

BRITISH STANDARD 3406 : Part 4 : 1963

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CONFIRMED APRIL 1985

METHODS FOR DETERMINATION OF PARTICLE SIZE DISTRIBUTION

Part 4. Optical microscope method

BRITISH STANDARDS INSTITUTION

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METHODS FOR DETERMINATION OF PARTICLE SIZE DISTRIBUTION

*As amended
April, 1984*

Part 4. Optical microscope method

B.S. 3406 : Part 4 : 1963

Incorporating amendment issued April, 1984 (AMD 4538)

CONFIRMED APRIL 1985

BRITISH STANDARDS INSTITUTION

Incorporated by Royal Charter

2 PARK STREET, LONDON, W1A 2BS

Telex: 266933

Telephone: 01-629 9000

THIS BRITISH STANDARD, having been approved by the Chemical Engineering Industry Standards Committee and endorsed by the Chairman of the Engineering Divisional Council, was published under the authority of the General Council on 15th November, 1963.

The Institution desires to call attention to the fact that this British Standard does not purport to include all the necessary provisions of a contract.

In order to keep abreast of progress in the industries concerned, British Standards are subject to periodical review. Suggestions for improvements will be recorded and in due course brought to the notice of the committees charged with the revisions of the standards to which they refer.

A complete list of British Standards, numbering over 4000, indexed and cross-indexed for reference, together with an abstract of each standard, will be found in the Institution's Yearbook.

This standard makes reference to the following British Standards:

B.S. 410. Test sieves.

B.S. 1796. Methods for the use of B.S. fine-mesh test sieves.

B.S. 2955. Glossary of terms relating to powders.

B.S. 3406. Methods for determination of particle size distribution.

Part 1. Sub-division of gross sample down to 0.2 ml.

B.S. 3625. Eyepiece and screen graticule for the determination of particle size of powders.

*As amended
April, 1984*

British Standards are revised, when necessary, by the issue either of amendment slips or of revised editions. It is important that users of British Standards should ascertain that they are in possession of the latest amendments or editions.

The following B.S.I. references relate to the work on this standard:
Committee reference CHE/50, CHE/50/1
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CO-OPERATING ORGANIZATIONS

The Chemical Engineering Industry Standards Committee, under whose supervision this British Standard was prepared, consists of representatives from the following Government departments and scientific and industrial organizations:

- *Association of British Chemical Manufacturers
- Association of Consulting Engineers (Incorporated)
- Board of Trade
- *British Chemical Plant Manufacturers' Association
- Coke Oven Managers' Association
- Engineering Equipment Users' Association
- Glass Manufacturers' Federation
- Institute of Petroleum
- *Institution of Chemical Engineers
- Institution of Structural Engineers
- Ministry of Transport
- United Kingdom Atomic Energy Authority

The scientific and industrial organizations marked with an asterisk in the above list, together with the following, were directly represented on the committee entrusted with the preparation of this British Standard:

Aluminium Federation
 Borough Polytechnic
 British Cast Iron Research Association
 British Coal Utilisation Research Association
 British Colour Makers' Association
 British Diamond Die Federation
 British Electrical and Allied Manufacturers' Association
 British Hard Metal Association
 British Pharmacopoeia Commission
 Cement and Concrete Association
 Cement Makers' Federation
 D.S.I.R.—Road Research Laboratory
 D.S.I.R.—Warren Spring Laboratory
 Imperial College of Science and Technology
 Incorporated National Association of British and Irish Millers Ltd.
 Institute of Physics and The Physical Society
 Institution of Mining and Metallurgy
 Ministry of Aviation
 Ministry of Power
 National Physical Laboratory (D.S.I.R.)
 Oil and Colour Chemists' Association
 Permanent Magnet Association
 Pharmaceutical Society of Great Britain
 Radio and Electronic Component Manufacturers' Federation
 Research Association of British Paint, Colour and Varnish Manufacturers
 Society of Chemical Industry
 Society of Cosmetic Chemists of Great Britain
 Toilet Preparations' Federation Ltd.
 University of London
 War Office
 Zinc Pigment Development Association
 Individual firms

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BRITISH STANDARD METHODS FOR DETERMINATION OF PARTICLE SIZE DISTRIBUTION

Part 4. Optical Microscope Method

FOREWORD

A conference on powders was convened by the British Standards Institution in 1952. This standard is the outcome of one of the projects then decided. It is one of a series which describes methods of determining the size distribution of particles in those fractions of powders which pass through a 75 micron British Standard test sieve*. The size distribution of particles retained on the sieve may be determined by sieving†.

Present standards in this series are as follows:

B.S. 3406 : Part 1. Sub-division of gross sample down to 0.2 ml.

Part 2. Recommendations for gravitational liquid sedimentation methods for powders and suspensions.

Part 3. Air elutriation methods.

Part 4. Optical microscope method.

Part 5. Recommendations for electrical sensing zone method (the Coulter principle).

Further standards will be compiled as necessary.

Accurate sampling of particulate material is an essential prerequisite for the determination of size distribution, especially when using methods in which the test portion may be relatively small in amount. The specified procedures described in Part 1 have been selected to prevent any alteration in the size grading of the gross sample, and to avoid segregation of different sized particles when taking the increments.

No single method of size analysis can be specified to cover the many different types of powder encountered, but it is possible to formulate recommended procedures which may be applied to the majority of cases. The purpose of these standards is to obtain uniformity in procedure for any one of the methods selected, in order to facilitate comparisons between size analyses made in different laboratories.

Alternative methods of size analysis are specified because of the varying properties of the powders and the differing circumstances of usage. The conditions of test should be co-ordinated with the conditions of use. A powder used in a wet process should be tested by liquid sedimentation. A dry powder may

* B.S. 410, 'Test sieves'.

† B.S. 1796, 'Methods for the use of British Standard fine-mesh test sieves'.

be tested by liquid sedimentation or other methods but if used in an air dispersed condition it may be better to analyse it by air elutriation. Such co-ordination is not always necessary or possible, but samples which are collected in the wet state must not be dried before analysis unless it can be proved that all aggregates formed on drying will be dispersed completely without any attrition of the particles.

The choice of the most suitable method will depend on the following considerations:

- the purpose for which the analysis is required, e.g. quality control, research, specification requirements;

- the size range and density of the particles;

- important properties of the powder, e.g. solubility in water, stickiness and difficulty of dispersion, agglomerating characteristics;

- the amount of material available for analysis;

- the method by which the gross sample has been collected.

The optical microscope is the only method in which direct observation is made of the size of particles. Even this method has a tendency to measure the largest dimensions unless the particles are intentionally dispersed with random orientations. The sedimentation and elutriation methods measure the free-falling velocities of the particles in a fluid. These depend not only upon the particle size, but are affected by particle shape and other properties as explained in Appendix G. Consequently, size analyses made on identical powders by the various methods may not show complete agreement in the size distributions, and the divergence will increase with irregularity of particle shape. It is therefore essential when reporting an analysis that the method employed be identified e.g. as the optical microscope method, B.S. 3406, Part 4.

The results of a series of comparative tests on a silica powder by different methods are given in Appendix H:

Good reproducibility or relative precision does not preclude bias caused by a combination of procedure and the properties of the particles.

The apertures of B.S. test sieves are in a $\sqrt{2}$ progression. The optical microscope method is arranged to continue this series by expressing size analyses of smaller particles in microns as cumulative percentages below sizes of a consecutive $\sqrt{2}$ series, namely:

75, 53, 37, 27, 19, 13, 9.4, 6.6, 4.7, 3.3, 2.3, 1.7, 1.2, 0.8*.

The size distribution is expressed in terms of weight or number of particles.

* It may be preferred to continue the international series of test sieves which has been written into some national standards (including B.S. 410) and which is a $\sqrt{2}$ series occupying the values intermediate between those of the series quoted above:

63, 45, 31, 22, 16, 11, 7.8, 5.5, 3.9, 2.8, 2.0, 1.4, 1.0.

The optical microscope method as given does not apply to this series. A different graticule would be needed.

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METHOD

1. INTRODUCTION

1.1 Terminology. For the purpose of this standard the terminology of B.S. 2955* applies with the addition of the following terms.

Laboratory sample. The portion of the gross sample which is delivered to the laboratory for determination of particle size distribution.

Analysis sample. The portion of the laboratory sample which is used in the size analysis apparatus.

Intermediate sample. A portion of the laboratory sample which includes the analysis sample.

1.2 Outline of method. This standard describes the determination by the optical microscope method of (a) the number and (b) the volume or weight of sizes of particles in a powder in terms of the diameters of circles having the same projected areas as the particles. The method is applicable to particles having projected diameters in the range 0.8–150 microns.

In the microscope method a representative sample of the powder to be sized is dispersed and placed on a glass slide and the particles are viewed through a microscope by means of transmitted light. The areas of the magnified images of the particles are compared with the areas of reference circles of known sizes inscribed on a graticule and simultaneously visible. The relative numbers of particles in each of a series of size classes are determined. These numbers, expressed as percentages, constitute the size distribution by number. Additionally, from the relative numbers in the size classes, it is possible to calculate the relative volumes, provided it is assumed that particles of all sizes have the same shape in the sense that the square root of the projected area of a particle stands in a constant ratio to the cube root of the volume of the particle for all sizes of particles. The fact that this assumption may not be justified does not preclude the use of the method but should be taken into account in interpreting the measurements. The relative volumes, expressed as percentages, constitute the size distribution by volume.

The size distribution by volume is also the size distribution by weight if particles of all sizes have the same density. For simplicity of presentation, the term size distribution by weight has been used throughout the standard, but it should be understood that the size distribution by volume is meant where the particles do not have a constant density.

The size classification of particles by the sizes of their magnified images depends for its accuracy on:

a. the optical quality of the images, which calls for the use of an adequate numerical aperture (N.A.) of the microscope objective and condenser for the size of the particle being examined,

* B.S. 2955, 'Glossary of terms relating to powders'.

b. the accurate measurement of the magnification at the plane of the graticule on which the reference circles are inscribed,

c. the reliability of the comparison of the areas of the images with those of the reference circles, which in turn rests on

- (i) the skill of the observer in making this judgment,
- (ii) the use of a magnification giving adequately large images, because the judgment of comparative sizes is more certain with larger images,
- (iii) the avoidance of fatigue, which is greatly affected by the working conditions, especially the colour and level of illumination.

Therefore conditions governing the selection and use of apparatus are given in Sections 2, 3 and 4 and a procedure for adjustment of the microscope in Appendix A. The graticule is of new design specified in B.S. 3625*.

Only a minute weight of sample is employed but even so the number of particles on the slide is so large that it is impractical to count and classify by size every particle present. Counting is restricted to sample areas of the slide and this procedure introduces a sampling error whose magnitude depends on the uniformity of the dispersion on the slide and on the number of particles counted. The minimum number of particles that must be counted to ensure that the sampling error will be smaller than some pre-determined value can be predicted from the statistical theory of sampling given in Appendix E. In order to avoid counting more particles than are necessary for reaching the pre-determined degree of precision, a counting procedure is given in Section 5 which differs according to whether the size distribution by number or by weight is required.

1.3 Sub-division of sample. The method gives the distribution of sizes of particles in a sample of powder dispersed on a microscope slide. Methods of preparing the laboratory sample so that it is representative of the gross sample are given in B.S. 3406 : Part 1†. Methods of preparing the analysis sample from the laboratory sample are given in Appendix C.

1.4 Size measured. The method gives the distribution of sizes of particles in terms of the diameters of circles having the same projected areas as the particles, for the particle orientations obtaining in the sample of powder dispersed on the microscope slide. Unless special precautions are taken in the preparation to secure a random orientation in three dimensions, the particles on the slide will usually have assumed a stable orientation and will present their largest projected areas for measurement. It is extremely difficult to determine whether particle orientation is or is not random. Special methods using viscous media exist by which randomly orientated samples may be prepared in particular cases.

* B.S. 3625, 'Eyepiece and screen graticule for the determination of particle size of powders.'

† B.S. 3406, 'Methods for determination of particle size distribution.'

Part 1, 'Sub-division of gross sample down to 0.2 ml'.

*As amended
April, 1984*

1.5 Size classes. The method gives the relative numbers or weights of particles contained within classes the size limits of which stand in a ratio of $\sqrt{2}$ to 1. The method does not specify the numerical values of the limits but it is recommended that they form a continuation of the B.S. test sieve series below 53 microns. Table 1 gives the recommended values of the size class limits, which have been calculated from a base value of 53.00 microns.

1.6 Lower limit of size. The method is applicable to sizes of particles not smaller than 0.8 micron. Smaller particles may be present in the sample but they should not be sized: their presence should however be stated in reporting the results of a determination. Even at particle sizes up to 2.3 microns considerable errors in size assessment may occur unless the observer has experience in the use of the microscope, and such errors may materially affect the results especially if a number distribution is being determined. It is recommended that monochromatic illumination be used when sizing particles smaller than 2.3 microns.

1.7 Upper limit of size. The method is preferably restricted to sizes of particles passing a 75 micron B.S. test sieve* but particles of sizes up to 150 microns may be counted and sized, provided that the weight of particles of sizes not passing a 75 micron B.S. test sieve does not amount to more than 10 per cent of the total weight of the powder. When the weight does exceed 10 per cent, these particles should be removed and analysed by sieving. The combination of results from sieve and microscope analyses is discussed in Appendix G.

1.8 Particle shape. The method is restricted to particles of such shape that the length of the smallest rectangle enclosing the projected image does not exceed four times the breadth of the rectangle. A procedure for the sizing of more elongated particles is given in Appendix F.

1.9 References. The method given in this specification is substantially that described by G. L. Fairs†. Appendix E has been supplied by W. R. Cousins, Imperial Chemical Industries Ltd., and has not been published elsewhere. Instructions on the use of the microscope have been supplied by P. G. W. Hawksley and B.B. Morgan of the British Coal Utilisation Research Association.

* Because of the difference between the 'sieve' and 'projected' diameters of a particle (see Appendix G) particles passing a 75 micron B.S. test sieve may appear under the microscope to be appreciably larger than 75 microns.

† G. L. Fairs, 'Developments in the technique of particle size analysis by microscopical examination', *J.R.Micr.Soc.*, 1951, 71, 209-22.

TABLE 1. RECOMMENDED VALUES FOR SIZE CLASSES*

Size class number	Upper and lower limit to size class in microns		Arithmetic mean of size class limits in microns (expressed to 3 significant figures) d	Weighting factor for class (to be used in derivation of weight distribution) [†] d^3
	Expressed to 2 decimal places	Rounded figures		
1	0.83 1.17	0.8 1.2	1.00	1.00
2	1.17 1.66	1.2 1.7	1.41	2.83
3	1.66 2.34	1.7 2.3	2.00	8.00
4	2.34 3.31	2.3 3.3	2.83	22.7
5	3.31 4.68	3.3 4.7	4.00	64.0
6	4.68 6.63	4.7 6.6	5.66	181
7	6.63 9.37	6.6 9.4	8.00	512
8	9.37 13.25	9.4 13	11.3	1 450
9	13.25 18.74	13 19	16.0	4 100
10	18.74 26.50	19 27	22.6	11 600
11	26.50 37.48	27 37	32.0	32 800
12	37.48 53.00	37 53	45.2	92 700
13	53.00 74.95	53 75	64.0	262 000
14	74.95 106.00	75 106	90.5	741 000
15	106.00 149.90	106 150	128	2 100 000

* Recommended values constitute a $\sqrt{2}$ series based on 53.00 microns (see Class 15).

[†] The values for weighting factor d^3 are computed from the means of the class limits (second column), not from the rounded means given in the fourth column.

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2. APPARATUS

2.1 Microscope. The microscope shall be provided with

- coarse and fine focusing,
- focusing and centring substage condenser,
- an adjustable substage condenser diaphragm,
- a mechanical stage giving two graduated movements at right angles each capable of being read to 0.1 mm by scale or micrometer screw.

The microscope shall be any one of three types:

Bench microscope, with a graticule mounted in the eyepiece, in which a real magnified image of the field formed by the objective in the plane of the graticule is viewed by means of the eyepiece simultaneously with the graticule. It is essential that the microscope be fitted with a graduated draw-tube so that the tube length may be adjusted over a range of at least 150–185 mm and preferably of 140–200 mm.

Projection microscope, with a graticule mounted in the eyepiece, in which a real magnified image of the field formed by the objective in the plane of the graticule is further magnified and projected as a real image together with a magnified real image of the graticule on to a projection screen. The microscope must be fitted with a graduated adjustable draw-tube as for the bench microscope.

Projection microscope, with a graticule incorporated in or superimposed on a projection screen, in which the image of the field magnified successively by the objective and the eyepiece is focused on the projection screen. This type of microscope may have either a graduated adjustable draw-tube like the other types or an adjustable projection distance.

2.2 Microscope lamp and filters. The source of illumination, which may be integral with the microscope, shall be capable of filling uniformly the whole field of view of the lowest power objective used. It shall be provided with an adjustable diaphragm or other means of controlling the area of the field illuminated.

Coloured and neutral filters are required for controlling the colour and intensity of the illumination. (See Appendix A, Clause A6.)

2.3 Objectives. The objectives shall be of good quality*, in sound condition and inscribed with their focal length and numerical aperture (N.A.). Objectives may be achromatic (or parachromatic), semi-apochromatic, fluorite or apochromatic.

* The optical quality of objectives cannot be judged without experience; they should be purchased from a reputable manufacturer. Especial care should be exercised in the case of the highest power objectives where slight misuse may result in displacement of the lenses.

Since no more than six, or exceptionally seven, size classes may be examined with any one objective it will usually be necessary to have available at least three objectives to cover the whole range of sizes from 0.8 to 150 microns, which comprises 15 size classes. (Table 1.)

2.4 Eyepiece. Only one eyepiece is required. It shall be of good quality, in sound condition and inscribed with its magnification at a virtual image distance of 250 mm. Eyepieces may be of Huygenian (negative) or compensating (negative or positive) type*. Compensating eyepieces should be employed with apochromatic, fluorite and the higher power achromatic objectives. Eyepieces in which graticules are mounted should be preferably of positive construction†. The lens system shall be adjustable within its mount to permit the focusing of the graticule when resting on the field stop; special focusing eyepieces are commercially available. The eyepiece of a bench microscope should preferably be of power not less than $\times 20$ but not greater than $\times 25$.

2.5 Substage condenser. The substage condenser shall be of good quality, in sound condition and shall have an aplanatic N.A. at least as large as the N.A. of the objective in use. A condenser for use with an objective of N.A. higher than 0.6 shall, in addition to being aplanatic, be achromatic. It may be necessary to have available more than one substage condenser, since it may not be possible to illuminate the whole field of view of low power objectives by means of a condenser having a numerical aperture adequate for high power objectives. A three-lens aplanatic condenser of 1.3 N.A. corrected for spherical and chromatic aberrations whose N.A. can be reduced by removing the top lens, is suitable for all objectives. Abbe, or improved Abbe, condensers normally marked with an N.A. of 1.2 have in fact an *aplanatic* N.A. not greater than 0.4 and may not be used with objectives of N.A. exceeding 0.4.

* See Appendix A.

† An additional advantage of positive construction is that this type of eyepiece can be made to have a greater eye clearance and is therefore more suitable for an operator wearing spectacles. The operator may still find that he needs to remove his spectacles and in this case it may be unwise for him to make routine use of a bench microscope.

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2.6 Graticule. The graticule (see Fig. 1) shall be ruled with rectangles and reference circles to the pattern and relative dimensions specified in B.S. 3625*. An eyepiece graticule shall be of such diameter as to fit without excessive play into the eyepiece used. A screen graticule shall be of such size as to be contained within the field of view at the projection distance employed; the field of view will usually have a diameter of about 150 mm at a projection distance of 250 mm measured from the eyepiece and will be proportionately larger for longer distances.

The diameters of the reference circle rulings should preferably be such that within the available range of adjustment of magnification (by tube length movement for eyepiece graticules or projection distance for screen graticules) the diameters shall correspond at the field with the dimensions set out in Table 1. (See Section 4 and Appendix B.)

2.7 Stage micrometer. The stage micrometer shall have 10 divisions each of 100 microns, one division at the end of the scale being further divided into 10 divisions each of 10 microns. Commonly such a micrometer is divided in 10 micron divisions throughout. The glass slide carrying the micrometer should not be so thick that the substage condenser cannot be adjusted properly. It is recommended that the micrometer accuracy be certified by the National Physical Laboratory.

3. SELECTION OF OBJECTIVES AND EYEPIECES

This Section details conditions governing the use of objectives and eyepieces and, for the benefit of those without previous experience, gives advice on the choice of objectives.

3.1 Minimum numerical aperture. An objective shall not be employed for sizing particles below the minimum particle size given in Table 2 appropriate to the type of objective and its nominal N.A. It is recommended that where possible sizing should not be extended below the size class given in the sixth column of Table 2.

The manufacturer's rated value for the N.A. as inscribed on the objective may be taken for the N.A., provided that when the rated value exceeds unity the particles are mounted in a medium of refractive index greater than 1.3 and both condenser and objective are oiled to the slide by immersion oil. When the particles are dry mounted, or the condenser or objective is not oiled to the slide, the nominal N.A. shall be taken as 1.0 or as the rated value whichever is the smaller.

* B.S. 3625, 'Eyepiece and screen graticule for the determination of particle size of powders.'

TABLE 2. MINIMUM PARTICLE SIZE FOR DIFFERENT OBJECTIVES AND
MINIMUM TOTAL MAGNIFICATION REQUIRED

Focal length of objective mm	Type of objective*	Nominal magnification of objective	Nominal numerical aperture not less than	Minimum permissible particle size microns	Recommended smallest size class microns	Minimum total magnification required for sizing down to	
						Minimum particle size	Recommended smallest size class
Dry objectives 32	Achromatic	× 5	0.13	12	19-27	130	80
	Achromatic	× 6.5	0.15	10	19-27	150	80
16	Achromatic	× 10	0.17	8.8	13-19	170	115
	Apochromatic	× 10	0.30	5.0	9.4-13	300	160
12	Achromatic	× 12.5	0.34	4.4	6.6-9.4	340	230
8	Achromatic	× 20	0.50	3.0	4.7-6.6	500	320
	Apochromatic	× 20	0.65	2.3	3.3-4.7	650	450
6	Achromatic	× 25	0.50	3.0	4.7-6.6	500	320
4	Achromatic	× 40	0.65	2.3	3.3-4.7	650	450
	Apochromatic	× 40	0.85	1.8	2.3-3.3	850	650
Oil immersion objectives 3.75 3.6		× 45	0.95	1.6	2.3-3.3	950	650
2.2 2.0 1.8	Achromatic	× 80-100	1.25	1.2*	1.7-2.3†	1250	880
	Apochromatic		1.30	0.8*	1.2-1.7†	1800	1250

* Achromatic includes parachromatic; apochromatic includes fluorite and semi-apochromatic.

† Providing particles are mounted in a medium of refractive index greater than 1.3 and both condenser and objective are oiled. Otherwise in both cases, the minimum particle size is increased to 1.5 microns and the recommended smallest size class to 2.3-3.3 microns; the minimum total magnifications become 1000 and 650.

The fact that the condenser will be stopped down in use so that the actual or working N.A. is less than its nominal value does not reduce the minimum particle size that may be sized with the objective.

The minimum particle size in microns stipulated in Table 2 is equal to 1.5 divided by the nominal N.A. (except in the case of an apochromatic objective of N.A. greater than 1.3). This condition ensures that the diameter of the smallest particle examined will be some five times that of the Airy disc.

3.2 Minimum total magnification of objective and eyepiece. The total magnification of the objective and eyepiece together shall be such that the magnified image of the smallest particle being sized exceeds 1.5 mm*.

If it is desired to use an objective for sizing particles down to the minimum particle size permitted in Table 2, the above condition requires that the total magnification of objective and eyepiece together shall be greater than 1000 times the nominal numerical aperture of the objective. This in turn requires a high eyepiece magnification for bench microscopes. Table 2 gives the magnifications required for sizing down to the minimum particle size and to the recommended smallest size class.

For the purposes of this section the total magnification shall be computed as follows:

Bench microscope. As the product of the rated magnifications of the objective and the eyepiece.

Projection microscope. As the actual magnification at the projection screen. This may be estimated by taking the product of the rated magnifications of the objective and eyepiece and multiplying by the projection distance in mm between the eyepiece and the screen and dividing by 250 mm (which is the assumed distance of the virtual image when viewed through the eyepiece and is the figure employed in designating the magnification of the eyepiece).

3.3 Maximum total magnification of objective and eyepiece. The total magnification employed shall not exceed 1500 times the N.A. of the objective.

3.4 Advice on choice of objectives. It is often convenient in determining a weight distribution, where a different total sample area is usually required for each size class, to change magnification more frequently than is essential to comply with Clauses 3.1 to 3.3. Having regard to these and to the recommendations given in Appendix D the following advice is given on the selection of objectives.

Number distribution. For sizing down to 0.8 microns a convenient series of objectives is

2 mm apochromat (oil immersion) for particle sizes 0.8 to 6.6 microns.

8 mm achromat (or apochromat) for particle sizes 6.6 to 27 microns.

25 mm (or 32 mm) achromat for particle sizes 27 to 150 microns.

* The minimum size of 1.5 mm ensures that the magnified image is not less than about 20 times the limit of resolution of the unaided eye.

If it is not necessary to size below 2.3 microns the use of oil immersion can be avoided, a 4 mm objective then being used as the highest power. A useful series is:

4 mm apochromat (or achromat) for particle sizes 2.3 to 13 microns.

16 mm achromat (or apochromat) for particle sizes 13 to 37 microns.

25 mm (or 32 mm) achromat for particle sizes 37 to 150 microns.

If particles as small as 0.8 or 2.3 microns are present it is unlikely that the full range of classes up to 150 microns will have to be assessed in establishing a number distribution and two objectives may suffice.

Weight distribution. Particles smaller than 2.3 microns often do not contribute significantly to a weight distribution and in such cases the following series of objectives is convenient:

4 mm apochromat (or achromat) for particle sizes 2.3 to 13 microns.

16 mm achromat (or apochromat) for particle sizes 13 to 37 microns.

25 mm (or 32 mm) achromat for particle sizes 37 to 150 microns.

If the weight of particles smaller than 2.3 microns is of importance a 2 mm oil immersion objective is necessary.

4. SELECTION OF GRATICULE AND ADJUSTMENT OF MAGNIFICATION

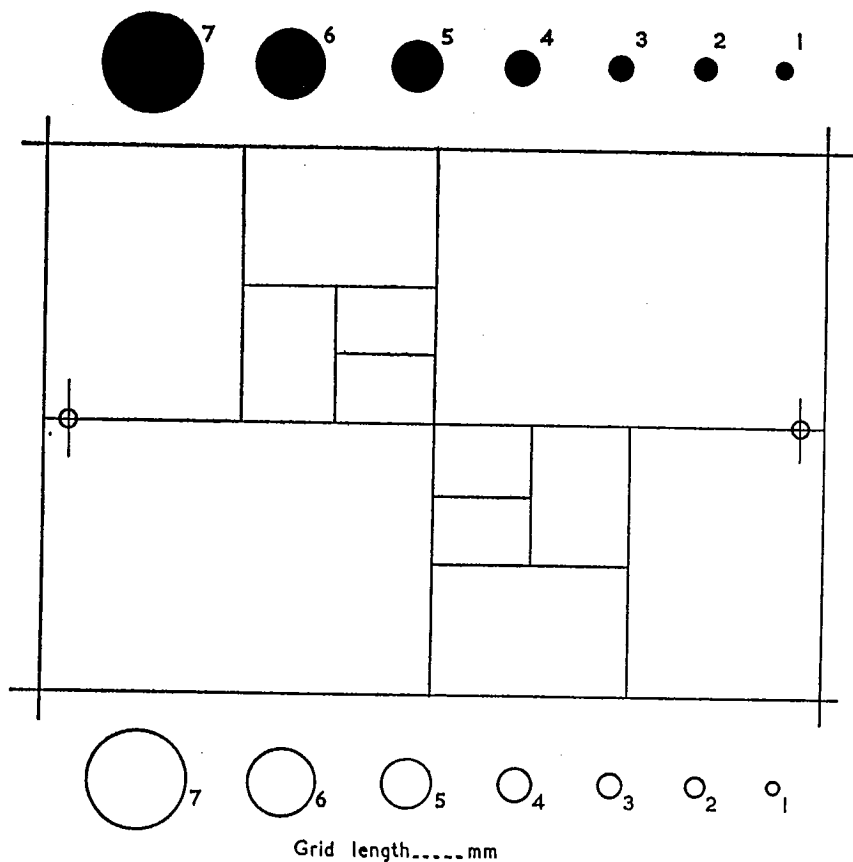
4.1 Standard graticule. The standard graticule shown in Fig. 1 is ruled with a rectangular grid, which is used to define the area of field within which particles are counted, and is provided with two sets of numbered circles of graduated sizes which serve as reference circles for classifying by size the particles counted.

The relative dimensions of the grid and circles are given in Table 3. The diameters of the reference circles increase in geometrical progression with the constant ratio of $\sqrt{2}$. The physical size of the graticule rulings is designated by the length of the rectangular grid, which is related to the diameters of the reference circles being 64 times the diameter of circle numbered 1. This length is marked on the graticule in millimetres to an accuracy of ± 2 per cent.

The sub-dividing lines of the grid form in the pattern shown the following areas: two each $\frac{1}{4}$, $\frac{1}{8}$, $\frac{1}{16}$ and $\frac{1}{32}$ and 4 each $\frac{1}{64}$ of the total area of the grid. These serve to define field areas smaller than that of the whole grid.

The standard graticule is also inscribed on the longer axis of the grid with two calibration marks at a specified distance apart. These are employed in adjusting the magnification of the microscope, as explained below in Clauses 4.3 and 4.4.

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MAKER'S
SYMBOL

Fig. 1. British Standard graticule

TABLE 3. RELATIVE DIMENSIONS OF BRITISH STANDARD GRATICULE

	Numerical value
	units*
Grid length	64
Grid breadth	45.3
Distance between calibration marks	60.4
Diameter of circle	
1	1.00
2	1.41
3	2.00
4	2.83
5	4.00
6	5.66
7	8.00

* The unit is $\frac{1}{64}$ th of the grid length.

4.2 Matching of reference circles with size class limits. The magnification of the microscope shall be so adjusted that the diameters of the reference circles correspond to the desired size class limits, which should preferably be the recommended size class limits given in Table 1. Table 4 shows the complete series of possible matchings of the reference circles with the recommended size class limits in the range from 0.8 to 150 microns. At any one matching up to 7 size classes, covering a range of $8\sqrt{2}$ to 1, can be counted and classified. For the whole size range from 0.8 up to 150 microns at least three different matchings are needed.

The matching is carried out by adjusting the magnification at the plane of the graticule in relation to the physical size of the reference circles as characterized by the length of the grid inscribed on the graticule. Since it is desirable, as a matter of manipulative convenience, to employ one graticule having a length of grid suitable for the various matchings required in any particular case, the magnification at the plane of the graticule should be adjustable in appropriate steps that are powers of $\sqrt{2}$. The relative magnifications required for this purpose are given in Table 4. The matching of the largest set of size classes, which has been assigned a relative magnification of unity, is usually made with a 32 mm or a 25 mm objective having an actual magnification of about $\times 4$ to $\times 6$. The choice of a suitable length of grid and the procedure for the adjustment of the magnification are described in the next two Clauses (4.3 and 4.4). In effecting the matchings, account must be taken of the conditions

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TABLE 4. COMPLETE SET OF MATCHINGS OF REFERENCE CIRCLES WITH
SIZE CLASS LIMITS

Relative magnification at plane of standard graticule	Size class limit in microns corresponding to graticule reference circle numbered							Length of stage micrometer to be matched with calibration marks on graticule	Area of rectangular grid of graticule	Minimum nominal numerical aperture of objective	Minimum total magnification
	†	7	6	5	4	3	2	1			
1*	150	106	75	53	37	27	19	13	microns	0.11	115
$\sqrt{2}$	106	75	53	37	27	19	13	9.4	800	0.16	160
2	75	53	37	27	19	13	9.4	6.6	566	0.23	230
$2\sqrt{2}$	53	37	27	19	13	9.4	6.6	4.7	400	0.32	320
4	37	27	19	13	9.4	6.6	4.7	3.3	283	0.45	450
$4\sqrt{2}$	27	19	13	9.4	6.6	4.7	3.3	2.3	200	0.65	650
8	19	13	9.4	6.6	4.7	3.3	2.3	1.7	141	0.90	900
$8\sqrt{2}$	13	9.4	6.6	4.7	3.3	2.3	1.7	1.2	100	1.25	1250
16	9.4	6.6	4.7	3.3	2.3	1.7	1.2	0.8	71	1.30	1800
									50		

This matching is made with a 32 mm or a 25 mm objective which usually has an actual magnification of $\times 4$ to $\times 6$.

The standard graticule is not inscribed with a reference circle of diameter corresponding to the size class limits in this column, which are $\sqrt{2}$ times larger than those listed under reference circle 7, but particles may be judged as being larger than reference circle 7 whilst smaller than an imaginary circle $\sqrt{2}$ times larger.