On the Resolving Power of Photographic Plates.

By C. E. Kenneth Mees, D.Sc.

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Introduction.—The convenience of the photographic plate as a recording instrument, in that it not only makes a record but also integrates impressions which are individually too faint to be observed, is so manifest that to a continually greater extent physicists are designing instruments for use solely or chiefly by photographic methods.

It is curious to note that while the resolving power of physical instruments generally has been completely investigated, very little indeed has been published upon the resolving power of the plates used as recording instruments.

In considering the resolving power of a photographic plate it is, of course, necessary to deal with the linear resolving power, so that we may define the resolving power to be the distance which must separate two lines of light falling upon the plate in order that the developed image may be recognised to be that of two separate lines.

This resolving power will then give the distance by which, *e.g.*, the images of two spectral lines must be separated in order that they may be recorded as separate lines, or the images of a double star in order that it may appear double. It is clearly of no use to obtain a higher resolving power in an instrument than the plate used in that instrument will possess.

The only attempt to state this resolving power appears to be that of Wadsworth.* Wadsworth states that two lines can be separated if between the particles in the maxima of the lines there are one silver particle and two spaces, that is to say, the linear distance between the two maxima or centres of the line is equal to four times the diameter of a particle. If the diameter of a particle be called e, then we may assume that for photographic resolution it is necessary that the linear distance between the centres of the lines be equal to $4e$.

E. C. C. Baly† states that e may be taken as lying between 0·005 to 0·025 mm. This statement is not confirmed, however, by other workers. Sheppard and Mees‡ give grain as varying from 0·0011 to 0·0034 mm.,

* 'Astrophys. Journ.,' vol. 3, pp. 188 and 321, 1896.

† 'Spectroscopy,' p. 339.

‡ 'Roy. Soc. Proc.,' A, vol. 76, 1905, p. 218.

which figures agree with those given by Schaum and Bellach.* It is not difficult to make slow plates in which the grain does not exceed a diameter of 0·0005 mm. According to Wadsworth these plates should therefore resolve lines which are not more than 2/1000 of a millimetre apart.

As rough experiments showed at once that the resolving power of such plates did not exceed about 1/20 to 1/40 of a millimetre, the subject was thoroughly investigated in the manner to be described.

Apparatus.—A box was constructed of 16 cm. square section and 330 cm. length. This was screwed to a platform fastened to two heavy beams set edgewise, and the whole was suspended by ropes from the roof, thus eliminating vibration. At one end was arranged an illuminating Nernst lamp and condenser, together with the holder where the slit and gratings shortly to be described were placed. At the other end was screwed a camera built of heavy brass tube, and containing a spectroscopic objective of 15 cm. focal length actuated for focussing by a very slow motion screw. The camera and objective were specially made by Messrs. Adam Hilger, Limited, for the work, and the latter has proved perfectly satisfactory, the images formed by it showing no degradation when examined by a microscope with an enlargement of 100 diameters. The images used in this work were always axial, and did not exceed 3 mm. in diameter. Microscopic examination justified me in assuming that the definition of the image was perfect. At the back of the camera tube was a brass face-plate against which the brass front of the dark slide fitted. The plates were forced up into a constant plane by springs at the back of the dark slide. The whole apparatus consisted in essence, therefore, of a reducing camera arranged to give a reduction of about 22 diameters, and to maintain a very exact focal plane.

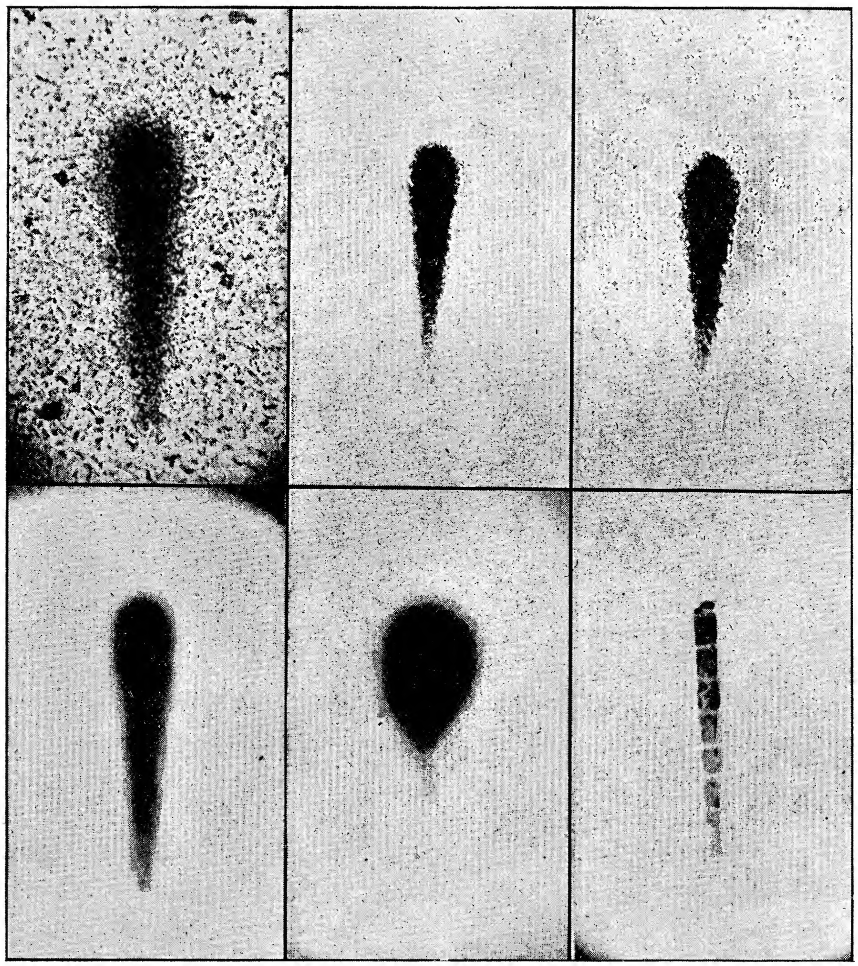
The Slit.—In order to discover what happens to a narrow line of light falling upon a plate, a spectroscopic slit was arranged at the end of the apparatus, and in front of the slit was placed a wedge of neutral black glass giving a variation of intensity in the length of the slit of about 1 to 60. The slit was 9 mm. long and 1 mm. in breadth, and the image was therefore 0·5 mm. high and 0·055 mm. wide. Since the top of the slit was transmitting 60 times as much light as the bottom, the spreading of light by the film of the plate (which is usually known as irradiation) caused the developed image to appear of a "tadpole"-like shape.

Plates backed and unbacked were used; the backing makes no difference, the effects measured being of a different order from those produced by reflection from the back of the glass.

* 'Die Struktur der Phot. Neg.'

All the plates used were of the same thickness. In the case of fast plates the results are not affected, within considerable limits, by the thickness of the film. In the case of slow plates it is explained later that the thinner the film the greater the resolving power.

Photomicrographs of the "tadpoles" obtained on various plates are shown below (fig. 1).



(*a*) (*b*) (*c*)

(*d*) (*e*) (*f*)

(*a*) Extra rapid plate.
(*b*) Process plate.
(*c*) Homogeneous grain plate.
(*d*) Lantern plate.
(*e*) Chlorobromide plate.
(*f*) Lippmann plate.

Fig. 1.

Now the grains of these plates are of the following orders of magnitude:—

An "Extra Rapid" plate	0·0015—0·004 mm.
A medium-speed "Process" plate	0·0010—0·0015 "
Homogeneous Grain (a special plate having all its grains of the same size)	0·0015 "
Chlorobromide plate	0·0008 "
A "Lantern" plate of silver bromide only	0·0004 "

It would therefore be expected that the amount of the irradiation would diminish steadily as the grain became smaller, vanishing in the very fine-grained plates. This is seen not to be the case at all: the irradiation is at a minimum in the medium-grained "Process," and "Homogeneous Grain" plates, being greatest in the chlorobromide plate.

It would therefore appear that irradiation is not due to one simple cause, but in all probability to at least two causes. These two forms of irradiation might be:—

(1) Irradiation due to reflection, operating in the plates of coarser grain, and to a much less extent in the plates of fine grain. This is the only form of irradiation which appears to have been recognised hitherto.

(2) Irradiation due to *diffraction*, operating in plates of fine grain, and only to a small extent in those of coarse grain.

These two separate causes of irradiation would produce the effects observed, since, as the reflection scatter disappeared, the diffraction scatter would grow, probably producing a minimum of scatter where the reflection scatter was small and the diffraction scatter was also small; and the scatter finally becomes small again as the grain of the plate falls below the wave-length of light.

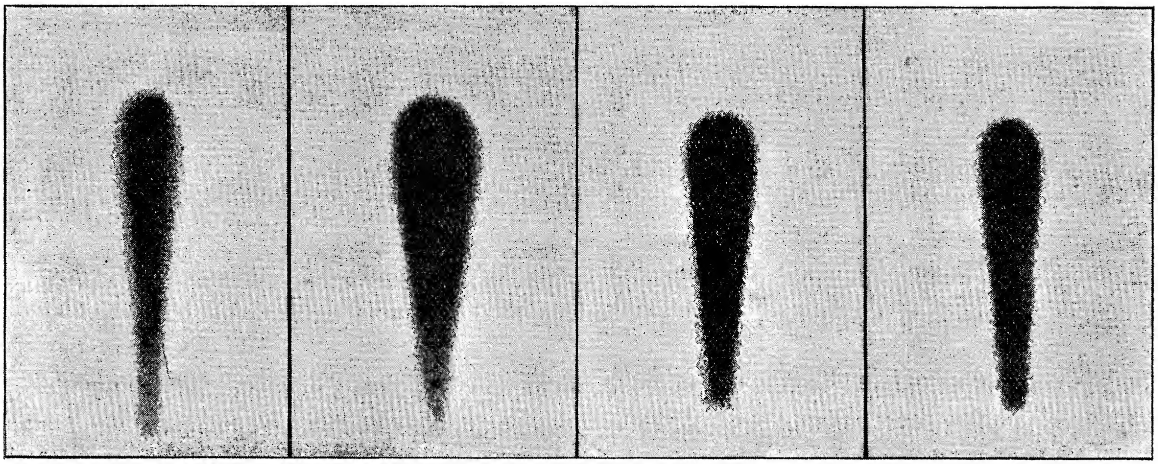
The effects produced by these two causes will differ:—

(1) Diffraction scatter will become less as the wave-length of the incident light increases. Reflection scatter will be unchanged by an alteration of wave-length.

(2) Diffraction scatter will be small upon the surface of the film, and will grow as the film is penetrated. Reflection scatter will be nearly constant throughout the film.

In order to investigate the first possibility, "Process" plates which were expected to show "reflection" scatter, and "Lantern" plates which were expected to show "diffraction" scatter, were made sensitive to red light by bathing them in a solution of pinacyanol. Two screens were then taken, the one, α, transmitting red light of from 660 to 720 $\mu\mu$; the other, θ, violet light of from 400 to 450 $\mu\mu$; and the slit was photographed on the two plates through the two screens. The result (fig. 2) shows that there is a very small, if any, difference between the results on the "Process" plate, but that on the "Lantern" plate the scatter is normal with the θ screen, but is greatly diminished by the use of the α screen.

Lantern plate. Process plate.



With a screen. With θ screen. With a screen. With θ screen.

FIG. 2.

In order to examine the second possibility, a photomicrographic apparatus was arranged behind the small camera, so that by opening the back of the dark slide the appearance of the image as scattered by the film of the plate could be photographed. This appearance, as scattered by the "Process" plate, is shown in fig. 3. No difference was observed in the image whether the front or the back of the film was photographed. But with a chloro-bromide plate (fig. 4) the scatter was small on the face of the film (4a) and great on the back of the film (4b).

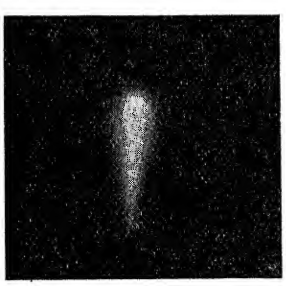
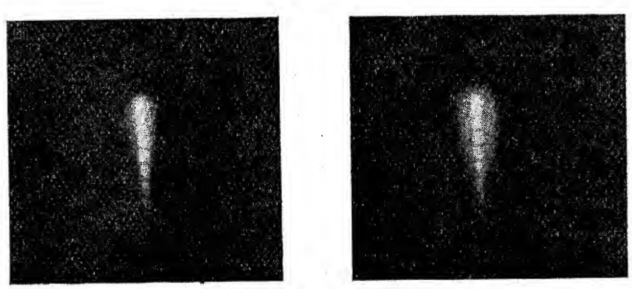


FIG. 3.



(a) (b)

FIG. 4.

We may therefore conclude :—

(1) That the resolution of a photographic plate is dependent on the amount of irradiation displayed by that plate.

(2) That irradiation is not directly proportional to the size of grain, but is caused by two different forms of scatter arising from (*a*) reflection and (*b*) diffraction.

(3) That the resolving power is likely to be much smaller than that indicated by the theory of Wadsworth.

In order to experimentally determine the resolving power, a series of black and white line gratings were constructed having alternate black and clear lines of equal width, the width of the clear glass being as in second column of table.

Grating.	Width of clear line in millimetres.	Distance apart of lines on plate in millimetres.
1	0·88	0·049
2	0·64	0·036
3	0·47	0·026
4	0·36	0·020
5	0·32	0·018
6	0·29	0·016
7	0·14	0·0078

After reduction in the camera (the grating being put in the place of the slit), these produced images in which the width of the black space (the distance between two lines) was as in third column.

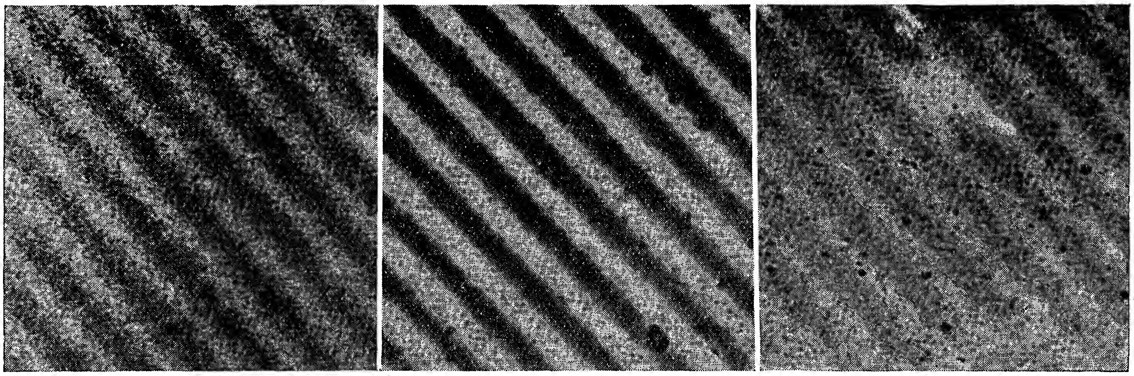
These gratings were then photographed upon the various plates and the effect observed. Some of the actual results obtained are shown as photo-micrographs in fig. 5 :—

I. Grating I was resolved by all the plates. Fig. 5—(*a*) shows effect on "Process"; (*b*) on "Lantern" with red light; (*c*) on "Lantern" with violet light.

II. On the "Process" plate and on the "Lantern" plate with violet light (460 to 400). No. 5 grating is just resolved. No. 6 not resolved. Fig. 6—(*a*) "Process" plate, No. 5 grating; (*b*) "Lantern" plate.

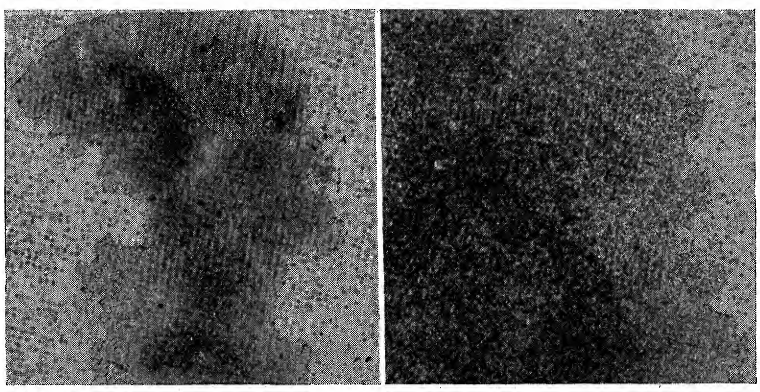
III. With screen on "Lantern." No. 7 just resolves. Fig. 7, *a*.
With (560 to 520). No. 6 resolves. Fig. 7, *b*.
With (520 to 470). No. 6 is just resolved (very faintly). Fig. 7, *c*.

So that the limit of resolution possessed by dry plates chemically developed may be stated to be as follows :—For an ordinary fine-grained plate, lines will be just resolved if they are separated by 0·018 mm. (For a coarser grain, as in all fast plates, about 0·030 mm. is necessary.)

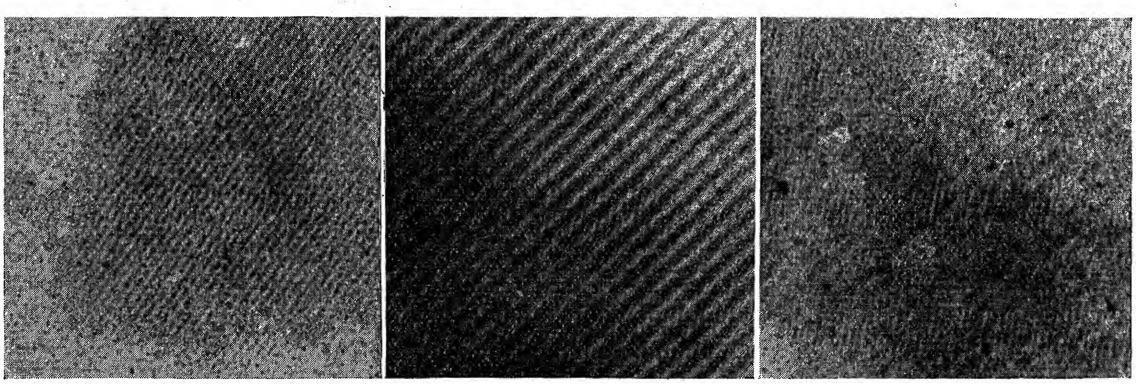


(*a*) (*b*) (*c*)

Fig. 5.



(*a*) Fig. 6 (*b*)



(*a*) (*b*) (*c*)

Fig. 7.

For very fine-grained plates for violet light, 0·018 mm. will be resolved; with red light, 0·008 mm. may be discerned.

The resolution *on the surface* of a fine-grained plate will obviously be much greater than this, as is shown by the very high resolving power possessed by the fine-grained "albumen" plates which are developed by the deposition of silver from an acid silver solution.

In order to discover whether or not a similar advantage would be shown by gelatine plates when developed in the same manner, the experiments on the resolving power of "Lantern" plates were repeated, the plates being developed in a solution suggested by Luppo-Cramer, namely:—

Metol, 2 grammes, to which is added, just before use, 10 c.c. of 10-per-cent. solution of silver nitrate.

Citric acid, 10 grammes.

Water, 100 c.c.

Although plates so developed show no trace of grain under 1/10-inch objective, yet the resolving power is not greater than in plates developed in the ordinary way.

This method of development enables us, however, to utilise gelatine plates having a very much thinner film than would otherwise be possible, and there was prepared on these lines a special plate, having the fine-grained lantern emulsion coated very thinly, and made panchromatic by bathing in pinacyanol. These plates are more sensitive to red than to blue, and seem to be suitable for photographic use in spectrographs of small dispersion.

With violet light it just resolves grating No. 7, corresponding to lines of 0·008 mm. separation; with red light lines of 0·004 mm. separation can be resolved. Fig. 8 shows grating No. 7 with red light on the special plate.

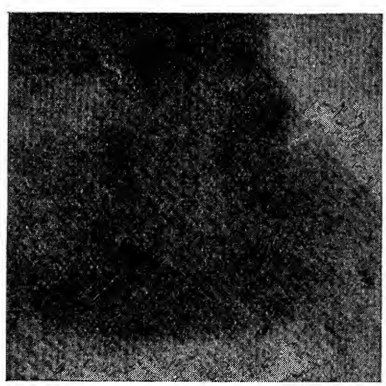


FIG. 8.

Application of these Results to Spectroscopy.—We have seen that in order to be resolved by an ordinary plate, lines need to be separated by 0·03 mm. Now, in the first order of a 6·5-metre focus Rowland grating of 14·438 lines per inch, 0·37 mm. length of the plate corresponds to 1 A.U.*

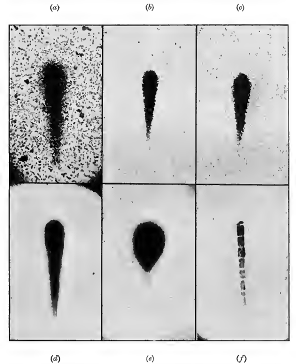
The plate will therefore just resolve lines separated by 1/10 of an A.U. Now, for a 5-inch grating the resolving power will be 75,000, or (at 5000 A.U.) 1/15 of an A.U. So that the limit of resolving power is fixed, even for spectroscopes of great dispersion, by the *plate* and not by the resolving power of the instrument. In the case of small spectroscopes having a dispersion of about 500 A.U. to 10 mm. on the plate, the resolving power is limited to about 2 A.U. With the special plate, this can be increased to 0·5 A.U., corresponding approximately with the resolving power of such small instruments.

The work on the effect of irradiation upon the diameter and position of spectral lines, star images, etc., is being continued.

My best thanks are due to Mr. E. J. Denney and Mr. Kenneth Hunter, who have made a great number of the measurements and photographs required, and also to Mr. S. H. Wratten, who has made many experimental plates. I am indebted also to Dr. L. N. G. Filon for his interest and advice.

My thanks are due to Messrs. Wratten and Wainwright, Limited, for permission to publish this work, which was done in their Research Laboratory.

* Baly, 'Spectroscopy,' p. 212.



(a) Extra rapid plate.
(b) Process plate.
(c) Homogeneous grain plate.
(d) Lantern plate.
(e) Chlorobromide plate.
(f) Lippmann plate.

FIG. 1.

Lantern plate. Process plate.

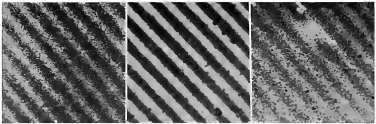
With α screen. With θ screen. With α screen. With θ screen.

Fig. 2.

Fig. 3.

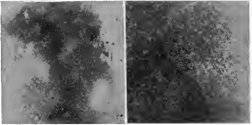
(a) (b)

Fig. 4.

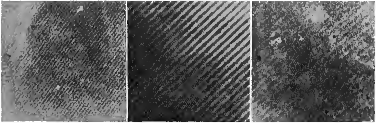


(a) (b) (c)

FIG. 5.



(*a*) Fig. 6 (*b*)



(a) (b) (c)

Fig. 7.

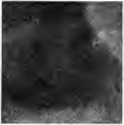


FIG. 8.