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Standard Test Method for Determination of the Red Dye Concentration and Estimation of the ASTM Color of Diesel Fuel and Heating Oil Using a Portable Visible Spectrophotometer¹

This standard is issued under the fixed designation D6756; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope*

1.1 This test method covers the determination of the red dye concentration of diesel fuel and heating oil and the estimation of the ASTM color of undyed and red-dyed diesel fuel and heating oil. The test method is appropriate for use with diesel fuel and heating oil of Grades 1 and 2 described in Specifications D396, D975, D2880 and D3699. Red dye concentrations are determined at levels equivalent to 0.1 to 20 mg/L of Solvent Red 26 in samples with ASTM colors ranging from 0.5 to 5. The ASTM color of the base fuel of red-dyed samples with concentration levels equivalent to 0.1 to 20 mg/L of Solvent Red 26 is estimated for the ASTM color range from 0.5 to 5. The ASTM color of undyed samples is estimated over the ASTM color range of 0.5 to 5.

1.2 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 ASTM Standards:²

D396 Specification for Fuel Oils

D975 Specification for Diesel Fuel Oils

D1500 Test Method for ASTM Color of Petroleum Products (ASTM Color Scale)

D2880 Specification for Gas Turbine Fuel Oils

D3699 Specification for Kerosine

D4052 Test Method for Density, Relative Density, and API Gravity of Liquids by Digital Density Meter

D4057 Practice for Manual Sampling of Petroleum and Petroleum Products

D4177 Practice for Automatic Sampling of Petroleum and Petroleum Products

D6045 Test Method for Color of Petroleum Products by the Automatic Tristimulus Method [6e60e6/astm-d6756-10](#)

[D6708 Practice for Statistical Assessment and Improvement of Expected Agreement Between Two Test Methods that Purport to Measure the Same Property of a Material](#)

E203 Test Method for Water Using Volumetric Karl Fischer Titration

E1655 Practices for Infrared Multivariate Quantitative Analysis

E2056 Practice for Qualifying Spectrometers and Spectrophotometers for Use in Multivariate Analyses, Calibrated Using Surrogate Mixtures

3. Terminology

3.1 Definitions:

3.1.1 *ASTM color, n*—the name of an empirical scale of expressing the color of a petroleum liquid darker than Saybolt color based on a scale of 0.5 (lightest) to 8 Dil (darkest) and determined by Test Method D1500.

3.1.2 *surrogate calibration, n*—a multivariate calibration that is developed using a calibration set which consists of mixtures with pre-specified and reproducible compositions that contain substantially fewer chemical components than the samples which will ultimately be analyzed. **E2056**

¹ This test method is under the jurisdiction of ASTM Committee D02 on Petroleum Products and Lubricants and is the direct responsibility of Subcommittee D02.05 on Properties of Fuels, Petroleum Coke and Carbon Material.

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² For referenced ASTM standards, visit the ASTM website, [www.astm.org](#), or contact ASTM Customer Service at [service@astm.org](#). For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

*A Summary of Changes section appears at the end of this standard.

3.1.3 *surrogate method, n*—a standard test method that is based on a surrogate calibration.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *red dye, n*—substance that, when added to fuel, absorbs green light and imparts a red color to the product. For this test method, red dyes are:

3.2.1.1 *product dyes, n*—alkyl derivatives of azobenzene-4-azo-2-naphthol (methyl derivatives of Color Index No. 26105) which are more soluble in diesel fuel.

3.2.1.2 *solvent red 26, n*—an azobenzene-4-azo-2-naphthol dye of a specific chemical structure that is used to gage the amount of red dye present in a given sample.

4. Summary of Test Method

4.1 A sample is introduced into the liquid specimen cell. The cell is placed into the light path of the apparatus. A beam of visible light is imaged through the sample onto a detector, and the detector response is determined. Wavelengths of the spectrum, which correlate highly with the red dye concentration and the ASTM color, are selected for analysis using selective bandpass filters. A multivariate mathematical model converts the absorption values from the filters to the red dye concentration and the estimated ASTM color.

5. Significance and Use

5.1 In the United States, high sulfur content (defined by the United States Environmental Protection Agency (USEPA)) middle distillate products and diesel fuel used for off-road purposes, other than aviation turbine fuel, are required by government agencies to contain red dye. The dye concentration required to be present in high sulfur and off-road diesel products is regulated by the United States Environmental Protection Agency and the United States Internal Revenue Service, respectively.

5.2 Some fuels that are readily exchanged in the market have a color specification. The color of the base fuel is masked by the presence of the red dye. This test method provides a means of estimating the base color of Number 1 and Number 2 diesel fuel and heating oil in the presence of red dye.

5.3 The test method provides a means to indicate conformance to contractual and legal requirements.

6. Interferences

6.1 The presence of colorants other than the hydrocarbons typical of Number 1 and 2 diesel fuel and heating oils, or the presence of red dye other than the specified types, can interfere with the accurate determination of the red dye concentration reported as Solvent Red 26 equivalent or the base fuel ASTM color.

7. Apparatus

7.1 *Filter Spectrophotometer*, is equipped with specimen chamber, visible wavelength source, four 10 ± 2 nm (full width at half transmission maximum) bandpass wavelength discriminating filters having center wavelengths at 450 ± 2 nm, 520 ± 2 nm, 650 ± 2 nm, and 700 ± 2 nm. The bandpass filters are used in conjunction with the visible wavelength source to produce light in the blue, green, red, and far-red regions of the electromagnetic spectrum. A detector converts the transmitted light to an electronic signal that is processed by an A-D converter and a microprocessor.^{3,4}

7.2 *Specimen Cell*, constructed of polymethacrylate or clear optical glass having a path length of approximately 1 cm. If more than one cell is used for calibration, qualification and sample measurement, the path length of the cells must be matched to ± 0.001 cm.

8. Sampling

8.1 Samples shall be taken in accordance with Practice D4057 or D4177.

8.2 Precautions must be taken to shield the samples from light prior to analysis.

9. Calibration and Standardization of the Apparatus

9.1 The instrument is calibrated according to the procedure described in Annex A2.

NOTE 1—The DT100C³ instruments are calibrated at the factory by the vendor.

9.2 The instrument is qualified according to the procedure described in Annex A3.

NOTE 2—The DT100C instruments are qualified at the factory by the vendor.

9.2.1 If the qualification procedure is performed by the vendor, then the user shall perform a quality control check according to the procedure described in Section 10.

³ DT100C instruments used to develop this precision statement are available from PetroSpec, Inc., 530 Main St., Acton, MA 01720.

⁴ The sole source of supply of the apparatus known to the committee at this time is PetroSpec, Inc. If you are aware of alternative suppliers, please provide this information to ASTM International Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee, which you may attend.

10. Quality Control Check

10.1 To confirm the performance of the instrument, periodically measure the red dye concentration and the ASTM color of three control samples using the procedure outlined in Section 11. The quality control check standards should be analyzed at least once a week or before the sample analysis if the instrument is used less frequently than weekly or if the instrument is moved to a different laboratory or field location.

NOTE 3—Quality control samples are available from DT100C⁵.

10.1.1 A standard of known dye concentration and ASTM color is made according to the information in A1.4. The set of quality control samples shall have a low, medium, and high red dye concentration (0 to 14 ± 2 mg/L) and a low, medium, and high ASTM color (0 to 5 ASTM color units).

10.1.2 The standards are stable for at least one year when stored in the dark in tightly sealed bottles.

10.2 If the red dye concentration determined for one of the quality control samples differs from the known value by more than 1.0 mg/L or if the estimated ASTM color for one of the quality control samples differs from the known value by more than 0.5 units, then the measurement system is out-of-control and cannot be used to determine the red dye concentration or used to estimate the ASTM color until the cause of the out-of-control behavior is corrected.

10.3 If correction of out-of-control behavior requires repair to the instrument or recalibration of the instrument, the qualification of instrument performance described in Annex A3 shall be performed before the system is used to measure red dye concentration or used to estimate ASTM color.

11. Procedure

11.1 Prepare the filter spectrophotometer for operation in accordance with the manufacturer's instructions.

11.2 Equilibrate the sample to between 20 and 25°C.

~~11.3 Fill~~ 11.3 Without filtering the sample (see 13.6), fill a clean, dry specimen cell. The external optical surfaces ~~must~~ shall be clean. If not, wipe clean and dry with a piece of lint-free paper (for example, lens paper).

11.4 Insert the specimen cell into the cell chamber of the instrument.

11.5 Record the Solvent Red 26 equivalent concentration and the estimated ASTM color.

12. Report

12.1 Report the red dye concentration to the nearest 0.1 mg/L as Solvent Red 26 equivalent dye.

NOTE 4—The number of milligrams per litre of Solvent Red 26 equivalents measured by the DT100C instrument is labeled as *ppm* on the display. The ppm unit reported by the DT100C instrument is equivalent to mg/L.

12.2 Report the estimated ASTM color value as: *estimated ASTM color using ASTM D6756*. Report the result to the nearest 0.1 color value.

12.2.1 The reported estimated ASTM color value can be converted to a value that mimics the reporting convention of the Test Method D1500. For estimated ASTM color values that are *x.0* or *x.5*, the estimated value is reported unchanged. For estimated color values between *x.1* and *x.4*, round up the value to the nearest *x.5* and place an *L* before the result. For estimated color values between *x.6* and *x.9*, round up the value to the nearest whole number and place an *L* before the result. If the estimated color value is greater than 8.0, report the estimated result as >8.

13. Precision and Bias

~~13.1 Interlaboratory tests of the procedure were carried out using sixteen samples covering the red dye concentration range equivalent to 0 to 16 mg/L of Solvent Red 26 equivalents and covering the range of ASTM color from 0.5 to 3.0. Seven laboratories participated in the interlaboratory tests. The precision of this procedure as determined by the statistical examination of the interlaboratory test results is as follows:⁵~~

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13.1.1 *Repeatability*—The difference between successive test results obtained with the same apparatus under constant operating conditions on identical samples would in the long run, in normal and correct operation of the test method, exceed the following value in only one case in twenty:

$$r = 0.22 \text{ mg/L}$$

for Solvent Red 26 equivalent dye concentrations between 0.1 and 20.0 mg/L, and

$$r = 0.085 \text{ ASTM color units}$$

⁵ Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR:D02-1521.

for samples in the ASTM color range of 0 to 5.

13.1.2 *Reproducibility*—The difference between two single and independent results obtained from different instruments on identical samples, would in the long run, in normal and correct operation of the test method, exceed the following value in only one case in twenty:

$$R = 0.86 \text{ mg/L}$$

for Solvent Red 26 equivalent dye concentrations between 0.1 and 20.0 mg/L, and

$$R = 0.20 \text{ ASTM color units}$$

for samples in the ASTM color range of 0 to 5.

13.2 *Bias*—Since there is no accepted reference material suitable for determining the bias for the procedure in this test method, bias has not been determined.

13.3 *Relative Bias (Dye Concentration)*—Some relative bias,⁵ among certain samples, was observed when the Solvent Red 26 concentration results were compared to the expected Solvent Red 26 concentrations. The bias between the theoretical and measured Solvent Red 26 concentration is observed with the test samples that were made using Solvent Red 164, the chemical used to commercially dye diesel fuel. The observed bias does appear to be of a systematic nature and is not known to be related to the accuracy of this test method, since the Solvent Red 26 equivalency of the Solvent Red 164 used in sample preparation has not been determined, only estimated.

13.4 *Relative Bias (ASTM Color)*—Relative bias,⁵ for one sample, was observed when the color results were compared to the Test Method D1500 results; however, this bias is near the reproducibility of the test methods and is inconclusive. The overall relative bias to Test Method D1500 is not significant.

NOTE 5—The average bias of the estimated ASTM color relative to Test Method D1500 was -0.17 . The largest average biases, -0.4 to -0.5 , were observed for four samples that had an ASTM color of 0.5 and red dye concentrations that ranged from 10 to 20 mg/L.

~~13.5 The precision statements in 13.1 were derived from the 1997 interlaboratory test program. Participants analyzed 4 sets of undyed base fuels and 12 sets of dyed base fuel/color combinations in duplicate in the ASTM color range of 0.5 to 3.0 and Solvent Red 26 equivalent dye concentration from 0 to 16 mg/L. Seven laboratories participated with the automatic filter apparatus and six laboratories participated with the manual Test Method~~

13.5 *Relative Bias (Unfiltered vs. Filtered Samples)*—A single laboratory analyzed a total of 99 separate split samples (unfiltered vs. filtered) to determine the impact that filtering samples can have on reported red dye concentration results.⁵ Based on a Practice D6708 analysis of the results, where the Y-method was unfiltered samples and the X-method was filtered samples, a bias correction formula of $Y = X - 0.107$ was determined. In short, filtering the samples led to a statistically significant bias being determined. As such, to ensure testing consistency between laboratories, samples are not to be filtered as indicated in 11.3. Inclusion of the Test Method D1500 apparatus. Information on the types of samples and their dye concentrations and colors are in the research report available at ASTM International Headquarters. Request ASTM RR:D02-1521. analysis formula is for information only and not intended to be used by laboratories as an official offset to apply to their data if samples were filtered.

13.6 The precision statements in 13.1 were derived from the 1997 interlaboratory test program. Participants analyzed 4 sets of undyed base fuels and 12 sets of dyed base fuel/color combinations in duplicate in the ASTM color range of 0.5 to 3.0 and Solvent Red 26 equivalent dye concentration from 0 to 16 mg/L. Seven laboratories participated with the automatic filter apparatus and six laboratories participated with the manual Test Method D1500 apparatus. Information on the types of samples and their dye concentrations and colors are in the research report available at ASTM International Headquarters. Request ASTM RR: RR:D02-1521.

14. Keywords

14.1 ASTM color; diesel fuel, heating oil; red dye concentration; visible spectrophotometry

ANNEXES

(Mandatory Information)

A1. PROCEDURE FOR PREPARATION OF RED DYE/ASTM COLOR STANDARDS, QUALIFICATION SAMPLES, AND QUALITY CONTROL SAMPLES

A1.1 Scope

A1.1.1 This annex is a description of the preparation of dye concentration and color standard samples used for calibration and qualification. It also describes the preparation of possible standard samples that can be used for periodic checks.

A1.2 Apparatus

A1.2.1 *Spectrophotometer*, equipped to measure the absorbance of solutions in the spectral region from 380 to 780 nm with an effective spectral slit width of 10 ± 2 nm or 5 ± 1 nm. Wavelength measurements shall be repeatable and known to be accurate to 0.1 nm. The photometric linearity is to be ± 0.5 % of full scale and a photometric reproducibility of ± 0.2 %.

A1.2.2 *Filter Spectrophotometer*, see 7.1.

A1.2.3 *Sample Cells*, see 7.2.

A1.2.4 *Balance*, with a readability of 0.1 mg or better.

A1.2.5 *Pipettes*, 0.5 mL, 1 mL, and 2 mL capacity, Class A.

A1.2.6 *Volumetric Flasks*, 100 mL, 200 mL, and 250 mL capacity, Class A.

A1.2.7 *Beaker*, 50 mL capacity.

A1.3 Reagents

A1.3.1 *Dyes*:

A1.3.1.1 *3-Methyl-1-(phenyl azo)-pyrazol-5-ol*, (Yellow 5GS-EX), CAS registry number 4314-14-1.

A1.3.1.2 *1-(phenyl azo)-2-naphthalenol*, (Orange EX), CAS registry number 842-07-9.

A1.3.1.3 *1,4 bis (butylamino)-9,10-anthracenedione*, (Blue SB), CAS registry number 17354-14-2.

A1.3.1.4 *1-[[4-(dimethylphenyl)azo]dimethylphenyl]azo]-2-naphthalenol*, (Red 5B-SP), CAS registry 1320-06-5.

A1.3.1.5 *1,5 (or 1,8)-bis[(4-methylphenyl)amino]-9,10-anthracenedione*, (Violet 3R), CAS registry number 8005-40-1.

A1.3.1.6 *1-hydroxy-4-[(4-methylphenyl)amino]-9,10-anthracenedione*, (Violet B-2R), CAS registry number 81-48-1.

A1.3.1.7 *1,4-bis[(4-butylphenyl)amino]-5,8-dihydroxy-9,10-anthracenedione*, (Green SG), CAS registry number 28198-05-2.

A1.3.1.8 *1-[[2,5-dimethyl-4[(2-methylphenyl)azo]phenyl]azo]-2-naphthol*, (Solvent Red 26), CAS registry number 4477-79-6.

A1.3.2 *1,1-bis(3,4-dimethylphenyl)ethane*, 90 % minimum purity, CAS registry number 1742-14-9.

A1.3.3 *Dodecane*, anhydrous, 99 % minimum purity, CAS registry number 112-40-3.

A1.3.4 *Xylenes- isomers plus ethylbenzene*, A.C.S. reagent grade, CAS registry number 1330-20-7.

A1.4 Preparation Procedure for the ASTM Standard Samples

A1.4.1 Measure 0.2500 ± 0.0005 g of Yellow 5GS-EX into a 50 mL beaker and dissolve the dye in 20 mL of 1,1-bis(3,4-dimethylphenyl)ethane. Quantitatively transfer the Yellow 5GS-EX solution to a 250 mL volumetric flask, dilute to the mark with 1,1-bis(3,4-dimethylphenyl)ethane and mix well. This solution is called the Yellow 5GS-EX dye solution.

A1.4.2 Repeat the above procedure for the Orange EX, Blue SB, Red 5B-SP, Violet 3R, Violet B-2R and Green SG. These solutions are called Orange EX dye solution, the Blue SB dye solution, the Red 5B-SP dye solution, the Violet 3R dye solution, the Violet B-2R dye solution, and the Green SG dye solution, respectively.

A1.4.3 Pipette 2 mL of the Yellow 5GS-EX solution into a 200 mL volumetric flask, dilute to the mark with dodecane, and mix well. Using separate flasks, repeat this procedure with the Orange EX dye solution, the Blue SB dye solution, the Red 5B-SP dye solution, the Violet 3R dye solution, the Violet B-2R dye solution, and the Green SG dye solution.

A1.4.4 At the wavelengths indicated in Table A1.1, measure the absorbance of these solutions using cells with 1 cm path lengths and dodecane as the reference material. If the measured absorbances are not within the indicated ranges, adjust the solution by either adding more of the solid dye, if the measured absorbances are less than the indicated absorbance range, or by adding more 1,1-bis(3,4-dimethylphenyl)ethane if the measured absorbances exceed the indicated absorbance range.

A1.4.5 Prepare the Solvent Red 26 solution by weighing 0.0750 g of Solvent Red 26 into a 250 mL volumetric flask, diluting to the mark with xylenes and mixing well. Calculate the concentration of the solution as follows:

$$C_i = \left(\frac{W}{0.250} \right) \quad (\text{A1.1})$$

where:

C_i = concentration Solvent Red 26 solution, mg/L, and

W = mass of the solid Solvent Red 26, mg.

A1.4.6 Prepare the ASTM mixed dye solutions by weighing into separate amber glass bottles the dye solutions prepared in A1.4.1 and A1.4.2 using the masses specified in Table A1.2. The ASTM color mixed dye solutions are called M1, M3, M5 and M7.

A1.4.7 To generate the color standard samples, weigh the amount of the ASTM color mixed dye solution and the Solvent Red 26 solution specified in Table A1.3 into a 250 mL volumetric flask, dilute to the mark with dodecane, and mix well. Calculate the concentration of the Solvent Red 26 in the color standard samples as follows:

$$C = C_i \times \frac{W}{(d \times 250)} \quad (\text{A1.2})$$

where:

C = concentration Solvent Red 26 in the color standard sample, mg/L,

C_i = concentration of Solvent Red 26 solution from A1.4.5,

W = mass of the Solvent Red 26 solution from A1.4.5, g, and

d = density at 15.6°C of the xylenes mixture using Test Method D4052.

A1.4.8 The ASTM color values assigned to the calibration samples listed in Table A1.3 can be confirmed using the device described in either Test Method D1500 or D6045, or the tristimulus method described in Annex X2.2 of Test Method D6045. Use the samples (1 to 4) detailed in Table A1.3 that do not contain Solvent Red 26 for the ASTM color determination. For samples

5 through 28, assign an ASTM color of 0 if no mixed dye solution is present. If the sample contains mixed dye solution M1, M3, or M5, assign it the same ASTM color as the sample 1, 2, or 3, respectively.

TABLE A1.1 Dye Solution Absorption Range

Dye Solution	Wavelength (nm)	Absorption
Yellow 5GS-EX	395	0.881 to 0.935
Orange EX	465	0.519 to 0.541
Blue SB	600	0.412 to 0.438
	645	0.465 to 0.494
Red 5 B-SP	515	0.673 to 0.715
Violet 3R	545	0.332 to 0.353
Violet B-2R	585	0.332 to 0.353
	635	0.400 to 0.424
Green SG	680	0.467 to 0.498

TABLE A1.2 Dye Solution Masses (g) for Synthesis of ASTM Color Mixed Dye Solutions

Dye Solution	M1	M3	M5	M7
Yellow 5GS-EX	42.000 ± 0.01	40.000 ± 0.01	40.000 ± 0.01	36.600 ± 0.01
Orange EX	5.200 ± 0.005	5.800 ± 0.005	11.600 ± 0.005	10.600 ± 0.005
Blue SB	0.400 ± 0.001	0.400 ± 0.001	...	0.200 ± 0.001
Red 5B-SP	...	1.400 ± 0.001	2.000 ± 0.001	2.600 ± 0.001
Violet 3R	2.600 ± 0.001	1.200 ± 0.001	3.200 ± 0.001	2.200 ± 0.001
Violet B-2R	...	0.800 ± 0.001	1.600 ± 0.001	3.200 ± 0.001
Green SG	0.600 ± 0.001	0.800 ± 0.001	1.600 ± 0.001	0.600 ± 0.001

TABLE A1.3 Indicated Dye Mixture Masses (g) for Synthesis of Calibration

Sample	ASTM Color	M1	M3	M5	M7	Solvent Red 26
1	1	2.467 ± 0.001	...	...	...	...
2	3	...	12.987 ± 0.006	...	...	...
3	5	...	...	23.956 ± 0.010	...	...
4	7	...	...	...	41.822 ± 0.020	...
5	1	2.467 ± 0.001	...	...	...	0.500 ± 0.005
6	3	...	12.987 ± 0.006	...	...	0.500 ± 0.005
7	5	...	...	23.956 ± 0.010	...	0.500 ± 0.005
8	0	...	...	...	...	0.500 ± 0.005
9	1	2.467 ± 0.001	...	...	...	1.000 ± 0.005
10	3	...	12.987 ± 0.006	...	...	1.000 ± 0.005
11	5	...	...	23.956 ± 0.010	...	1.000 ± 0.005
12	0	...	...	...	...	1.000 ± 0.005
13	1	2.467 ± 0.001	...	...	...	3.500 ± 0.005
14	3	...	12.987 ± 0.006	...	...	3.500 ± 0.005
15	5	...	...	23.956 ± 0.010	...	3.500 ± 0.005
16	0	...	...	...	...	3.500 ± 0.005
17	1	2.467 ± 0.001	...	...	...	7.000 ± 0.005
18	3	...	12.987 ± 0.006	...	...	7.000 ± 0.005
19	5	...	...	23.956 ± 0.010	...	7.000 ± 0.005
20	0	...	...	...	...	7.000 ± 0.005
21	1	2.467 ± 0.001	...	...	...	14.000 ± 0.01
22	3	...	12.987 ± 0.006	...	...	14.000 ± 0.01
23	5	...	...	23.956 ± 0.010	...	14.000 ± 0.01
24	0	...	...	...	...	14.000 ± 0.01
25	1	2.467 ± 0.001	...	...	...	28.000 ± 0.01
26	3	...	12.987 ± 0.006	...	...	28.000 ± 0.01
27	5	...	...	23.956 ± 0.010	...	28.000 ± 0.01
28	0	...	...	...	...	28.000 ± 0.01