
**Plastics — Determination of average
molecular weight and molecular
weight distribution of polymers using
size-exclusion chromatography —**

**Part 1:
General principles**

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*Plastiques — Détermination de la masse moléculaire moyenne
et de la distribution des masses moléculaires de polymères par
chromatographie d'exclusion stérique —*

ISO 16014-1:2019

Partie 1: Principes généraux

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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.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 61, *Plastics*, Subcommittee SC 5, *Physical-chemical properties*.

This third edition cancels and replaces the second edition (ISO 16014-1:2012), which has been technically revised. The main changes compared to the previous edition are as follows:

- publication dates of references have been removed;
- the term “system peak” has been added to [Figure 4](#);
- molecular mass has been changed to molecular weight according to IUPAC rule.

A list of all parts in the ISO 16014 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Plastics — Determination of average molecular weight and molecular weight distribution of polymers using size-exclusion chromatography —

Part 1: General principles

1 Scope

This document specifies a general method for determining the average molecular weight and the molecular weight distribution of polymers using size-exclusion chromatography (SEC).

The average molecular weight and the molecular weight distribution are calculated from a calibration curve constructed using polymer standards if using one of the SEC techniques described in ISO 16014-2 to ISO 16014-4 or from a calibration curve constructed using absolute molecular weight data if using size-exclusion chromatography coupled with light-scattering detection (SEC-LS) as described in ISO 16014-5.

2 Normative references

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The following documents are referred to in the text in such a way that some or all of their content constitutes requirements 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 472, *Plastics — Vocabulary*

ISO 16014-2, *Plastics — Determination of average molecular weight and molecular weight distribution of polymers using size-exclusion chromatography — Part 2: Universal calibration method*

ISO 16014-3, *Plastics — Determination of average molecular weight and molecular weight distribution of polymers using size-exclusion chromatography — Part 3: Low-temperature method*

ISO 16014-4, *Plastics — Determination of average molecular weight and molecular weight distribution of polymers using size-exclusion chromatography — Part 4: High-temperature method*

ISO 16014-5, *Plastics — Determination of average molecular weight and molecular weight distribution of polymers using size-exclusion chromatography — Part 5: Light-scattering method*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 472 and the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- ISO Online browsing platform: available at <https://www.iso.org/obp>
- IEC Electropedia: available at <http://www.electropedia.org/>

3.1

light-scattering detection

LS detection

technique for determining the mass or size of polymer molecules dissolved in solution by measuring the light scattered by the polymer molecules

4 Principle

A polymer sample is dissolved in a suitable solvent to make a dilute solution. This solution is injected into the mobile phase and onto the SEC column, which is packed with non-adsorbing material made up of small particles having pores of similar or varying size. As the polymer sample passes through the column, the polymer molecules are separated from each other according to the difference in their molecular masses, or more precisely, the difference in their molecular sizes (i.e. their hydrodynamic volume). In SEC, the larger-size molecules cannot permeate into the pores, and thus elute faster, while smaller molecules can permeate into the pores and elute more slowly. The polymer concentration in the eluate is continuously monitored by a concentration-sensitive detector (coupled to a light-scattering detector if SEC-LS is being used) to give an SEC chromatogram.

In the SEC techniques described in ISO 16014-2 to ISO 16014-4, the molecular weight at any elution time on the SEC chromatogram is determined from a calibration curve which is constructed using reference polymer standards with a narrow molecular weight distribution. In SEC-LS, described in ISO 16014-5, a calibration curve constructed using absolute molecular weight data obtained from the SEC-LS chromatogram at any elution time is used. The average molecular weight and the molecular weight distribution of the unknown polymer are calculated by using the molecular weight and concentration data corresponding to each elution time.

5 Reagents

5.1 Eluent

The required purity of the eluent used for SEC varies with the application, but in general the solvent should be free of particulate matter and substances that react with the polymer or interfere with detection of the polymer. Additives such as antioxidants and salts can be used to prevent the degradation of the eluent, the aggregation of polymer molecules, the adsorption of the polymer on the packing material and for other purposes. A mixed eluent may also be used in the SEC techniques described in ISO 16014-2 to ISO 16014-4 to modify the solubility and the refractive index, or to reduce the cost of the mobile phase. A mixed eluent cannot be used for SEC-LS measurements, however, because the polymer selectively adsorbs the components of the mixed eluent, thus giving an erroneous result.

5.2 Reagent for column evaluation

A low molecular weight compound is used for the determination of the theoretical plate number, asymmetry factor and resolution factor of the column.

5.3 Molecular weight standards

The test methods described in ISO 16014-2 to ISO 16014-4 are not absolute methods but relative ones; they require a calibration curve for the calculation of the average molecular weight and the molecular weight distribution from the SEC chromatogram. This calibration curve is plotted using standards of known molecular weight and narrow molecular weight distribution. The value of M_w and/or M_n of the standard determined by an absolute method, such as light scattering, membrane osmometry, vapour pressure osmometry, ultracentrifugation or end-group analysis. The polydispersity M_w/M_n is calculated by dividing the absolute value of M_w by the absolute value of M_n . The polydispersity of the polymer standards shall lie within the following ranges:

$$\begin{array}{ll} M_p < 2 \cdot 10^3 & M_w/M_n < 1,20 \\ 2 \cdot 10^3 \leq M_p < 10^6 & M_w/M_n < 1,10 \\ 10^6 \leq M_p & M_w/M_n < 1,20 \end{array}$$

where

M_w is the mass-average molecular weight;

M_n is the number-average molecular weight;

M_p is the molecular weight at peak maximum.

M_p can be calculated from [Formula \(1\)](#):

$$M_p = (M_n \times M_w)^{1/2} \quad (1)$$

NOTE Some commercially available molecular weight standards specify the value of M_w and M_n but not M_p . In such cases, [Formula \(1\)](#) can be used to provide the value of M_p , provided the molecular weight distribution of the polymer sample is a logarithmic normal distribution.

Some examples of commercially available molecular weight standards are given in [Annex B](#).

In the case of SEC-LS (see ISO 16014-5), such molecular weight standards are unnecessary because SEC-LS is an absolute method.

5.4 Reagent for flow rate marker (internal standard)

A low molecular weight compound is used to monitor the accuracy of the elution time, i.e. to evaluate whether or not the data are within the specification.

5.5 Additives

Additives to the eluents may be used to improve SEC performance and prevent sample degradation and the like.

6 Apparatus

6.1 General

A schematic diagram of an SEC system is shown in [Figure 1](#). The essential components are an eluent reservoir, a pumping system, an injector, column(s), a detector, tubing, a recorder, a temperature-control system, and a data-processing system. For SEC-LS measurements, a light-scattering detector, i.e. a molecular-weight-sensitive detector, is coupled to the normal (concentration-sensitive) detector. Any light-scattering detector that meets the requirements specified for this method may be used.

6.2 Eluent reservoir

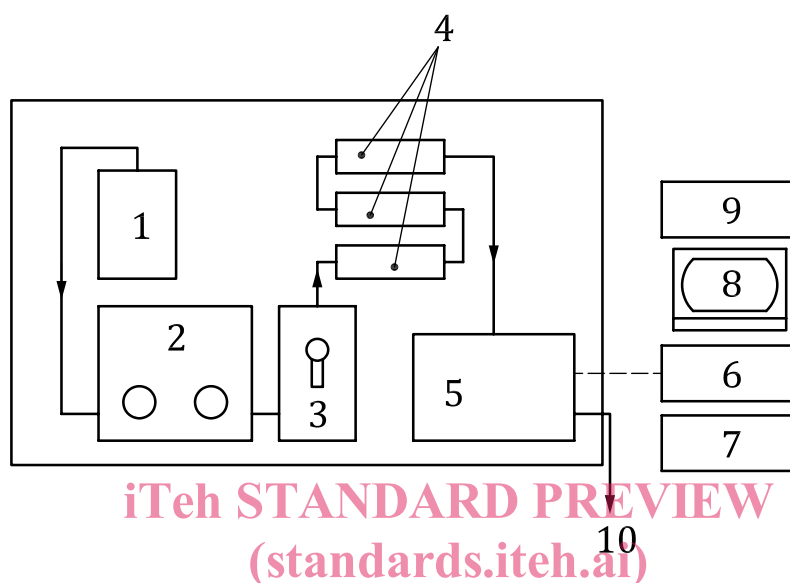
The eluent reservoir should preferably have sufficient capacity to hold the amount of eluent required for column calibration and successive measurements. Dissolved air in the eluent should preferably be removed before use by placing the solvent in a suitable container designed to reduce the pressure and placing this container in an ultrasonic bath, or by using a vacuum degasser between the reservoir and the pumping system. Particles in the eluent may be removed by membrane filtration. It is desirable in addition to bubble an inert gas through the eluent in the reservoir and blanket the surface of the eluent with the gas, and to shield the reservoir from light.

6.3 Pumping system

A constant, pulseless flow of eluent through the column is desirable. The flow rate should preferably be approximately 1 cm³/min for a column of approximately 8 mm inner diameter. The SEC system

shall have an overall flow-rate precision of within $\pm 0,3$ %. Lower flow rates are recommended for high molecular weight and/or shear-sensitive polymers and viscous eluents. To keep the flow rate constant, temperature control providing a stability of at least ± 1 K is required for the pumping system.

The flow rate shall be monitored by the use of an internal standard, or by a direct method such as volume or mass measurements (see A.2), and corrected in the event of significant deviations. In the methods described in ISO 16014-2 to ISO 16014-4, knowledge of the value of the flow rate is not required because the method is a relative one in which the result is calculated from a calibration curve constructed from measurements on molecular weight standards.



Key

- 1 eluent reservoir
- 2 pump
- 3 injector
- 4 columns
- 5 detector
- 6 computer
- 7 recorder
- 8 display
- 9 plotter
- 10 to waste

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Figure 1 — Schematic diagram of SEC system

6.4 Injector

In addition to having an eluent bypass capability, the injector shall be able to hold the sample solution and inject the sample solution into the columns with minimum band broadening and minimum pressure change.

To maintain the required precise flow rate, temperature control equipment, or a precise air conditioner, is required for the injection system.

6.5 Columns

6.5.1 General

The function of the columns is to separate the sample molecules according to differences in their molecular size (mass). Columns usually consist of a stainless-steel tube with end fittings, filters and a porous packing material. There is no limitation on the column length or diameter or on the packing-material particle size.

6.5.2 Determination of theoretical plate number

Use a low molecular weight compound, such as ethylbenzene, to obtain a peak (see [Figure 2](#)) and calculate the theoretical plate number N of the set of columns from [Formulae \(2\)](#) or [\(3\)](#):

$$N = 5,54 \times (t_e / W_{1/2})^2 \quad (2)$$

$$N = 16 \times (t_e / W)^2 \quad (3)$$

where

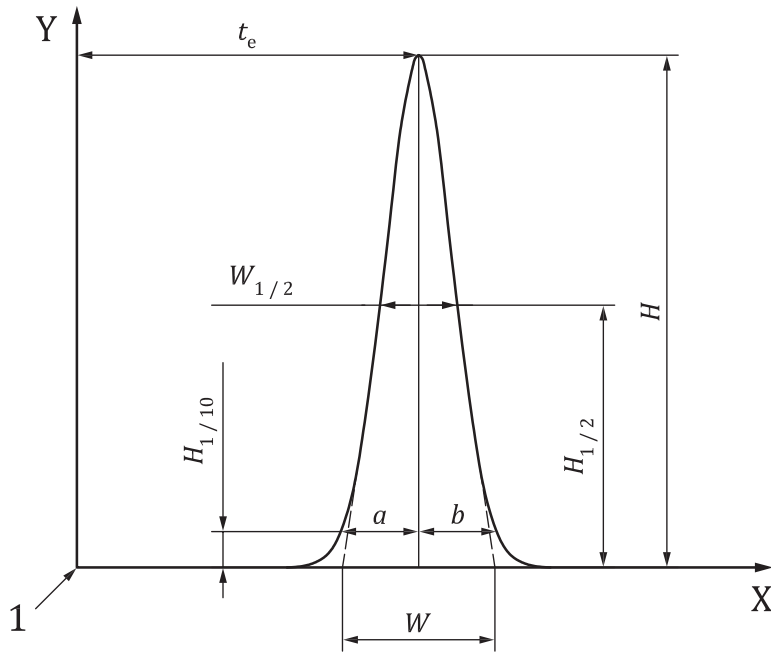
t_e is the elution time to the peak maximum;

$W_{1/2}$ is the peak width at half height;

W is the distance between the points of intersection of the two tangents to the peak with the baseline.

Requirements for the theoretical plate number are specified in ISO 16014-3 and ISO 16014-4.

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Key

- 1 injection
- H height of peak
- $H_{1/10}$ one-tenth of peak height
- $H_{1/2}$ half of peak height
- W distance between the points of intersection of the two tangents to the peak with the baseline
- $W_{1/2}$ peak width at half height
- a width of the leading half of the peak at 10% peak height
- b width of the trailing half of the peak at 10% peak height
- t_e elution time to the peak maximum
- X elution time, min
- Y refractive index, mV

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Figure 2 — SEC chromatogram of a low molecular weight compound

6.5.3 Determination of resolution factor

The resolution factor R of the set of columns can be calculated from [Formula \(4\)](#) by the use of the calibration curve (see [9.1](#) and [Figure 5](#)) and a molecular weight standard (see [5.3](#) and [Figure 3](#)) with a narrow molecular weight distribution that elutes at a point close to the apex of the sample peak:

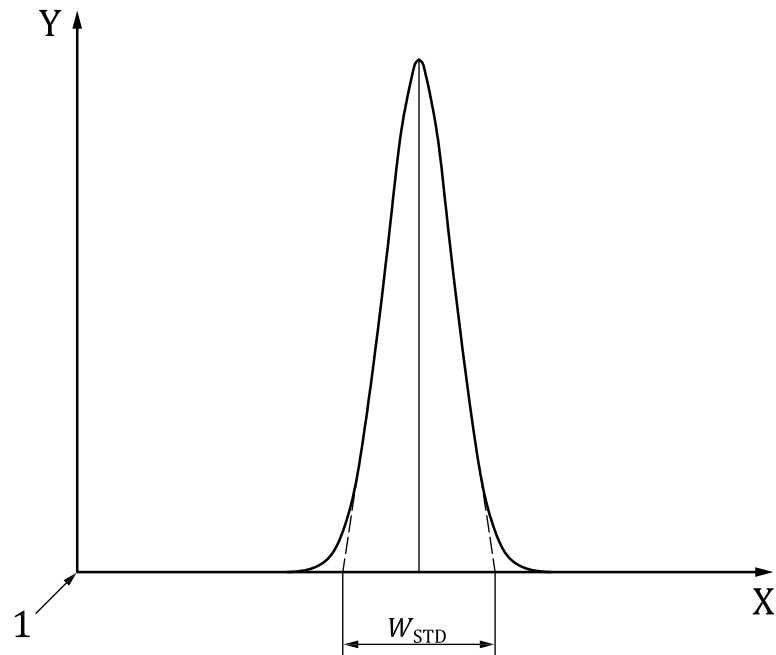
$$R = -1 / (D \times W_{STD}) \tag{4}$$

where

D is the slope of the calibration curve at the point corresponding to the apex of the sample peak;

W_{STD} is the peak width at the baseline of the molecular weight standard.

Requirements for the resolution factor are specified in ISO 16014-3 and ISO 16014-4.

**Key**

1 injection

 W_{STD} peak width at the baseline of the molecular weight standard

X time

Y signal strength

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Figure 3 — SEC chromatogram of a narrow molecular weight distribution standard

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6.5.4 Determination of asymmetry factor

The asymmetry factor, A_S , of the set of columns can be calculated from [Formula \(5\)](#), using data obtained from the peak produced by a low molecular weight compound such as ethylbenzene (see [Figure 2](#)):

$$A_S = (a + b) / (2 \times a) \quad (5)$$

where

A_S is the asymmetry factor;

a is the width of the leading half of the peak at 10 % peak height;

b is the width of the trailing half of the peak at 10 % peak height.

Requirements for the asymmetry factor are specified in ISO 16014-3 and ISO 16014-4.

6.6 Detector

The detector is used to continuously monitor the concentration of the polymer in the eluent coming off the columns. There are several types of commercially available concentration-sensitive detector, such as the refractive index detector, ultraviolet/visible detector, infrared detector and fluorescence detector. For SEC-LS measurements, a light-scattering detector connected directly to the SEC system is used.

The volume of the flow cell shall be sufficiently small so as to maintain the narrow molecular weight distribution of the molecules separated by the columns and to maintain the overall theoretical plate number and the resolution factor of the set of columns determined in [6.5.2](#) and [6.5.3](#).