list of parameters that influence the frequency of the standard might vary for different wavelengths and system. Some of the ones relevant for a typical 633 nm standard is included in the list.

D7. Measurements and parameter settings[6]

Parameter settings (different parameters can be important for different kind of standards)

Parameter	value	Uncertainty	Unit	Comments
Output power	*93*	*2*	μW	
Modulation width	*6.0*	*0.1*	MHz	
Iodine cell cold finger temperature	*15.0*	*0.1*	°C	
Cell wall temperature	*28*	*0.6*	°C	*Uncertainty from 2°C with a rectangular distribution*

Compilation of measurement and results

Two types of uncertainty can be identified in the measurements, the one that comes from the measurement of the standard, u_1, and the one that results from the uncertainty in the parameter setting for the standard, u_2.

D8. u_1.

Typical sources of uncertainty in the measurements could be[5.6]

source	Value	unit	comments
See in report			

D9. u_2.

Typical contributions to the uncertainty from the parameter settings[6]

Source	Value	unit	comments
Laser power	*0.09*	kHz	
Modulation width	*0.56*	kHz	
Iodine cold finger temperature	*1.34*	kHz	
Cell wall temp	*0.12*	kHz	
Electronic offset	*1.0*	kHz	
Alignment	*0.58*	kHz	
Total	*1.86*	kHz	

D10. Results:

See report

Appendix 7, MSLNZ,MSL-1.
Comparison report, APMP.L-K11.

Add new lines in the tables as needed and modify names of sensitivity coefficients and operational parameters as relevant for the standard being compared.

D1. Host laboratory[19]

Lab. Name	*NIM*
Contact person	*J. Qian*
Address	*NIM, 18, Bei san huan donglu, Bejing, China*
Tel.	
e-mail	*qianjin@nim.ac.cn*

D2. Measurements[5]

Quantity compared	*The frequency of the output beam of the laser when this is stabilized to the f component of the 11-5, R(127) transition in* $^{127}I_2$ *contained in a glass tube.*
Period	*25/11 – 5/12 2004*
Describe measurements	*The frequency difference between lasers was measured using the heterodyne technique following the technical protocol for the method BIPM.L-K11 m3. A AOM was used to shift the frequency of one of the lasers to access direct frequency difference between same component.*
References and/or other documentation	

[19] To be filled in by the host laboratory

Detailed description of standard[20]

Give description of the standard, one page for each participating standard (here examples for 633 nm)

D3. Laboratory

Lab. Name	*MSLNZ*
Operators	*Eleanor Howick*
Address	*Industrial Research, Gracefield Road, PO Box 31-310, Gracefield, Lower Hutt, New Zealand*
Tel.	
e-mail	*E.Howick@irl.cri.nz*

D4. Standard

Designation of laser standard	*MSL-1, REO, LTRP-0051-BW / SN 153*
Standard last compared	*I2 Cell in BIPM 7 14/8/1996*
Modification on standard since	
Spectroscopy	*Saturation spectroscopy*
Modulation technique	*Frequency modulation*
Modulation frequency /kHz	*8.33kHz*
Modulation width or index /	*6 MHz peak-to-peak*
Laser cavity length /cm	*26*
Mirror curvature R1 (tube side) /cm	*30*
Mirror curvature R2 (cell side) /cm	*∝ (plane mirror)*
Mirror transmission T1 (tube side) / %	*0.7*
Mirror transmission T2 (cell side) / %	*0.4*
Output mirror, 1 or 2.	
Designation of iodine cell	*BIPM #236 S*
Cell length /Brewster /flat windows/origin	*10 cm, Brewster, BIPM*

[20] To be filled in by the participating NMI.

D5. Description of measurements[5,6]

Give a brief description of the measurements made and the techniques used.

- Method: *The method described in the Protocol for BIPM.L-K11 method m3 was used. An Acousto-Optic Modulator (AOM) was used to shift the frequency of one of two lasers, both locked to the f component of the 127(R) 11-5 transition. The frequency of the AOM was controlled by a signal generator (ROHDE & SCHWARZ 300.1000.53). The frequency was measured by a frequency counter and then used to correct the beat frequency.*

D6. Sensitivity coefficients[6]

Parameter	**Sens. Coeff. Value**	**Uncertainty**	**Unit**	**Comments.**
Modulation width	*-9.5*	*2.6*	kHz/MHz	
Iodine pressure	*-8.3*	*0.2*	kHz/Pa	
Power (output)	*-0.063*	*0.04*	kHz/µW	
Cell wall temperature	*0.5*	*1*	kHz/ °C	

The list of parameters that influence the frequency of the standard might vary for different wavelengths and system. Some of the ones relevant for a typical 633 nm standard is included in the list.

D7. Measurements and parameter settings[6]

Parameter settings (different parameters can be important for different kind of standards)

Parameter	**value**	**Uncertainty**	**Unit**	**Comments**
Output power	*85*	*2.1*	µW	
Modulation width	*6.0*	*0.1*	MHz	
Iodine cell cold finger temperature	*15.0*	*0.1*	°C	*Uncertainty from 0.4*°C *with a rectangular distribution*
Cell wall temperature	*27.6*	*1.0*	°C	*Uncertainty from 1*°C *with a rectangular distribution*

Compilation of measurement and results

Two types of uncertainty can be identified in the measurements, the one that comes from the measurement of the standard, u_1, and the one that results from the uncertainty in the parameter setting for the standard, u_2.

D8. u_1.

Typical sources of uncertainty in the measurements could be[5.6]

source	**Value**	**unit**	**comments**
See in report			

D9. u_2.

Typical contributions to the uncertainty from the parameter settings[6]

Source	**Value**	**unit**	**comments**
Laser power	*0.16*	kHz	
Modulation width	*0.98*	kHz	
Iodine cold finger temperature	*1.51*	kHz	
Cell wall temp	*0.58*	kHz	
Electronic offset	*0.58*	kHz	
Alignment	*0.58*	kHz	
Total	*2.07*	kHz	

D10. Results:

See report

Appendix 8, CSIR-NML,CSIR-4.
Comparison report, APMP.L-K11.

Add new lines in the tables as needed and modify names of sensitivity coefficients and operational parameters as relevant for the standard being compared.

D1. Host laboratory[21]

Lab. Name	*NIM*
Contact person	*J. Qian*
Address	*NIM, 18, Bei san huan donglu, Bejing, China*
Tel.	
e-mail	*qianjin@nim.ac.cn*

D2. Measurements[5]

Quantity compared	*The frequency of the output beam of the laser when this is stabilized to the f component of the 11-5, R(127) transition in* $^{127}I_2$ *contained in a glass tube.*
Period	*25/11 – 5/12 2004*
Describe measurements	*The frequency difference between lasers was measured using the heterodyne technique following the technical protocol for the method BIPM.L-K11 m3. A AOM was used to shift the frequency of one of the lasers to access direct frequency difference between same component.*
References and/or other documentation	

[21] To be filled in by the host laboratory

Detailed description of standard[22]

Give description of the standard, one page for each participating standard (here examples for 633 nm)

D3. Laboratory

Lab. Name	*CSIR-NML*
Operators	*Louise Mostert*
Address	*Dimensional Laboratory CSIR-NML, South Africa*
Tel.	
e-mail	*LMostert@csir.co.za*

D4. Standard

Designation of laser standard	*CSIR-4, Micro G Solutions tube*
Standard last compared	*May-04*
Modification on standard since	
Spectroscopy	*Saturation spectroscopy*
Modulation technique	*Frequency modulation*
Modulation frequency /kHz	*1.024*
Modulation width or index /	*6 MHz peak-to-peak*
Laser cavity length /cm	*32.5*
Mirror curvature R1 (tube side) /cm	*60*
Mirror curvature R2 (cell side) /cm	*∝ (plane mirror)*
Mirror transmission T1 (tube side) / %	*0.9*
Mirror transmission T2 (cell side) / %	*0.9*
Output mirror, 1 or 2.	
Designation of iodine cell	*BIPM 119*
Cell length /Brewster /flat windows/origin	*7.5 cm, Brewster, BIPM*

[22] To be filled in by the participating NMI.

D5. Description of measurements[5,6]

Give a brief description of the measurements made and the techniques used.

- Method: *The method described in the Protocol for BIPM.L-K11 method m3 was used. An Acousto-Optic Modulator (AOM) was used to shift the frequency of one of two lasers, both locked to the f component of the 127(R) 11-5 transition. The frequency of the AOM was controlled by a signal generator (ROHDE & SCHWARZ 300.1000.53). The frequency was measured by a frequency counter and then used to correct the beat frequency.*

D6. Sensitivity coefficients[6]

Parameter	Sens. Coeff. Value	Uncertainty	Unit	Comments.
Modulation width	*-9.9*	*0.6*	kHz/MHz	
Iodine pressure	*-7.4*	*1.1*	kHz/Pa	
Power (output)	*-0.23*	*0.06*	kHz/μW	
Cell wall temperature	*0.2*	*0.06*	kHz/ °C	

The list of parameters that influence the frequency of the standard might vary for different wavelengths and system. Some of the ones relevant for a typical 633 nm standard is included in the list.

D7. Measurements and parameter settings[6]

Parameter settings (different parameters can be important for different kind of standards)

Parameter	value	Uncertainty	Unit	Comments
Output power	*92.2*	*2*	μW	
Modulation width	*6.0*	*0.25*	MHz	
Iodine cell cold finger temperature	*15.0*	*0.1*	°C	
Cell wall temperature	*22*	*1.2*	°C	

Compilation of measurement and results

Two types of uncertainty can be identified in the measurements, the one that comes from the measurement of the standard, u_1, and the one that results from the uncertainty in the parameter setting for the standard, u_2.

D8. u_1.

Typical sources of uncertainty in the measurements could be[5.6]

source	Value	unit	comments
See in report			

D9. u_2.

Typical contributions to the uncertainty from the parameter settings[6]

Source	Value	unit	comments
Laser power	*0.48*	kHz	
Modulation width	*2.48*	kHz	
Iodine cold finger temperature	*1.2*	kHz	
Cell wall temp	*0.25*	kHz	
Electronic offset	*1.0*	kHz	
Alignment	*1.44*	kHz	
Total	*3.31*	kHz	

D10. Results:

See report

Appendix 9, NIMT, NIMT-1.
Comparison report, APMP.L-K11.

Add new lines in the tables as needed and modify names of sensitivity coefficients and operational parameters as relevant for the standard being compared.

D1. Host laboratory[23]

Lab. Name	*NIM*
Contact person	*J. Qian*
Address	*NIM, 18, Bei san huan donglu, Bejing, China*
Tel.	
e-mail	*qianjin@nim.ac.cn*

D2. Measurements[5]

Quantity compared	*The frequency of the output beam of the laser when this is stabilized to the f component of the 11-5, R(127) transition in* $^{127}I_2$ *contained in a glass tube.*
Period	*25/11 – 5/12 2004*
Describe measurements	*The frequency difference between lasers was measured using the heterodyne technique following the technical protocol for the method BIPM.L-K11 m3. A AOM was used to shift the frequency of one of the lasers to access direct frequency difference between same component.*
References and/or other documentation	

[23] To be filled in by the host laboratory

Detailed description of standard[24]

Give description of the standard, one page for each participating standard (here examples for 633 nm)

D3. Laboratory

Lab. Name	*NIMT-1*
Operators	*Anusorn Tonmueanwai*
Address	*3/5 Moo 3, Klong 5, Klong Luang, Pathumthani, 12120 Thailand*
Tel.	
e-mail	*anusorn@nimt.or.th*

D4. Standard

Designation of laser standard	*NIMT-1,Neoark / AIST Model: NEO-92SI-NF-H / SN 02023*
Standard last compared	
Modification on standard since	
Spectroscopy	*Saturation spectroscopy*
Modulation technique	*Frequency modulation*
Modulation frequency /kHz	*3*
Modulation width or index /	*6 MHz peak-to-peak*
Laser cavity length /cm	*25*
Mirror curvature R1 (tube side) /cm	$\propto$ *(plane mirror)*
Mirror curvature R2 (cell side) /cm	*60*
Mirror transmission T1 (tube side) / %	*0.5*
Mirror transmission T2 (cell side) / %	*0.5*
Output mirror, 1 or 2.	
Designation of iodine cell	*051,November 22, 2002*
Cell length /Brewster /flat windows/origin	*6.5 cm, Brewster,*

[24] To be filled in by the participating NMI.

D5. Description of measurements[5,6]

Give a brief description of the measurements made and the techniques used.

- Method: *The method described in the Protocol for BIPM.L-K11 method m3 was used. An Acousto-Optic Modulator (AOM) was used to shift the frequency of one of two lasers, both locked to the f component of the 127(R) 11-5 transition. The frequency of the AOM was controlled by a signal generator (ROHDE & SCHWARZ 300.1000.53). The frequency was measured by a frequency counter and then used to correct the beat frequency.*

D6. Sensitivity coefficients[6]

Parameter	**Sens. Coeff. Value**	**Uncertainty**	**Unit**	**Comments.**
Modulation width	*-11.4*	*1.2*	kHz/MHz	
Iodine pressure	*-8.2*	*1*	kHz/Pa	
Power (output)	*-0.22*	*0.05*	kHz/μW	
Cell wall temperature	*1*	*0.5*	kHz/ °C	

The list of parameters that influence the frequency of the standard might vary for different wavelengths and system. Some of the ones relevant for a typical 633 nm standard is included in the list.

D7. Measurements and parameter settings[6]

Parameter settings (different parameters can be important for different kind of standards)

Parameter	**value**	**Uncertainty**	**Unit**	**Comments**
Output power	*52*	*2*	μW	
Modulation width	*6.0*	*0.1*	MHz	
Iodine cell cold finger temperature	*15.0*	*0.1*	°C	
Cell wall temperature	*25*	*0.7*	°C	*Uncertainty from 2.5*°C *with a rectangular distribution*

Compilation of measurement and results

Two types of uncertainty can be identified in the measurements, the one that comes from the measurement of the standard, u_1, and the one that results from the uncertainty in the parameter setting for the standard, u_2.

D8. u_1.

Typical sources of uncertainty in the measurements could be[5.6]

source	**Value**	**unit**	**comments**
See in report			

D9. u_2.

Typical contributions to the uncertainty from the parameter settings[6]

Source	**Value**	**unit**	**comments**
Laser power	*0.45*	kHz	
Modulation width	*1.15*	kHz	
Iodine cold finger temperature	*1.32*	kHz	
Cell wall temp	*0.81*	kHz	
Electronic offset	*0.0*	kHz	
Alignment	*0.0*	kHz	
Total	*1.98*	kHz	

D10. Results:

See report