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Acoustics — Sound-scattering properties of surfaces —

Part 1:
Measurement of the random-incidence scattering coefficient in a reverberation room

Acoustique — Propriétés de dispersion du son par les surfaces —

Partie 1: Mesurage du coefficient de dispersion sous incidence aléatoire en salle réverbérante

Reference number
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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 17497-1 was prepared by Technical Committee ISO/TC 43, *Acoustics*, Subcommittee SC 2, *Building acoustics*.

ISO 17497 consists of the following parts, under the general title *Acoustics — Sound-scattering properties of surfaces*:

— *Part 1: Measurement of the random-incidence scattering coefficient in a reverberation room*

The following part is under preparation:

— *Part 2: Measurement of the directional diffusion coefficient in a free field*

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Introduction

The degree of acoustic scattering from surfaces is very important in all aspects of room acoustics (e.g. in concert halls, sound studios, industrial halls and reverberation chambers). Insufficient scattering may cause strong deviations from exponential sound pressure decay. On the other hand, an approximately diffuse sound field may be obtained with highly scattering surfaces in a room. The degree of scattering in a room can be an important factor related to the acoustic quality of the room.

The scattering coefficient is introduced as a new concept in this part of ISO 17497. Together with the absorption coefficient, the scattering coefficient will be useful in room acoustic calculations, simulations and prediction models. For some time it has been known that modelling of the scattering from surfaces is very important for obtaining reliable predictions of room acoustics. This part of ISO 17497 presents a measurement method to quantify the scattering properties of a surface to replace formerly applied but not generally accepted estimation methods.

The work has been coordinated with the working group of the Audio Engineering Society, AES SC-04-02 for the Characterization of Acoustical Materials. This group emphasized the development of a measurement method for the directional diffusion coefficient, which is different from (but related to) the random incidence scattering coefficient. While the scattering coefficient is a rough measure that describes the degree of scattered sound, the diffusion coefficient describes the directional uniformity of the scattering; i.e. the quality of the diffusing surface. Therefore there is a need for both concepts and they have different applications.

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Acoustics — Sound-scattering properties of surfaces —

Part 1:
Measurement of the random-incidence scattering coefficient in a reverberation room

1 Scope

This part of ISO 17497 specifies a method of measuring the random-incidence scattering coefficient of surfaces as caused by surface roughness. The measurements are made in a reverberation room, either in full scale or on a physical scale model. The measurement results can be used to describe how much the sound reflection from a surface deviates from a specular reflection. The results obtained can be used for comparison purposes and for design calculations with respect to room acoustics and noise control.

The method is not intended for characterizing the spatial uniformity of the scattering from a surface.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 354, *Acoustics — Measurement of sound absorption in a reverberation room*

ISO 9613-1, *Acoustics — Attenuation of sound during propagation outdoors — Part 1: Calculation of the absorption of sound by the atmosphere*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 354 and the following apply.

3.1
specular reflection
reflection that obeys Snell's law, i.e. the angle of reflection is equal to the angle of incidence

NOTE Specular reflection can be obtained approximately from a plane, rigid surface with dimensions much larger than the wavelength of the incident sound.

3.2
diffuse sound field
sound field in which the incident sound intensity on a plane surface is equally distributed over all solid angles covering a hemisphere

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3.3
scattering coefficient

s_θ

value calculated by one minus the ratio of the specularly reflected acoustic energy to the total reflected acoustic energy

NOTE Theoretically, s_θ can take values between 0 and 1, where 0 means a totally specularly reflecting surface, and 1 means a totally scattering surface. The subscript θ may be used to indicate the angle of incidence relative to the normal of the surface. Random incidence is understood if there is no subscript.

3.4
random-incidence scattering coefficient

s

value calculated by one minus the ratio of the specularly reflected acoustic energy to the total acoustic energy reflected from a surface in a diffuse sound field

3.5
random-incidence absorption coefficient

α_s

value calculated by one minus the ratio of the total reflected acoustic energy to the incident acoustic energy, on a surface in a diffuse sound field

3.6
random-incidence specular absorption coefficient

α_spec

value calculated by one minus the ratio of the specularly reflected acoustic energy to the incident acoustic energy, on a surface in a diffuse sound field

NOTE This is the apparent absorption coefficient when the losses include the scattered as well as the absorbed acoustic energy. α_spec may take values in the range from α_s to 1.

3.7
physical scale ratio

$1{:}N$

ratio of any linear dimension in a physical scale model to the same linear dimension in full scale

NOTE The wavelength of the sound used in a scale model for acoustic measurements obeys the same physical scale ratio. So, if the speed of sound is the same in the model as in full scale, the frequencies used for the model measurements will be a factor of N times higher than those in full scale.

4 Principle

The general principle of the method can best be explained by looking at the effect of reflection and scattering in the time domain. Figure 1 shows three bandpass-filtered pulses which were reflected from a corrugated surface for different orientations of the test sample in the free field.

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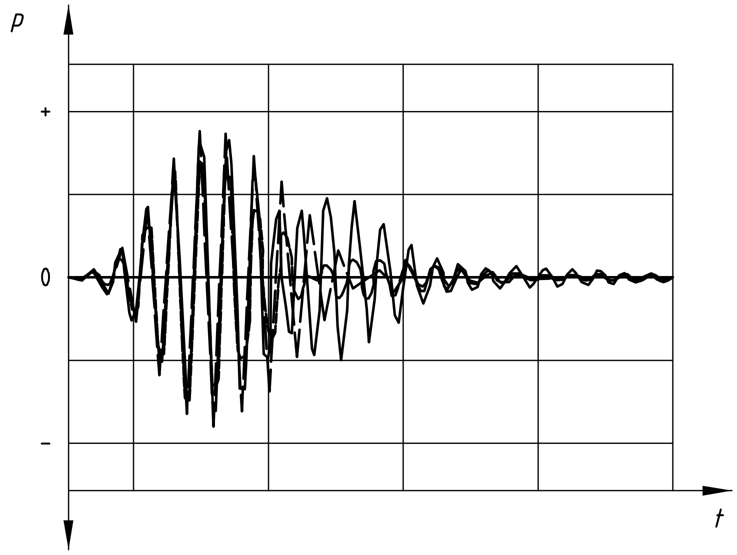

Key

p sound pressure, in pascals
t time, in milliseconds

Figure 1 — Examples of band-pass filtered impulse responses measured at three different positions of the test sample

Obviously, the initial parts of the reflections are highly correlated. This coherent part is identical with the specular component of the reflection. In contrast, the later parts are not in phase and depend strongly on the specific orientation. The energy in the “tail” of the reflected pulse contains the scattered part.

The principle of the measurement method is to extract the specular energy from the reflected pulses. This is done by synchronized (phase-locked) averaging of the impulse responses obtained for different sample orientations.

The principle can be directly applied to measurements in the reverberation room. In addition to conventional measurements of absorption coefficient, the (circular) sample is placed on a turntable and impulse responses are obtained for different sample orientations. By synchronized averaging of the pressure impulse responses, the specular components add up in phase, whereas the scattered sound interferes destructively.

Assuming statistical independence between scattered components, it can be shown (see [1]) that after synchronized addition of n room impulse responses, the initial decay is related to the combined effects of absorption and an apparent energy loss due to sound scattered from the sample.

5 Frequency range

The measurements should be performed in one-third-octave bands with centre frequencies covering the frequency range from 100 Hz to 5 000 Hz. This refers to full-scale measurements. If a physical scale factor of 1:N is used, the centre frequencies should cover the frequency range from $N \times$ 100 Hz to $N \times$ 5 000 Hz.

NOTE If the scale model is filled with a gas in which the speed of sound is different from that in atmospheric air, the measurement frequencies should be chosen in such a way that the wavelength obeys the physical scale ratio 1:N.

NOTE High frequencies may be omitted from the measurements if the attenuation in the air is too high; see 6.1.3.

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6 Test arrangement

6.1 Reverberation room

6.1.1 General

The specifications for the reverberation room are given in ISO 354. Diffusing elements shall be in fixed positions; i.e. moving diffusers like rotating vanes shall not be used. The room and its contents should be invariant, as far as possible. The temperature and humidity have a very significant effect; see 7.4. Any devices such as circulation systems that cause movement or change the properties of the air in the room should not be operated.

6.1.2 Volume of room

The volume V of the reverberation room, in cubic metres, shall be at least

$$V \geqslant 200 \times N^{-3}$$

6.1.3 Absorption in empty room

The equivalent absorption area of the empty room, A_1, including the air attenuation, should not exceed

$$A_1 \leqslant 0{,}30 \times V^{2/3}$$

NOTE According to the requirements for sample size in 6.3.1, this leads to the rule-of-thumb: $A_1/S \leqslant 1$, where S is the area of the test sample.

6.2 Turntable and base plate

A turntable is required in order to rotate the sample. The turntable shall be provided with a circular rigid base. The base plate shall be symmetrical with respect to the axis of rotation. The size of the base plate shall correspond to the maximum dimension of the test sample; see 6.3.

No part of the turntable may be closer than $N^{-1} \times 1{,}0$ m to the walls of the room; see Figure 2.

The scattering coefficient for the base plate itself shall be measured to check the quality of the arrangement; see 8.1.4. The frequency-dependent values listed in Table 1 shall not be exceeded.

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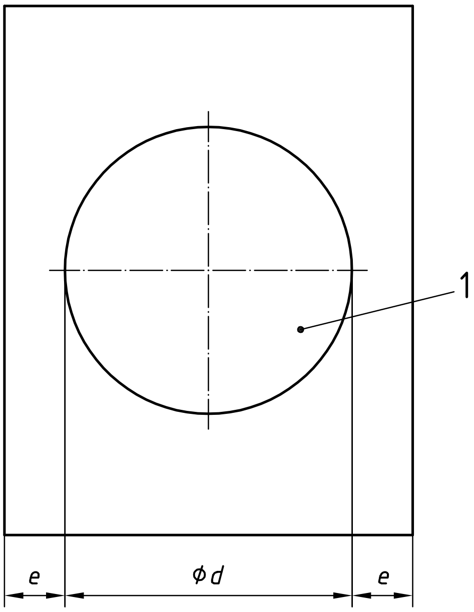

Key

1 turntable

d diameter

e minimum distance to the walls of the room

Figure 2 — Plan of a reverberation room with a turntable for the test sample

Table 1 — Maximum scattering coefficient for the base plate alone

Frequency (f/N), Hz	100	125	160	200	250	315	400	500	630
Scattering coefficient, s_{base}	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,10

Frequency (f/N), Hz	800	1 000	1 250	1 600	2 000	2 500	3 150	4 000	5 000
Scattering coefficient, s_{base}	0,10	0,10	0,15	0,15	0,15	0,20	0,20	0,20	0,25

6.3 Test sample

6.3.1 Area of test sample

The area should be as large as possible in order to obtain good measurement accuracy. The test sample should be circular and the minimum diameter should be $N^{-1} \times 3{,}0$ m.

Alternatively, the test sample may be square with a minimum edge size of $N^{-1} \times 2{,}65$ m. In this case the base plate shall have a minimum diameter of $N^{-1} \times 3{,}75$ m. The test sample shall be flush-mounted if it is not circular.

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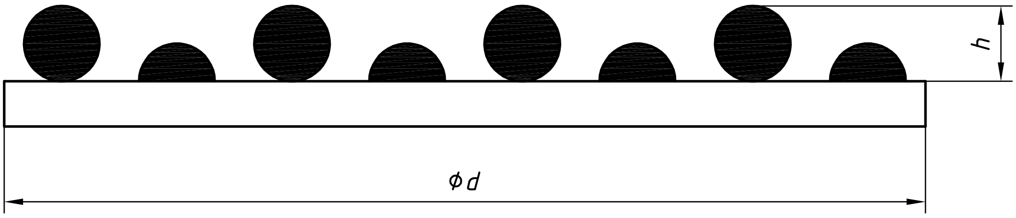
6.3.2 Structural depth of test sample

The measurement method is intended for surface roughness. Thus, the results are only reliable if the structural depth is sufficiently small compared to the size of the test sample. The structural depth should be

$$h \leqslant d/16$$

where d is the diameter of the turntable.



Key

d diameter of the test sample

h structural depth

Figure 3 — Definition of the structural depth

NOTE Edge effects can occur due to variations in the height of the sample along the edge of the test sample. This can lead to scattering coefficients which are too high compared to that of an infinitely extended surface with the same structure as the test sample. The edge effect can occasionally cause measured scattering coefficients $s > 1$.

6.3.3 Position of test sample on turntable

The surface of the perimeter of the test sample should be as smooth and rigid as possible. Do not cover the perimeter with a rigid border of fixed height. Openings along the perimeter of the sample shall be sealed.

If a test sample has rotational symmetry, it shall be placed on the turntable in such a way that the centre of symmetry is displaced from the centre of the turntable by at least $d/8$, where d is the diameter of the turntable.

6.3.4 Absorption of test sample

The absorption coefficient of the test sample should not exceed a value of $\alpha_s = 0{,}50$. However, if sound absorption is part of the sound-scattering structure, this absorption shall also be present in the test sample.

NOTE The measurement method will not produce reliable results for samples with a high absorption coefficient, see Annex A.

7 Test procedure

7.1 Test signals

The test signal shall be deterministic since the evaluation requires a coherent averaging. The integrated impulse response method shall be applied.

It is recommended to use periodic pseudo-random noise signals such as MLS in order to obtain the impulse response. For other requirements concerning the test signal (e.g. sine sweep, period length, spectral energy density, filtering), refer to ISO 354.

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7.2 Source and receiving equipment

For the specification and positioning of sources and receiving devices, refer to ISO 354.

Dimensions given in ISO 354 should be scaled by the scale factor N.

7.3 Measurement of impulse responses

Impulse responses are measured without and with the test sample following ISO 354 and giving the reverberation times T_1 and T_2, respectively. At least two source positions and three microphone positions shall be used, giving a total of six measurements. The reverberation time is the arithmetic average of the individual reverberation times determined in each position.

For each combination of source and receiver positions, a multiple of a periodic pseudo-random signal is continuously radiated and received while the turntable is rotating. The total measurement duration should be equal to the time of one revolution of the turntable. For example, using a pseudo-random periodic signal with a period of 5 s and a revolution speed of 1 min^{-1}, it is necessary to continuously radiate 12 signal periods.

Alternatively, it is possible for each source-receiver position to perform n measurements with the sample rotated between each measurement by $\Delta\phi = 360°/n$. The number of coherent averages n should be in the interval $60 \leqslant n \leqslant 120$. A value of $n = 72$ is preferred, corresponding to angular steps of $\Delta\phi = 5°$.

The excitation signal shall be identical from measurement to measurement. In order to obtain a time-invariant response, a phase-locked averaging of the n measurements is required. This can be done either by averaging the pressure impulse responses or by averaging the received signal before calculating the impulse response.

The result of the measurement with a stepwise or continuously rotating turntable, including the base plate but without the test sample, is the reverberation time T_3. The result with the rotating test sample is the reverberation time T_4.

Table 2 — Measurement conditions for the four different reverberation times

Reverberation time	Test sample	Turntable
T_1	not present	not rotating
T_2	present	not rotating
T_3	not present	rotating
T_4	present	rotating

In order to avoid measurement errors due to air movements or other unstable conditions in the room, the measurements should not be started until $15/N$ min after leaving the room and closing the door. In order to minimize the influence of drifting temperature, etc., the measurements should be made as rapidly as possible.

7.4 Temperature and relative humidity

Changes in temperature and relative humidity during the course of a measurement can have a large effect on the measurement results, especially at high frequencies. Reducing the air attenuation improves the measuring accuracy. The temperature and relative humidity shall be measured in the room before and after each of the four measurement situations (see 7.3). The mean values for each measurement situation are used for corrections as described in Clause 8.

7.5 Evaluation of decay curves

Evaluation of the impulse responses is carried out by the integrated impulse response method as specified in ISO 354. In particular, the backward integration shall be restricted to the linear slope of the impulse response

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level. The decays for T_1, T_2 and T_3 should be linear down to the background noise level, whereas the decay for T_4 consists of two superposed decay curves, and only the first decay should be evaluated.

Set the integration limit at –30 dB and evaluate the reverberation time in the range between –5 dB and –20 dB provided that the first decay is within the range.

Carry out the spatial averaging of the reverberation time according to ISO 354.

8 Expression of results

8.1 Method of calculation

8.1.1 Calculation of the random-incidence absorption coefficient α_s

The random-incidence absorption coefficient α_s shall be calculated using the formula

$$\alpha_s = 55{,}3\frac{V}{S}\left(\frac{1}{c_2T_2} - \frac{1}{c_1T_1}\right) - \frac{4V}{S}(m_2 - m_1) \qquad (1)$$

where

V is the volume of the reverberation room, in cubic metres (m^3);

S is the area of the test sample, in square metres (m^2);

T_1 is the reverberation time obtained without sample, but with the base plate present, in seconds (s);

T_2 is the reverberation time obtained for the test sample, in seconds (s);

c_1 is the speed of sound in air, in metres per second (m/s), during the measurement of T_1;

c_2 is the speed of sound in air, in metres per second (m/s), during the measurement of T_2;

m_1 is the energy attenuation coefficient of air, in reciprocal metres (m^{-1}), calculated according to ISO 9613-1, using the temperature and relative humidity during the measurement of T_1;

m_2 is the energy attenuation coefficient of air, in reciprocal metres (m^{-1}), during the measurement of T_2.

The reverberation times T_1 and T_2 are measured without rotation of the turntable.

NOTE In accordance with ISO 9613-1, the speed of sound in atmospheric air can be calculated from

$$c = 343{,}2\sqrt{\frac{273{,}15 + t}{293{,}15}} \quad \text{(m/s)} \qquad (2)$$

where t is the air temperature, in degrees Celsius.

In the same standard the sound pressure attenuation coefficient α is given in dB/m. The energy attenuation coefficient m can be calculated by

$$m = \frac{\alpha}{10\lg(e)} \approx \frac{\alpha}{4{,}343} \quad \left(\mathrm{m}^{-1}\right) \qquad (3)$$

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8.1.2 Calculation of the random-incidence specular absorption coefficient α_{spec}

The specular absorption coefficient α_{spec} shall be calculated using the formula

$$\alpha_{\text{spec}} = 55{,}3\frac{V}{S}\left(\frac{1}{c_4 T_4} - \frac{1}{c_3 T_3}\right) - \frac{4V}{S}(m_4 - m_3) \tag{4}$$

where

T_3 is the reverberation time obtained for the rotating base plate without sample, in seconds (s);

T_4 is the reverberation time obtained for the sample on a rotating turntable, in seconds (s);

c_3 is the speed of sound in air, in metres per second (m/s), during the measurement of T_3;

c_4 is the speed of sound in air, in metres per second (m/s), during the measurement of T_4;

m_3 is the energy attenuation coefficient of air, in reciprocal metres (m^{-1}), during the measurement of T_3;

m_4 is the energy attenuation coefficient of air, in reciprocal metres (m^{-1}), during the measurement of T_4.

The other symbols are as described in 8.1.1.

8.1.3 Calculation of random-incidence scattering coefficient s

The random-incidence scattering coefficient s shall be calculated using the formula

$$s = 1 - \frac{1 - \alpha_{\text{spec}}}{1 - \alpha_{\text{s}}} = \frac{\alpha_{\text{spec}} - \alpha_{\text{s}}}{1 - \alpha_{\text{s}}} \tag{5}$$

8.1.4 Calculation of the scattering coefficient for the base plate s_{base}

Under ideal conditions, the reverberation times T_1 and T_3 should be equal. However, a slightly non-symmetrical base plate can cause a shorter T_3. It is assumed that this error also appears with a test sample present. The scattering coefficient for the base plate itself as mentioned in 6.2 is calculated using the formula

$$s_{\text{base}} = 55{,}3\frac{V}{S}\left(\frac{1}{c_3 T_3} - \frac{1}{c_1 T_1}\right) - \frac{4V}{S}(m_3 - m_1) \tag{6}$$

where the symbols are as described above.

8.2 Precision

The accuracy of the measurement result depends on the sample size, the absorption coefficient of the sample, and the equivalent absorption area of the empty measuring room. It may be calculated as described in Annex A.

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8.3 Presentation of results

For all frequencies of measurement, the following results shall be reported, presented in the form of a table and a graph:

- the sound absorption coefficient, α_s;
- the scattering coefficient, s.

In the table, the results shall be rounded to 0,01. Values < 0 shall be truncated. Values > 1 can occur (e.g. due to the edge effects, see 6.3.2) and shall be reported.

In the graphical presentation, the points of measurement should be connected by straight lines, the abscissa giving the frequency on a logarithmic scale and the ordinate showing the results on a linear scale. Both results may be shown in the same graph if the two curves are clearly marked. The frequency may be given as the equivalent full-scale frequency (f/N) with a statement of the scale ratio 1:N.

The ratio of the ordinate distance from 0 to 1 to the abscissa distance of five octaves should be 2:3.

9 Test report

The test report shall make reference to this part of ISO 17497 and shall include the following information:

a) the name of the organization that performed the test;

b) the date of test;

c) a description of the test sample, its surface area, the structural depth and the mounting on the turntable, preferably by means of drawings;

d) the shape of the reverberation room, its diffusion treatment, and the number of microphone and source positions;

e) the dimensions of the reverberation room, its volume and total surface area;

f) the temperature and relative humidity for each of the four measurement situations;

g) the results, reported in accordance with 8.3;

h) an estimate of the measurement accuracy.

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Annex A
(informative)

Accuracy of the measurement results

For each of the reverberation times (T_1, T_2, T_3 and T_4) used in Equations (1) and (4) the standard deviation (δ_1, δ_2, δ_3 and δ_4) can be obtained by the formula

$$\delta = \sqrt{\sum_{i=1}^{N} \frac{(T_i - \overline{T})^2}{N(N-1)}} \qquad \text{(A.1)}$$

where N is the number of measurements of the reverberation time, and the spatial average of the reverberation chamber is

$$\overline{T} = \frac{1}{N} \sum_{i=1}^{N} T_i \qquad \text{(A.2)}$$

The uncertainties in the absorption coefficients of Equations (1) and (4) are

$$\delta_{\alpha_\mathrm{s}} = \frac{55{,}3V}{cS} \sqrt{\left(\frac{\delta_2}{T_2^2}\right)^2 + \left(\frac{\delta_1}{T_1^2}\right)^2} \qquad \text{(A.3)}$$

$$\delta_{\alpha_\mathrm{spec}} = \frac{55{,}3V}{cS} \sqrt{\left(\frac{\delta_4}{T_4^2}\right)^2 + \left(\frac{\delta_3}{T_3^2}\right)^2} \qquad \text{(A.4)}$$

Finally, the standard deviation in the scattering coefficient is

$$\delta_\mathrm{s} = \left|\frac{\alpha_\mathrm{spec} - 1}{1 - \alpha_s}\right| \sqrt{\left(\frac{\delta_{\alpha_\mathrm{spec}}}{\alpha_\mathrm{spec} - 1}\right)^2 + \left(\frac{\delta_{\alpha_\mathrm{s}}}{1 - \alpha_\mathrm{s}}\right)^2} \qquad \text{(A.5)}$$

The 95 % confidence limit in the scattering coefficient may be estimated as two times the standard deviation.

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