International Standard ISO 6328

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Photography — Photographic materials — Determination of ISO resolving power

Photographie — Surfaces sensibles — Détermination du pouvoir résolvant

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Foreword

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Draft International Standards adopted by the technical committees are circulated to the member bodies for approval before their acceptance as International Standards by the ISO Council.

International Standard ISO 6328 was developed by Technical Committee ISO/TC 42, *Photography*, and was circulated to the member bodies in April 1980.

It has been approved by the member bodies of the following countries :

Australia	Italy	South Africa, Rep. of
Belgium	Japan	Spain
Canada	Korea, Dem. P. Rep. of	Switzerland
Czechoslovakia	Netherlands	USA
Egypt, Arab Rep. of	Romania	USSR

The member bodies of the following countries expressed disapproval of the document on technical grounds :

France
United Kingdom

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Photography — Photographic materials — Determination of ISO resolving power

0 Introduction

The resolving power of a photographic material is an estimate of the smallest detail that may be visually observable when recorded on the material, and combines the effects of modulation transfer function, graininess and contrast, all of which contribute to overall image quality, and human observers, each of whom may differ in their assessment of quality. The method is particularly useful for appraising materials that will be viewed at high magnification such as microfilm, 8 mm and 16 mm motion picture film, etc. However, resolving power should not be expected to predict overall image quality in every situation, because image quality is too complex to be described by a single factor. This is particularly the case for low contrast continuous-tone products.

Resolving power as measured by photographing suitable test charts is very dependent on conditions of measurement and the structure of the test pattern. It depends markedly on the photographic conditions employed and on the presence of background glare from the illuminated target. It is affected by such factors as the colour of the light used, the exposure level, the focus, processing procedures, the lens aperture at which the test is made, the contrast of the target and the magnification of the camera lens and that through which the images are observed, etc.

The judgement exercised by the human observer in determining resolving power can be a source of significant experimental error. The criterion of resolution given in this International Standard was selected as it appeared to admit less latitude in interpretation than others.

1 Scope and field of application

This International Standard specifies a method for determining the resolving power of photographic films, plates and papers, including black-and-white films, black-and-white printing papers, colour reversal films, colour negative films, and colour printing papers. Materials designed for X-ray and other high-energy radiation are excluded, as are materials having photopolymer, diazo, etc. light-sensitive layers.

2 Reference

ISO 497, *Guide to the choice of preferred numbers and of series containing more rounded values of preferred numbers.*

3 Definitions

For the purpose of this International Standard, the following definitions apply :

3.1 test pattern : Three parallel bars of equal width and separated by interspaces of the same width.

3.2 test chart : Array of test patterns, each identical in form but decreasing sequentially in size.

3.3 spatial period : Distance between successive corresponding points on a periodic pattern.

3.4 spatial frequency : Reciprocal of the spatial period expressed as cycles per millimetre (c/mm). It denotes the number of identical line pairs that can be contained within an overall width of 1 mm.

3.5 contrast ratio : Ratio of the luminance of the bars of the test pattern to the luminance of the surround.

3.6 camera : Optical system by which the test chart is imaged and recorded, with suitable reduction in size, on the photographic material being tested.

3.7 reference surface : Flat surface against which the emulsion side of the photographic material is pressed during exposure.

3.8 qualification (of a camera) : The attainment of the necessary high optical performance of a camera, essential for its use in determining resolving power.

3.9 replicate set : Series of images of the chart made at the same focus and exposure settings.

3.10 exposure series : Series of images made at different exposure settings.

3.11 focus series : Series of images of the resolution chart made at different focus settings.

3.12 resolving power : Ability of a photographic material to maintain in the developed image the separate identity of parallel bars when their separation is small. Numerically equal to the spatial frequency of the smallest pattern that can be resolved.

3.13 resolving power of a replicate set : Median of the resolving powers of the test material in images of the replicate set.

3.14 maximum resolving power : Resolving power of the test material under conditions of optimum focus and exposure.

4 Sampling and storage

4.1 Product sampling

In determining the ISO resolving power of a product, it is important that the samples evaluated are representative of those used by the consumer. No fewer than three samples shall be obtained from the plant of the manufacturer or from an accredited distributor if they cannot be obtained directly from the manufacturer. In any case, the samples should be taken from products stored according to the manufacturer's recommendations and available in the market. Each sample shall represent a different batch of product.

4.2 Storage of samples

After procurement from the manufacturer or distributor, all samples of a product shall be stored in the unopened package for 2 to 4 months under conditions recommended by the manufacturer. When no specific recommendation is made, storage shall be at 23 ± 5 °C and a relative humidity of (50 ± 20) %. At the end of this storage period, samples should be tested. The basic objective in selecting and storing samples as described above is to ensure the film characteristics obtained are representative of those obtained by a consumer at the time of use.

5 Method of test

5.1 Principle

The resolving power of a material is determined by visual inspection of the image of the test chart recorded on the test material by means of a suitable camera system. It depends on exposure, and passes through a maximum as the exposure is increased from a value at the toe of the characteristic curve to a value toward the shoulder. Furthermore, the resolving power passes through a maximum as the focus setting is given successive values that vary from one side of the correct focus to the other.

In brief, the procedure is to first determine the exposure for which the resolving power is maximized; the focus setting used is that found to be optimal during the qualification test. Then with the exposure so determined, the focus is changed by a series of small increments, and the resolving power at the best focus is determined. This is the ISO resolving power of the material.

Because of the variable effect of granularity, a set of pictures made with the same exposure and same focus setting often yields a range of resolving power values. To mitigate the effect of this variable, the International Standard resolving power is defined below in terms of the median value of a set of not less than nine replicated measurements.

Lacking definitive guidance, the criterion that the observer uses to decide whether a given test is or is not resolved is highly individual. Some observers, particularly inexperienced ones, tends to require clear separation of the bars while others are satisfied with much less distinct separation. Experience indicates that without a carefully defined and agreed upon criterion, observers may differ by as much as a factor 2, or even more, in the resolving power value they assign to the same image. However, with training, experienced observers should agree to within ± one pattern or about ± 12 % in terms of cycles per millimetre.

Describing a resolving power criterion in such a way that the same criterion is used by all observers is difficult. The criterion used in this International Standard is arbitrary, as any criterion must be, but was selected because it appears to admit less latitude in interpretation than any other criterion.

5.2 Apparatus

5.2.1 Test pattern

The test pattern shall be the three-bar pattern inscribed in a square as shown in figure 1. The shaded part of figure 1 represents the darker portion, and the unshaded part the lighter portion, of the field of view. In terms of displacement L of the bars, the dimensions of the square are 2,5 L × 2,5 L. The shaded part of figure 1 is termed the "surround".

The overall width and length of the pattern in figure 1 shall be within 5 % of the nominal value 2,5 L. The width of the bars and the width of the interspaces shall be the same within 5 %.

The spatial frequency of the test patterns shall be calculated by measuring the overall pattern width (2,5 L) and using the formula :

$$\text{Spatial frequency (cycles per millimetre)} = \frac{2{,}5}{\text{Overall pattern width, in millimetres}}$$

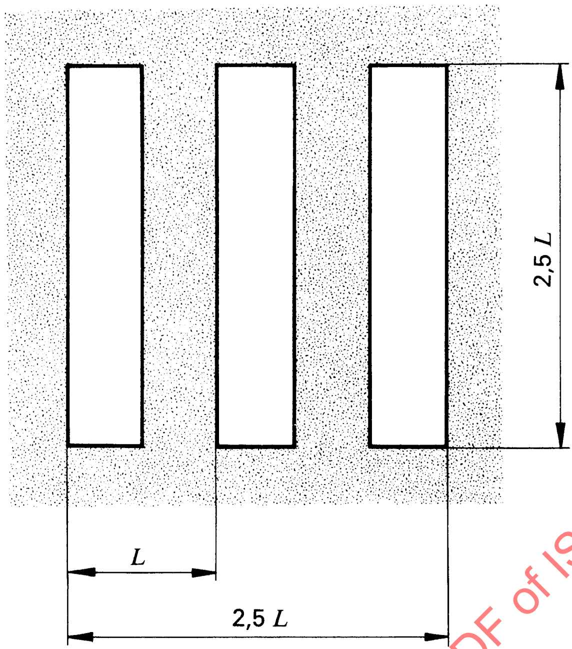

Figure 1 — Three-bar square test pattern

5.2.2 Test chart

The test chart may be an array of test patterns as illustrated in figure 2. The cycles of the test patterns in the array may be as shown in table 1. The change is spatial frequency between successive patterns shall be equal to $20 \sqrt{10}$. This corresponds to increments of about 12 %.

The test chart shall be a non-selective neutral transparency.

The array of test patterns in figure 2 is approximately 100 mm square and is centered in a surround that is about 125 mm square. The two horizontal lines are 100 ± 0,5 mm apart and are used to determine the magnification.

The luminance of the three bars of each test pattern and the luminance of the surround shall be measured[1)] at the position of the eyepiece which serves as the imaging lens.

This International Standard defines two different kinds of resolving power corresponding to test charts of two different contrast ratios.

5.2.2.1 High-contrast test chart

For the high-contrast test chart, the common logarithm of the contrast ratio shall be at least 2,0. This is equivalent to a contrast ratio of 100.

5.2.2.2 Low-contrast test chart

For the low-contrast test chart, the common logarithm of the contrast ratio shall be 0,20 ± 0,02. This is equivalent to a contrast ratio of 1,6.

5.2.2.3 Illumination of the test chart

The test chart shall be transilluminated by a diffuse light source and the illuminance shall not vary more than 5 % over the area of the chart. The light transmitted by the test chart shall have spectral characteristics similar to those for which the material is designed, and be specified when quoting International Standard resolving power.

The luminance of the surround of the low-contrast test chart shall be as uniform as the state-of-the-art permits when the test chart is placed before a uniform diffuse source of light. In particular, the luminance shall be uniform to within ± 5 % up to a distance of 10 mm outwards from the edges of the test pattern.

1) A spot photometer may be used to measure the luminance of the surround and that of the largest bars to verify contrast ratio of the test chart in position in the resolving power test instrument. Since it will not be feasible to measure the luminance of the smaller bars with the spot photometer, a micro-densitometer may be used to verify the contrast uniformity of the test chart from the largest to the smallest test patterns.

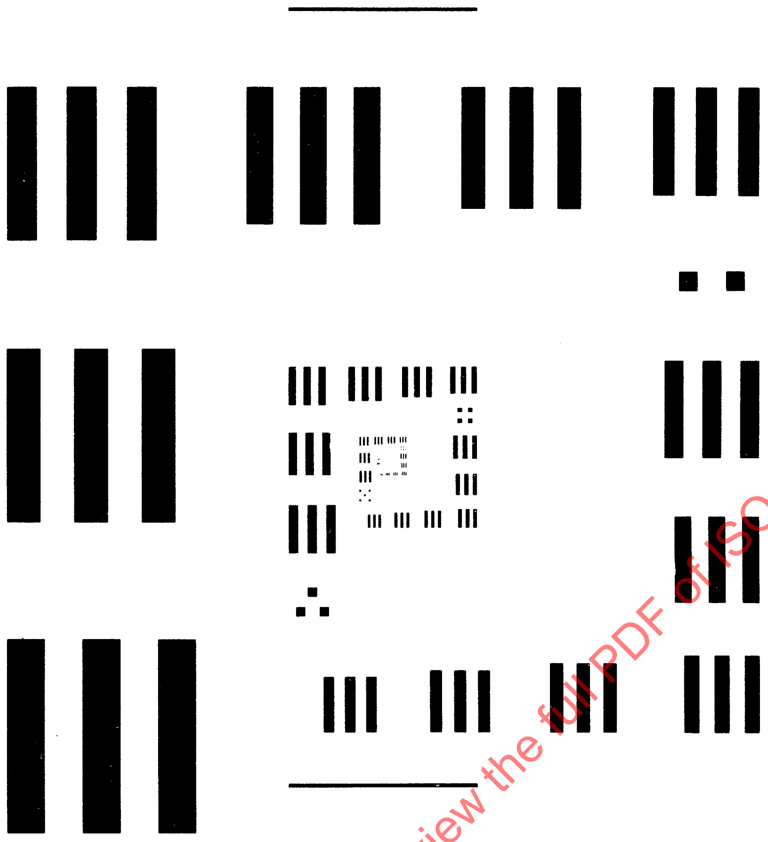

Figure 2 — Test chart

(Although the test chart has light bars on a darker background, for the sake of clarity of reproduction, the figure shows the bars black against a white background.)

NOTE — For those who may contemplate laying out a test chart similar to that in figure 2, one principle used in constructing the array is that each test pattern shall be surrounded by a uniform surround that extends a distance of at least L from the nearest point of the enveloping square of that pattern. A second principle is that the smaller test patterns shall lie closer to the centre of the array. A third is that the lay-out should be arranged so that it is easy to identify each test pattern.

Table 1 — Spatial frequency of test patterns

Values of frequency in cycles per millimetre

Pattern within the group	Group number						
	1 –	2 –	3 –	4 –	5 –	6 –	7 –
1	0,100	0,200	0,398	0,794	1,58	3,16	6,31
2	0,112	0,224	0,447	0,891	1,78	3,55	7,08
3	0,126	0,251	0,501	1,00	2,00	3,98	7,94
4	0,141	0,282	0,562	1,12	2,24	4,47	
5	0,158	0,316	0,631	1,26	2,51	5,01	
6	0,178	0,355	0,708	1,41	2,82	5,62	

NOTE — The entries are the values of L^{-1} in reciprocal milimetres for the 39 test patterns in the test chart of figure 2. The number of square dots in figure 2 indicates the group number. A convenient way to identify each pattern for recording purposes is to use the form 3-2, where 3 is the group number and 2 indicates the second pattern in that group.

5.2.3 Camera[1]

The camera may consist of a compound microscope (objective, eyepiece, and draw tube), means to position accurately the objective with respect to the photographic material, and means for holding the photographic material flat.

A typical camera of this type is shown in figure 3. Design, construction, and mounting of the camera should be such as to minimize the possibility of unintended relative motion, resulting from vibration, etc., between the microscope and the photographic material being exposed. It is also important to control flare and interreflections in the optical system to avoid undesirable degradation of the image of the test chart at the focal plane.

5.2.3.1 Microscope objectives

The microscope objectives shall be apochromatic and may have two special modifications : they may be blackened on the inside, and may be adjusted to operate without a cover-glass.

A camera using one of the two following objectives is suggested :

a) an apochromatic objective with a focal length of approximately 16 mm and a numerical aperture of 0,25 to 0,30 for high contrast resolving powers up to 300 c/mm;

b) an apochromatic objective with a focal length of approximately 8 mm and a numerical aperture of 0,60 to 0,65 for high contrast resolving power greater than 300 c/mm.

5.2.3.2 Microscope eyepiece

The microscopic eyepiece should be designed for use with the objective used in the camera (a X 10 compensating eyepiece has been found acceptable).

A diaphragm shall be located in the plane of the ocular ring. Its diameter shall be the same as the objective pupil through the eyepiece.

5.2.3.3 Draw tube

The eyepiece and the objective shall be mounted rigidly in a draw tube. Since some objectives perform best at a mechanical tube length significantly different from the nominal value, the mechanical tube length should be optimized for the objective used.

5.2.3.4 Reference surface

The camera may contain a flat reference surface against which the emulsion side of the photographic material is pressed during exposure. The central hole in the reference surface shall be as small as practical, but shall not block any of the relevant light and shall not interfere mechanically with the objective. The area of the reference surface shall be held to a minimum to minimize the risk of dust and dirt affecting the focus. Provision must be made to hold films and papers flat; a flat vacuum back has been found satisfactory for this purpose.

5.2.3.5 Precision of the focus setting

The focus setting of the camera shall be capable of being reset to within 1 µm.

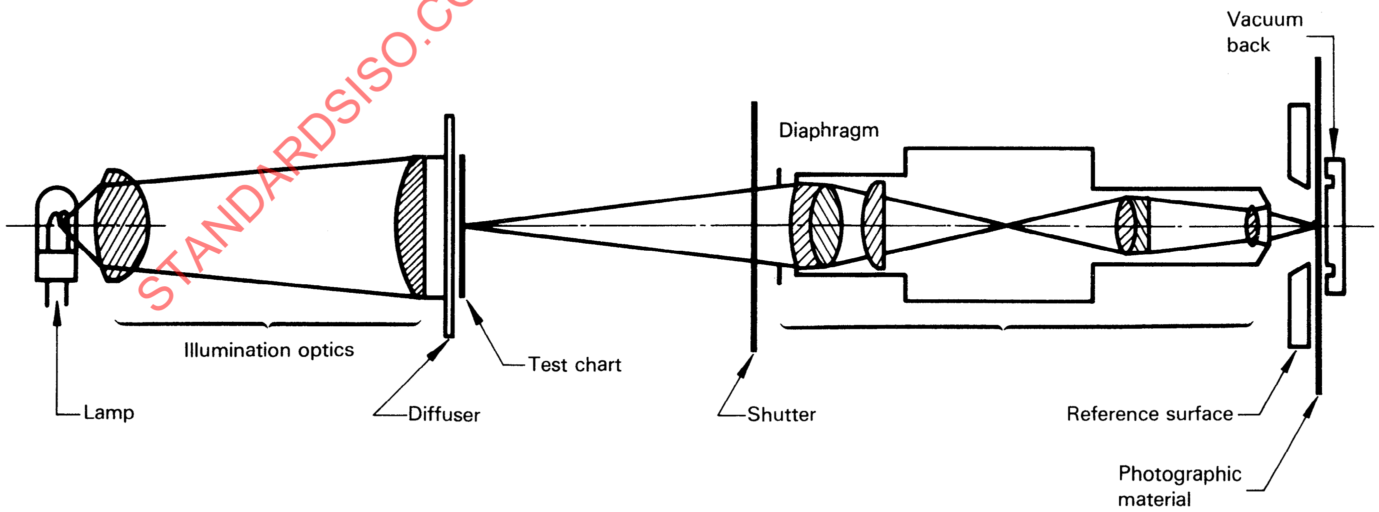

Figure 3 — Resolving power camera

1) ALTMAN, J. H. *Photographic Science and Engineering*, Vol. 5, No. 1, January-February 1961.

5.2.3.6 Reduction ratio of the camera

For materials having an high contrast ISO resolution up to 300 c/mm, the spatial frequencies in the image on the photographic material shall be 200 times the values given in table 1. For materials of higher resolution, the spatial frequencies shall be 400 times the values given in table 1.

5.2.3.7 Qualification of the camera

A camera shall be deemed to have qualified if it meets the following requirements :

a) the camera shall be capable of determining the resolving power of very high resolution material[1];

b) the camera for measurement of high-contrast resolutions up to 300 c/mm shall yield an International Standard high-contrast resolving power of at least 900 c/mm and an International Standard low-contrast resolving power of at least 600 c/mm on the cited material[1];

c) the camera for measurement of high-contrast resolutions above 300 c/mm shall yield an International Standard high-contrast resolving power of at least 1 800 c/mm and an International Standard low-contrast resolving power of at least 900 c/mm on the cited material[1].

5.2.4 Viewing microscope

The processed photographic material shall be evaluated by inspection with a microscope.

Ordinary high quality achromatic microscope objectives are satisfactory for the viewing microscope.

The magnification of the viewing microscope shall be between 0,5 and 1,0 times the resolving power (in cycles per millimetre) that is being determined.

For resolving powers under 1 000 c/mm, the numerical aperture of the objective shall be not less than 0,001 times the resolving power that is being determined.

The luminance of the developed image seen by the observer should be adjusted to a comfortable value. The light source should have a continuous spectrum. In particular, a source having spectral lines shall not be used with colour materials.

Images of the test chart shall be evaluated with the same type of illumination normally used with the material. Normally, films are viewed by transmitted light and papers by reflected light, but there are exceptions and these should be noted. Care shall be taken to ensure that the illumination is sufficient when inspecting papers.

An objective of X 100 magnification and a total magnification of at least X 1 000 shall be used for the camera using the cited material[1].

5.3 Optimum exposure test

5.3.1 Ambient conditions

Samples shall be exposed at a temperature of 23 ± 5 °C and relative humidity of (50 ± 20) %.

5.3.2 Exposure

Make an exposure series with the camera focus set close to the best focus. The series shall have approximately equal increments in the relative logarithm of exposure. Make replicate exposures at each exposure level which shall contain an odd number of pictures, with a minimum of three.

To avoid problems with failure of the reciprocity law, the duration of the exposure shall be comparable to that ordinarily used for the material.

5.3.3 Delay before processing

In the time between exposing and processing, the latent image may change. This characteristic should be recognized when establishing the optimum exposure.

5.3.4 Processing

The chemicals, processing steps, equipment, and processing conditions shall be those ordinarily used for the material. Where relevant, the processing may be as the manufacturer recommends for the material being evaluated.

Since processing can influence the measured resolving power, specifications for the process should be described when reporting the International Standard high (or low)-contrast resolving power for a material.

5.3.5 Evaluation of images

5.3.5.1 Criterion of resolution

In order that an observer may judge that a pattern image is resolved, the image of the bars shall be perceived in such a way that the number of bars can be counted with reasonable confidence even if the number is not known to be three. Otherwise, the image of a test pattern is judged, not resolved. The key concept in the criterion of resolution is that of "reasonable confidence". It is intended to indicate a level of confidence that is halfway between full confidence and no confidence at all.

1) Kodak spectroscopic film, Type 649-GH (developed 3 min in KODAK D-19 developer at 20 °C) or equivalent.

Each pattern image shall be judged independently, regardless of the appearance of other pattern images in the image of the chart.

A pattern image is judged to be not resolved if the pattern image of the next lower spatial frequency is not resolved by the criterion described above.

5.3.5.2 Procedure for evaluating the resolving power of a replicate set

The criterion of 5.3.5.1 shall be used to determine whether a pattern image is resolved. The resolving power is defined as the greatest spatial frequency of the pattern image that is resolved by this criterion.

The resolving power of a replicate set of images is defined as the median of the resolving powers of the images in the replicate set. The median of an ordered set of values is the value above and below which fall an equal number of values.

5.3.6 Optimum exposure

Determine the resolving power of each image of the exposure series. Table 2 shows the exposure series obtained for a typical film. Plot the median resolving power for the replicate set of each exposure level versus the logarithm of the relative exposure as illustrated in figure 4. Draw a smooth curve through the plotted points, and determine the exposure corresponding to the maximum; this is termed the "optimum exposure".

To ensure that the optimum exposure is correctly determined, two requirements must be fulfilled. First, the total range used in the exposure series shall be sufficient to ensure that the curve passes through a maximum.

The second requirement ensures that the increment in the log exposure series is not too large. Draw a vertical line in the plot at the optimum exposure. Then select the four plotted points that lie closest to this line, two on either side of the line. (In figure 4, these are the points with the abscissa 0,6 — 0,7 — 0,8 and 0,9.) The largest resolving power in this set of four shall be not more than two times the smallest resolving power in the set.

Table 2 — Exposure series

Exposure setting	Replicates			Median
	No. 1	No. 2	No. 3	
1	—	—	—	
2	—	—	—	
3	—	—	—	
4	45	45	45	45
5	89	100	79	89
6	126	126	112	126
7	126	158	126	126
8	141	141	126	141
9	126	141	112	126
10	126	112	100	112

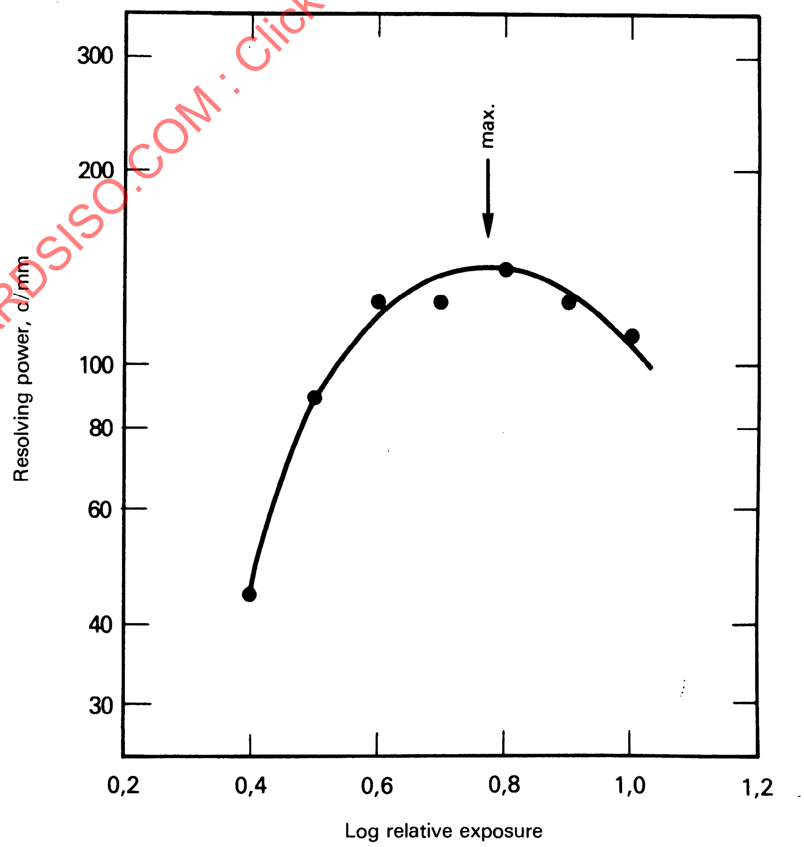

Figure 4 — Exposure series plot

5.4 Optimum focus test

5.4.1 Ambient conditions

The sample shall be exposed at a temperature of 23 ± 5 °C and a relative humidity of (50 ± 20) %.

5.4.2 Exposure

Make a focus series using the optimum exposure determined. Focus settings shall be separated by equal increments. The replicate sets made at each focus setting shall contain an odd number of pictures, with a minimum of nine.

5.4.3 Delay before processing

Same as 5.3.3.

5.4.4 Processing

Same as 5.3.4.

5.4.5 Evaluation of images

Same as 5.3.5.

5.4.6 Optimum focus

Determine the median resolving power of each replicate set. Table 3 shows the focus series values obtained for a typical film. Plot the median resolving power of each of the replicate sets for each focus setting versus the focus setting, as illustrated in figure 5. Draw a smooth curve through the plotted points and determine the focus setting corresponding to the maximum; this is termed the "optimum focus".

5.5 Maximum resolving power

The resolving power at the maximum of the focus series plot is termed the maximum resolving power of the material.

To ensure that the maximum resolving power is correctly determined, two requirements must be fulfilled. First, the total range of the focus setting shall be sufficient to ensure that the curve passes through a maximum. The second requirement ensures that the increment of the focus setting in the focus series is not too large. Draw a vertical line in the plot through the maximum of the curve. Then select the four plotted points that lie closest to this line, two on either side of the line. The largest resolving power in this set of four shall be not more than two times the smallest resolving power in the set.

Table 3 — Focus series

Focus point	Replicates									Median
	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7	No. 8	No. 9	
− 2	158	100	126	141	112	158	141	112	100	126
− 1	141	126	141	126	141	126	158	141	89,1	141
0	141	141	126	141	141	158	126	126	89,1	141
+ 1	141	158	126	126	141	141	178	141	89,1	141
+ 2	112	126	141	141	126	126	141	112	79,4	126

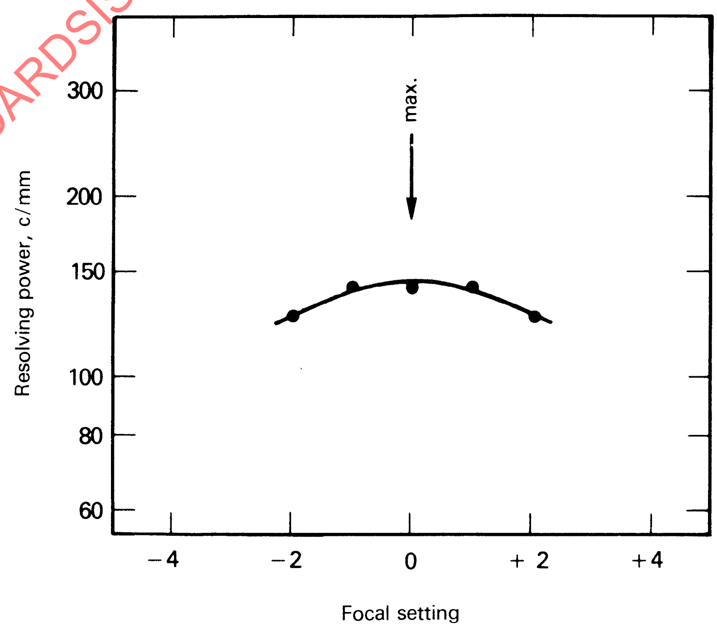

Figure 5 — Focus series plot