PHOTOGRAPHIC FILM SENSITOMETRY
Enlarger Photometer (Version 14.2 2019/02/19)

Contents

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INTRODUCTION

This document is primarily for users with an enlarger photometer manufactured by MCA Electronics.

Using a precision *enlarger* photometer removes all requirements to make corrections for Callier effects produced by the enlarger.

This instrument removes much of the complexity associated with the alternative bench_densitometer_13_1 document as in that case, it is necessary for the photographer to either measure Callier corrections for their enlarger or use generic values.

Photographers are encouraged by film manufacturers to determine their own development times and techniques using their own equipment.

However, without the facility to measure film density, this can be rather hit and miss especially when things go wrong.

The ability to make measurements of film parameters and then analyse the results with a simple spreadsheet will provide the photographer with all the essential information to optimise their processing and to compare their results with others and the manufacturer.

Once the correct basic information has been determined, photographers are then free to experiment with confidence.

The following is provided:

1. Lists of equipment required.

2. Detailed experimental procedures and worksheet templates for a variety of film speeds.

3. Two spreadsheets. A simple version that uses manual calculation methods and does not require curve fitting. This is probably accurate enough for most practical photographic uses.

The other version uses a similar curve fitting program to the one used for the bench densitometer processing and therefore produces a full set of data for the enlarger used to make the measurements.

EQUIPMENT REQUIRED

1. A suitable 35mm camera, preferably with electronic shutter, full manual control, and a normal or 85 - 100 mm short telephoto lens, preferably f/2 but f/4 can be giving a reduction of 1 stop in the measurement range. A typical low cost example would be an Olympus OM10 with manual adapter .

2. A photographic light meter, incident reading or spot metering.

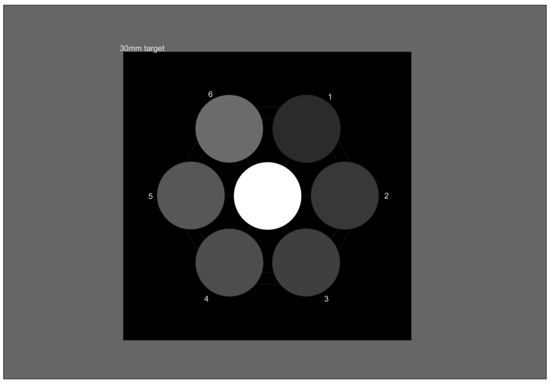
3. An A4 test card with 3 stop range in half stop intervals. A typical design is shown in this document. A calibrated version is provided with the enlarger photometer and replacements can be purchased via ebay.

4. Two suitable lights such as modern studio fluorescent types, with 3 x 135W lamps. A maximum exposure level of 10 EV is required.

PHOTOGRAPHING THE TEST CHART AND CURVE FITTING

Appendix 2 shows a typical lighting arrangement for photographing the test chart.

Two test charts are available, large and small. The small chart has 30 mm circles of test tones and the large chart has 75 mm circles. The type used depends on the measurement circle in the densitometer / photometer.



Typical test chart

Table 1 shows a sample set of results ready for entry onto the spreadsheet.

CURVE FITTING TO MODEL THE TEST DATA

A program (currently fproc14_1.exe), written in c, is provided for this stage together with a sample text file (fproc_data_14_1.txt) into which the test data is entered. Notepad or a similar text editor can be used for this purpose.
The spreadsheet calculates the film density from the test data (see Table 1A) and this is copied and pasted into the file “fproc_data_14_1.txt”. See Tables 1A and 2.

The program uses an iterative process to arrive at a best fit to the data. The film is modelled as a sigmoid (S function) using the well known 3 PL or 3 Parameter Logistic equation.
To get a better fit at low density levels, around a density of 0.1 to 0.3, the program automatically runs again using a different custom equation, fits the data again to a restricted data range and determines the speed point and related parameters.
This is an important parameter giving the relative exposure at a density of 0.1 which is usually close to the start of the useful exposure range.

An explanation of the text file is given in Table 2.

Early versions of the program used a variety of well known sigmoid equations. The 5PL equation has the most parameters available for adjustment but it still has difficulties achieving a good fit around the speed point with underdeveloped films, and with unusual films such as Fuji Acros.

See Appendix 1 for more details.

TABLE 1: PRIMARY TEST DATA EXAMPLE

This example is a 4 frame test chart and can cover up to 12 stops range with correct exposure.
The photometer is easily capable of accurately measuring densities above 3. In practice, information above a density of 2 to 2.5 is somewhat academic as we should aim to be printing up to a maximum density of 1.5 (with a diffuser enlarger). This would only be exceeded if the negative is overexposed.

Both 3 and 4 frame tests give enough practical information covering 9 to 12 stop range. Other versions are available but this version minimises the number of frames and can be used with f/4 lenses.

4 FRAME TEST WITH ENLARGER PHOTOMETER 100 ISO EV9

FILM: ____ DATE: ____ LENS: ____ CAMERA: ____

DEVELOPER: ____ TIME: ____ (20C) ASSUMED FILM SPEED: 100

AGITATION: Ilford Std / Continuous ENLARGER: ____

Incident Exposure Meter Grey Card Reading (EV100)*: 9 **Centre Exposure: 1/8s f/8** (100ISO,normally 1/15s f/8)

TEST DESCRIPTION:

* 100ISO, EV10 = 2560 lx 400ISO, EV8 = 640 lx

NOTES:

RESULTS

SP :
Av. Grad. :
Max. Grad. :
Fitted Grad. :
$\overline{G}$:
G2 :
Overall Av. Grad. :

EXPOSURE SCHEDULE

18% Grey

Aperture				f/16						f/8						f/4						f/4		
Shutter Speed				1/30						1/15						1/8						1		
Frame	1	2	3	1 4	5	6	1	2	3	2 4	5	6	1	2	3	3 4	5	6	1	2	3	4 4	5	6
Exp. H	.15	.30	.45	.6	.75	.9	1.05	1.2	1.35	1.5	1.65	1.8	1.95	2.1	2.25	2.4	2.65	2.7	2.85	3.0	3.15	3.3	3.45	3.6
Linear Dens. Reading																								
Log. Dens. D																								

Reference: B+f: Leader: photo_record.cdr page 8

Table 1A

FILM 1

	reading V	rel. Exp H	rel density D
No Film	1.7090		
Base+fog	1.0570		0.209
density reading 1	1.0570	0.000	0.000
2	1.0570	0.151	0.000
3	1.0500	0.301	0.003
4	1.0430	0.452	0.006
5	1.0110	0.602	0.019
6	0.9630	0.753	0.040
7	0.8450	0.903	0.097
8	0.7680	1.054	0.139
9	0.6420	1.204	0.217
10	0.5560	1.355	0.279
11	0.4560	1.505	0.365
12	0.3070	1.806	0.537
13	0.2240	2.107	0.674
14	0.1650	2.408	0.807
15	0.1140	2.709	0.967
16	0.0830	3.010	1.105
17	0.0665	3.311	1.201
18	0.0417	3.612	1.404
19	0.0307	3.913	1.537
20	0.0152	4.214	1.842
21	0.0076	4.515	2.144
22	0.0060	4.816	2.246
23		6.000	2.440

Copy and paste into fproc_data_13_1.txt (see Table 2)

TABLE 2. fproc_data_14_2.txt file parameters Version 14.2 and above

```
FILM TEST ACROS 6m40s ID11b 1:1 10/8/16
max number data pairs: 40
number of spdata pairs: 8
enlarger correction: 2 1.1244 0.8138
coefficients a_f: 3.4 -4 0 0 0 0
SP coefficients a_f: 0 4 1 3 .001 0
break_point1 break_point2: 6000 1000
start increment: 0.0001
SP start increment: 0.00005
increment mult/minimum: 1.0   0.000001
iteration limit: 50000000
max R Square main/SP/diff:  0.998  0.90 0.00002
lower_upper multipliers for averaging gradient: 0.7 0.9
upper printable densities: 1.2 1.5
fractional gradient coefficient: 0.3
paper coeff a-g: 0.0107 6.88 2.75 1.98 25.2 2.2 2
min paper gradients lower upper: 0.45 0.15
paper key densities: 0.04 1.85
weighting: w
output file name: fproc_data_out.txt
x        y        data pairs
0.000    0.000
0.151    0.000
0.301    0.003
0.452    0.006
0.602    0.019
0.753    0.040
0.903    0.097
1.054    0.139
1.204    0.217
1.355    0.279
1.505    0.365
1.806    0.537
2.107    0.674
2.408    0.807
2.709    0.967
3.010    1.105
3.311    1.201
3.612    1.404
3.913    1.537
4.214    1.842
4.515    2.144
4.816    2.246
6.000    2.440
```

Film description, 60 characters maximum.

Maximum number of data pairs

Coefficients used for Callier correction and enlarger type

These are start values for the main iteration process

These are start values for the speed point calculation.

Break point 1 sets the number of times the whole iteration process runs. After this point, the increment value is reduced and the process continues. Break point 2 is not used.

Main start increment value

Speed Point start increment value

The start increment is multiplied by the first parameter at the end of each break point until the minimum is reached and no further reduction takes place.

The iteration process stops when this is exceeded.

This is R Square, a ‘goodness of fit’ measurement. Iteration stops when these limits are reached.

coefficients for average gradient calculation

coefficients for gradient G2 calculations

This defines the ratio of the average gradient to the minimum useful gradient. See text for more details.

paper coefficients for overall simulation

minimum gradients for overall response

Key densities for ISO paper grades

"s" = Normal sum of squares error weighting
"w" = weighted sum of squares, weight = 1/y
"l" = sum of absolute is used
“w” weighting is preferred.

The output from the program is displayed on the screen and saved in the file specified here by the user.

Enter your exposure / density data here.

Note that half stop intervals are used at low exposure levels to increase the accuracy of the simulation around the speed point.

This line is the density of the developed film leader on the sample. It is at best an estimate and can be omitted. This represents the maximum density asymptote.
The x value is normally 6 to 10 to ensure a well defined

Text added after the data is ignored by the program.

The important point is that the user can change the data pairs, number of pairs and the output file name and leave the more technical parameters alone.

The first x y pair can include x=0 but this is not allowed in any other line. If x=0 in any other pair, a fatal warning will occur.

Note that if the number of data pairs entered is greater than the number present, the program will read x=0 and also abort.

Appendix 1 outlines the installation of the program and the text file and general information about the equations used.

Note the program will terminate when the required value of R Square have been met or if the number of iterations is greater than the iteration limit.

TABLE 3. Typical output file parameters fproc_data_out.txt

```
FILM OUTPUT DATA   build 3-03-2018  VERSION 11.3
FILM TEST ACROS 6m40s ID11b 1:1 10/8/16
5PL Sigmoidal HYBRID CURVE FITTING PROGRAM
Processed Thu Apr 12 13:59:43 2018

Coefficients a - e:  2.440655e+000 -3.188594e+001 5.026684e+000 -2.273390e-002
4.911671e-002

x          y          calc y      error       pc error

0.000000  0.000000  -0.001674   0.001674   -1.#INF00
0.151000  0.000000  -0.001626   0.001626   -1.#INF00
0.301000  0.003198   0.000074   0.003124   -97.671562
0.452000  0.006396   0.008232  -0.001836    28.698165
0.602000  0.020254   0.026799  -0.006545    32.315826
0.753000  0.042640   0.057592  -0.014952    35.065616
0.903000  0.103402   0.099912   0.003490   -3.375405
1.054000  0.148174   0.153087  -0.004913    3.315432
1.204000  0.231322   0.214845   0.016477   -7.123020
1.355000  0.297414   0.284403   0.013011   -4.374574
1.505000  0.389090   0.359370   0.029720   -7.638227
1.806000  0.572442   0.522452   0.049990   -8.732827
2.107000  0.718484   0.695890   0.022594   -3.144685
2.408000  0.860262   0.873993  -0.013731    1.596109
2.709000  1.030822   1.052927  -0.022105    2.144418
3.010000  1.177930   1.230164  -0.052234    4.434402
3.311000  1.280266   1.404070  -0.123804    9.670176
3.612000  1.496664   1.573621  -0.076957    5.141905
3.913000  1.638442   1.738209  -0.099767    6.089123
4.214000  1.963572   1.897506   0.066066   -3.364571
4.515000  2.285504   2.051377   0.234127   -10.243980
4.816000  2.394236   2.199815   0.194421   -8.120394
6.000000  2.601040   2.733137  -0.132097    5.078635

Residual Sum of errors: 0.051874  R Square: 0.994567
Number of iterations : 18011807

Other data: Main cycles - SP cycles  13   19
-------------------------------------------------------------------
SPEED POINT DATA ( 5PL Data )
Exposure for speed point of 0.1 : 0.921300

Coefficients a - e:  1.776251e+000 -1.479063e+000 7.099799e-001 1.015252e-003
5.562133e+000

x          y          calc y      error       pc error

0.000000  0.000000   0.001015  -0.001015    1.#INF00
0.151000  0.000000   0.001018  -0.001018    1.#INF00
0.301000  0.003198   0.001400   0.001798   -56.226970
0.452000  0.006396   0.005340   0.001056   -16.509413
0.602000  0.020254   0.019306   0.000948   -4.680626
0.753000  0.042640   0.048625  -0.005985    14.035639
0.903000  0.103402   0.093590   0.009812   -9.489241
1.054000  0.148174   0.152035  -0.003861    2.605595

Residual Sum of errors: 0.001748  Number of iterations: 9379934
Maximum gradient = 0.5951
Fractional gradient density = 0.0166   Fractional gradient exposure = 0.6536
Upper frac grad exposure = 17.54   Film dynamic range (stops) = 56.13

Ilford Gbar: Overall Av. grad: Linear grad: Gradient G2: DR min grad method: DR key
density method: SP Exp. Paper Grade

0.52 0.96 0.70 0.90 6.25 6.36 0.92130 2.00
Enlarger corr. (0 = no correction, 1 = cond, 2 = diff):  2
-------------------------------------------------------------------
```

Table 2 explains most of the parameters shown.

As the program runs twice, there are 2 sets of coefficients a - e.

As this is an ACROS film, the fit gets progressively worse as the toe is reached.

pcerror is a percentage error. In the main section, the error settles down to a few percent.

In the speed point data below, the error is reduced to a few percent at and around speed point values giving an excellent estimate of the speed point.

The fractional gradient data is somewhat academic and will be discussed in later sections.

The coefficients and parameters in red are intended to be copied and pasted back into the spreadsheet.

These are the only results that need to be copied into the 'minimum' spreadsheet

MINIMISED SPREADSHEET DETAILS VERSION 13

Version 13+ software adds a number of more complicated calculations to the external c program. This all relates to our main objective, matching film to paper.

The alternative minimised spreadsheet contains the original measured data for a number of film types. Each set of data has been processed and the output data copied into the spreadsheet.

If you want to add your own test data, follow the procedure below.

If your data was measured using an enlarger densitometer, then no Callier correction is necessary for that enlarger.

The output file displays the input and simulation output data and coefficients. The input data is after any Callier correction has been applied. The bottom section has a summary which is all that is required by the spreadsheet. It is shown below:

```
Ilford Gbar: Overall Av. grad: Linear grad: Gradient G2: DR min grad method: DR key density
method: SP Exp. Paper Grade

0.43 0.81 0.60 0.90 7.24 7.66 0.80780 2.00          copy and paste this line into the spreadsheet
Enlarger corr. (0 = no correction, 1 = cond, 2 = diff):  2     this line indicates the enlarger type
```

Repeat for other film development times and the spreadsheet can then provides 3 sets of modelled output data:

1. Ilford Gbar at different development times.
2. Average Overall and related gradients at different development times.
3. G2 gradient at different development times.

Together with the estimated relative film speeds given in the spreadsheet, this is all the photographer needs.

This spreadsheet also provides coefficients for the full range of available grades to enable other combinations of film and paper to be tried. (See ‘paper coeff a-g’ in ‘fproc_data_xxx.txt’)

MAIN SPREADSHEET DETAILS VERSION 13.1 , 14.1

ENTERING DATA INTO THE SPREADSHEET Page 1 'Film'

Note data can normally only be entered into yellow fields. The rest is password protected to prevent accidental corruption. The password is included at the top of the spreadsheet.

<u>Copy and Paste in OpenOffice Spreadsheets</u>
A line of coefficients can be copied from the output file as follows:

1. Copy the line of text
2. Paste into the first coefficient (a). At this point all the coefficients appear in the same cell.
3. Click on the Data menu and select 'Text to Columns'
4. Enable 'Space' as an extra separator followed by OK and the data should be updated into the row of cells.

Cells are colour coded as follows:

light cyan	calculated fields
yellow	data that must be entered
light purple	optional comments
light blue	constants

The locations below, which are coloured yellow in the spreadsheet, are required to complete all the calculations.

Section 1.0
Film development times plus other details

Section 1.1
Input Test Data is saved here for each film.
Line 23 extends the data by adding an artificial asymptote.

Section 1.2
Enter the main equation coefficients from the curve fitting program in this section.

Section 1.3
Enter the speed point equation coefficients in this section.

Section 1.4
Processing constants and the film assumed film speed
Unless there is a good reason, use the manufacturers normal speed recommendation.

Section 1.5
If required, add other initial parameters from the iteration program as follows :-

line 2. Fractional gradient exposure
line 3. Upper fractional gradient exposure
These are now considered to be of academic value only.

The following sections do not require data entry

Section 2.0
Any gradient calculations and summary

Section 2.1
Printable dynamic range summary

Section 2.2
Film speed calculations

Section 2.3
Film base+fog summary

Table 3.0
Gradient modelling data

Table 3.1
Film speed modelling data

Table 3.2
Printable dynamic range modelling data

Major Version 12 and 13 Additions

The zone system attempts to tailor scene dynamic range to the process of making a black and white print. This project was started in an attempt to identify and impose objective measurements in photography on to a coherent system from scene to print. It was clear that the zone system still relied heavily on the photographer's experience and good judgement at all stages and was therefore unacceptable.
The initial reaction to this problem was based on defining film dynamic range and how much of it that we can print with little examination of photographic paper characteristics. It quickly became clear that altering the dynamic range of negative or print altered the final tonal scale in an unacceptable manner.
This led to a change of direction and the abandonment of dynamic range and overall gamma as workable ways to control print quality.

Why Did The Overall Gradient System Fail ?

The 'overall gradient method' highlighted the following:

1. Film dynamic range, described previously as printable dynamic range, has little effect on the overall print dynamic range. However, film gamma affects the overall gamma as much as the paper gamma. This is a simple consequence of the overall gamma being a multiple of film and paper gammas.

2. In practice, with regard to overall gamma, it was shown that there is little to be gained by altering film development times. Changing paper grades was the preferred method to alter the final gamma of the print. There is still a different optimum development time for condenser and diffuser enlargers. Other procedures are also still available such as dodging and burning in the print and, in difficult cases, using filters to alter the effective dynamic range on the film.

Why Did It Not Give Good Prints ?

Test photographs of typical scenes in a variety of lighting conditions with an overall gradient of 1 showed the flaw in the method. The film gamma, when printing on grade 2, is too low and the problem is easy to see when we photograph a white card and grey card together in a scene and print it.

If we use a print time that renders the grey card correctly, the white card prints an unnatural grey tone. If we use a print time that renders the white card correctly, the grey card is too light. The film is underdeveloped.

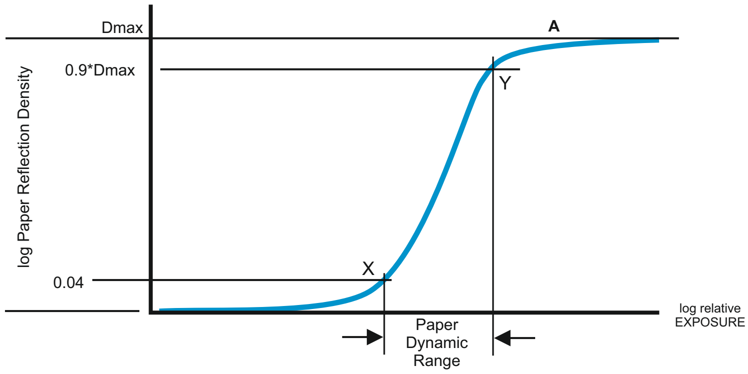
We need to consider a more appropriate measure of film gradient according to the following suggested criteria:

- 1. It must directly address the range of the film characteristic curve that has the greatest impact on our final image.

ISO PAPER GRADE
Key Points

The ISO Grade is defined as:-

100 x log paper dynamic range



- 2. The gradient vs development time should ideally be as linear as possible over a significant time range for example, 2 :1, typically 7 to 14 minutes
- 3. The rate of change of gradient with development time should be as high as possible.
-

The Solution: Gradient Measurement G2

We already have the following gradient definitions provided by the program and spreadsheet:

Ilford $\overline{G}$, Maximum gradient, Average gradient, Overall Average gradient

In the light of the above, a new gradient may be preferable, which we will call G2, This is shown on the graphs on the following page. It is the gradient from where the grey and white cards sit on the characteristic curve and will be seen to satisfy the 3 criteria above. The theoretical values are calculated in Figure 1.

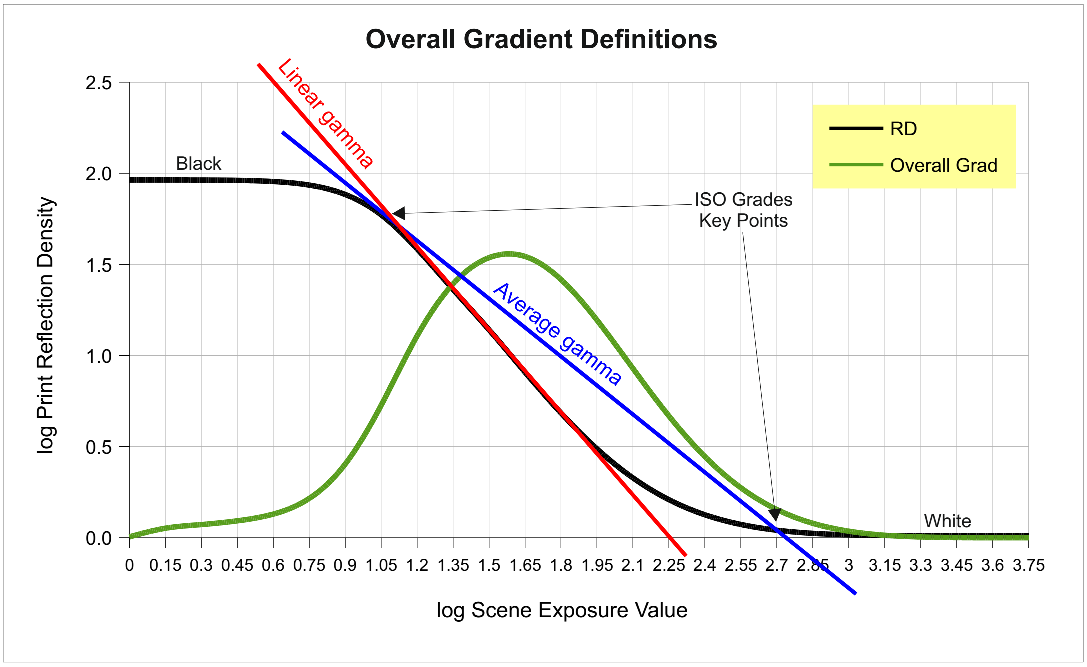
The characteristic curves shown below (page 12) are for Panf+, developed for 6 minutes and 7.5 minutes, in ID11b, 1 to 1 dilution. Film 1 gives an overall gamma close to 1.0 and a $\overline{G}$ of 0.55 as suggested on the previous page. The location of the exposures for a white and grey cards are shown. The grey card is assumed to be 2.5 stops down from the white card. The density and exposure values are actual values.

As you can see, in film 1, the grey card is not in the centre of the density range and will print too light whereas film 2, has the correct calculated value for G2 and a correct density for the grey card.

There is good correlation between Ilford $\overline{G}$ and G2. G2 is typically 15% greater than $\overline{G}$. Some film / developer / agitation combinations deviate considerably from this rule. This always occurs when a significant change of development time, i.e. as much as 30 - 40%, produces little change of G2. See FP4 in Rodinal for a good example.

Constant Agitation

A further problem was noticed when fully exposed rolls of 120 test films were used. At this stage, each roll of 120 film incorporated a test frame with a grey and white card. Normal film testing uses short lengths of 35 mm film developed in a spiral tank. With the 120 film test, it was clear that the film gamma was not as high as expected from the partial 35 mm tests. The close proximity of the spirals in the film holder were suspected of



limiting the access to fresh developer with standard Ilford agitation.
The high G2 gamma requirements of 0.9 for diffuser enlargers was difficult to obtain with some film, developer and agitations combinations. Also spiral tank data is not compatible with tray development of large format negatives, which normally uses constant agitation, and so it was decided to repeat selected film testing with continuous agitation and to adopt this agitation method for future tests and general use.
The graph data shows that G2 consistently satisfies our requirements for a linear gradient except when the original data has short a development time (PanF+). In practice, G2 is calculated in the fproc programs by finding the expected density of the grey card at an exposure related to the white card density called the Upper Printable Density (see Fig. 1 below). In the data text file this is currently set at 1.2 for condenser and 1.5 for diffuser enlargers.

Table 2 shows a comparison of the gradient values at different development times for a selection of films.

Test Chart Calibration (from versions 13.1 , 14.1)

Each test chart is supplied with reflection coefficients for each half stop increment. This data is entered in to the calibration section of the spreadsheet and the final corrected values are used as exposure data for the test.

Figure 1

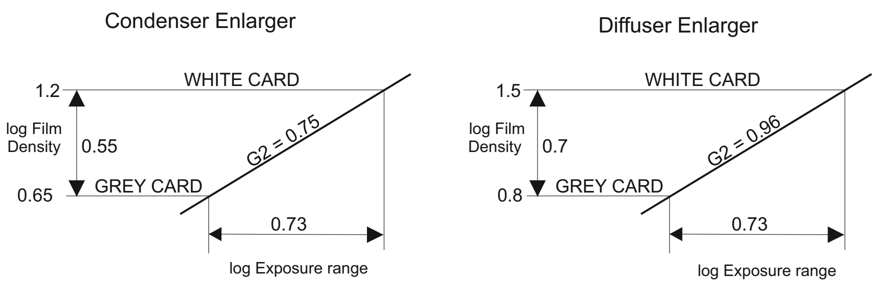
Theoretical Exposure Range

White card reflectance = 97%

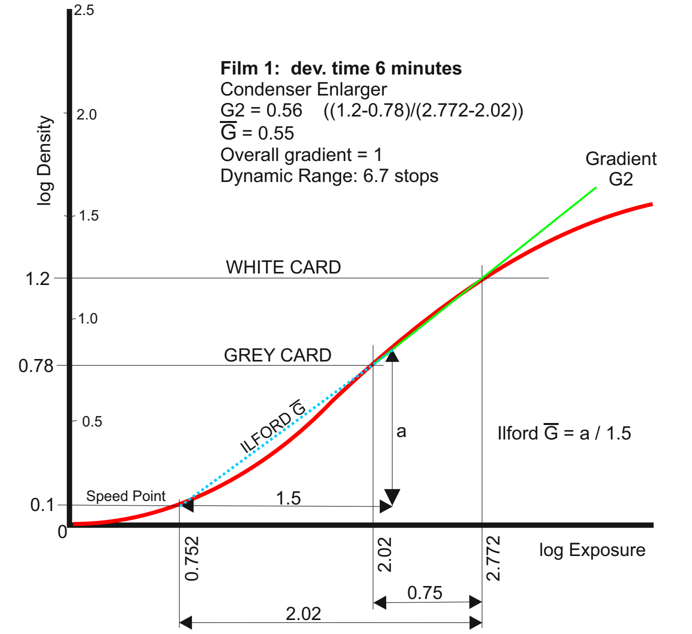
Grey Card Reflectance = 18%

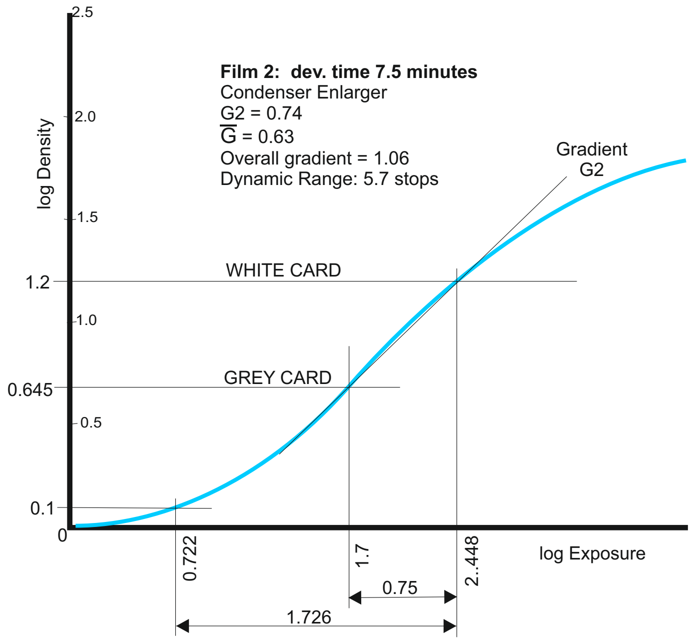
log Exposure Range = log (18/97)

= 0.73



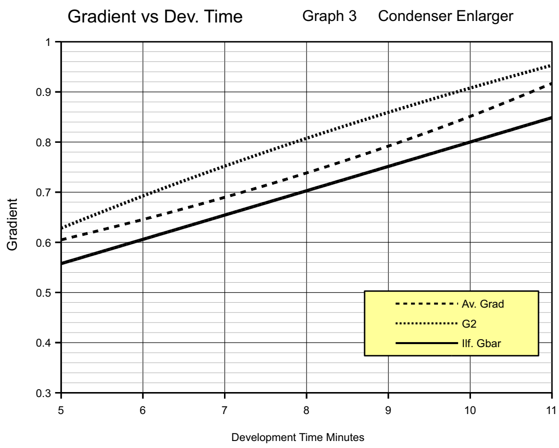
Graphs Relating To Overall Gamma Failures and G2

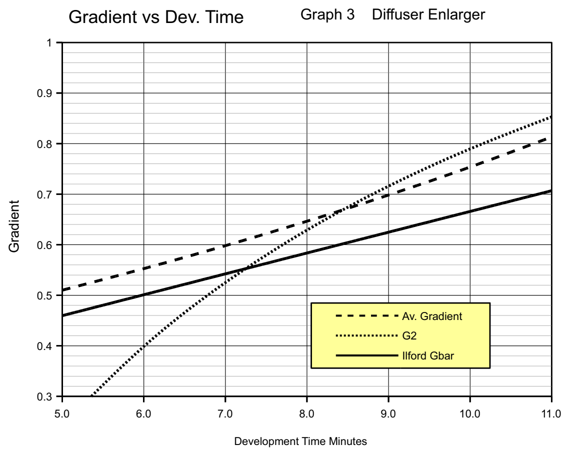




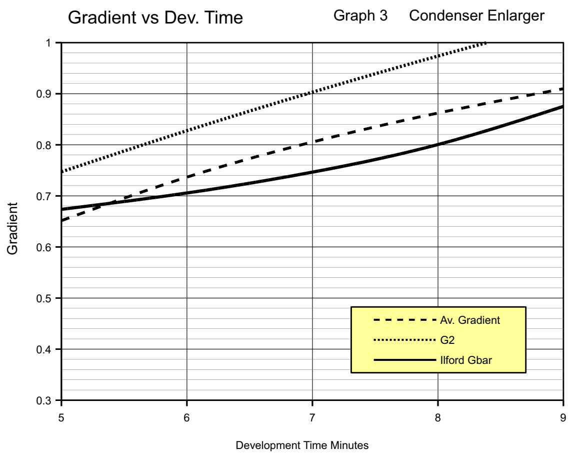
Example Negative Gradient Graphs Including G2

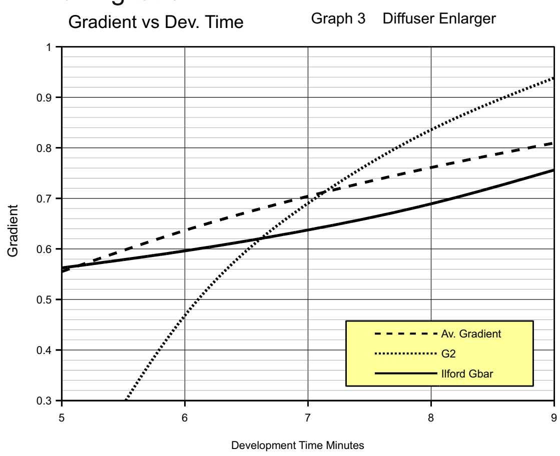
Delta 100 ID11b 1:1 Full Agitation



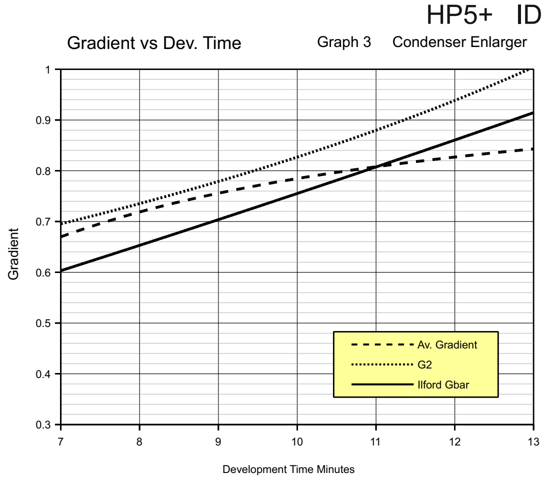


PanF+ ID11b 1:1 Full Agitation





HP5+ ID11b 1:1 Full Agitation



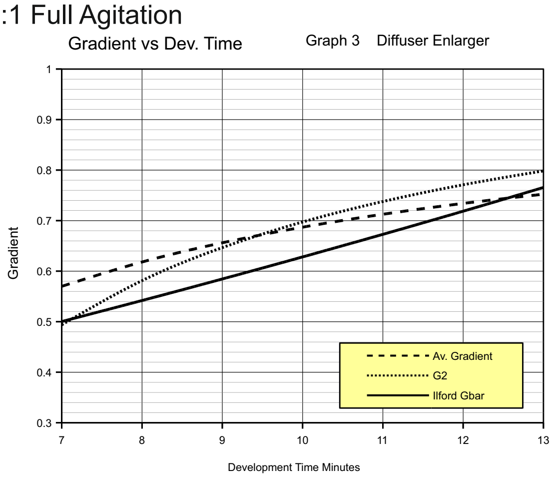


Table 2 *Comparison of gradients*

	Condenser Enlarger (Constant Agitation)								
	Delta 100			PanF+			HP5+		
Dev Time	**5**	**7**	**10**	**5**	**7**	**10**	**7**	**9**	**12.75**
$\overline{G}$	0.56	0.65	0.80	0.67	0.75	0.99	0.60	0.70	0.90
G2	0.63	0.75	0.91	0.75	0.90	1.10	0.70	0.78	0.99
Average G	0.61	0.69	0.85	0.65	0.81	0.95	0.67	0.76	0.84
Max. G	0.66	0.76	0.95	0.80	0.95	1.22	0.70	0.79	1.01
Overall Average	0.99	1.09	1.23	1.14	1.19	1.42	1.02	1.13	1.38

	Diffuser Enlarger (Constant Agitation)								
	Delta 100			PanF+			HP5+		
Dev Time	**5**	**7**	**10**	**5**	**7**	**10**	**7**	**9**	**12.75**
$\overline{G}$	0.46	0.54	0.67	0.56	0.64	0.85	0.50	0.58	0.75
G2	0.24	0.53	0.79	0.09	0.69	1.02	0.49	0.65	0.79
Average G	0.51	0.60	0.75	0.56	0.70	0.85	0.57	0.66	0.75
Max. G	0.55	0.64	0.82	0.66	0.81	1.06	0.60	0.69	0.85
Overall Average	0.87	0.96	1.10	1.01	1.09	1.31	0.91	1.00	1.22

Most films have a fairly linear relationship between G2 and $\overline{G}$. Tables and graphs are included in version 13 spreadsheets.

Suggested Development Time Based on G2 CONSTANT AGITATION		
	Condenser (G2 = 0.73)	Diffuser (G2 = 0.9)
Delta 100	6.62	11.85
PanF+	4.80	8.59
HP5+	7.87	19.08 (extrapolated)

13.8 = 13m 48s

Testing G2 Gradients

A photograph was taken on Delta 100 5x4 sheet film which included a white card, Kodak grey card and black card all mounted vertically. Exposure values were determined using a Pentax spot meter reading from the grey card. The photograph was taken in full sun and the negative was developed in ID11b 1:1 for the calculated 11.87 minutes at 20C, in a 5x7 tray with full continuous agitation and 150 ml of developer.
The negative was printed at grade 2 on Ilford Multigrade glossy paper using a modified DeVere 101 enlarger.
The density measurements of the cards, negative and print are as follows.

Negative Densities:

	densitometer	corrected diffuser density
Black card	0.80	0.72
Grey card	1.17	1.03
White card	1.74	1.55 (target density = 1.5)

Card Reflection Densities:

Black card (4%)	1.40
Grey card (18%)	0.74
White card	0.0 (reference)

Print Reflection Densities: (print time adjusted to give accurate grey card density)

Black card	1.60
Grey card	0.74 (reference)
White card	0.07

The black density for the print time used was 1·95 which is essentially the paper maximum.
.
The printed white card is slightly but acceptably grey as expected. The higher print density for the black card is probably mainly due to the printing paper non linearity.

<u>Conclusion</u>
The overall print measured accurately in the black and white key points and the subjective impression of the print was an accurate replica of the original high contrast scene including, surprisingly, good shadow detail 4.5 stops below the white card exposure value.

CONVERTING ID11b DEVELOPMENT TIMES TO ID11

Condenser Enlarger:

$$\frac{\text{Development Time in IDllb 1:1}}{\text{Development Time in stock ID11}} = 1.83$$

Condenser Enlarger:

$$\frac{\text{Development Time in IDllb 1:1}}{\text{Development Time in ID11 1:1}} = 1.42$$

Diffuser Enlarger:

$$\frac{\text{Development Time in IDllb 1:1}}{\text{Development Time in stock ID11}} = 1.66$$

Diffuser Enlarger:

$$\frac{\text{Development Time in IDllb 1:1}}{\text{Development Time in ID11 1:1}} = 1.29$$

The above ratios are based on comparing Ilford $\overline{G}$ at 0.64 for condenser enlargers and 0.52 for Diffuser enlargers.

APPENDIX 1a

INSTALLING CURVE FITTING PROGRAMS

Here are typical installation instructions for Windows 10.

These are fast executable programs written in c and run in “command mode”.

1. Download the file, photometer_14_2.zip which contains all the files for the 14.2 release.

   RIGHT CLICK on the download box "photometer_14_2.zip" at the bottom left hand of the page and select "Open in Folder”

   Copy the zip file.

2. Open Windows Explorer. If your user name was xxx, clear the current location using backspace and type the following

   \users\xxx

   The location should now say
   > This PC > Local Disk (C:) > Users > xxx
   which is really
   C:\Users\xxx>

3. Right click anywhere in the window and create a new folder called “fproc”

4. Paste the zip file into this folder and unpack it there.

5. Copy the batch file “fproc_14_2.bat" , back up into the previous location “\Users\xxx” and paste the batch file there.

6. Now shift into command mode. Hold down the “Windows” key and press R. Enter “cmd” into the text box and press enter. The black command window should now open with the following text:

   C:\Users\xxx>

7. Type “fproc_14_2" on the command line and the batch file will run. Press enter and the program "fproc_3pl-14_2" should run.

Output data is saved in the output file "fproc_data_out_14_2.txt" in the "\Users\xxx\fproc" folder.

The program can be repeated in command mode by pressing the up key followed by enter.

Appendix 1b

THE 3 PARAMETER LOGISTIC EQUATION FOR FILM CURVE FITTING (VERSION 14.2)

$y = a/(1+(x/c)^b)$ y = film density, x = relative exposure
a, b and c are coefficients

This simplified sigmoidal equation, gives a good fit, at least as good as the related 5PL equation when the whole shoulder is not of interest. A fit is achieved very quickly without the risk of multiple solutions and one parameter balancing out another giving the risk of a poor fit.
From version 13.1 and 14.1, a custom equation is used for the toe region called the Hyperbolic X ((C) MCA Electronics) shown below.

$$y = (a + b*x^d) / (c + x^{d-1})$$

THE HYPERBOLIC B EQUATION

$$y = (a + b*x) / (c + x)$$

This equation has been adopted for the spreadsheet post processing of data for graphs.

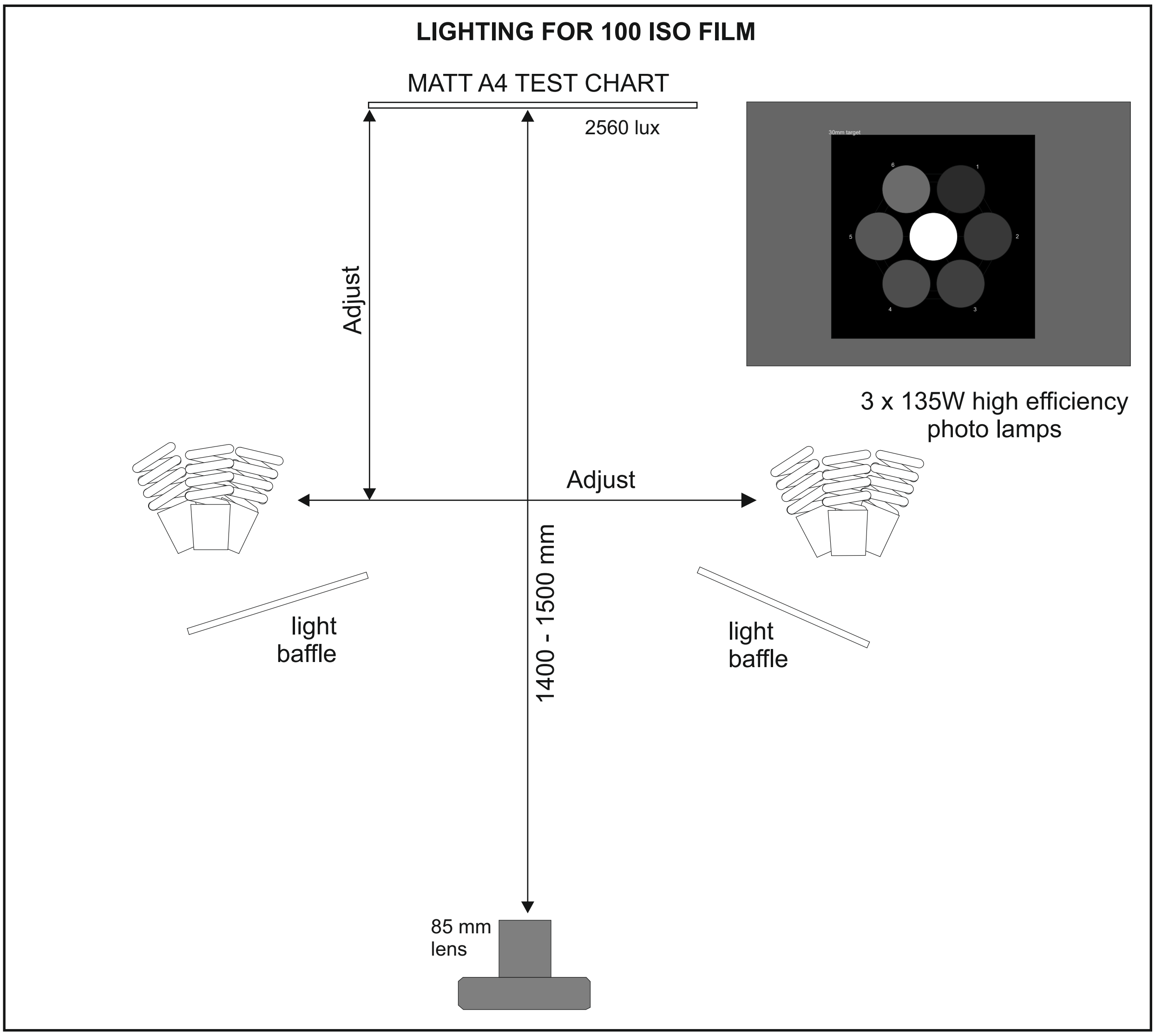
x is usually a development time, y may be a gradient type, film speed or similar parameter that is modelled from 3 data pairs corresponding to 3 different development times.

The hyperbolic B equation is normally a more natural fit to this data and having 3 coefficients, and can be made to fit the data exactly. Coefficients are all calculated automatically by the spreadsheet.

APPENDIX 2

Exposure of the Test Film, Version 13 and above

Version 13 and above makes use of a different design of test chart as shown in the example below (copyright MCA Electronics). The circular arrangement, if placed in the centre of the film, minimises and equalises the effects of any slight vignetting when the image is photographed or projected.



FOR 100 ISO FILM
The light source can be adjusted to give an incident exposure reading of 10 EV_{100} or a light reading of 2560 lux evenly across the test chart which is approximately the centre of the dynamic range of interest.
A centre point exposure of 1/15s at f/8 is normal with 100 ISO film. Using 6 frames, 18 measurements are obtained, and 4 separate runs per cassette of 35 mm film.

With some practice and experience, this can be reduced to 5 frames.

A suitable record sheet that can be used to note process details and measurements is included.

FOR 400 ISO FILM
Reduce the number of bulbs to 1 or 2 and adjust the light sources to give 8 EV_{100} equivalent to 640 lux. This ensures that the same shutter and aperture settings are used as for 100 ISO.

At the end of the test run, in the darkroom, remove the film cassette partially from the camera, pull the film

APPENDIX 2 continued

from the cassette a further 10 mm, cut the used film free and remove it from the camera ready for loading into the developing tank.

TYPICAL LIGHTING EQUIPMENT :

Stands	£10-12 each
Single lamp heads	£10 each
Triple lamp adapters	£12 each
Lamps 135W	£15 each
Low cost lux meter	£10-£15

All the required equipment is available from sellers on ebay.

APPENDIX 3

SIMPLE PRINTING PAPER CHECKS

We are going to determine maximum black time, maximum white time and the time to print a standard grey (18%) tone. This is quite straightforward, but I will describe the process anyway just in case an obvious technique is missed.

We will use glossy grade 2 initially. Grade 2 gives a fairly symmetrical gradient or gamma curve each side of the gradient peak.

Maximum black:
Set up your enlarger in the normal way with a magnification required to give a full frame 8” x 10” print and a typical aperture. In the film holder, place a clear piece of the film you are interested in which represents the b+f density.

Do a test strip and determine the exposure time required to just give a maximum black. View in a bright light i.e. 1000 lux, and *after the print is dry*. That is roughly the light level available standing next to a north facing window on a bright day or a light level that gives an exposure value off a grey card, at 100 ISO film speed, of EV 8.6, or a third of a stop below 1/8 f8 with 100 ISO film speed.

Maximum White:
Same again but this time we select a test negative frame that has been previously measured.

We have to define Dmax. This is the maximum density (relative to b+f which is what we normally measure) that will give a pure white with our standard grade 2 print time. We still have to decide on our standard printable density so, for the time being for condenser enlargers it is assumed to be 1.2, for diffuser enlargers it is 1.5 .

The negative density should be close to 1.2 or 1.5 depending on the enlarger type. Any deviation can be corrected later.
It helps to place a small coin on the paper test strip as you approach the maximum value as it makes it very easy to see small differences in density.

Standard Grey Print Time
Select a negative close to a density of 0.6 and repeat the procedure for maximum white. Compare the test strips with your standard grey card, and check again when they are dry.

If you are using a diffuser enlarger, use Dmax of 1.5 and a grey density of 0.75

Here are the print times from my equipment, grade 2 MGIV, condenser enlarger :

Maximum black time	24s no film
b+f density	0.27
Corrected time	$24 \times 10^{0.27} = 44$s
Maximum white time	45s
negative density	1.23
Corrected time	$45 \times 10^{(1.2-1.23)} = 42$s
Standard grey time	36s
Negative density	0.58
Corrected time	$36 \times 10^{(0.6-0.58)} = 38$s

These are remarkably similar thanks to Ilford. If you want to correct the grey key point, then the target film density should be:

$$0.6 + \log10(43/38) = 0.65$$

using an average of white and black key points of 43s.

The above tells us that with the above parameters maintained, print times should be above 43 seconds to achieve a a maximum black. Other magnifications will require a different minimum time but this can be easily calculated by measuring the enlarger light level on the baseboard at different magnifications.

EXPOSURE TEST CARDS

Calibrated test charts are provided with each enlarger photometer or separately.

APPENDIX 4

References

1. **Practical Sensitometry**, George L Wakefield, 1970, Fountain Press
   ISBN 0 852 42310 1

2. **The Science of Photography**, Dr. H Baines, E. S. Bomback, second edition 1967,
   Fountain Press.
   Aimed at the photographer. Contains a good description of film speed history.

3. **Enlarging,** C.I Jacobson, L.A Mannheim, 22nd revised edition October 1975
   Focal Press

4. **Exposure, Theory and Practice**, W.F Berg, 5th edition 1975
   Focal Press

5. **A Textbook of Photographic Chemistry**, D.H.O John, G.T.J Field, 1963
   Chapman & Hall Ltd, London
   Covers most of photography including sensitometry.

Used versions of the above are available at such low cost now, thanks to the digital camera, that the interested photographer may as well buy them all !

APPENDIX 5 Running programs in command mode

```
This is an extract from the screen information as the program proceeds
.......
1.505000   0.428000
1.806000   0.606000
2.107000   0.777000
2.408000   0.950000
2.709000   1.126000
3.010000   1.264000
3.311000   1.362000
3.612000   1.474000
3.913000   1.542000
4.214000   1.597000
7.500000   1.720000

coeff:2 0.087000 0.000045 a=1.72596,b=2.45827,c=4.49744,d=-1.71697,e=4.13165

x          y          calc y     error      pc error

0.00000   0.00700   0.00898   -0.00198    28.31429
0.15100   0.01800   0.01067    0.00733   -40.72682
0.30100   0.02200   0.01815    0.00385   -17.48290
0.45200   0.03300   0.03376   -0.00076     2.29881
0.60200   0.06100   0.05864    0.00236    -3.86512
0.75300   0.08200   0.09394   -0.01194    14.56172
0.90300   0.14200   0.13947    0.00253    -1.78006
1.05400   0.18300   0.19564   -0.01264     6.90909
1.20400   0.26400   0.26106    0.00294    -1.11473
1.35500   0.33000   0.33552   -0.00552     1.67177
1.50500   0.42800   0.41664    0.01136    -2.65351
1.80600   0.60600   0.59423    0.01177    -1.94212
2.10700   0.77700   0.77948   -0.00248     0.31925
2.40800   0.95000   0.95881   -0.00881     0.92752
2.70900   1.12600   1.12176    0.00424    -0.37689
3.01000   1.26400   1.26204    0.00196    -0.15496
3.31100   1.36200   1.37744   -0.01544     1.13327
3.61200   1.47400   1.46881    0.00519    -0.35220
3.91300   1.54200   1.53893    0.00307    -0.19878
4.21400   1.59700   1.59142    0.00558    -0.34957
7.50000   1.72000   1.72257   -0.00257     0.14931
Sum of errors: 0.01112012

Number of iterations = 60000130

Calculating speed point: number data pairs = 10
coeff:2 0.000253 a=0.00804,b=0.04584,c=0.00254,d=-0.01138,e=0.23655 f=-0.11235
Speed point exposure = 0.798100   rss = 0.000253  iterations = 60008032

maximum gradient = 0.6174   lower frac grad exposure = 0.5969
upper frac grad exposure = 4.1054 film dynamic range (stops) = 11.66

C:\Users\xxx>
```

An extract of the input data

This number is the current residual sum of squares which reduces as the iteration process progresses.

This is the amount that R Square varied at the end of each break point. Iteration stops when R Square is greater than a value specified in the input data. This is around 0.998.

The characteristic curve coefficients are updated as the iteration process continues.

This number indicates the breakpoint stage, 0 is the initial setting with maximum increment or decrement specified by the start parameters.

This data is displayed after the iteration process has finished.

Speed Point calculations now start in a similar manner to the above.

End of program, back to prompt, type 'exit' to return to windows.

Each iteration process should stop automatically when R Square has almost been maximised.

If the minimum R Square value cannot be reached, iterations will continue until the iteration limit is reached.