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Color Correction for Telescopic Objectives.

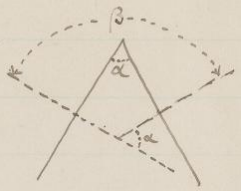
Charles P. Howard
Hartford
Conn

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Index of Refraction

$$n = \frac{\sin \frac{1}{2}(\alpha + \delta)}{\sin \frac{1}{2}\alpha}$$



n = Index of Refraction

α = angle of Prism = $180° - \beta$ = $180° - \beta$



δ = deviation of ray ~~by prism of~~ minimum ~~deviation~~.

Index of Refraction

Lenie of Spectrum	$3\frac{1}{2}$ in. O. G.		$4\frac{1}{2}$ in. O. G.	
	Crown	Flint	Crown	Flint
A			1.50725	1.60816
B			1.50917	1.61156
C	1.51328	1.58079	1.51002	1.61323
λ = 5614	1.51685	1.58611	1.51343	1.61968
X = λ = 5092	00561	0086	1.51686	1.62640
F	1.52246	1.59476	1.51865	1.63010
$\frac{1}{3}$ F & G			1.52020	1.63341
G			1.52400	1.64121
g			1.52489	1.64324
H			1.52853	1.65105

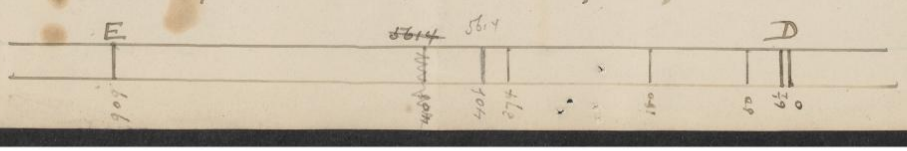
Three rays to measure the index of refraction of, are

F ray,

5614 ray

and ray whose index of refraction through the crown, is as much less than the 5614 ray as that of the F ray is greater

add about 1 for each F. deviation of red side



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Selection of the Glass.

C. P. H. Method, To show graphically the comparative irrationality of the spectra produced by the several kinds of glass, so that the crown and flint whose comparative irrationality is least can be combined together.

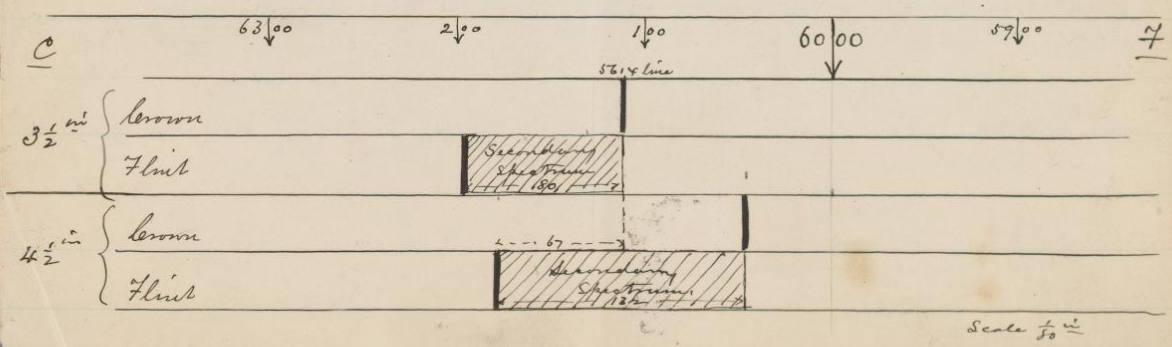
n_7 = index of refraction for the 7 line &c.

	$3\frac{1}{2}^{in}$		$4\frac{1}{2}^{in}$	
	Crown	Flint	Crown	Flint
$n_7 - n_C$	.00918	.01397	.00864	.01687
$n_7 - n_{5614}$	.00561	.00865	.00522	.01042
$n_7 - n_7$	.0	0	0	0

Representing the interval $n_7 - n_C$ by 10000 we complot on some scale

$n_7 - n_C$	10000	10000	10000	10000
$n_7 - n_{5614}$	6112	6192	6047	6179
$n_7 - n_7$	0	0	0	0
Diff of fractions of 5614 line	80/60		132/100	

Representing the position of the 5614 line graphically, when the interval between n_7 and n_C = 10000. we obtain the following diagram.



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which represents to the eye the relative magnitude of the secondary spectrum, produced by the glasses used in the $3\frac{1}{2}$" and $4\frac{1}{2}$" object glasses.

It is there plain that whereas the $3\frac{1}{2}$" has a secondary spectrum represented by the number 80, and the $4\frac{1}{2}$" by the number 132. If the crown glass of the $3\frac{1}{2}$" had been combined with the flint glass of the $4\frac{1}{2}$" an object glass could have been produced having a secondary spectrum of 67, or only half what it now is in the $4\frac{1}{2}$".

If the crown of the $4\frac{1}{2}$" had been combined with the flint of the $3\frac{1}{2}$" it would have made the most possible combination of these four glasses - for the secondary spectrum would then have equalled - 145,

---

The secondary, chromatic aberration of the $3\frac{1}{2}$" is 60 per cent that of the $4\frac{1}{2}$".

516
113
826
289
3 7.36

512
512
104
260
27.

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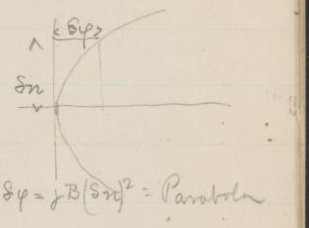
Hasting method of measuring the secondary spectrum.
see American Journal of Science Vol. 37 April 1889.

where –

$\varphi = \frac{1}{f}$ $\quad f$ = focal length of the combination

$\delta\varphi = \varphi_0 - \varphi_n \qquad \delta n = n_0 - n_n$

$$\delta\varphi = -\tfrac{1}{2} A \frac{dn_0}{dn'_0} \cdot \frac{d^2n'}{dn^2} \cdot (\delta n)^2 \quad *$$



" which is the measure for the secondary chromatic aberration".

where – $\frac{A}{B} = \frac{1}{r_1} + \frac{1}{r_2}$ the curvature sum of the positive lens
$\frac{1}{r_3} + \frac{1}{r_4}$ " " " negative "

$\frac{dn_0}{dn'_0} = \frac{dn}{dn'}$ nearly $= \beta + 2\gamma n_0$

$\frac{1}{2} \cdot \frac{d^2n'}{dn^2} = \gamma$

β & γ are found from $n' = \alpha + \beta n + \gamma n^2$

n' = flint indices
n = crown "

Comparison of $3\frac{1}{2}^{\text{in}}$ and $4\frac{1}{2}^{\text{in}}$ O.G.'s $f = 1$

Constants for	$3\frac{1}{2}^{\text{in}}$	$4\frac{1}{2}^{\text{in}}$
α	7.619	29.800
β	− 9.476	− 39.167
γ	3.625	13.576
A †	7.603	5.216
B †	− 4.998	− 2.708
Secondary chromatic aberration for the γ ray. $\delta\varphi_\gamma = \varphi_0 - \varphi_\gamma$	− .000570	− .001002

The chromatic aberration of the $3\frac{1}{2}^{\text{in}}$ is 57 per cent that of the $4\frac{1}{2}^{\text{in}}$ which agrees well with the value already found on opposite page.

$$\delta\varphi = -\tfrac{1}{2} A \frac{dn_0}{dn'_0} \cdot \frac{d^2n'}{dn^2} \cdot (\delta n)^2 = \gamma B (\delta n)^2$$ CRH

† $\varphi_0 = (n_0 - 1)A + (n'_0 - 1)B$
$A = -B(\beta + 2\gamma n_0)$
} Hastings condition of best color correction
to find A and B

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To find how close an approximation to the true value of $\delta\varphi$ is obtained by the formula $\delta\varphi = \gamma B(\delta n)^2$ the following table was calculated,

Chromatic Aberration $4\frac{1}{2}$ in. O. G. $\gamma = 1$

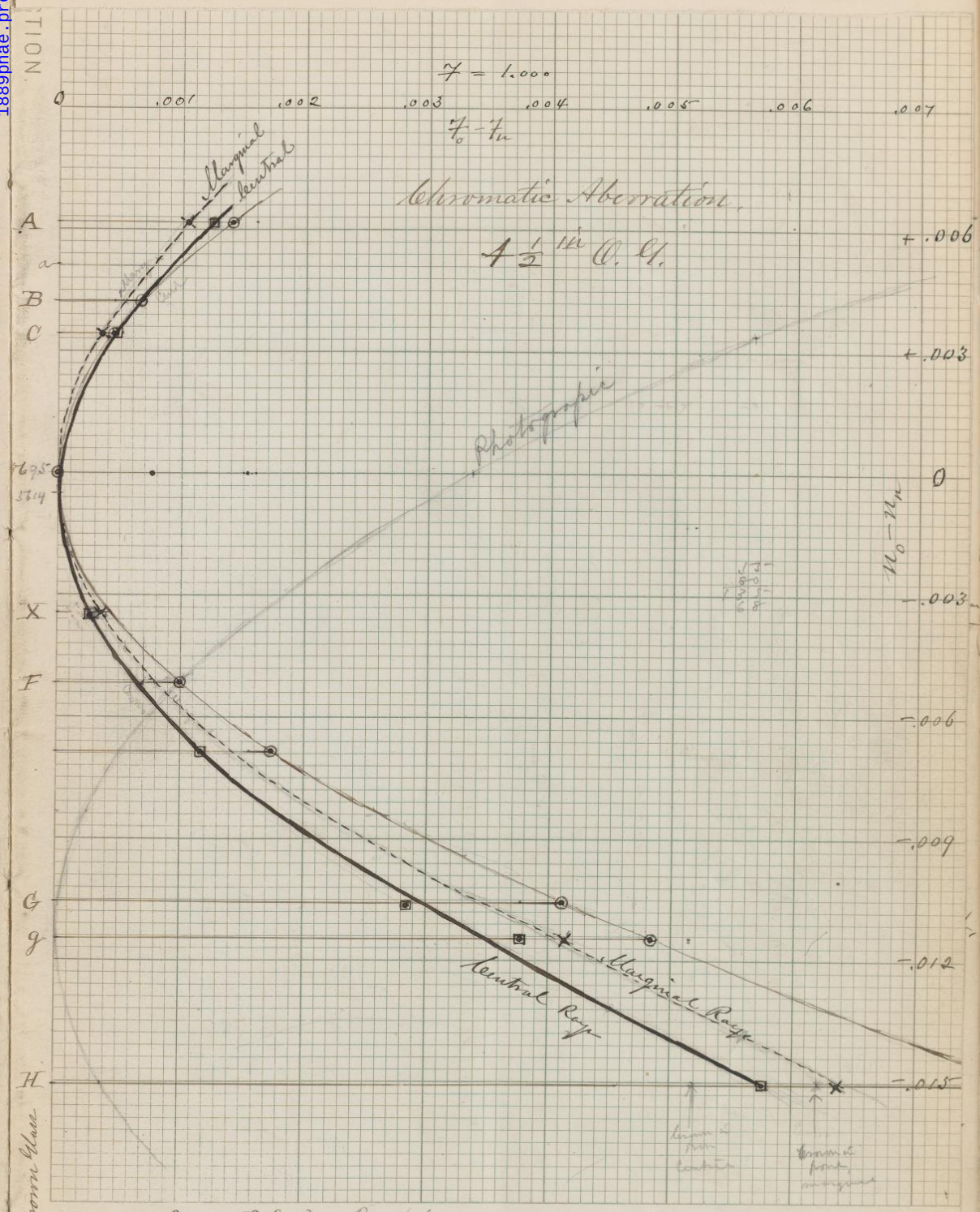
Ray	$\delta n = n_0 - n_n$	$\delta\varphi = \gamma B(\delta n)^2$	$\delta\varphi$ by rigid formula for central rays	$\delta\varphi$ for Marginal R_y
A	.00618	.00140	.00124	.00104
B	.00426	.00067		
b	.00341	.00043	.00046	.00036
$\lambda = 5695$	0	0	0	0
$\chi = \lambda = 5704$			.00016	.00036
F	.00522	.00100	.00065	
$\frac{1}{3}$ (F+G)	.00687	.00174	.00116	
G	.01057	.00411	.00282	
g	.01146	.00483	.00378	.00413
H	.01510	.00838	.00575	.00638
Indicated on Diagram thus —		⊙	⊡	✕

In the Diagram on the opposite page the numbers in the above table are plotted and each of the last three columns represented by a curve, shows clearly the degree of the approximation and that the actual O. G. gives a better color correction than this formula indicates.

It will be observed that the formula $\delta\varphi = \gamma B(\delta n)^2$ is that of a Parabola — If written $(\delta n)^2 = \frac{1}{\gamma B} \cdot \delta\varphi$ we have by inspection the abscissa of the focus $a = \frac{1}{4\gamma B}$ (origin at vertex)
(Eg. of Parabola, origin at vertex $y^2 = 4ax$)

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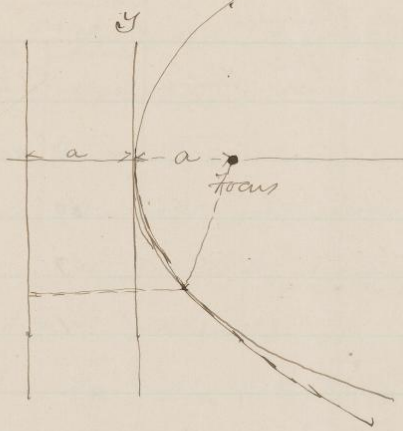
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Hence knowing γB for any pair of crown & flint glasses the parabola measuring the secondary chromatic aberration can at once be drawn in terms of $L = 1$.



		To scale of diagram $a =$
In $4\frac{1}{2}^{in}$	$a = \frac{1}{4\gamma B} = -.00680$	.00076
$3\frac{1}{2}^{in}$	$a = \quad = -.01379$	.00153

here $y' = \frac{1}{3}y$

$(3y')^2 = y^2$ &c

That O. G. is best in which a is greatest, that is in which γB is smallest, and when $\gamma B = 0$ the color correction is perfect.

This agrees with Hastings color correction viz

substitute $n' = \alpha + \beta n + \gamma n^2$ in $\varphi = (n-1)A + (n'-1)B$

then $\frac{d\varphi}{dn} = A + \beta B + 2\gamma B n$

and $\frac{d^2\varphi}{dn^2} = 2\gamma B$ which $= 0$ for perfect color correction.

Because $\delta\varphi = \gamma B(\delta n)^2$ it follows that $\delta f = \gamma B(\delta n^2) = \delta\varphi$

$\delta\varphi = \frac{1}{f_0} - \frac{1}{f_n} = \frac{f_n - f_0}{f_0 f_n} = \frac{\delta f}{f_0 f_n}$ but $f_0 = 1 = f_n$ to within 3 significant figures

hence $\delta\varphi = \delta f = \gamma B(\delta n)^2$.

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7

Comparison of Color Correction of other Telescopes

Ray.		δF when F = 1								
		L. P. Howard		Encyclopedia Britonica				American Journal of Science Vol. 19. p. 454. Young		
Lines in Spectrum	λ	32 in.	42 in.	Fraunhofer	Grubb	Schröder	Hastings	blank Gauss	blank Lettrow	Fraunhofer
A	7600		00120				00135	.00145	.00172	
B	6866		55	47	64	106	66	69	97	64?
C	6561		40	36	41	78	41	37	49	52
D	5890			0	8	23	0	1	0	2
	5617		0							
	5092		35							
F	4860		70	64	56	33	73	42	129?	72
G	4307		300	171	226	243	287	262		289
g										
H	3968		600					575	650	582

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A third method of selecting the best combination of glass for a double objective would be to start with the formulae for infinitely small and thin lenses, thus

$$\varphi_c = (n_c - 1)A + (n'_c - 1)B$$

$$\varphi_7 = (n_7 - 1)A + (n'_7 - 1)B = 1 \qquad (1)$$

Unite the C + F rays, make $\varphi_c = \varphi_7$, subtracting

$$0 = (n_7 - n_c)A + (n'_7 - n'_c)B$$

$$A = -B\left(\frac{n'_7 - n'_c}{n_7 - n_c}\right) \qquad (2)$$

(1) + (2) give A + B, then,

$$\left.\begin{aligned} \varphi_{\not 7} &= (n_{\not 7} - 1)A + (n'_{\not 7} - 1)B \\ \varphi_0 &= (n_0 - 1)A + (n'_0 - 1)B \end{aligned}\right\} \text{no good}$$

$$\delta\varphi = \varphi_{\not 7} - \varphi_0 = (n_{\not 7} - n_0)A + (n'_{\not 7} - n'_0)B \qquad (3)$$

which-ever two glasses when combined make $\varphi_{\not 7} - \varphi_0$ the least, will give the best color correction.

By this method,

	O. G. $3\frac{1}{2}$ in.	O. G. $4\frac{1}{2}$ in.
A	7.896	5.094
B	−4.992	−2.606
$\delta\varphi = \varphi_7 - \varphi_0$	−0.000053	−0.000056
$\varphi_0 - \varphi_c$	.000056	.000056

These calculations were repeated and no mistake found

Comparing these values with those derived by Hastings method on page 4 - and C.R.M.'s method on page 2. we find that it does not agree with them. The secondary chromatic aberration being here indicated as about equal for both O. G.'s instead of the $3\frac{1}{2}$ in being only 60 % of that of the $4\frac{1}{2}$ in.

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The best Color Correction

Having, the two pieces ~~of glass~~ selected from all the glass attainable which combined together give the least chromatic aberration, ~~for all those attainable~~, the following is Hastings's methods of finding the curvature of the four surfaces ~~to obtain~~ give the best color correction ~~attainable with the glass~~. see American Journal of Science Vol. 23 March 1882.

n = Index of refraction of the crown glass

n' = " " " flint "

$n' = \alpha + \beta n + \gamma n^2$ is true to great accuracy

$\frac{dn'}{dn} = \beta + 2\gamma n$ $\quad \frac{dn'^2}{dn^2} = 2\gamma$

$$\frac{1}{f} = \varphi = (n-1)A + (n'-1)B$$

$$\varphi = (n-1)A + (\alpha + \beta n + \gamma n^2 - 1)B \qquad (a)$$

$$\frac{d\varphi}{dn} = A + \beta B + 2\gamma n B$$

When a small change in n produces no change in φ $\frac{d\varphi}{dn} = 0$ and φ is at a maximum - to obtain this condition we must put $A + \beta B + 2\gamma n B = 0$

when $A = -B(\beta + 2\gamma n)$ $\qquad A = -B\frac{dn'}{dn}$

For a telescope Obj. this condition must hold good for the brightest ray viz wave length 5614. about. when we must take

$$A = -B(\beta + 2\gamma n_{5614}) \qquad (1)$$

For photographic Obj. $A = -B(\beta + 2\gamma n_G)$

When $f_{5614} = 1$, $\quad \varphi_{5614} = 1 = (n_{5614} - 1)A + (n'_{5614} - 1)B \qquad (2)$

Formulae (1) and (2) give the values of A and B required.

$1 = (n_{5614} - 1)B\frac{dn'}{dn} + (n'_{5614} - 1)B$

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To find what ray must be united at the same focus with the C ray to give the best color correction,

With the values of A and B just found find φ_c in the equation

$$\varphi_c = (n_c - 1)A + (n'_c - 1)B$$

then find the two values of n that will satisfy the equation

$$\varphi_c = \gamma B n^2 + (A + \beta B) n + (\alpha - 1)B - A \quad (4)$$

from (a)

one of these values of n must be n_c and the other the index of refraction of the crown glass for the ray to be combined with it, which we will call n_x

then $n'_x = \alpha + \beta n_x + \gamma n_x^2$ for the flint.

Referring to the diagram opposite page 5, it is plain that n_x must be as much greater than n_{5614} as n_c is greater than n_{5614}. (All indices of refraction of the crown) This is the easiest way to calculate n_x and can be used as a check on the above.

For the 4½° O.G. Eq. 4 gave. $n = 1.51343 \pm .00342$

hence $n = \begin{cases} 1.51002 \\ 1.51686 \end{cases}$

1.51343 is n_{5614}

1.51002 is n_c

1.51686 is Index of Refr. of Ray b be combined with C, and is as much greater than n_{5614} as n_c is less.

Ray F should be combined with ray a ~~between A & B lines~~ B

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The Best color Correction, taking into account the Distance between the Lenses —

— C. P. Howards method —

Prof. Hastings method of obtaining the best color, can be by a simple modification adapted to take into account the distance between the lenses, and thus give a closer approximation — thus

$$\frac{1}{f} = \frac{1}{f'} + \frac{1}{f''} = (n-1)A + (n'-1)B, \quad \text{for lenses in contact}$$

If the second lens instead of being in contact with the first is placed at a distance K behind it, we can substitute in the formula for conjugate foci of the second lens

$$\frac{1}{d''} + \frac{1}{f_0} = (n'-1)\left(\frac{1}{r_3} + \frac{1}{r_4}\right) \qquad (1)$$

as follows —

$f'-K$ for d'', $\frac{1}{f}$ for $\frac{1}{f_0}$ and $\frac{1}{f''}$ for $(n'-1)\left(\frac{1}{r_3} + \frac{1}{r_4}\right)$

f' being the focal length distance of the first lens for parallel rays

f'' " " " " " " second " " " "

and we have

$$\frac{1}{f'-K} + \frac{1}{f} = \frac{1}{f''}$$

which can be written

$$\frac{1}{f} = \frac{1}{f'-K} + \frac{1}{f''}$$

until the signs of the quantities are fixed by the case considered

Expressing K as some fractional part of f' as that is $K = af'$ we have

$$\frac{1}{f} = \frac{1}{f'-af'} + \frac{1}{f''} = \left(\frac{1}{1-a}\right)\frac{1}{f'} + \frac{1}{f''}$$

f being now the distance of the focal plane from the second lens.

Substituting Hastings notation we have for best telescopic color correction,

$$\frac{1}{f} = \varphi = \frac{1}{1-a}\left(\underset{5614}{n-1}\right)A + \left(\underset{5614}{n'-1}\right)B = 1$$

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and

$$A = -B(1-a)(\beta + 2\gamma n_{5b})_4$$

when the positive lens is in front -

If the negative lens is placed in front. in equation (1) $d'' = f' + K$ and we have for the condition of best color correction

$$\frac{1}{f} = \varphi = \frac{1}{1+a}\left((n'_{5b\,4}-1)B + (n_{5b\,4}-1)A\right) = 1$$

$$A = -\frac{B}{1+a}(\beta + 2\gamma n_{5b\,4})$$

$K = a f_1$ (flint)

Comparison of value of A and B, obtained in different ways.

$4\frac{1}{2} = 04$

	$\delta = 1$	
	$A = \frac{1}{r_1} + \frac{1}{r_2}$	$-B = \frac{1}{r_3} + \frac{1}{r_4}$
True - Marginal C and X ray united ($\lambda = 509.2$), lenses in front	5.129	2.639
" " " " " " flint " "	5.159	2.664
By Hasting Best color correction p. 9.	5.216	2.708
" C.P.H. do. distance between lenses. p. 11. + 12		
lenses in front. $K = .30$ inch	5.148	2.709
flint in front "	5.	2.
By Formulae (1) and (2) p. 8 C + 7 ray	5.094	2.606
" " " C + X "	5.219	2.711

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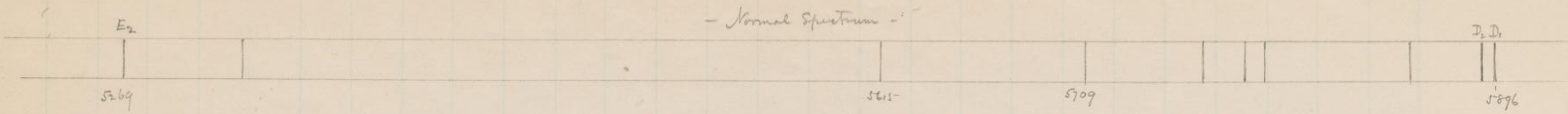
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Secondary Chromatic Aberration

Prof. Hastings - American Journal of Science April 1899

$$\varphi = (n-1)A + (n'-1)B$$
$$\varphi_0 = (n_0-1)A + (n'_0-1)B = 1$$

For an achromatic combination we must have

$$\frac{d\varphi}{dn} = 0 = A + \frac{dn'}{dn}B \qquad \therefore\ B = -A\frac{dn}{dn'}$$

To find an expression for the secondary chromatic aberration -

$$\varphi_0 = (n_0-1)A - (n'_0-1)\frac{dn_0}{dn'_0}A$$

$$\varphi_n = (n_0+\delta n-1)A - (n'_0+\delta n'-1)\frac{dn_0}{dn'_0}A$$

$$(1) \qquad \varphi_0 - \varphi_n = \delta\varphi = \left(\delta n - \delta n'\frac{dn_0}{dn'_0}\right)A$$

$$n' = \alpha + \beta n + \gamma n^2$$
$$n'_m = \alpha + \beta(n+\delta n) + \gamma(n^2 + 2n\delta n + \delta n^2)$$
$$n' - n'_m = \delta n' = \beta\delta n + 2\gamma n\delta n + \gamma\delta n^2$$
$$(2) \qquad \delta n' = (\beta + 2\gamma)\delta n + \gamma\delta n^2$$

also, $\beta + 2\gamma = \frac{dn'}{dn}$ and $\gamma = \frac{1}{2}\frac{d^2n'}{dn^2}$

$$\delta n' = \frac{dn'}{dn}\cdot\delta n + \frac{1}{2}\frac{d^2n'}{dn^2}\delta n^2$$

substituting this value of $\delta n'$ in (1) and calling $\frac{dn'}{dn} = \frac{dn'_0}{dn_0}$

$$\delta\varphi = \left\{\delta n - \frac{dn_0}{dn'_0}\cdot\frac{dn'}{dn}\cdot\delta n + \frac{1}{2}\cdot\frac{dn_0}{dn'_0}\cdot\frac{d^2n'}{dn^2}\cdot\delta n^2\right\}A$$
$$= -\frac{1}{2}A\frac{dn_0}{dn'_0}\cdot\frac{d^2n'}{dn^2}\cdot\delta n^2$$

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As $B = -A\frac{dn'}{dn}$ and $f = \frac{i'}{2}\frac{d^2n'}{dn^2}$

this can be written

$$\delta\varphi = Bf\,\delta n^2$$ C.R.H.

B is calculated from the formulae

$$\frac{1}{B} = (n'-1) - (n-1)\frac{dn'}{dn}$$

$$= (n'_0 - 1) - (n_0 - 1)\frac{n'_7 - n'_c}{n_7 - n_c}$$

f is found approximately as follows

From (2) $\quad \delta n' = (\beta + 2f)\delta n + f\delta n^2$ C.R.H.'s method

$$= \frac{dn'}{dn}\cdot\delta n + f\delta n^2$$

$$n'_7 - n'_D = \frac{n'_7 - n'_c}{n_7 - n_c}(n_7 - n_D) + f(n_7 - n_D)^2$$

$$n'_D - n'_c = \frac{n'_7 - n'_c}{n_7 - n_c}(n_D - n_c) + f(n_D - n_c)^2$$

Find the value of f that will satisfy both of these equations by eliminating the constant $\frac{n'_7 - n'_c}{n_7 - n_c}$.

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Example - 23 - 31

$n'_7 - n'_C$ = 0.01438 ✓ = 8.1578 ✓

$n_7 - n_C$ = 0.01049 ✓ = 8.0208 ✓

0.1370 ✓

$n_D - 1$ = 0.5368 ✓ = 9.7298 ✓

0.7359 ✓ = 9.8668 ✓

$n'_D - 1$ = 0.5900 ✓

− 0.1459 ✓ = 9.1641 ✓

B = −6.854 ✓ = 0.8359 ✓

0.1370 ✓

A = 9.397 ✓ = 0.9729 ✓

Flint F-D 0.01022 ✓ = C × Crown F-D 0.00743 ✓ + J × .00005521 ✓

D-C 0.00416 ✓ = C × D-C 0.00306 ✓ + J × .00000936 ✓

0.010102 ✓ = C × 0.00743 ✓ + J × .00002274 ✓

0.000118 ✓ = + J × .00003247

F-D .00743 ✓ = 7.8710 ✓ × 2 = 5.7420 ✓

D-C .00306 ✓ = 7.4857 ✓ × 2 = 4.9714 ✓

0.3853 ✓ 0.3853 ✓

.00416 ✓ = 7.6191 ✓ 5.3567 ✓

8.0044 ✓

6.0719 ✓

5.5115 ✓

J = 3.63 = 0.5604 ✓

B = − = 0.8359 ✓

δn^2_{7-D} = 5.7420 ✓

$\delta\varphi_{7-D}$ = − .001375 = 7.1383 ✓

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0.144 : 0.103

'5 – 36 to obtain flat curves –

0.01709 = 8.2327

0.00797 = 7.9015

0.3312

0.5100 = 9.7076

1.0935 = 0.0388

0.6202

– 0.4733 = 9.6751

B = – 2.113 = 0.3249

0.3312

A = + 4.530 0.6561

0.01220 = C × .00539 + J × .00003125

0.00489 = C × .00238 + J × .00000566

0.011484 = .1330

.000726 = 0 + J × .00001795

.00539 = 7.7474 × 2 = 5.4948

.00238 = 7.3766 × 2 = 4.7532

0.3708 0.3708

.00489 = 7.6893 5.1240

8.0601

6.8609

5.2541

J = +40.44 = 1.6068

B = – = 0.3249

δn^2 = = 5.4948

δy = –.002670 = 7.4265

which gives chromatic abirration twice as great as 23 – 31

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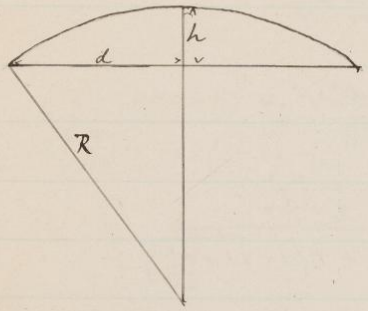
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The Spherometer

I Legs end in perfect points –



$$R^2 = d^2 + R^2 - 2Rh + h^2$$

$$2Rh = d^2 + h^2$$

$$R = \frac{d^2}{2h} + \frac{h^2}{2h}$$

$$R = \frac{d^2}{2h} + \frac{h}{2} \qquad (1).$$

S = number of turns of screw to measure h

with 100 threads per inch $h = \frac{S}{100}$ as in C.R.M.'s spherometer

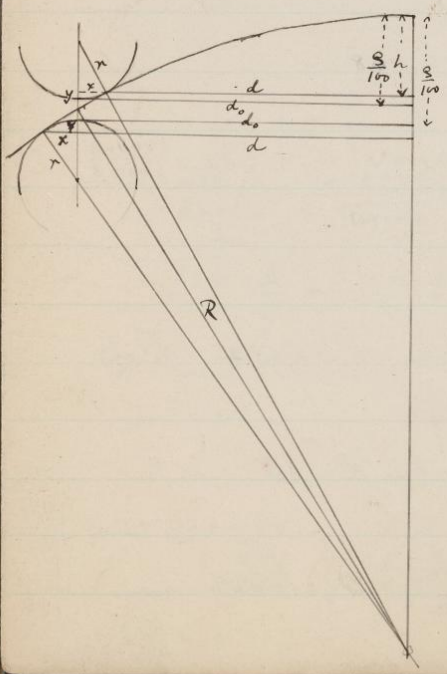
where also $d = 2.001$

If $K = \frac{d^2}{2h} = \frac{k}{S}$ the value for R can be written

$$R = K + \frac{h}{2}$$

$$\text{where } \log K = \log k - \log S \qquad \Big\} \qquad (2),$$

II. It is impossible to have the legs end in absolute points so that it is best to have them end in very small spheres –



r = radius of the small terminating spheres

which here = .008

$R : r :: d_0 : x$ nearly

hence $x = \frac{r}{R} \cdot d_0$

$$y = r - \sqrt{r^2 - x^2}$$

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convex

$$d = d_0 - x = d_0 - \frac{r}{R}\cdot d_0 = \left(1 - \frac{r}{R}\right) d_0$$

$$h = h_0 - y = \frac{s}{100} - y$$

$$K = \frac{d^2}{2h}$$

$$K = \frac{\left(1 - \frac{r}{R}\right)^2 d_0^2}{2\left\{\frac{s}{100} - r\left(1 - \sqrt{1 - \frac{d_0^2}{R^2}}\right)\right\}}$$

when $R = 16.$
$r = .008$
$d_0 = 2.001$

$\frac{r}{R} = .0005$

$\frac{d_0}{R} = \frac{1}{8}$

$$K = \frac{d^2}{2h} = \frac{(1 - .0005\ \ )^2 4.004}{2\left\{\frac{s}{100} - .008\left(1 - \sqrt{1 - \frac{1}{64}}\right)\right\}}$$

reducing

$$K = \frac{4.000}{\frac{s - .00628}{50}} = \frac{200.0}{s - .00628} \qquad (a)$$

when $R = 16$, (b) $16 = \frac{200.0}{s - .00628} + \frac{s}{200}$

from eq (1), and (a) calling $\frac{s-4}{200} = \frac{s}{200}$

=

$$s^2 - 3200\,s + (1600)^2 = 2560000 - 40020$$

$$s = 12.5556$$

$$K = \frac{200.0}{s - \frac{s}{1999.36}} \text{ from (a)} = \frac{200.0 \times \frac{1999.36}{1998.36}}{s}$$

$$K = \frac{200.10}{s} = \frac{k}{s} \quad \text{hence}$$

$$\log k = 2.30125$$

when $R = 16$,

Note $\frac{1999.36}{1998.36} = \log 0.000022$

concave

$$d = d_0 + x = d_0 + \frac{r}{R}\cdot d_0 = \left(1 + \frac{r}{R}\right) d_0$$

$$h = \frac{s}{100} + y$$

$$K = \frac{d^2}{2h}$$

$$K = \frac{\left(1 + \frac{r}{R}\right)^2 d_0^2}{2\left\{\frac{s}{100} + r\left(1 - \sqrt{1 - \frac{d_0^2}{R^2}}\right)\right\}}$$

R etc same as for convex

$$K = \frac{d^2}{2h} = \frac{(1 + .0005\ \ )^2 4.004}{2\left\{\frac{s}{100} + .008\left(1 - \sqrt{1 - \frac{1}{64}}\right)\right\}}$$

$$K = \frac{4.008}{\frac{s + .00628}{50}} = \frac{200.4}{s + .00628}$$

when $R = 16$ $= \frac{200.4}{s + .00628} + \frac{s}{200}$

as for convex

$$s = 12.5568$$

$$K = \frac{200.4}{s - \frac{s}{2001.3}} = \frac{200.4 \times \frac{2001.3}{2000.3}}{s}$$

$$K = \frac{200.51}{s} = \frac{k}{s}$$

$$\log k = 2.30212$$

when $R = 16$

Note $\frac{2001.3}{2000.3} = \log 0.000022$ same

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convex

$R = 32.$

$\frac{r}{R} = .00025^-$

$\frac{d_o}{R} = .\frac{1}{16}$

$$K = \frac{(1 - .00025^-)^2\, 4.004}{2\left\{\frac{8}{100} - .008\left(1 - \sqrt{1 - \left(\frac{1}{16}\right)^2}\right)\right\}}$$

concave

$$K = \frac{(1 + .00025^-)\, 4.004}{2\left\{\frac{8}{100} + .008\left(1 - \sqrt{1 - \left(\frac{1}{16}\right)^2}\right)\right\}}$$

From measurements of inner surfaces of 4½" R.G. given below the difference between log k (concave) and log k (convex) should be .00058 these two surfaces having the same curvature.

As calculated on the opposite page this difference is .00089 or .00029 too much. Dividing this between these

		see next page
for convex surface R=16	log k = 2.30139	2.30117
" concave " "	log k = 2.30197	2.30175
	diff	58

4½" inside surfaces — to make t = 14.959

			to make t = 14.959
	K =	2.30128⁻	2.30122
S = 13.436	=	1.12827	
	14.893 =	1.17298	1.17295⁻
$\frac{h}{2}$ =	.067		
t =	14.960		

			to make t = 14.959
		2.30212	2.30180
S = 13.454	=	1.12885⁻	
	14.903 =	1.17327	
	.067		
t =	14.970		

$\therefore \log k_{concave} - \log k_{convex} = .00058$ for radius of 16 in.

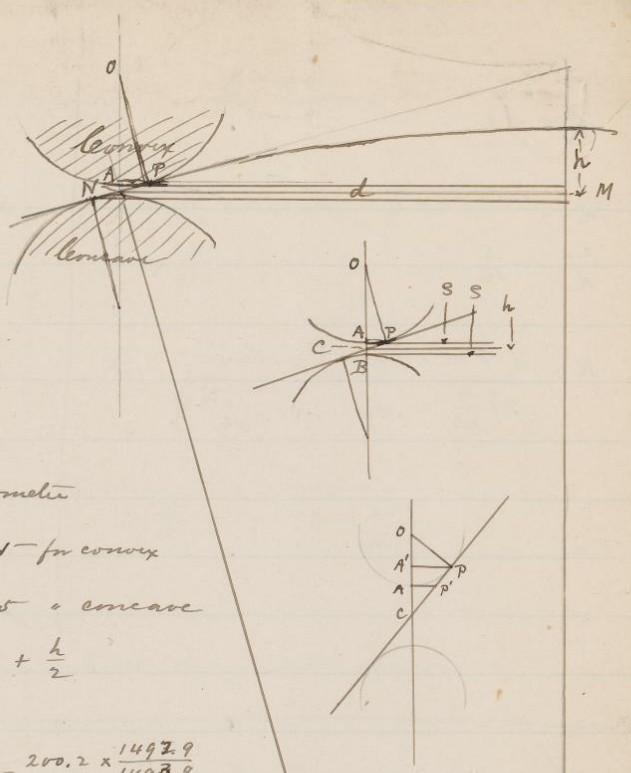
Plane	13.089	0.650
	0.653	13.087
	13.436	13.437

$t_2 = t_3 = 14.959$ in.

	13.606	13.607
Plane	.152	.152
	13.454	13.455⁻

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By measurement of inner surface of 4½" O.G.

when $r_2 = r_3 = 14.957$

$S = 13.436$ for convex

" $= 13.454$ " concave

when $d = 2.001$ in CRH spherometer

$h = 13.436 + .009 = .13445$ for convex

$h = 13.454 - .009 = .13445$ " concave

$$R = \frac{d^2}{2h} + \frac{h}{2} = K + \frac{h}{2} = \frac{k}{S} + \frac{h}{2}$$

$$K = \frac{4.004}{\frac{2}{100}(S + .009)} = \frac{200.2}{S + \frac{S}{1492.9}} = \frac{200.2}{\frac{1493.9}{1492.9}S} = \frac{200.2 \times \frac{1497.9}{1493.9}}{S}$$

$\log k = 2.30117$ - convex

$$K = \frac{4.004}{\frac{2}{100}(S - .009)} = \frac{200.2}{S - \frac{S}{1497.9}} = \frac{200.2}{\frac{1497.9}{1493.9}S} = \frac{200.2 \times \frac{1493.9}{1497.9}}{S}$$

$\log k = 2.30175$ convex

diff = .00058 for 15" radius

For any other radius, triangle APC is similar to AOP, which is similar to MLN,

$$AC : .009 :: \frac{1}{R} : \frac{1}{15}$$

$$AC = \frac{.009 \times 14.957}{R} = \frac{.134613}{R}$$

when $R = 100$, $AC = .00134613$

$h = .020024$

$\frac{S}{100} = .018678$

$S = 1.8678$

$$K = \frac{4.004}{\frac{2}{100}(S + .00135)} = \frac{200.2}{S + \frac{S}{1380.1}} = \frac{200.2}{\frac{1381.1}{1380.1}S} = \frac{200.2 \times \frac{1380.1}{1381.1}}{S} \quad \therefore \log k = 2.30114$$

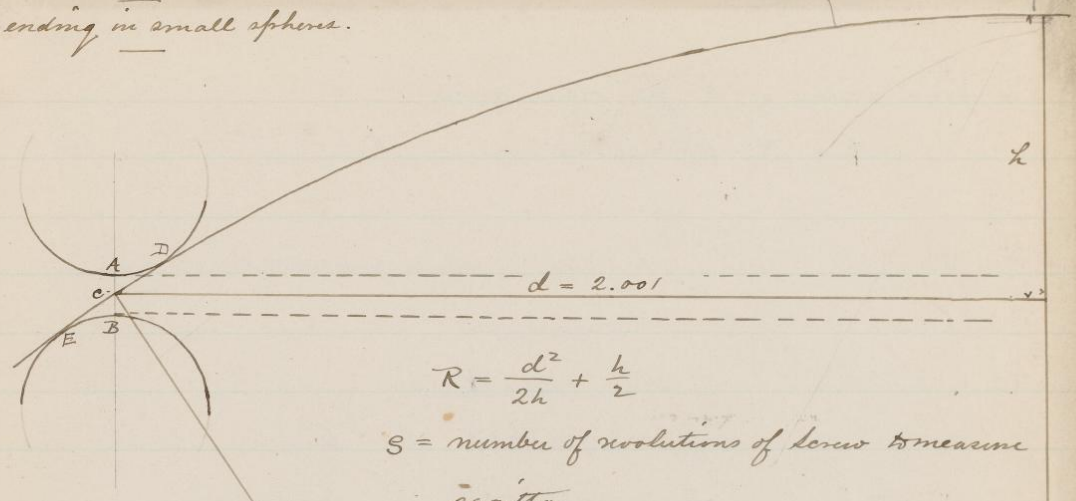
$$K = \frac{4.004}{\frac{2}{100}(S + .00135)} = \frac{200.2}{S - \frac{S}{1380.1}} = \frac{200.2}{\frac{1379.1}{1380.1}S} = \frac{200.2 \times \frac{1380.1}{1379.1}}{S} \quad \log k = 2.30177$$

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– Spherometer –

Legs ending in small spheres.



$$R = \frac{d^2}{2h} + \frac{h}{2}$$

S = number of revolutions of screw to measure sagitta.

write $R = \frac{k}{S} + \frac{h}{2}$. to find k.

$$= \frac{k}{S} + \frac{S}{200}$$

So long as DE is sensibly straight, Ab = BC, and is inversely proportional to R

In G. P. H.'s Spherometer on inner surfaces of 4/5 = 0.4.

convex surface $h = .13436 + .00009 = .13445$

concave " $h = .13454 - .00009 = .13445$

$$\frac{d^2}{2h} = \frac{4.004}{\frac{2}{100}(S + .009)} = \frac{200.2}{S + \frac{S}{1492.9}} = \frac{200.2}{\frac{1493.9}{1492.9} S} = \frac{200.2 \times \frac{1492.9}{1493.9}}{S}$$

Hence $k = 200.2 \times \frac{1492.9}{1493.9}$ = log 2.30117 for convex

$k = 200.2 \times \frac{1494.9}{1493.9}$ = " 2.30175 " concave

for radius = 14.957

For any other radius –

$$AC : .00009 :: \frac{1}{R} : \frac{1}{14.957}$$

$$AC = \frac{.00009 \times 14.957}{R} = \frac{.001346\,13}{R}$$

Nov. 12, S = 13.432½) k = 2.30109 2.30113

13.455½) k = 2.30184 2.30179

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To find value of k for other radii –

$$k = R - \sqrt{R^2 - 4.004} \quad (a) \qquad R = \frac{2.002}{k} + \frac{k}{2} \quad (b)$$

$R = 30$, from (a) $k = .06680$ which substituted in (b) gives

$$k = .0668076$$

$$\Delta k = \frac{.00134613}{30} = \Delta k \; .0000448710$$

$$\frac{s}{100} = .0667627 \text{ for convex}$$

$$\frac{s}{100} = .0668525 \text{ " concave}$$

$$\frac{d^2}{2k} = \frac{4.004}{\frac{2}{100}(s + .00449)} = \frac{200.2}{s + \frac{s}{6.67627}} = \frac{200.2}{s + \frac{s}{1487.9}} = \text{for convex,}$$

$.00448710$

$$\frac{d^2}{2k} = \frac{200.2}{\frac{1488.9}{1487.9}s} = \frac{200.2 \times \frac{1487.9}{1488.9}}{s} \text{ convex} \qquad \frac{200.2}{\frac{1488.9}{1489.9}s} = \frac{200.2 \times \frac{1489.9}{1488.9}}{s} \text{ concave}$$

For convex $k = 200.2 \times \frac{1487.9}{1488.9} = \log 2.30117$

" concave $k = 200.2 \times \frac{1489.9}{1488.9} = \text{"} \; 2.30175$ } same as before

---

$R = 1000$, from (a) $k = .002$

" (b) $k = .002000200$

$$\Delta k = \frac{.00134613}{1000} = .000001346\overline{13}$$

$$\frac{s}{100} = .00200066 \text{ for convex}$$

$$\frac{s}{100} = .00200334 \text{ for concave}$$

$$\frac{d^2}{2k} = \frac{4.004}{\frac{2}{100}(s + .0000013\overline{4})} = \frac{200.2}{s + \frac{s}{.002000\overline{7}}} = \frac{200.2}{s + \frac{s}{1486.2}} = \frac{200.2}{\frac{1487.2}{1486.2}s} \text{ for convex}$$

$.000001346\overline{13}$

$$= \frac{4.004}{\frac{2}{100}(s - .0000013\overline{4})} = \frac{200.2}{s - \frac{s}{.002000\overline{33}4}} = \frac{200.2}{s - \frac{s}{1488.2}} = \frac{200.2}{\frac{1487.2}{1488.2}} \text{ for concave}$$

$.000001346\overline{13}$

For convex $k = 200.2 \times \frac{1486.2}{1487.2} = \log 2.30117$

" concave $k = 200.2 \times \frac{1488.2}{1487.2} = \text{"} \; 2.30175$ } as before

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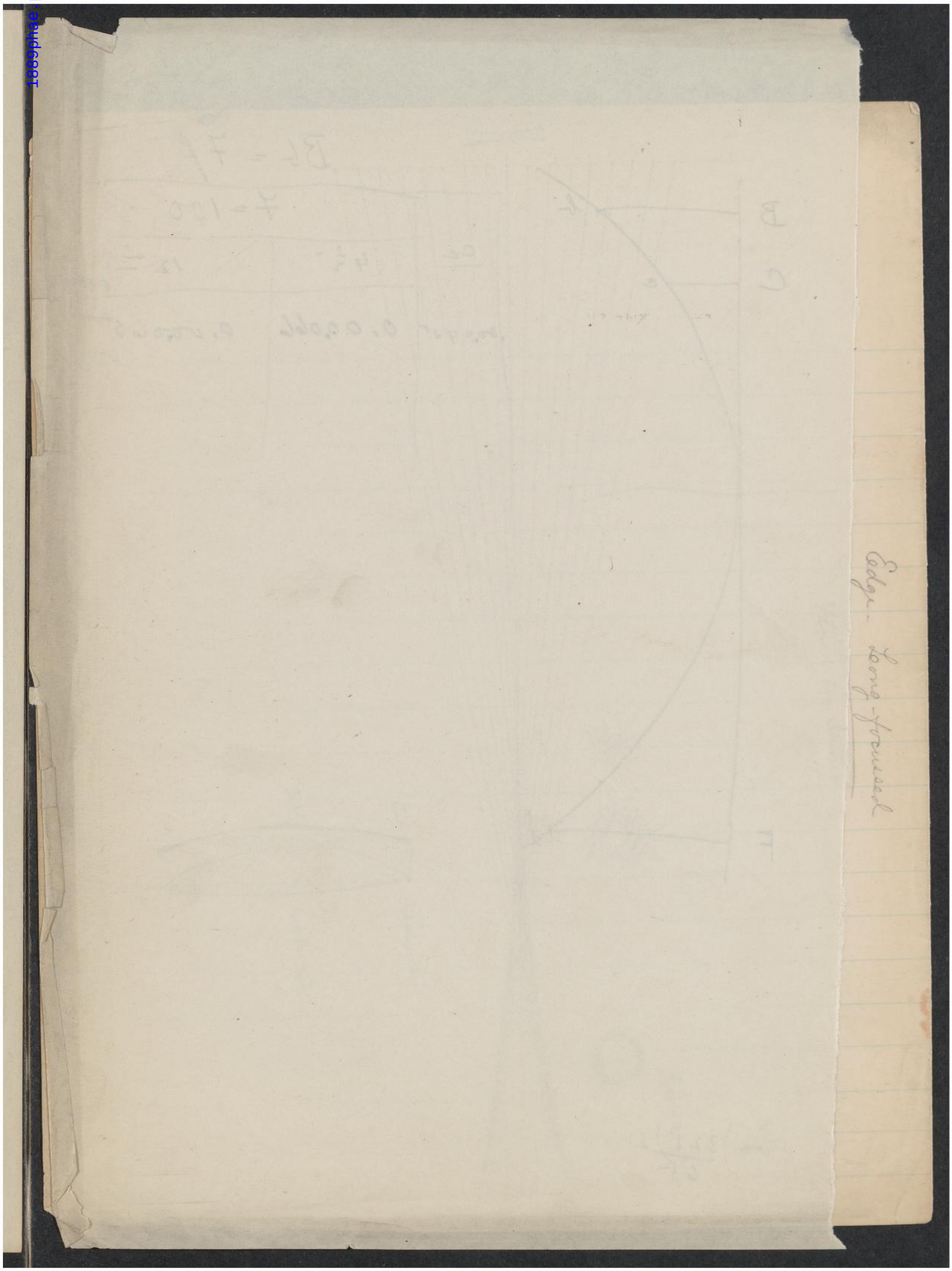
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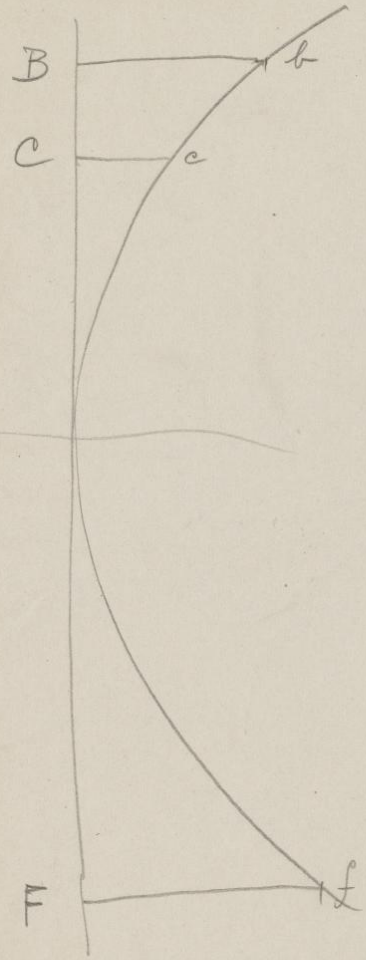
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Bb = 7f

7 = 100

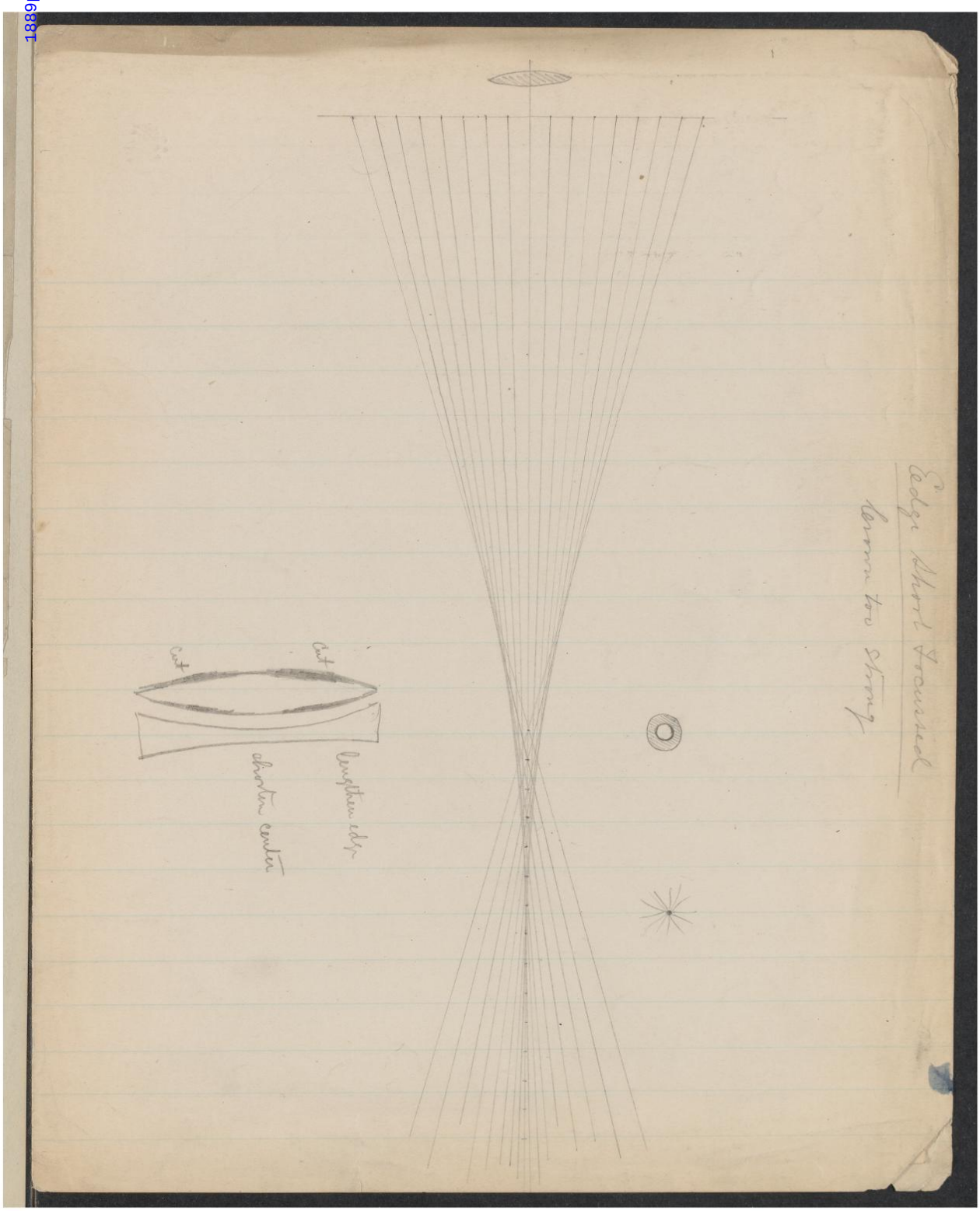
Cc	$4\frac{1}{2}$"	12"
.00045	0.00066	0.00065

p187

500) 325 (5
65

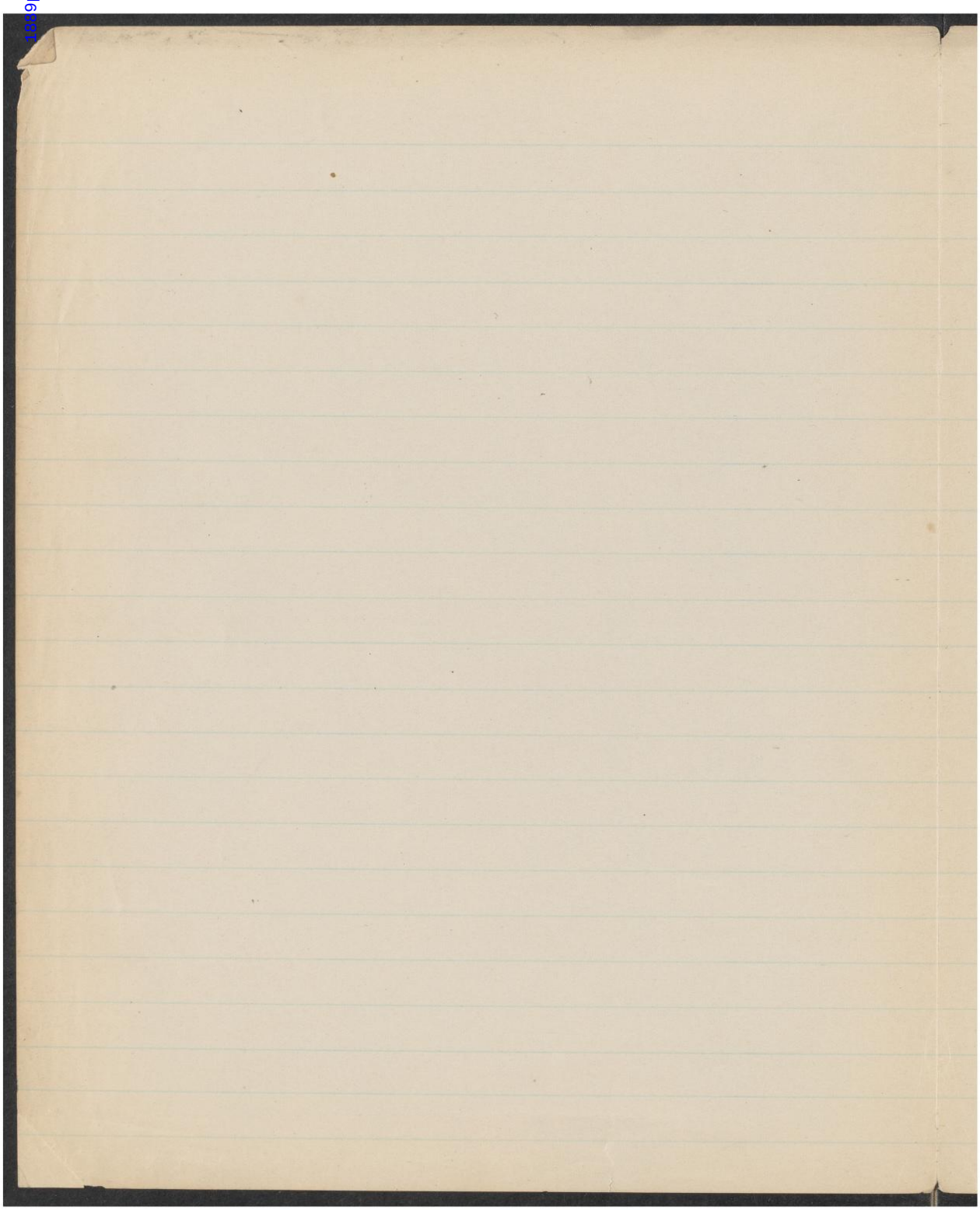
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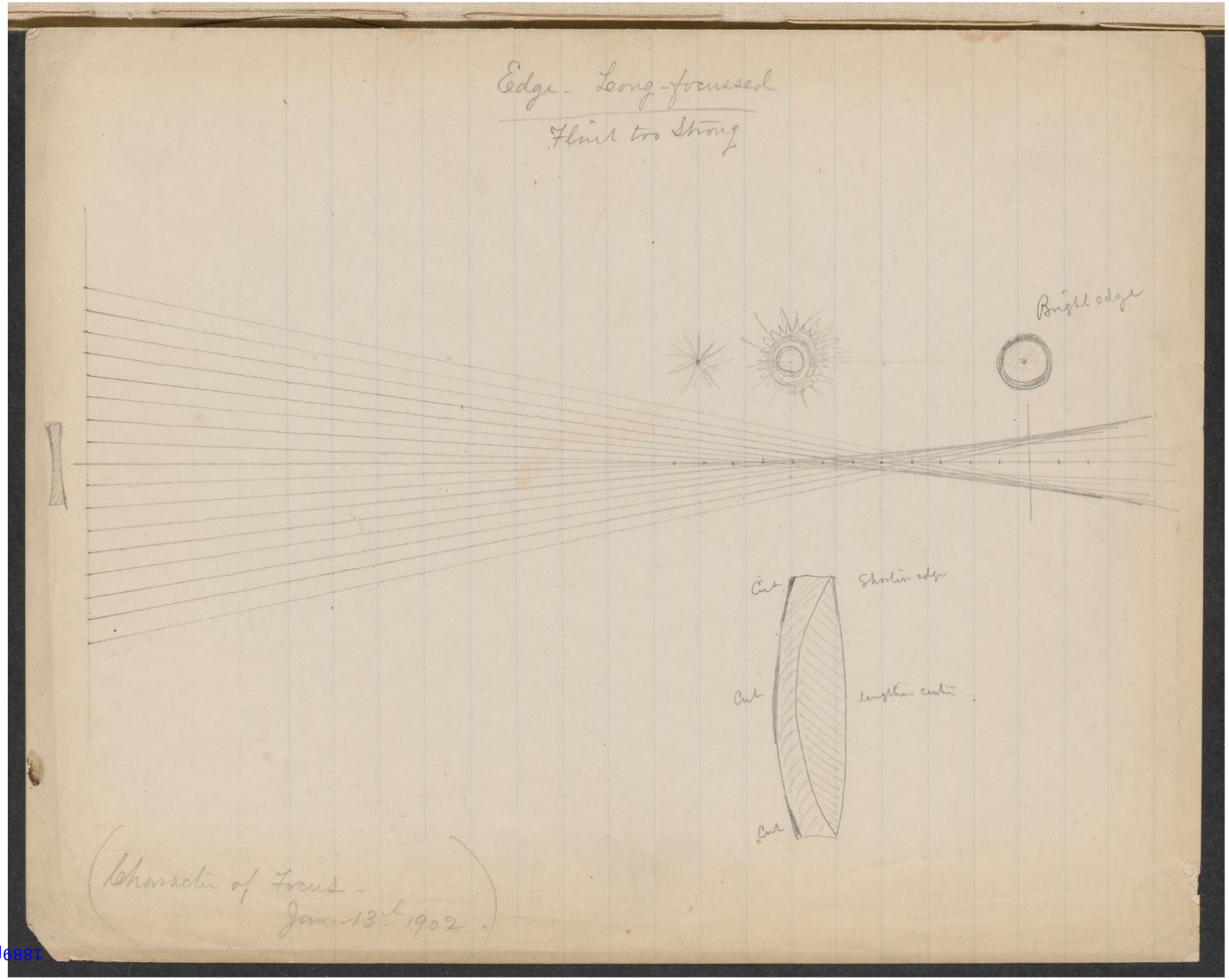


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.350
.180
.250
2) .780
.390
52.55
52.95

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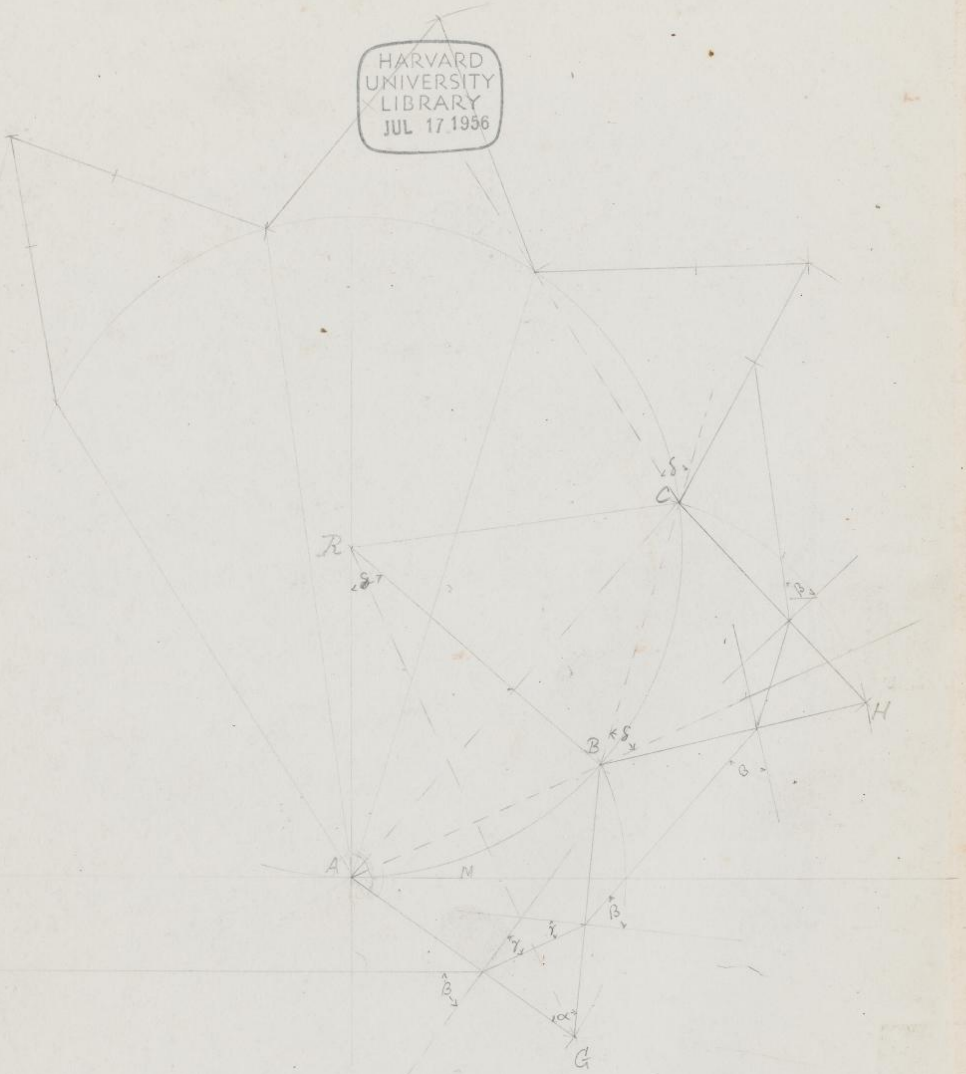
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Train of Prisms

Problem – Given any number of prisms having equal angle between their refracting surfaces, and equal indices of refraction for the same monochromatic ray of light – to find the position of each prism in order that the direction of a given monochromatic ray passing through each prism may be equally inclined to the two refracting faces; ∴ may pass through at the angle of minimum deviation.

Let the prisms be so placed that the lines where the planes of their faces intersect shall be equally distant from each other ∴ AB = CD = DE &c –

Let I = Index of refraction of the given ray.

α = Angle between refracting faces of prisms

β = " incident ray makes with normal to 1st surface of each prism –

γ = Angle which the refracted ray makes with normal to 1st surface of each prism.

δ = Change of direction of the ray through two adjacent prisms.

R = Radius of circle which passes through the points A, B, C &c.

$$I = \frac{\sin\beta}{\sin\gamma}. \quad \gamma = 90° - (90° - \tfrac{1}{2}\alpha) = \tfrac{1}{2}\alpha \quad \therefore I = \frac{\sin\beta}{\sin\frac{1}{2}\alpha}$$

$$\sin\beta = I \sin\tfrac{1}{2}\alpha.$$

δ = exterior angle ABC. $- 180° = 2\{\frac{1}{2}(180° - \alpha)\} + 180° - \{2(90° - \beta)\} - 180°$

$= 180° - \alpha + 180° - 180° + 2\beta - 180° = 2\beta - \alpha.$

This is true at any of the points B, C, D &c – ∴ the points A B C D &c lie in the circumference of a circle.

Angle RAM = ang. RAQ $- (90° - \beta) = 180° - \frac{1}{2}\delta - \frac{1}{2}\alpha - 90° + \beta$

$= 90° - \beta + \frac{1}{2}\alpha - \frac{1}{2}\alpha + \beta = 90°$

∴ The centre of the circle which passes through A B C D &c always lies in a line through A whose direction is perpendicular to the direction of the incident ray.

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In the triangle R.A.B.

$$A = \tfrac{1}{2}(180° - \delta) = 90° - \tfrac{1}{2}\delta = 90° - (\beta - \tfrac{1}{2}\alpha)$$

$$R = \frac{AB \sin A}{\sin \delta} = \frac{AB \sin\{90° - (\beta - \tfrac{1}{2}\alpha)}{\sin(2\beta - \alpha)}$$

$$= \frac{AB \cdot \cos(\beta - \tfrac{1}{2}\alpha)}{\sin(2\beta - \alpha)} \text{ or } \frac{AB \cos(\beta - \tfrac{1}{2}\alpha)}{\sin 2(\beta - \tfrac{1}{2}\alpha)}$$

where $\sin\beta = I \sin\alpha$ as above.

Let $\varepsilon = \tfrac{1}{2}\delta = \beta - \tfrac{1}{2}\alpha$. and $P = AB, BC, \&c.$

" A be the origin of coordinates X. the horizontal axis and Y the vertical.

The coordinates of the point B are

$$\left.\begin{aligned} x &= P\cos\varepsilon \\ y &= P\sin\varepsilon \end{aligned}\right\} \quad (1.)$$

The coordinates of the point C are

$$\left.\begin{aligned} x &= P(\cos\varepsilon + \cos 3\varepsilon) \\ y &= P(\sin\varepsilon + \sin 3\varepsilon) \end{aligned}\right\} \quad (2.)$$

The coordinates of the point D are

$$\left.\begin{aligned} x &= P(\cos\varepsilon + \cos 3\varepsilon + \cos 5\varepsilon) \\ y &= P(\sin\varepsilon + \sin 3\varepsilon + \sin 5\varepsilon) \end{aligned}\right\} \quad (3.)$$

The coordinates of the point E are

$$\left.\begin{aligned} x &= P(\cos\varepsilon + \cos 3\varepsilon + \cos 5\varepsilon + \cos 7\varepsilon) \\ y &= P(\sin\varepsilon + \sin 3\varepsilon + \sin 5\varepsilon + \sin 7\varepsilon) \end{aligned}\right\} \quad (4.)$$

The coordinates of the point F. are

$$\left.\begin{aligned} x &= P(\cos\varepsilon + \cos 3\varepsilon + \cos 5\varepsilon + \cos 7\varepsilon + \cos 9\varepsilon) \\ y &= P(\sin\varepsilon + \sin 3\varepsilon + \sin 5\varepsilon + \sin 7\varepsilon + \sin 9\varepsilon) \end{aligned}\right\} \quad (5.)$$

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To find the coordinates of the centre of the circle which will pass through three positions of the several points C. D E &c.

The general equation of the circle is

$$(x-a)^2+(y-b)^2=R_1^2$$

Let $x_1 y_1$ = the coordinates of one position of one of the points C D &c
" $x_2 y_2$ = " " " a second " " the same point.
" $x_3 y_3$ = " " " a third " " " " " " .

Substituting these values in the equation of the circle we have the three equations

$$\begin{aligned}(x_1-a)^2+(y_1-b)^2&=R_1^2\\(x_2-a)^2+(y_2-b)^2&=R_1^2\\(x_3-a)^2+(y_3-b)^2&=R_1^2\end{aligned}\qquad (6.)$$

From which to find the corresponding values of a and b the coordinates of the centre of the required circle, and R, its radius.

$$a=\frac{(x_1^2-x_2^2)(y_2-y_3)-(x_2^2-x_3^2)(y_1-y_2)+(y_1^2-y_2^2)(y_2-y_3)-(y_1-y_2)(y_2^2-y_3^2)}{2\{(x_1-x_2)(y_2-y_3)-(x_2-x_3)(y_1-y_2)\}}\qquad (7.)$$

$$b=\frac{(x_1^2-x_2^2)(x_2-x_3)-(y_2^2-y_3^2)(x_1-x_2)+(y_1^2-y_2^2)(x_2-y_3)-(x_1-x_2)(x_2^2-x_3^2)}{2\{(y_1-y_2)(x_2-x_3)-(y_2-y_3)(x_1-x_2)\}}$$

or

denominator may be written $-2\{(x_1-x_2)(y_2-y_3)-(x_2-x_3)(y_1-y_2)\}$

Equation (1.) can be reduced to the form

$$x^2+y^2=P^2$$

which is the equation of a circle whose centre is at A.

From the figure it will be seen that the coordinates of the point B have the relation

$$y=x\tan\varepsilon$$

Equation (2.) can be reduced to the form

$$x^2+y^2=4P^2\cos^2\varepsilon$$

or

$$x^2+y^2=2P^2\left(1+\frac{x}{\sqrt{x^2+y^2}}\right)$$

and from the figure

$$y=x\tan 2\varepsilon.$$

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Given a train of five prisms of specific gravity 3.87 - having an angle of 60° between refracting faces. and connected together by means of hinges so placed that their centres are in the intersections of the planes of the faces and at a distance of $1\frac{13}{16}$ inches apart.

To find the coordinates of the centre and radius of the circle, whose circumference passes through the three points occupied by the centre of each hinge when the prisms are adjusted for the angle of minimum deviation for the B line, the F line and the H line of the solar spectrum.

Enc. Brit. Vol XVI pp. 589 + 590.

Spec Grav. of Prism	I_B	I_F	I_H
3.51	1.6020	1.6200	1.6404
3.72	1.6266	1.6467	1.6697
.21	.0246	.0267	.0293

3.72
3.87
15

$\therefore$ I for 3.87 is to be increased over that for 3.72 by that amount equall to $\frac{5}{7}$ of amount which I for 3.51 is less than I for 3.72.

Spec Grav.	I_B	I_F	I_H
3.72	1.6266	1.6467	1.6697
15	.0176	.0191	.0210
3.87	1.6442	1.6658	1.6907

$P = 1.8125$ in. $\alpha = 60°$. $\sin\beta = I \sin\frac{1}{2}\alpha$. $\varepsilon = \beta - \frac{1}{2}\alpha$

	Line in Solar Spectrum	I.	β	ε
1	B	1.6442	55° 17′ 40″	25° 17′ 40″
2	F	1.6658	56° 23′ 50″	26° 23′ 50″
3	H	1.6907	57° 42′ 40″	27° 42′ 40″

$\therefore$ For point C - from (2)

B. $x_1 = 2.0808$ inches $y_1 = 2.5321$ inches

F. $x_2 = 1.9634$ " $y_2 = 2.5861$ "

H. $x_3 = 1.8214$ " $y_3 = 2.6423$ "

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Substituting these values in equations (5) and (4) we have for the point C-

$a_c = 0.9346$ inches

$b_c = -0.02383$ "

Substituting these values in equation (6.) we have

$R_c = 2.801$ inches

$R_c = 2.805$ "

$R_c = 2.809$ "

The average of which is 2.805 inches.

For the point D-

$x_1 = 1.0034$ inches $\quad y_1 = 3.9897$ inches

$x_2 = .7509$ " $\quad y_2 = 3.9331$ "

$x_3 = .4627$ " $\quad y_3 = 3.8419$ "

$a = 1.5924$ inches

$b = .7772$ "

$R_D = 3.2659$ inches

$R_D = 3.2662$ "

$R_D = 3.2663$ "

For the point E-

$x_1 = -.8067$ inches $\quad y_1 = 4.0826$ inches

$x_2 = -1.0553$ " $\quad y_2 = 3.7820$ "

$x_3 = -1.2962$ " $\quad y_3 = 3.4042$ "

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R+E

$a = 1.6849$ inches

$b = 1.7687$ "

$R_E = 3.4003$ inches

$R_E = 3.4002$ "

$R_E = 3.4003$ "

For point 7.

$x_1 = -2.0278$ inches $\quad y_1 = 2.7430$ inches

$x_2 = -2.0271$ " $\quad y_2 = 2.2521$ "

$x_3 = -1.9339$ " $\quad y_3 = 1.7076$ "

$a = 1.0701$ inches

$b = 2.5018$ "

$R_7 = 3.1073$ inches

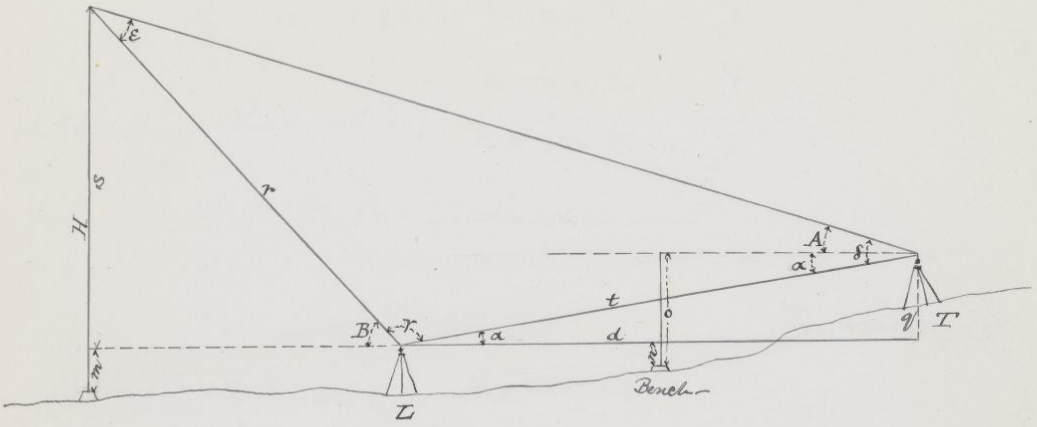
$R_7 = 3.1073$ "

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To find the height of an object above a given plane.

First Method - All measurements made in the same vertical plane.



Instrument at I -

Measure the vertical angle A which the object makes with the horizontal. and - the height of the instrument o above the bench - located nearly equally distant from I and L.

Instrument at L. -

Measure the angle B, and the height n. and also the height of the instrument m. above the given plane.

Measure the horizontal distance d between the stations I and L.

From the above it follows - that

$$q = o - n. \quad \text{and.}$$

$$\tan \alpha = \frac{q}{d}.$$

also. $t = \sqrt{d^2 + q^2}$, $\gamma = 180° - (B + \alpha)$, $\delta = A + \alpha$, and $\varepsilon = B - A$.

$$r = t \sin \delta \cos \varepsilon = t \sin (A + \alpha) \operatorname{cosec} (B - A)$$

$$S = r \sin B = t \sin B \sin (A + \alpha) \operatorname{cosec} (B - A)$$

$$H = m + t. \sin B. \sin (A + \alpha). \operatorname{cosec} (B - A).$$

If the station I were on a lower level than the station L, n would be larger than o, and q and therefore α would be minus quantities.

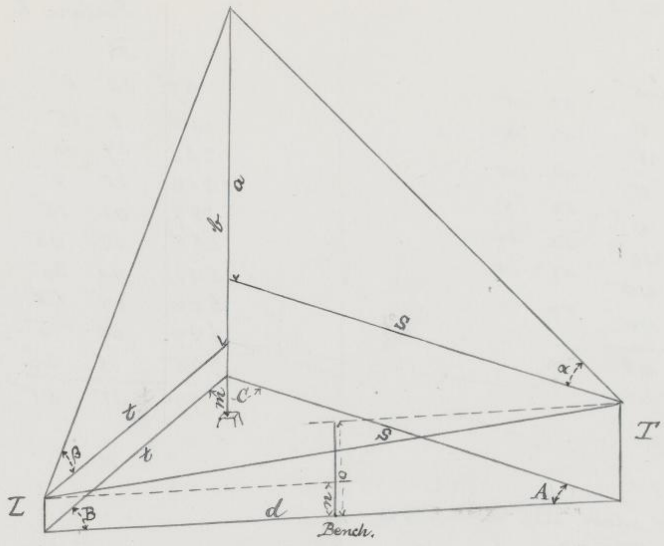
Note - $\operatorname{cosec} \alpha = \frac{1}{\sin \alpha}$.

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To find the height of an object above a given plane.

Second Method -



Instrument at I'.

Measure the horizontal angle A between the object and the station L. the vertical angle α which the object makes with the horizontal, and the height of the instrument o above the bench. located nearly equally distant from I' and L.

Instrument at L.

Measure the horizontal angle B, between object and station I', the elevation β of the object above the horizontal, and the height of the instrument n above the bench.

Measure the horizontal distance d between station I' and L,

Then -

$$C = 180° - (A + B)$$
$$S = d \sin B \operatorname{cosec} C$$
$$t = d \sin A \operatorname{cosec} C$$
$$a = S \tan \alpha = d \sin B \operatorname{cosec} C \tan \alpha$$
$$b = t \tan \beta = d \sin A \operatorname{cosec} C \tan \beta$$

Hence $H = m + o + a = m + o + d \sin B \operatorname{cosec} C \tan \alpha$
or $= m + n + b = m + n + d \sin A \operatorname{cosec} C \tan \beta$

With equal base lines, on nearly level ground, this method is much more accurate than the former, because in this case the angle C is considerably greater than the angle E.

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Height of the Spire of the Asylum Hill Cong. Church above the northeast corner of the first front door step. at 20 Farmington Ave.

Station I.

A.

90°	50′	45″	– 52′	15″
180	43	0	– 52	15
272	35	15	– 51	45
363	27	0	– 52	0
454	19	0	– 52	30
545	11	30	– 52	15
636	3	45	– 52	0
726	55	45		
90°	51′	58″		

Station L

B

77°	34′	0″	– 34′	15″
155	8	15	– 31	0
232	39	15	– 30	45
310	10	0	– 31	15
387	41	15	– 31	30
465	12	45	– 32	45
542	45	30	– 32	15
620	17	45	– 31	15
697	49	0	– 29	30
775	18	30		
77°	31′	51″		

o.

Datum Plane above step = 24 5/8 in.
Instrument below D.P. = 15 5/8 "
9 in

n.

24 5/8
15 5/8
9 inches

α.

20° 45′ less {19 div. of vernier / 11 " " " for 0°.
9′ = – 30
20° 36′

β

20° 15′ less {55 div. of vernier / 9 " " "
4′ = – 14
20° 11′

$d = 109^{ft}\ 6\tfrac{1}{4}^{in} = 1314.2$ inches

$d = 1314.2$ = log. 3.11866
$B = 77°31'50''$ = log sin 9.98963
$\alpha = 20°36'$ = " tan 9.575704
2.68333
$C = 11°36'10''$ = log sin 9.30347
2398.1^{in} = log 3.37986
$o = 9$
$H = 2407.1$ inches
$= 200^{ft}\ 7.1^{in}$.

$d =$ = log 3.11866
$A = 90°52'0''$ = log sin 9.99995
$\beta = 20°11'$ = " tan 9.56537
2.68398
$C =$ = log sin 9.30347
2401.7^{in} = log 3.38051
$n = 9$.
$H = 2410.7$ inches
$= 200^{ft}\ 10.7^{in}$.

An error of 1 inch in the base line = error of 1.6 inches in the height
" " " 1′ in A or B = " " 3.2 " " " "
" " " 1′ in α or β = " " 2.2 " " " "

∴ Height of Spire above step is $200^{ft}\ 9^{in}$. which is probably correct to within 5 inches.

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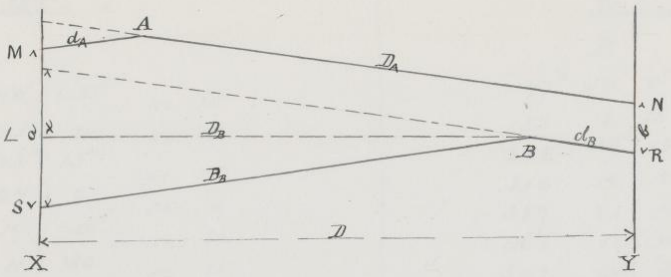
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Positive Adjustment for Levelling Instruments.

To find a point, such that when the telescope is set upon it and clamped, it is exactly horizontal, so that the instrument is correctly adjusted, by bringing the bubble directly to its central position.



A, is the first position of the level placed as near as possible to the vertical surface X.

B, is the second position of the level similarly located with regard to Y.

M, and N, are the sights from A on the surfaces X and Y respectively.

R, and S, " " " " B " " " Y " X "

d_A, is the distance of A from X.

D_B, " " " B " ".

D_A, " " " A " Y

d_B " " " B " Y

a is the distance between the sights M and S on X

b " " " " " " N " R " Y

L is a point in X on the same level with B,

$\frac{1}{2}x$ is the distance of L from S.

I. R taken below N.

1st. case. When a is greater than b and S falls below M.

Let α be the angle which the axis of the level makes with the horizontal when the instrument is set apparently level.

Then $$x = a + d_A \cdot 2\sin\alpha - b \qquad (1)$$

also $$x = D_B \cdot 2\sin\alpha \qquad (2)$$

Therefore $$2\sin\alpha = \frac{a-b}{D_B - d_A}.$$

Substituting this value in equation (2.)

$$x = (a-b)\cdot\frac{D_B}{D_B - d_A}.$$

Half of which or the distance of L above S, =

$$\tfrac{1}{2}x = \tfrac{1}{2}(a-b)\cdot\frac{D_B}{D_B - d_A}. \qquad (1).$$

If $d_A = d_B = d$.

$$\tfrac{1}{2}x = \tfrac{1}{2}(a-b)\cdot\frac{D}{D-2d}. \qquad (2)$$

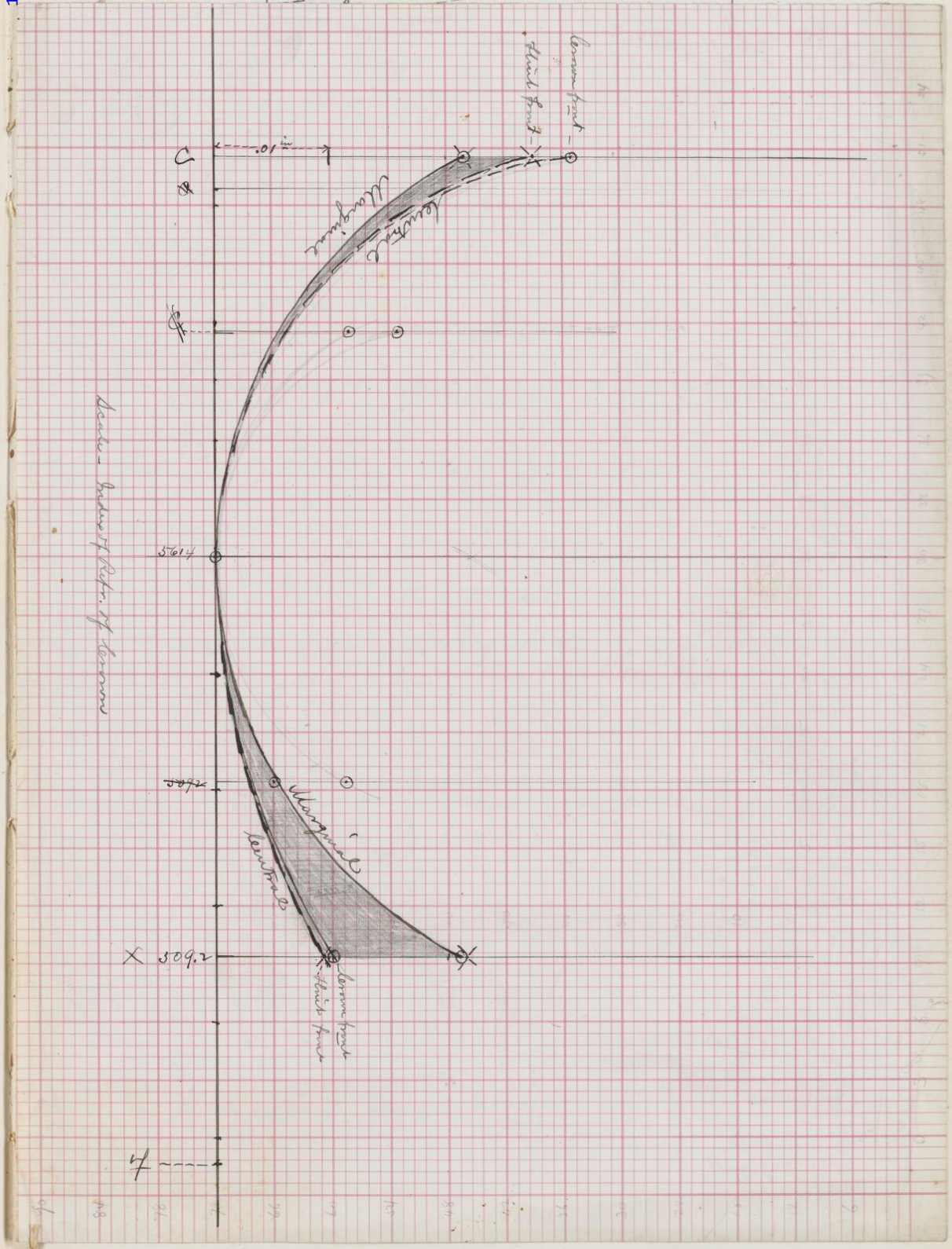
When $a = b$, $x = d_A \cdot 2\sin\alpha$ and $\tfrac{1}{2}x = \tfrac{1}{2}d_A \cdot 2\sin\alpha$

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2nd case. When a is ~~less~~ equal to or greater than b, ~~or when~~ S falls above M, or when a is less than b.

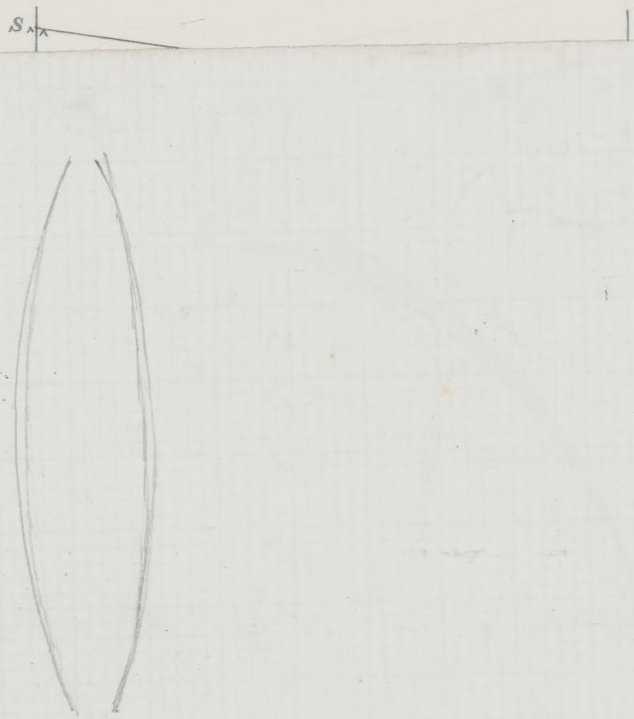




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2nd case. When a is ~~less~~ equal to or greater than b, ~~S~~ S falls above M, or when a is less than b. at the same time that



$\phi = 10.1$

$\frac{1}{\phi} = \frac{1}{10.1} = .09$

$\phi - \frac{1}{\phi} = .026$

$\phi = .09 + .026 = .116$

$\frac{1}{\phi} = 8.6$

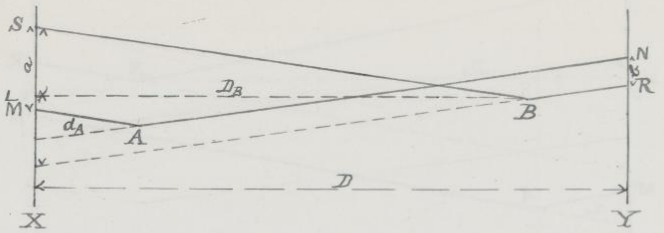
$\frac{.0274}{.116} \overline{)3.0000} \; 236$

0.026

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2nd case. When a is ~~less~~ equal to or greater than b, ~~or when~~ at the same time that S falls above M, or when a is less than b.



In this case,

$$x = D_B \cdot 2\sin\alpha$$

$$x = a + d_A \cdot 2\sin\alpha + b$$

Therefore $2\sin\alpha = \dfrac{a+b}{D_B - d_A}$.

Hence $x = (a+b)\dfrac{D_B}{D_B - d_A}$.

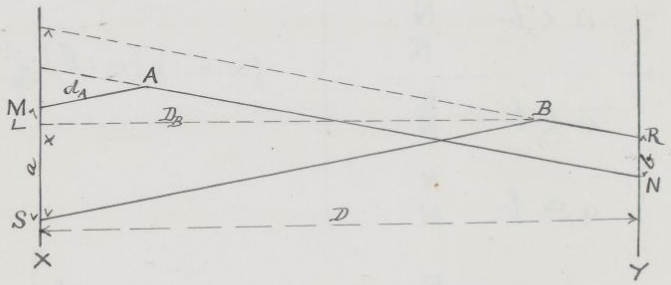
The distance of L below S $= \frac{1}{2}x = \frac{1}{2}(a+b)\dfrac{D_B}{D_B - d_A}$. (1).

If. $d_A = d_B = d$

$$\frac{1}{2}x = \frac{1}{2}(a+b)\cdot\frac{D}{D-2d}. \qquad (2).$$

II. R taken above N.

1st case. When a is equal to or greater than b, at the same time that S falls below M. or when a is less than b. ~~at the same time that S falls above M.~~



$$x = D \cdot 2\sin\alpha$$

$$x = a + d_A \cdot 2\sin\alpha + b$$

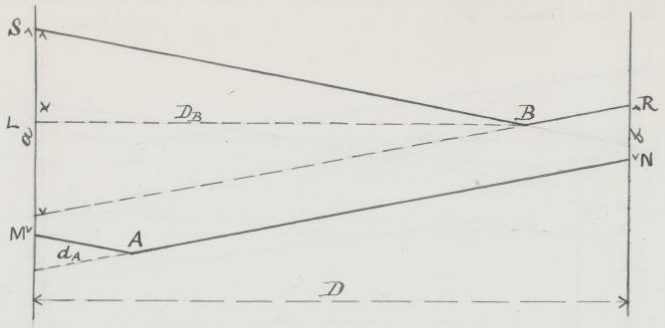
$\frac{1}{2}x = \frac{1}{2}(a+b)\dfrac{D_B}{D_B - d_A}$. measured up from S. (1)

If $d_A = d_B = d$, $\frac{1}{2}x = \frac{1}{2}(a+b)\dfrac{D}{D-2d}$, " " " " (2.)

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2nd Case. When a is greater than b, and S fall above M.



$$x = D_B \cdot 2\sin\alpha$$

$$x = a + d_A \cdot 2\sin\alpha - b$$

$$\tfrac{1}{2}x = \tfrac{1}{2}(a-b)\frac{D_B}{D_B - d_A} \qquad \text{down from } S \qquad (1).$$

If $d_A = d_B = d$.

$$\tfrac{1}{2}x = \tfrac{1}{2}(a-b)\frac{D}{D-2d}. \qquad " \quad " \quad " \qquad (2).$$

M S	$a > b$	N R	$\tfrac{1}{2}x = \tfrac{1}{2}(a-b)\frac{D_B}{D_B - d_A}$.
S M	$a \leq b$	N R	$\tfrac{1}{2}x = \tfrac{1}{2}(a+b)\frac{D_B}{D_B - d_A}$.
	$a < b$	N R	
	$a < b$	R N	
M S	$a \geq b$	R N	
S M	$a > b$	R N	$\tfrac{1}{2}x = \tfrac{1}{2}(a-b)\frac{D}{D_B - d_A}$.

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Magnetic Variation and Latitude of Hartford. Dec. 16th 1877.

Upper transit of Polaris.

Polaris and Alioth (ε Ursae Majoris) in some vertical plane - at $7^h 6^m 10^s$ observed time by C.P.H's watch. -

Calculated Jan 1st 1878 - $23^m 54^s$ -

17 minutes later instrument clamped on Polaris -, for true north.

Angle between true north and vertical plane through Polaris and Alioth at $7^h 6^m 10^s = 0° 9' 0''$. Calculated after intervals of $23^m 54^s = 11' 30''$

Reading of horizontal circle set true north -- $359° 51' 0''$

" " "	Mag. needle at 0° ---	349° 32 30	C.P.H.
" " "	"	36 15	C.B.R.
" " "	"	32 0	" E
" " "	"	34 30	C.P.H.
" " "	"	30 30	"
" " "	"	34 0	"
	Call	$349° 32' 0''$	

Magnetic Variation = Error true north $10° 18'$ − 2 30 = $10° 15' 30''$

Altitude of Polaris - Observed - $43° 15'$ less $7' 48'' = 26.0$ | 18.5 div. of vernier; 7.5 " " " 40

Apparent Altitude = $43° 7' 12''$

Correction for Refraction = 1 2

True Altitude = $43° 6' 10''$ — $43° 6' 10''$

P.D. of Polaris Jan 1st 1878 = 1 20 18 should be 1 20 29

Latitude of Hartford = $41° 45' 52''$ — $41° 45' 41''$

59
41
18"

Calculated ☌ Polaris on Meridian at $7^h 33^m 45^s$

Observed 7 30 4

Error of Watch - $3^m 41^s$ slow

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Magnetic Variation – Hartford – Sept. 12th 1909

N. line by Transit of δ Ursae Min. & θ Sagittarii.

South End of Needle	1st meas.	10°	48′
	2nd "	10	51

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To find interval of time between the instant that the stars α Ursae Minoris and ε Ursae Majoris have the same Azimuth, and the instant that α U. Min. (Polaris) crosses the Meridian. Jan. 1st 1878. Lat. 41° 45' 59".

α Ursae Minoris R.A. $1^h\ 14^m\ 2^s.3$ Decl. D. 1° 20' 29"

ε Ursae Majoris " $12^h\ 48^m\ 39^s.6$ " 33° 22' 42"



Triangle αPε. Chauv. Trig. p. 181. (125).

$$\tan \chi = \tan P\varepsilon \cdot \cos P.$$

$$\cot \alpha = \frac{\sin(P\alpha - \chi)\cot P}{\sin \chi}$$

$$P = \begin{array}{r} 12^h\ 48^m\ 39^s.6 \\ 1\ 14\ 2.3 \\ \hline 11\ 34\ 37.3 \end{array} = 173°\ 39'\ 19".5$$

$P\varepsilon$	$= 33°\ 22'\ 42"$	= log tan	9.818 7590
P	$= 173°\ 39'\ 19".5$	= " cos	9.997 3319 —
$180° - \chi$	$= 33°\ 12'\ 57"$	= " tan	9.816 0909 —
χ	$= 146°\ 47'\ 3"$		
$P\alpha - \chi$	$= 145°\ 26'\ 34"$	= log sin	9.753 7575 —
P	$= 173°\ 39'\ 19".5$	= " cot	0.954 6012 —
χ	$= 146°\ 47'\ 3"$	=	0.708 3587 +
		" sin	9.738 6209
α	$= 6°\ 7'\ 11"$	= " cot	0.969 7378
$P\alpha Z$	$= 180° - \alpha = 173°\ 52'\ 49"$		

Triangle αPZ. Chauv. Trig. p.

$$\sin PZ\alpha = \frac{\sin P\alpha Z \sin P\alpha}{\sin PZ}$$

$P\alpha Z$	$= 173°\ 52'\ 49"$	= log sin	9.027 7820
$P\alpha$	$= 1°\ 20'\ 29"$	= " sin	8.369 3924
			7.397 1754
PZ	$= 48°\ 14'\ 1"$	= " sin	9.872 6613
$PZ\alpha$	$= 0°\ 11'\ 30"$	= " sin	7.524 5141

∴ The True North is 11'30" West of α and ε when they are in the same vertical line.

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Triangle αPZ. Chauv. Trig. p.

$$\cot \vartheta = \tan \alpha \cos P\alpha$$
$$\cos \vartheta' = \cos \vartheta \tan P\alpha \cot PZ$$
$$ZP\alpha = \vartheta - \vartheta'$$

α	$= 173^\circ 52' 49''$	$=$ log tan	9.030 2650	−
$P\alpha$	$= 1^\circ 20' 29''$	$=$ " cos	9.999 8809	
$180^\circ - \vartheta$	$= 83^\circ 52' 55''$	$=$ " cot	9.030 1459	−
ϑ	$= 96^\circ 7' 5''$	$=$ " cos	9.027 6654	−
$P\alpha$	$= 1^\circ 20' 29''$	$=$ " tan	8.369 5114	
PZ	$= 48^\circ 14' 1''$	$=$ " cot	9.950 8749	
$180^\circ - \vartheta'$	$= 89^\circ 52' 20''$	$=$ " cos	7.348 0517	−
ϑ'	$= 90^\circ 7' 40''$			

$\vartheta = 96^\circ 7' 5''$
$\vartheta' = 90^\circ 7' 40''$

$ZP\alpha = 5^\circ 59' 25'' = 0^h 23^m 57^s.7$ Sidrial Time.
3.9

∴ Interval of Time Required $= 0^h 23^m 53^s.8$ Mean Solar Time

---

To find the interval of time between the instant that α Ursae Minoris crosses the meridian, and the instant that α Ursae Minoris and η Ursae Majoris have the same Azimuth. Jan. 4th 1878. Lat. 41° 45' 59".

α Ursae Minoris — R.A. $1^h 14^m 2^s.3$ N.P.D. $1^\circ 20' 29''$
η Ursae Majoris — " $13^h 42^m 35^s.0$ " $40^\circ 4' 38''$
42 44



Triangle αPη. Chauv. Trig. p. 179. (123).

$$\tan \varphi = \tan \eta P \cos P$$
$$\cot \alpha = \frac{\sin(P\alpha - \varphi) \cot P}{\sin \varphi}$$

13^h	42^m	$35^s.0$
1	14	2.3
12	28	32.7
−24	0	0
$P = 11^h$	31^m	$27^s.7 = 172^\circ 51' 49''$

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$\eta P = 40^\circ\ 4'\ 38'' = \log \tan\ 9.925\ 0020$

$P = 172^\circ\ 51'\ 49'' = \text{"}\ \cos\ \underline{9.996\ 6226 -}$

$180^\circ - \varphi = 39^\circ\ 51'\ 28'' = \text{"}\ \tan\ 9.921\ 6246 -$

$\varphi = 140^\circ\ 8'\ 32''$

$R - \varphi = -138^\circ\ 48'\ 3'' = \log \sin\ 9.818\ 6735 -$

$P = 172^\circ\ 51'\ 49'' = \text{"}\ \cot\ \underline{0.902\ 3902 -}$

$0.721\ 0637$

$\varphi = 140^\circ\ 8'\ 32'' = \text{"}\ \sin\ \underline{9.806\ 7794}$

$\alpha = P\alpha\eta = \underline{6^\circ\ 56'\ 44''} = \text{"}\ \cot\ 0.914\ 2843$

$180^\circ - \alpha = P\alpha Z = 173^\circ\ 3'\ 16''$

Triangle $P\alpha Z$ Chauv. Trig p. (148).

$$\sin Z = \frac{\sin \alpha \sin P\alpha}{\sin PZ}.$$

$\alpha = 173^\circ\ 3'\ 16'' = \log \sin\ 9.082\ 5202$

$P\alpha = 1^\circ\ 20'\ 29'' = \text{"}\ \sin\ \underline{8.369\ 3924}$

$7.451\ 9126$

$PZ = 48^\circ\ 14'\ 1'' = \text{"}\ \sin\ \underline{9.872\ 6613}$

$Z = 0^\circ\ 13'\ 3'' = \text{"}\ \sin\ 7.579\ 2513$

∴ The true North is 13' 3" East of α and η when they are in the same vertical line.

Triangle $P\alpha Z$. Chauv. Trig p.

$$\cot \vartheta = \tan \alpha \cos P\alpha$$
$$\cos \vartheta' = \cos \vartheta \tan P\alpha \cot PZ$$
$$ZP\alpha = \vartheta - \vartheta'$$

$\alpha = 173^\circ\ 3'\ 16'' = \log \tan\ 9.085\ 7188 -$

$P\alpha = 1^\circ\ 20'\ 29'' = \text{"}\ \cos\ \underline{9.999\ 8809}$

$180^\circ - \vartheta = 83^\circ\ 3'\ 23'' = \text{"}\ \cot\ \underline{9.085\ 5997 -}$

$\vartheta = 96^\circ\ 56'\ 37'' = \text{"}\ \cos\ 9.082\ 3992 -$

$P\alpha = 1^\circ\ 20'\ 29'' = \text{"}\ \tan\ 8.369\ 5114$

$PZ = 48^\circ\ 14'\ 1'' = \text{"}\ \cot\ \underline{9.590\ 8749}$

$180^\circ - \vartheta' = 89^\circ\ 56'\ 12'' = \text{"}\ \cos\ 7.042\ 7853 -$

$\vartheta' = 90^\circ\ 3'\ 48''$

$\vartheta = 96^\circ\ 56'\ 37''$

$\vartheta' = \underline{90^\circ\ 3'\ 48''}$

$ZP\alpha = 6^\circ\ 52'\ 49'' = 0^h\ 27^m\ 31^s.3$ Sidereal Time

4.5

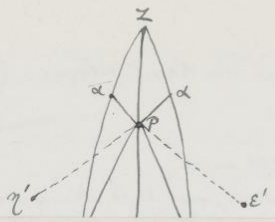
$0^h\ 27^m\ 26^s.8$ Mean Solar Time

∴ Interval of time required =

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Which - of the preceding -



Effect on the rationality of the Spectrum of turning the prism each side of the angle of Minimum Deviation.

Flint Prism 60°

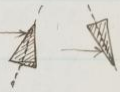
Measured with Micrometer, Nov. 2, 1893 - C line at Min. Dev.

I. Angle of Prism turned about 10° towards the light



C	D	(5614)	E	F
30.01	21.65	16.69	10.43	0
10000	4438	5562		0

II. Angle of Prism turned about 10° away from light.



C	D	(5614)	E	F
22.35	16.01	12.27	7.62	0
10000	4511	5489		0

In the second case the spectrum is much longer than the other that is the dispersion is greater, for the same Deviation, which was nearly the same in both cases.

Rationality I $\frac{16.69}{20.01} = .5562$ ✓ Red end shortened - blue lengthened

II $\frac{12.27}{22.35} = \frac{.5489}{.0073}$ ✓ Red end lengthened, - blue shortened

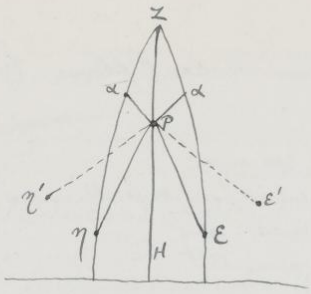
D at Min. Dev.

Lithium line

C	D	5614	Thallium	E	Strontium	F
26.90	17.96	13.80		8.60		0

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ε' = position of ε Ursae Majoris when α Ursae Minoris is on the meridian.
η' = " " η " " " " " " " " " "

$\varepsilon P\varepsilon' = ZP\alpha_\eta$ and $\eta P\eta' = ZP\alpha_\varepsilon$

For ε — $\alpha P\varepsilon = 173^\circ\ 39'\ 19''$; $\alpha PZ = 5^\circ\ 59'\ 25''$; $179^\circ\ 38'\ 44''$; $\varepsilon PH = 0^\circ\ 21'\ 16''$

For η — $\alpha P\eta = 172^\circ\ 51'\ 49''$; $\alpha PZ = 6^\circ\ 52'\ 49''$; $179^\circ\ 44'\ 38''$; $\eta PH = 0^\circ\ 15'\ 22''$

$\therefore\ \eta P\varepsilon = 0^\circ\ 36'\ 38'' = 0^h\ 2^m\ 26.^s52$
$\varepsilon P\varepsilon' = 5^\circ\ 59'\ 25'' = 0^h\ 23^m\ 57.^s67$
$\eta P\eta' = 6^\circ\ 52'\ 49'' = 0^h\ 27^m\ 31.^s26$
Diff of R.A of ε on η $= 13^\circ\ 28'\ 52'' = 0^h\ 53^m\ 55.^s4$

R.A of η $= 13^h.\ 42^m\ 35.^s0$
" " ε $= 12\ \ 48\ \ 39.6$
$0^h\ 53^m\ 55.^s4$

To find the interval of time between the instant that α Ursae Minoris is on the meridian and the instant that it and ζ Ursae Majoris are in the same vertical plane — Lat. 41° 45' 59" June 24, 1878.

	R.A.	N.P.D.
α Ursae Minoris	$1^h\ 14^m\ 3.^s5$	$1^\circ\ 20'\ 29''$
ζ " Majoris	" $13\ 19\ 1.0$	$34\ 26\ 15$
	$P = 11^h\ 55^m\ 2.^s5 = 178^\circ\ 45'\ 37''$	

Using same figure as for η.

$\alpha ZP = 0^\circ\ 2'\ 15''$.
$\alpha PZ = \vartheta - \vartheta' = 1^\circ\ 11'\ 16'' = 4^m\ 45.^s7$ Sidereal Time
$= 4^m\ 44.^s5$ Mean Solar Time.

The Diff of R.A. chuetes as above.

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Observations. Dec. 28th 1877.

α U. Minor and ε U. Major in same vertical plane. by C.R.H. watch $6^h\ 20^m\ 10^s$

Circle set to read 0° 0′ 0″

α U. Minor on the Meridian by C.R.H. watch ——— $6^h\ 44^m\ 4^s$

" " " Calculated from Naut. Almanac. $6^h\ 42^m\ 41^s$

C.R.H. Watch slow $1^m\ 23^s$

fast

At $6^h\ 44^m\ 4^s$ Set on α —

Hz. circle read 359° 48′ 10″

α Moved in 20ˢ 0° 11′ 50″ = E. Az. of Vert. plane —

10″

0° 11′ 40″ = " " " "

Vertical Circle — = Altitude of α. observed — 43° 15′ less 16 dia of Ven. 8 " " "

7′ 12″ = 24

= 43° 7′ 48″

Struck leg of Theodolite with knee, as last the meridian.

α on meridian ——— $6^h\ 44^m\ 4^s$

27ˢ 27ˢ

α & η in Vertical plane ——— $7^h\ 11^m\ 31^s$

at which time α is 13′ 3″ W. of Meridian —

At that time set on α and turned back 13′ 3″ for approx. meridian

Mag. Variation 10° 28′ 0″

Star	Time of crossing Wire C.R.H. watch. h. m. s.		Calc. Time of do.	Diff.	N. P. D. (N.A)
α Draconis	7 31 4	good	$7^h\ 29^m\ 35^s$	$0^h\ 1^m\ 29^s$	25° 2′ 29″
δ Ursæ Minoris	7 57 45	poor	7 56 14	1 31	13 45 26
β " "	8 21 1	good	8 19 26	1 35	15 20 47
γ " "	8 46 52	" !	8 49 13	1 28	17 43 54
ζ " "	9 18 2	"	9 16 39	1 23	11 49 52
η Draconis	9 51 53	"	9 50 27	1 28	28 12 34

Temperature 32° Fahr. Barometer 30.06 inches at $9^h\ 0^m\ 0^s$.

Star	Apparent Altitude Observed.	True Altitude Loomis Nat P.	True Alt. + NPD − Latitude of Inst.	Diff from Mean.
α Draconis	16° 47′ 6″	16° 43′ 48″	41° 46′ 17″	−2″
δ Ursæ Minoris	28 2 6	28 0 13	41 45 57	−22
β " "	26 28 0	26 25 59	41 46 46	+27
γ " "	24 4 30	24 2 16	41 46 10	−9
ζ " "	29 58 0	29 56 15	41 46 17	−2
η Draconis	13 38 6	13 34 1	41 46 35	+16
α Ursæ Minoris	43 7 48	43 6 41	41 46 12	−7

41° 46′ 19″

Latitude of Instrument. being the mean value of above

" of 30 Farmington Ave north of old State House.

" of Old State House

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Observations. Dec. 31st 1877

α U. Minoris and ε U. Majoris in same vertical plane. CRH watch. $6^h\ 8^m\ 28^s$.
Hor. circle set at 180° 0' 6".
$23^m\ 54^s$

α U. Min. on the Meridian by CRH's watch $6^h\ 32^m\ 22^s$
" " " " " Am. Naut. Almanac $6^h\ 34^m\ 48^s$
3 U. Maj Observed on Meridian at $6^h\ 37^m\ 20^s$. " ~~Stone~~ Feet by $2^m\ 26^s$
1 35 feet.

At $6^h\ 32^m\ 22^s$ Instrument set on α U. Min. for True North.

Reading α and ε in Vertical plane 180° 0' 0"
" α on the Meridian 179° 48'
12' 0"

In the above and the following observations the wire was illuminated from the right hand side.

Reading for True North 179° 48' 0"
" Mag. Needle at 0° Inside circle 169° 28' 0"
" " " " " " 169° 28' 0"

Magnetic Variation 10° 20'
less Half apparent throw of vertical wire. illuminated from R. & L. side 0 46"
Throw of wire illuminated R. & L. Hands. = 1' 35".
10° 19' 15"

8° 22' Capt Boyles 1st at July 25th 79
1860 7° 26' 7° 49' 8° 07 } U.S. Coast survey 1879
70 7° 49' 8° 07
80 8° 09

Instrument set up. to face south. Mg. Var. 10° 20' turned off and circle swung around 180°.

Groups of 3rd mag. stars. Somewhat less Altitude than Rigel.

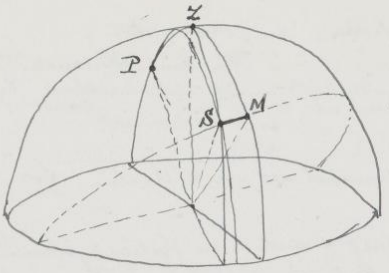
Stars	on a/p. Meridian CRH. watch.				True time of transit			Diff	Error of time of transit
	h	m	s						
A Above	7	42	3	× left	6	23			
B "	7	48	26	× left	7	08			
C "	7	53	34	× "	4	35			
D "	8	0	19	× "					
γ Eridanus	9	14	10	34° 22' Alt.					
ν_4 "	9	26	27		9	34	01 v	W.f. 2 25	4 52
								2 26	4 52
ν_5 "	9	42	37		9	50	11 v		
	9	57	20	44° 40' Alt.					
ν_7 "	9	58	42		9	51	21 v	W.f. 0m 11s	5 37
β "	10	23	0		10	22	33	W.f. 0m 27s	2m 53s
Rigel	10	29	56		10	29	24 v	W.f. 0m 32s	2m 58s

Jan 1st 8.20 A.M. Reading Mag. Needle at 0° 12' too little 179° 48' 0"

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To find the Error of the Time of the Transit of a star on the Equator corresponding to an Error of 10′ in the Azimuth of the transit Instrument.



In the right angled triangle Z S M.

M = 90°.
Z = 10′
ZM = Latitude of Place = 41° 46′ 10″. (30° Farmington Ave.)
SM = Time Angle required –

tang SM = tang Z cos ZM.

Z = 0° 10′ 0″ = Log tang 7. 463 7273
ZM = 41° 46′ 10″ = " cos 9. 823 5621
SM = 0° 6′ 40″ = " tang 7. 287 2894
" = 0ʰ 0ᵐ 26.ˢ7

Therefore error of 0° 10′ 0″ in the Azimuth of the transit inst. would cause an error of 0ʰ 0ᵐ 26.ˢ7 in the time of crossing the ~~apparent~~ meridian of a star on the equator.

R. A. of * = T of transit + R. A of Mean ⊙ – 24ʰ.
T of transit = R. A. of * + 24ʰ. – R. A. of Mean ⊙.

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Observations for Time. Jan. 18th 1878.

Time taken by C.P.H. watch, unchanged since Dec. 28th 1877.

N.P.D.			Mean Time	Observed Time by C.P.H. watch.	Calculated Time	
		α Ursae Majoris in same vertical Plane with	h m s	h m s		
15° 21' 16"	β	Ursae Minoris	— — at	6 49 20 ✓	6 48 9.8 ✓	1m 10s fast.
	11	" "	"	7 14 25 ✓		
17° 44' 22"	γ²	" "	1 56 18.7	7 17 30 ✓	7 16 18.7 ✓	1m 11s fast
	ι	Draconis	(!) "	7 22 35 ✓		
11° 50' 19"	ζ	Ursae Minoris	2 16 58.9	7 38 29 ✓	7 37 4.9 ✓	1m 24s fast
	θ	Draconis	"	7 58 20 ✓		
	η	Ursae Minoris	"	8 10 33 ✓		
28° 12 58	η	Draconis	(!!) 2 57 40.1	8 19 13 ✓	8 17 46.1 ✓	1 27 fast
	ζ	"	(!) "	9 1 50 ✓		
38° 20 11"	γ	"	after 2nd M. 4h 28m 38s.6 ✓ (uncertain about 2s) "	9 46 31 ✓	9 48 44.6 ✓	2m 14m slow

Observations for Time. (see two leaves over)

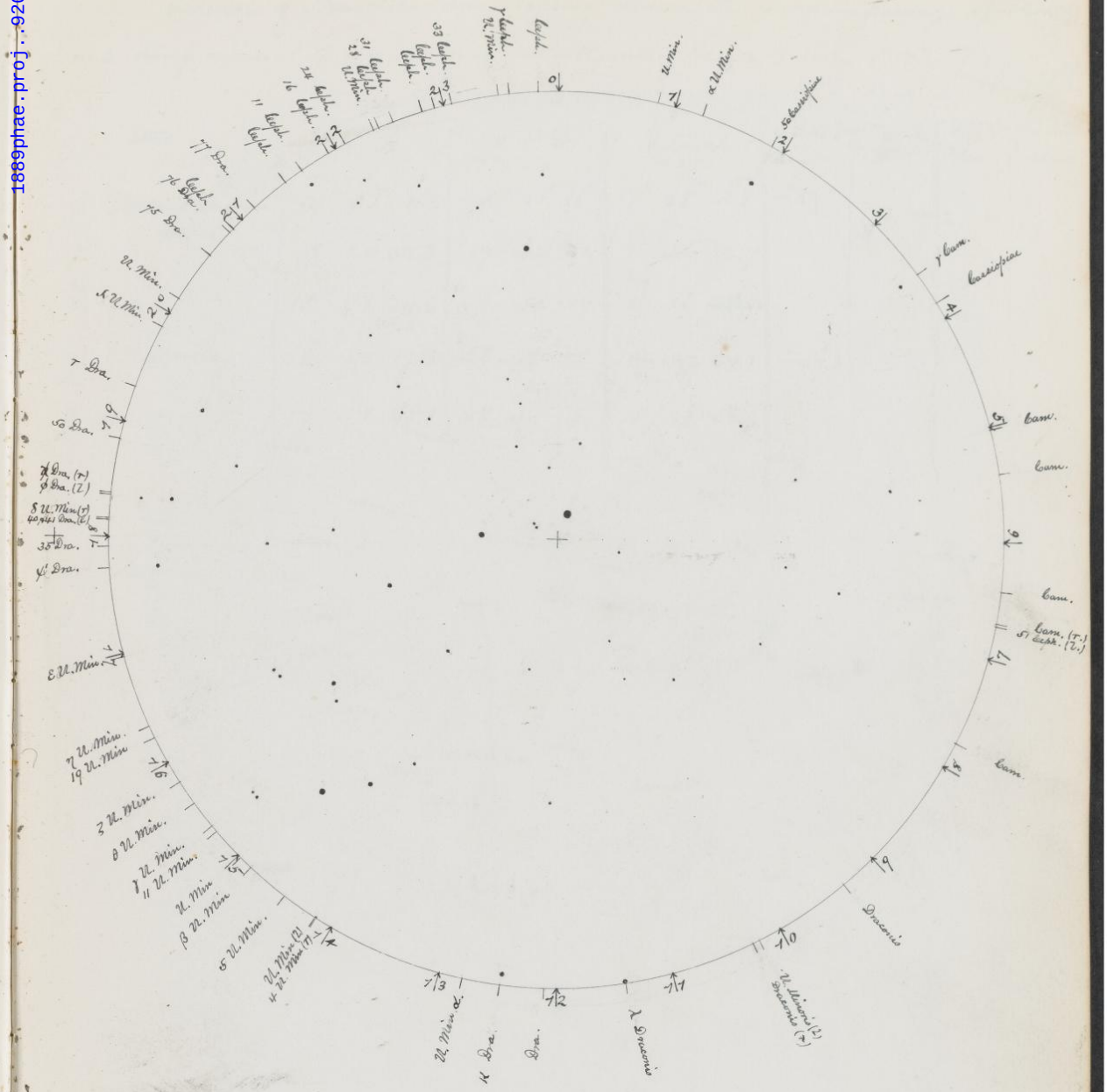
Date. 1878.		Star		In vertical line with Polaris Observed	Calculated	Error of Watch	Interval.
				h m s	h m s	h m s	
January	25	η	Draconis	7 52 0	7 50 18.2	0 1 47.7	
"	28	"	"	7 40 13 ±2	7 38 27.9	1 48 "	
"	"	)	"	9 11 14 ±2	9 9 23.2	1 47 "	
"	"	(ξ	")	(9 7 40)			
February	3	η	"	7 17 10 ±2	7 14 47.8	2 22 7.	
	4	"	"	7 13 11 ±2	7 10 52.6	2 18 7.	
	5	)	"	8 40 20 ±5	8 37 53.1	2 27 7.	
		ξ		(8 36 45 ±20			

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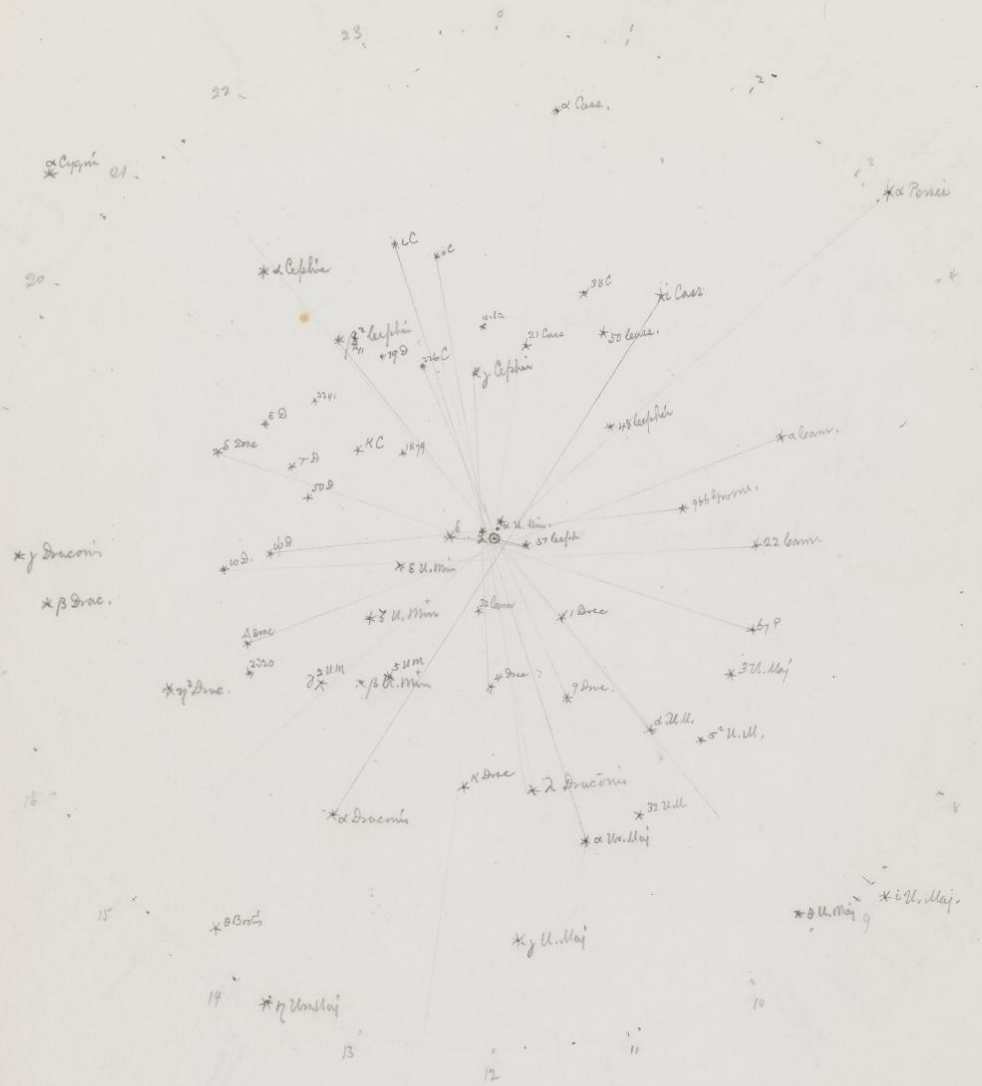
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Interval of Mean Solar Time elapsing between the meridian passage of Polaris and ~~star~~ moment of star's passing vertically under Polaris – RA = $1^h 18^m 41.^s9$ } June 18th 1878
NPD = $1^o 20' 2''$ }

– Calculated for June 18th 1878 –

Star	R. A.	N. P. D.	Interval M.S.T.	Diff. for 1m in R.A. Polaris	Diff. for 1m in R.A. of star	Diff. for 1′ in N.P.D. Polaris	Diff. for 1′ in N.P.D. star
β Ursae Minoris	$14^h 51^m 41.^s6$	$15^o 21' 16''$	$1^h 28^m 3.^s8$	−8?.			
j^2 " "	15 20 55.3	17 44 22	1 56 12.7				
ζ " "	15 48 24.6	11 50 19	2 16 58.9				
η Draconis	16 22 19.5	28 12 58	2 57 40.1	$-5.^s7.3$	+57.3		
γ "	17 53 45.1	38 20 4	4 28 38.6				
δ "							
ε "							
α Lesphei							
β "							

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Observations to compare Aneroid #1442 with Mercurial Barometer.

Height of Low water mark above tide water — 3.08 feet
" " kerb East corner of 30 Farmington Ave. above Low Water Mark — 98.86 "
" " 4th Floor & stone window sill above curb — 6.63 "
" " Zero of Barometer above floor — 2.73 "
" " " " " " Tide water — 100.94 "

Date.	Time.	Temperature	Mr. Hall's Mercurial Barometer. Observed	Corrected 32°	C. P. Horrod Aneroid #1442	C. B. Richard Aneroid #7516.	R
Aug. 8th 1878.	8.20 P.M.	77° -	29.782	29.652	29.685	29.725	.033
" "	9.30 "	" -	.775	.645	.675	.715	.03
" "	10.30 "	76 +	.777 (2 3)	.649	.68	.72	.031
" 9	9.10 A.M.	75	.719 (2 3)	.596	.625	.665	.026
" "	1.35 P.M.	81	.620 (3 3)	.482	.53	.555	.048
" "	7.00 "	76	.597 (2 3)	.472	.495	.51	.023
" "	8.25 "	74½	.619 (2 1)	.499	.545	.555	.047
" "	10.30 "	74½	.663	.542	.585	.60	.043
" 10	8.55 A.M.	72½	.784 (3)	.666	.71	.735	.044
	Above this the thousandths are unreliable as the tube was not full.					broke down on way to Norfolk.	
" 12	2.05 P.M.	74½	.924 (123)	.801	.83		.029
" "	7.02 "	73½	.919 (120)	.799	.82		.029
" "	9.00 "	72¼	.936 (117)	.819	.85		.031
" "	10.15 "	71 ¾	.936 (116)	.820	.85		.03
" "	11.00 "	73½	.948 (118)	.830	.86		.03
" 13	1.45 P.M.	75¾	29.955 (126)	29.829	29.86+		.031
" "	6.20 "	74½	.962 (123)	.839	.875		.036
" "	9.00 "	72½	.996 (118)	.878	.91		.032
" "	10.55 "	71½	.995 (115)	.880	.905		.025
" 14	8.00 AM	69¼	30.007 (109)	29.898	.93		.032
" " "	1.45 P.M.	75⅓	30.024 (125)	.899	.925		.026
" "	6.45 "	74⅓	30.012 (123)	.889	.91		.021
" "	8.10 "	73⅓	30.022 (120)	.902	.925		.023
" "	11.00	72⅔	30.044 (118)	.926	.96?		.031
" 15	8.50 A.M.	69¾	30.126 (110)	30.016	30.04		.024
" "	1.50 P.M.	72⅔	30.136 (117)	.019	30.045		.026
" "	2.33 "	72¾	30.126 (119)	.007	30.03		.023
" "	6.23 "	73	30.144 (119)	.025	30.055		.03
" "	7.00 "	73½	30.164 (121)	.043	30.07		.027
" "	7.15 "	73¾	30.172 (121)	.051	30.075		.024
" "	7.30 "	74	30.166 (122)	.044	30.065+		.023
" "	7.45 "	74½	30.168 (123)	.045	30.065+		.022
" "	8.00	75	30.169 (125)	.044	30.065		.025
" "	10.30	74¼	30.172 (122)	.050	30.07		.02
" "	11.30	74⅓	30.180 (123)	.057	30.09		.033
" 16	8.50 A.M.	73½	30.236 (121)	.115	30.145		.03

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Date	Time	Temp.	Green's Marginal Barometer 1916. Observed	Reduced to 32°.	Aneroid #1142	Correction of Aneroid.
Aug. 16th 1878	1.45 p.m.	75⅓	30.206 121	30.081		
	8.15 "	74¼	30.171 122	30.049		
	9.00 "	74⅔	30.176 120	30.052		
	.30 "	74½	30.176 123	30.053		
	10.00 "	74½	30.178	30.055		
	.30 "	74¼	30.164 122	30.042		
	.45 "	74½	30.159 123	30.036		
	11.00 "	74	30.160 122	30.038		
Aug. 20th 1878.	8.54 a.m.	71°	29.670 112	29.538	29.58	.022
	1.25 p.m.	73.3	29.638 118	29.520	29.535	.015
	2.30 "	73.8	29.630 119	29.511	29.525	.014
	7.00 "	72.1	29.669 115	29.534	29.58	.026
21st "	1.50 "	73.	29.761 119	29.642	29.67	.028
	7.00 "	70	29.837 111	29.726	29.755	.029
22nd "	8.45 am	69.7	30.039 110	29.929	29.955	.026
23rd "	8.00 "	65	30.202 098	30.103	30.13	.027
25th "	9.20 am	68.3	29.649 105	29.534	29.58	.036
	9.50 "	69	29.631 107	29.527	29.56	.033
26th "	1.40 pm	67.7	29.947 105	29.842	29.85	.008
28th "	7.00 pm	70.8	29.988 114 96 113	29.874 883	29.91	.027

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Observations for determining the Elevation of Norfolk Ct.

Station. 30 Farmington Ave. Hartford. Zero of Barometer 100.9 feet above sea

Date 1878.	Time of Observation	Attached Thermometer	Mercurial Barometer: Observed reading	Mercurial Barometer: reduced to 32° Fah.	Temp. of Air	Wet Bulb thermom.	Relative Humidity	
Aug. 17	1.28 p.m.	76°	30.077 (127)	29.950				
	2.28 "	76.5	30.061 (129)	.932				
	4.15 "	77	30.044? (130)	.914?				
	6.00 "	75.75	30.036 (126)	.910				
	.15 "	76	30.046 (127)	.919				
	.30 "	75.75	30.050 (126)	.924				
	.45 "	75.7	30.060 (126)	.934	75°			
	7.00 "	75.6	30.055 (126)	.929				
	.15 "	75.6	30.058	.932	75°			
	.30 "	77.	30.050 (130)	.920				
	.45 "	78.3	30.060 (133)	.927				
	8.00 "	77.3	30.075 (131)	.944	74.75	72	.854	Wind S.
	.15 "	76.8	30.064 (129)	.935	74.5	72	.865	
	.30 "	76.3	30.053 (128)	.925	74.5	71.7	.851	
	.45 "	76.	30.058 (127)	.931	74.2	72.	.880	Cloudy: paper damp.
	9.00 "	76.	30.057	.930	74.2	72.	.880	
	.15 "	75.9	30.051 (127)	.924	74.	72.2	.901	
	.30 "	75.7	30.049 (126)	.923	74.	72.1	.895	
	.45 "	75.7	30.044	.918	73.8	72.	.901	very damp
	10.00 "	75.7	30.038	.912	73.8	72.1	.906	
	.15 "	75.6	30.033 (126)	.907	73.8	72.	.901	
	.30 "	75.7	30.034 (126)	.908	73.6	72.	.911	
	.45 "	75.7	30.030	.904	73.7	71.8	.895	
	11.00 "	76.	30.025 (127)	.898	73.6	71.8	.901	Cloudy, broken
	.15 "	76.5	30.024 (129)	.895	73.8	72.1	.906	
	.30 "	76.8	30.023 (129)	.894	73.6	71.8	.901	
	.45 "	77.	30.023 (132)	.893	73.6	72.	.911	
	12.00	77	30.021	.891	73.6	72.1	.916	Wind S.
								Thunder storm — rain —
Aug. 18.	8.30 am.	74.3	29.940 (123)	29.817	74.7	67.5	.656	Clear. Wind N.W.
	.45 "	74.7	29.945 (124)	.821	75.1	68.1	.663	
	9.00 "	75	29.945 (125)	.820	75.3	68.	.652	
	.15 "	75	29.944	.819	76.2	68.	.620	
	.30 "	75	29.944	.819	77.	68.2	.600	
	.45 "	75.6	29.942 (126)	.816	77.3	69.5	.622	
	10.00 "	75.5	29.942 (126)	.816	78.2	70.3	.636	
	.15 "	76.	29.943 (127)	.816	78.2	68.6	.576	
	.30 "	76.	29.942	.815	79.1	70.2	.601	
	12.30	75	29.909 (125)	29.784	80.0	67.	.474	
	.45	75.7	29.905	.780	79.5	69.3	.557	

The thermometer used for Humidity was 74° Fah. Its corrections at 65° were 74.0, 72.9, 74.5, 68.

Next Leaf Forward

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Observations for determining the Elevation of Norfolk Jct.
By C. B. Richards. Aug. 17th & 18th 1878. Watches set to agree. Aug 17th 78.
Summit of Grade of Conn. Western Ry. by leveling. 1336 feet. above mean tide.

Station.	Time	C. P. Ho Aneroid 7442. Observed Reading	Corrected -.03	Temperature of the Air.
				7
Summit of Grade. in Car.	6.19 p.m	28.68	28.65	77
Depot Norfolk. in Car.	.22 "	28.77	28.74	77
House. " sitting room table.	.50 "	28.595	28.565	76
" " "	7.00 "	28.59	28.56	
" " "	7.30 "	28.595	28.565	
" " "	8.00 "	28.60	28.57	
" " "	9.00 "	28.58	28.55	72
" " "	9.30 "	28.59	28.56	
House sitting room table (1st Floor)	8.00 a.m.	28.51	28.48	68
"	.45 "	28.51	28.48	68
"	9.00 "	28.505	28.475	68
"	.30	28.505	28.475	69
"	10.	28.505	28.475	68
"	.30	28.505	28.475	71
"	11.00	28.50	28.47	71
"	.30	28.49	28.46	71
"	12.00	28.48	28.45	72
"	.30	28.47	28.44	72.5

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Observations for Elevation of Norfolk Ct. continued. Sta. Hartford. El. 100 feet.

Date. 1878	Time of Observation	Attached Thermometer	Mercurial Barometer Observed.	Barometer Corrected for 32°	Temperature of the Air	Wet Bulb Thermometer	Relative Humidity	
Aug. 18.	1. 00 p.m.	76.	29.903	29.776	80	70.5	.633	Wind N.W. Air very clear. Few clouds.
	.15 "	76.2	29.903	.775	80.5	70	.551	
	.30 "	76.3	29.900	.772	80.8	69.9	.539	
	.45 "	76.	29.898	.771	79.2	67.7	.517	
	2.00 "	76.5	29.894	.765	80.	69.2	.539	
	.15 "	76.5	29.889	.760	80.1	69.	.530	
	.30 "	77	29.886	.756	80.3	68.2	.500	
	.45 "	77	29.885	.755	80.3	68.9	.522	
	3.00 "	77	29.882	.752	80.3	69.8	.551	
	.15 "	77	29.880	.750	80.	67.8	.500	
	.30 "	77.2	29.872	.742	79.8	68.1	.511	
	.45 "	77.	29.867	.737	79.8	68.9	.536	
	4.00 "	77	29.864	.734	79.6	68.	.514	
	.15 "	77	29.860	.730	79.2	66.8	.490	
	.30 "	76.7	29.860	.731	79.	65.7	.464	
	.45 "	76.7	29.859	.730	78.8	67.	.506	
	5.00 "	76.5	29.856	.727	78.8	67.	.496	
	15 "	76.5	29.852	.723	78.2	66.	.492	
	30 "	76.5	29.851	.722	77.8	67.2	.540	
	45 "	76.2	29.846	.718	77.	67.	.538	
	6.00 "	76.	29.842	.715	76.8	68	.600	
	.15 "	76.	29.845	.718	76	68.2	.634	
	.30 "	75.2	29.845	.720	75.1	69.4	.716	
	.45 "	74.7	29.845	.721	74.1	68.1	.702	
	7.00 "	74	29.846	.724	73	67.7	.731	
	.15 "	73.7	29.848	.727	72	67.4	.759	
	.30 "	73.2	29.848	.728	71	65.2	.702	
	.45 "	73.4	29.849	.729	70.8	65.	.702	
	8.00 "	73.6	29.852	.731	70.3	63.9	.676	
	.15 "	73.9	29.858	.736	69.4	63.8	.709	
	.30 "	73.6	29.858	.737	68.8	63.8	.734	
	.45 "	72.6	29.856	.738	68.8	63.3	.710	
	9.00 "	72.2	29.856	.739	68.5	63.2	.718	
	.15 "	71.6	29.854	.739	67.2	63	.769	telecor.
	.30 "	71.4	29.853	.738	67.1	64	.823	Cirrus from N.W.
	.45 "	71.	29.850	.736	66.8	63	.787	Few thin clouds in N. Sky
	10.00 "	70.6	29.850	.737	66.4	62	.759	telecor.
	.15 "	70.3	29.851	.739	66.3	63	.812	
	.30 "	69.7	29.855	.745	66.4	63.7	.844	
	.45 "	69.9	29.854	.743	65.8	62.8	.827	
	11.00 "	71.	29.853	.739	64.9	62.	.830	
	.15 "	72.	29.853	.736	64.3	61.5	.835	
	.30 "	72.7	29.856	.738	66.5	61.2	.714	Clear. Cirrus N.W. Little Cirrus.
	.45 "	73.	29.859	.740	65.	61.	.743	
	12.00 "	73.4	29.858	.738	64.2	60.3	.776	
Aug. 19.	8.23 am	69.3	29.798	.689	67.8	62.3	.707	
	.45 "	69.4	29.796	.686	69.2	63.2	.689	

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Norfolk. Ist. continued.

Station	Time of Observation	C. P. Howards Aneroid No 1442 Observed.	Reduced .03 to correspond with Stand.	Temp. of the Air
House. sitting room table.	1.00 p.m.	28.47	28.44	71
"	.30 "	28.46	28.43	73
"	2.00 "	28.455	28.425	74
"	.30 "	28.45	28.42	74
"	3.00 "	28.445	28.415	74
"	.30 "	28.43	28.40	74
Top of Hill. "dead tree",	4.30 "	28.165	28.135	72
" "	4.55 "	28.185	28.155	72
House sitting room table	5.33 "	28.405	28.375	72
"	6.00 "	28.405	28.375	72
Top of Hill. "sunset"	.30 "	28.235	28.205	67
" "	.55 "	28.23	28.20	66
House, sitting room table.	7.35 "	28.405	28.375	68
"	8.00 "	28.41	28.38	68
"	.30 "	28.42	28.39	64
"	9.00 "	28.415	28.385	63
Depot rail	7.10 a.m.	28.555	28.525	64
"	8.00 "	28.55	28.52	65
Depot. rail	8.30 a.m.	28.545	28.515	66

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Height of Norfolk Lot. (Geo. R. Bigelow's table. first floor.)

Aug. 18th 78.

Time.	h.	H.	t+t'	a+á	A.	I.	Q.	M.	Cal. Elevation +101 feet = ht. above Sea.
	Simultaneous Observations.				Calculation, by Williamsons tables.				
Ave. of 5 observations	in.	in.	°						
8.45 – 10.30	29.818	28.476	145.5	1.26	1207.6	100.3	3.7	8.7	1421.3
Ave of 7 observations									
12.30 – 3.30	29.764	28.424	153.	1.00	1208.1	109.4	3.7	8.3	1429.4
Ave of 2 observations									
5.30 – 6.00	29.718	28.375	149.3	1.20	1212.8	104.9	3.7	8.9	1431.3
Ave of 4 observations									
7.30 – 9.00	29.734	28.382	136.	1.42	1220.5	89.4	3.7	8.2	1422.8
						Average of above.			1426.2
8.45	29.821	28.48	68+1473	1.30	1206.6	101.9	3.7	8.6	1421.8
9.00 AM.	.820	.475	68+1473	1.25	1210.3	102.1	3.7	8.2	1425.3
9.30 "	.819	.475	69+1476	1.20	1209.5	100.9	3.7	8.4	1423.5
10.00 "	.816	.475	68+1476	1.20	1206.8	100.8	3.7	8.4	1420.7
10.30 "	.815	.475	71+1550	1.20	1205.9	105.6	3.7	9.0	1425.4
12.30 PM.	29.784	28.44	72+1552.5	1.20	1211.0	109.1	3.7	8.2	1432.0
1.00 "	.776	.44	71+1551	1.20	1203.9	106.7	3.7	9.5	1428.8
1.30 "	.772	.43	73+1554	1.10	1209.6	110.7	3.7	9.2	1434.2
2.00 "	.765	.425	74+1554	1.00	1207.8	110.6	3.7	8.4	1431.5
2.30 "	.756	.42	74+1554	1.00	1204.7	110.3	3.7	8.4	1428.1
3.00 "	.752	.415	74+1554	1.00	1205.0	110.3	3.7	8.4	1428.4
3.30 "	.742	.40	74+1554	1.00	1200.9	111.0	3.7	8.4	1434.0
5.30 "	29.722	28.375	72+1550	1.10	1216.7	106.6	3.7	7.9	1428.9
6.00 "	.715	.375	72+1549	1.25	1210.1	104.7	3.7	8.9	1428.4
7.30 "	29.728	28.375	68+1539	1.40	1221.6	93.4	3.7	8.5	1428.2
8.00 "	.731	.38	68+1538	1.40	1219.6	91.9	3.7	8.4	1424.6
8.30 "	.737	.39	64+1533	1.40	1215.6	85.4	3.7	7.7	1413.4
9.00 "	.739	.385	63+1525	1.40	1221.1	83.9	3.7	7.5	1417.2
							Average		1426.4

Height of Hill. "dead tree". N.E. of Bigelows House.

2obs. 4.30 – 5.00.	29.729	28.13	152	1.00	1449.9	129.9	4.5	9.3	1694.6

Height of Hill. "sunset" E. of Bigelows House

2obs. 6.30 – 7.00	29.722	28.202	140	1.00	1376.6	106.8	4.4	7.2	1596.0

Height of rail at Conn Western depot. Norfolk Lot.

Aug. 19. 5.30 am.	29.688	28.575	138°	1.40	1057.2	79.8	3.3	7.2	1248.5

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Height of Hill "dead tree". from observations of Aug. 11th-78. 10.00 a.m.

Bigelows House.	$h = 28.352$	2732.9
	$H = 28.098$	2709.3.0
		23.5.9
	$t + t' = 146°$	19.7
		235.6
	Lat.	.0
	Gravity on mercury	.8
	" " air	.0
		256.4
	$a + a' = 1.40$	2.4
		258.8 feet above house
		1427.
		1686. " " ocean.

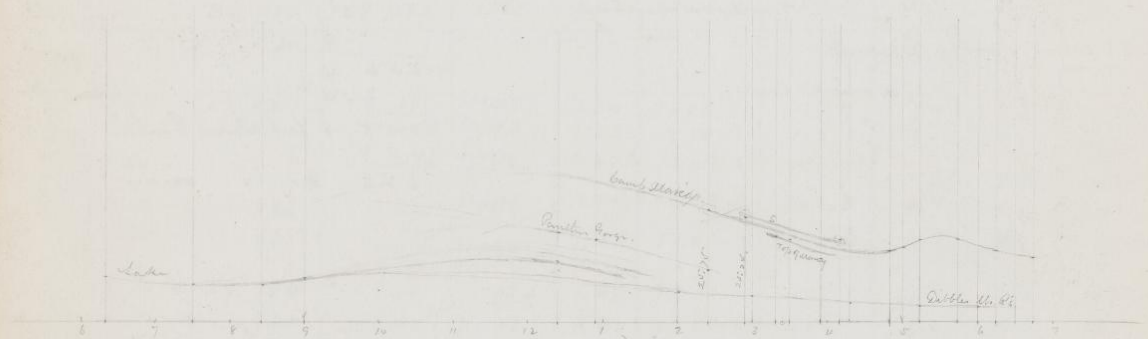
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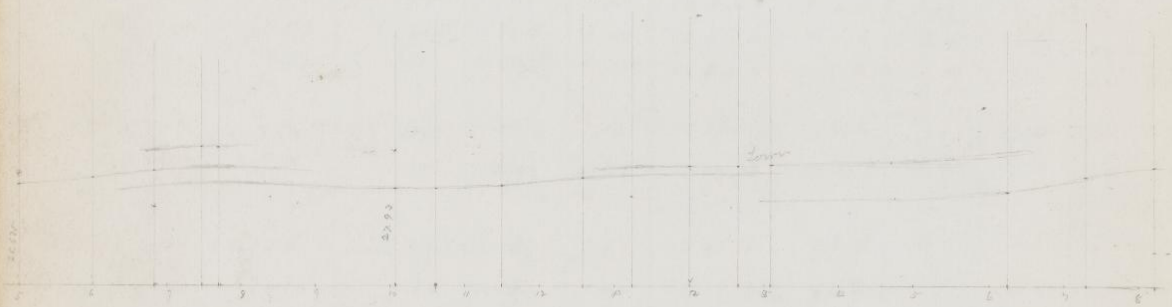
Height of Mt. Marcy. Vinyle Aneroid Barometer
Sept 16-18. 1878.



16



17



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Going

Sept. 16. 8.00 A.M.

Dibble House. Office Floor	h = 29.17		28074.0
Upper Ausable Pond.	H = 28.177		27166.5
	$t+t'$ = 56°+53°		908.4
	= 109°		41.6
			950.0
	Lat = 44½°		.0
	Dv		.1
			950.1
	$a+a'$ = 1.20.		2.4
Diff. of Altitude.			953.0 1102
			973.4
			20.4 +

Sept. 17. 12.25 P.M.

Upper Ausable Pond.	h = 28.08		27076.1
Panther Gorge Camp.	H = 26.71		25764.4
			1311.7
	$t+t'$ = 70°+66° = 136°		95.5
			1407.2
	$a+a'$ = 1.20 × 7.		8.4
Diff of Altitude			1415.6
			1383.2
			32.3 -

Sept 17. 2.20 P.M.

Panther Gorge Camp.	h = 26.67		25725.1
Camp Marcy.	H = 25.75		24804.5
			920.6
	$t+t'$ = 70°+67° = 137°		68.4
			989.0
	$a+a'$ = 1.20 × 5.2		6.3
Diff. of Altitude			995.3
			977.6
			17.7 -

Sept 17. 3.30 P.M.

Camp Marcy	h = 25.715		24768.8
Mt. Marcy. summit.	H = 24.807		23826.2
			942.6
	$t+t'$ = 60°+54° = 114°		47.8
			990.4
	$a+a'$ = 1.50 × 3.4		5.1
Diff of Altitude			995.5

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Returning

Sept 18. 3.00 P.M.

Dibbles House Office Floor.	h = 28.913		27842.9
Upper Ausable Pond	H = 27.95		26954.5
			888.4
	$t+t'$ = 77°+73° = 150°		77.8
			966.2
	$a+a'$ = 1.20 × 6		7.2
Diff. of Altitude			973.4

Sept. 18. 7.42 A.M.

Upper Ausable Pond	h = 27.938		26943.3
Panther Gorge Camps.	H = 26.585		25641.4
			1301.9
	$t+t'$ = 63°+58° = 121°		75.4
			1377.3
	$a+a'$ = 1.20 × 5.0		6.0
Diff. of Altitude			1383.3

Sept. 18. 6.50 A.M.

Panther Gorge Camps.	h = 26.58		25636.5
Camps Marcy	H = 25.655		24707.6
			928.9
	$t+t'$ = 57°+53° = 110°		43.5
			972.4
	$a+a'$ = 1.50 × 3.5		5.2
Diff. of Altitude			977.6

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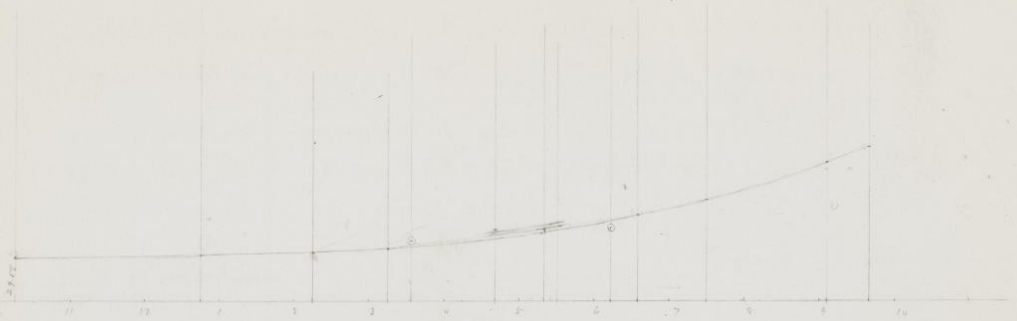
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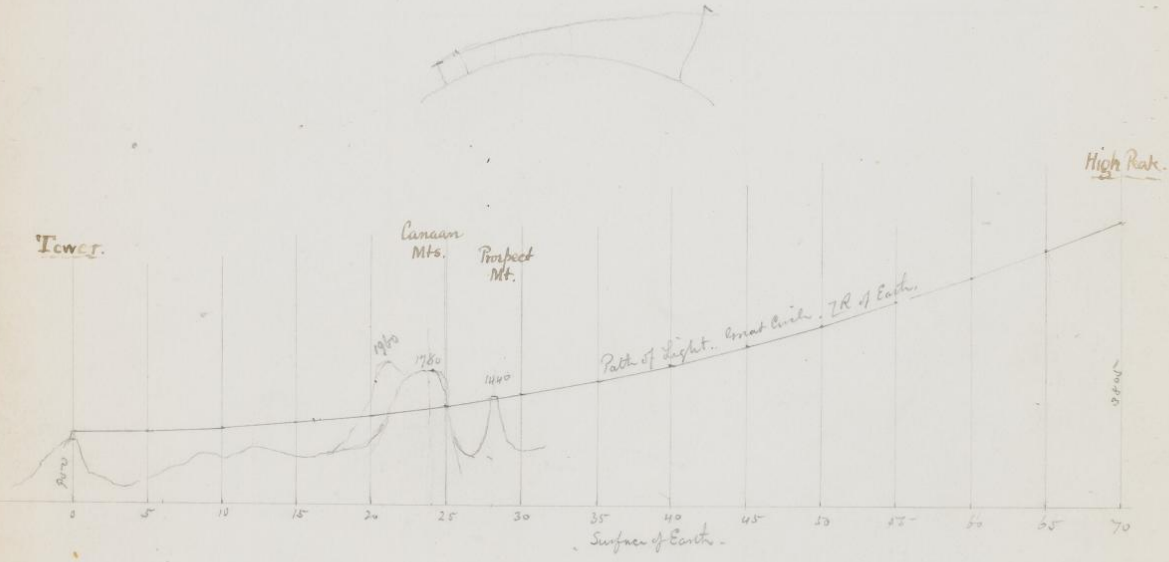
Height of East Mountain Rutland Vt. Sept. 22nd 1878.

Single Aneroid Barometer.



5.30 P.M.

House, first floor.	h = 29.595	28454.2
E. Mt. N. Rock. S of Summit.	H = 27.903	26910.0
		1544.2
	$t+t'$ = 56°+51° = 107°	67.6
		1611.8
	$a+a'$ = 1.00	16.
Height above House		1628.
House " R.R.		55.
R.R. " Sea.		530.
		2213.



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Comparison of Aneroid 1442 with Green's Standard Mountain Barometer № 2362

(Thermometer attached to № 2362 reads 0.4 too high.)

Date. 1878.	Time.	Bar. № 2362. Sta. 100.9 feet above tide water. Observed Attached Thermometer.	Temp. of Mercury.	Observed height of Mercury Column.	Ht. of Bar. reduced to 32°.	Aneroid 1442 at Temp. of air	Error of 1442	Thermometer "Town Mfg Co's" Hung on same board as that № 2362. "Green"	"Town"
Oct. 7th	6.20 P.M.	63.3	62.9	30.169	30.077	30.105	+.028	65°	68°
"	9.35 "	68.4	68.0	30.167	30.061	30.095	+.034	66.9	70°
8	10.30 "	67.4		30.124	30.021	30.05	+.029	67.4	70°
9	7.15 "	69.4		29.726	29.619	29.67	+.051		
	8.15 "	69.9		29.705	29.652	29.70	+.048	67.9	70
	10.30	67.3		29.795	29.693	29.73	+.037	67.6	69.8
								67.2	69.1

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Observations to determine the errors of reading of three thermometers marked A, B, and C. to be used as dry and wet bulbs in Estimating the height of Prospect mountain near Lakeville Ct.

The standard of comparison used was one of James Green's standard pocket thermometers belonging to Mr. Joseph Hall and believed by him to be correct.

Oct. 10. 1878.

Standard.	A.	B.	C.	Error A.	Error B.	Error C.
32°.5	34°.0	32°.3	32°.5	+ 1°.5	−0°.2	0°.
39. 4	40. 9	40. 0	40. 0	1.5	+0.6	+0.6
40. 2	42. 0	40. 8	41. 0	2.0	0.6	0.8
49. 8	51. 3	51. 0	50. 3	1.5	1.2	0.5
60. 1	62. 5	62. 7	60. 7	2.4	2.6	0.6
70. 0	72. 1	72. 8	70. 5	2.1	2.8	0.5
80. 4	81. 9	83. 0	80. 7	1.5	2.6	0.3
90. 0	91. 0	91. 7	90. 5	1.0	1.7	0.5
100. 2	100. 2	101. 3	100. 8	0.	1.1	0.6
	36°.0	35°.0	35°.0			
	50. 6	50. 5	49. 5			
	62. 9	63. 0	61. 0			
	81. 2	82. 0	80. 0			
	100. 0	100. 7	100. 0			

Observations to determine the constant difference of reading between Green's Stand. Mt. Bar's "2362 and "2372.

Barometers hung side by side on same hook in back window in Hall. 1st floor (Level 101 ft.)

Date.	Time.	Barometer "2362 Attched Therm.	Barometer "2362 Observed Ht. of Mercury	Barometer "2362 Bar. 32°	Barometer "2372 Attched Therm.	Barometer "2372 Observed Ht. of Mercury	Barometer "2372 Bar. 32°	Diff. No 2372
Oct 11. '78.	1.30 p.m.	64.2	30.011	29.966	64.6	30.036	29.939	+.023
"	1.55 "	61.4	30.010	.923	61.4	30.034	.946	+.023
"	6.45 "	61.2	30.024	.936	61.0	30.049	.962	+.026
"	8.30 "	60.6	30.030	.945	60.3	30.055	.970	+.025
"	10.15 "	60.6	30.020	.935	60.2	30.043	.948	+.013
"	11.05 "	60.7	30.006	.921	60.3	30.026	.941	+.020
12	9.05 "	54.3	29.916	.848	54.4	29.940	.871	+.023
"	1.40 "	55.7	29.808	.736	55.5	29.834	.762	+.026
15	1.45 "	66.7	30.026	.925	64.8	30.022	.925	.000

Subsequent observations invariably proved that when both barometers were subjected to continued tapping so as to keep the mercury columns in vibration for half a minute or so. they both read alike.

When the tube of one was inclined a little, so as to raise the column of mercury in setting back it acted sluggish and required continued tapping to bring it down to level. which however invariably took place in less than half a minute.

From the above is is inferred that both barometers read alike

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The following observations were taken with the precaution to raise the mercury column in the tube by swinging the cistern sideways and then rapping to equilibrium.

Date 1878.	Time.	Barometer № 2362			Barometer № 2372			Diff. of № 2372
		Attch. Therm.	Obs. Reading	32°	Attch. therm.	Obs. Reading	32°	
Oct 19th	9.00 AM.	63°.8	29.523	29.431	63°.7	29.523	29.430	−.001
	1.40 PM.	63.7	.533	.441	63.	.533	.439	−.002
	6.20 "	59.5	.628	.547	59.5	.630	.548	+.001
	7.50 "	59.4	.660	.579	59.3	.660	.579	.000
	11.25 "	58.7	.676	.597	58.4	.676	.597	.000
20th		57.0	.830	.756	56.7	.830	.756	.000
		59.3	.862	.780	59.0	.854	.779	−.005
		59.4	.986	.904	59.2	.965	.903	−.001
		56.8	30.153	30.078	56.7	30.149	30.073	−.005
		63.2	.115	.023	62.8	.112	.020	−.003
22nd	8.55 AM.	57.0	.172	.097	56.4	.167	.092	−.005
	1.40 PM.	62.2	.115	.020	63.8	.111	.016	−.004
	8.00 "	61.8	.071	29.983	61.7	.073	29.984	+.001
23rd	8.40 AM.	59.3	29.752	.672	59.3	29.751	.670	−.002
	8.55 "	"	.734	.654	"	.736	.655	+.001
	1.40 PM.	61.2	.463	.378	61.1	.463	.377	−.001
	2.32 "	62.2	.442	.354	62.0	.445	.357	+.003
	6.30 "	63.9	.441	.349	63.6	.442	.349	.000
	11.45 "		.320					
24th	8.45 AM.	58.6	.821	.741	58.4	.822	.742	+.001
	1.50 PM.	61.6	.911	.823	61.5	.906	.818	−.005
	7.25 "	59.6	30.074	29.992	59.2	30.076	.994	+.002
	10.45 "	59.4	.149	30.067	59.0	.149	30.067	.000
25th	9.00 AM.	53.2	.259	.188	53.2	.250	.178	−.010
	1.50 PM.	58.2	.224	.145	58.0	.224	.145	.000
	6.40 "	59.5	.268	.186	59.2	.260	.178	−.008
26th	9.05 AM.	53.8	.370	.303	53.6	.370	.303	.000
	1.40 PM.	67.8	.315	.211	67.3	.310	.206	−.005
	8.00 "	69.2	.280	.172	68.7	.280	.172	.000
	9.30 "	69.9	.280	.170	69.3	.279	.170	.000
	10.40 "	(69.8)	.275	.165	68.8	.275	.167	+.002
27th	9.00 AM.	65.6	.185	.087	65.0	.185	.087	.000
	9.45 "	67.4	.180	.077	66.9	.179	.076	−.001
	10.30 "	68.6	.165	.059	68.0	.164	.058	−.001
	11.00 "	69.0	.159	.052	68.6	.153	.048	−.004
	.30 "	69.3	.148	.039	68.9	.147	.039	.000
	12.00 M.	69.3	.132	.023	69.0	.130	.021	−.002
	.30 PM.	69.8	.114	.004	69.3	.111	.002	−.002
	1.00 "	69.3	.104	29.995	68.8	.100	29.992	−.003
	.30 "	71.0	.094	.984	70.4	.090	.978	−.006
	2.00 "	71.4	.097	.983	71.0	.093	.979	−.004
	.30 "	70.6	.082	.970	70.0	.079	.968	−.002
	3.00 "	70.1	.074	.964	69.7	.069	.959	−.005
	.30 "	69.6	.058	.947	69.4	.051	.941	−.006
	6.30 "	70.2	.011	.900	69.8	.011	.900	.000
	8.30 "	69.3	29.981	.872	69.0	29.985	.876	+.006
	10.00 "	69.3	.951	.843	68.8	.949	.841	−.002
28th	8.35 AM.	(68.4)	30.080	.982	68.0	30.078	.980	−.002
	1.35 PM.	68.5	.070	.972	67.5	.072	.975	+.003
29th	8.40 AM.	66.3	.266	30.166	64.4	.264	30.168	+.002
							Ave.	−.0015

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Date 1878.	Time.	Barometer #2362 Attch'd Therm.	Barometer #2362 Obs. Reading.	Barometer #2362 32°	Barometer #2372 Attch'd Therm.	Barometer #2372 Obs Reading.	Barometer #2372 32°	Diff. of #2372
		Out.						
Aug 29th	1.40 P.M.	68.0	30.210	30.105	66.8	30.208	30.105	.000
30th	2.00 "	71.2	29.784	29.671?	69.3	29.798	29.689?	—
	6.20 "	70.4	.794	.683	70.0	.794	.683	.000
		71.2	.797	.684	70.5	.794	.681	−.003
31st	9.05 A.M.	69.3	.681	.575	68.8	.680	.574	−.001
	1.45 P.M.	65.6	.586	.489	65.5	.588	.491	+.002
	6.30 "	68.1	.634	.531	67.5	.634	.531	.000
	10.35 "	66.3	.677	.578	65.0	.678	.582	+.004
Nov. 1st	9.00 A.M.	72.5	.950	.833	70.5	.945	.832	−.001
	1.45 P.M.	65.5	.969	.871	64.0	.968	.873	+.002
	10.20 "	68.3	30.032	.926	67.3	30.030	.926	.000
2nd	9.00 A.M.	64.3	.109	30.014	63.8	.103	30.008	−.006
	1.35 P.M.	70.3	29.992	29.881	69.7	29.990	29.880	−.001
2nd	6.45 "	70.3	.980	.879	69.9	.980	.979	.000
	9.50 "	69.6	.978	.869	68.9	.977	.869	.000
3rd	9.35 A.M.	74.4	30.237	30.115	71.8	30.227	30.111	−.004
	1.00 P.M.	66.0	.200	.101	64.0	.192	.097	−.004
	10.00? "	66.2	.244	.144	64.9	.240	.142	−.002
4th	1.45 "	65.8	.058	29.956	63.6	.046	29.951	−.005
	"	64.0	.120	30.026	62.0	.113	30.023	−.003
5th	8.40 A.M.	57.5	.170	.101	53.0	.170	.004	+.003
	1.45 P.M.	67.8	.132	.028	66.6	.123	.021	−.007
	10.35 "	59.0	.106	.025	57.0	.097	.021	−.004
6th	8.50 A.M.	64.7	.005	29.909	62.7	.000	29.908	−.001
	2.00 P.M.	64.4	29.867	.772	62.6	29.857	.766	−.006
	8.50? "	66.4	.859	.758	64.0	.850	.755	−.003
	11.00 "	66.1	.858	.758	65.0	.850	.752	−.006
7th	9.05 A.M.	70.5	.827	.716	69.0	.823	.714	−.002
	2.00 P.M.	70.9	.671	.568	70.0	.670	.561	+.001
	6.40 "	67.8	.641	.532	66.9	.640	.539	+.007
	10.25 "	68.0	.578	.475	67.0	.575	.474	−.001
8th	8.45 A.M.	65.8	.623	.526	65.2	.621	.524	−.002
	2.10 P.M.	65.5	.692	.596	62.8	.691	.601	+.005
	11.40 "	61.0	.804	.718	59.0	.796	.714	−.004
10th	8.55 A.M.	65.8	.706	.607	64.0	.699	.604	−.003
12th	8.45 "	66.5	.477	.376	66.3	.475	.374	−.002
	1.35 P.M.	70.5	.492	.381	70.3	.487	.375	−.006
13th	9.10 A.M.	71.6	.667	.553	70.7	.665	.552	−.001
	4.30 P.M.	66.9	.781	.679	66.1	.780	.679	.000
14th	8.20 A.M.	67.5	30.270	.167	65.6	30.264	.165	−.002
	2.20 P.M.	68.5	.281	.175	66.2	.277	.176	+.001
	7.00 "	70.0	.392	.282	69.0	.392	.283	+.001
	10.00 "	66.7	.402	.301	65.0	.402	.304	+.003
15th	8.45 A.M.	68.5	.542	.441	63.7	.547	.453	+.012
	?	71.0	.576	.403	68.8	.517	.409	+.006
	5.40 P.M.	69.0	.507	.400	67.8	.511	.406	+.006
16th	8.45? A.M.	69.8	.530	.439	60.8	.533	.446	+.007
	1.30 P.M.	68.3	.458	.352	67.0	.460	.357	+.005
	7.50 "	66.0	.417		64.9	.420		
17th	9.30 A.M.	68.4	.346		66.2	.348		
	1.45 P.M.	66.7	.260		65.2	.253		
	9.05 "	70.0	.234		69.0	.230		
18th	8.00 A.M.	63.1	.080		61.6	.078		
	—	72.1	29.959		70.5	29.963		
	7.25 P.M.	67.7	.914		66.9	.912		

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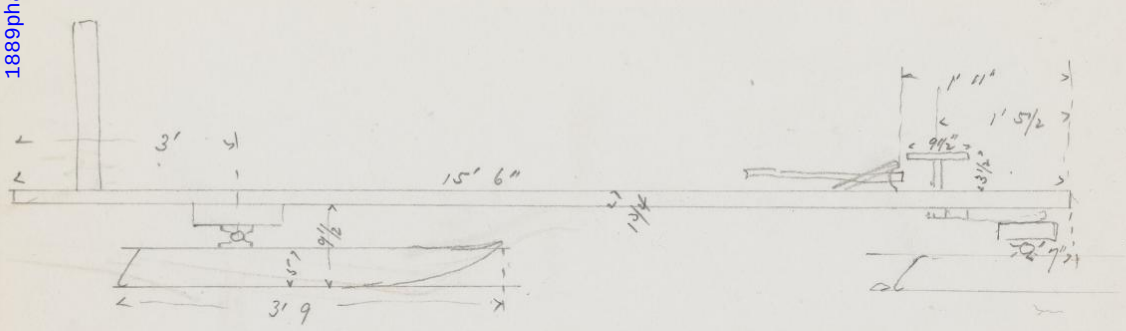
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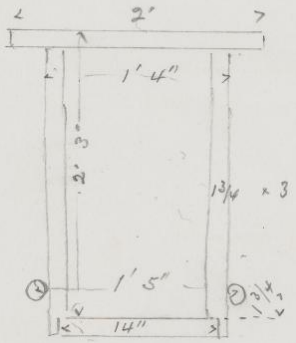
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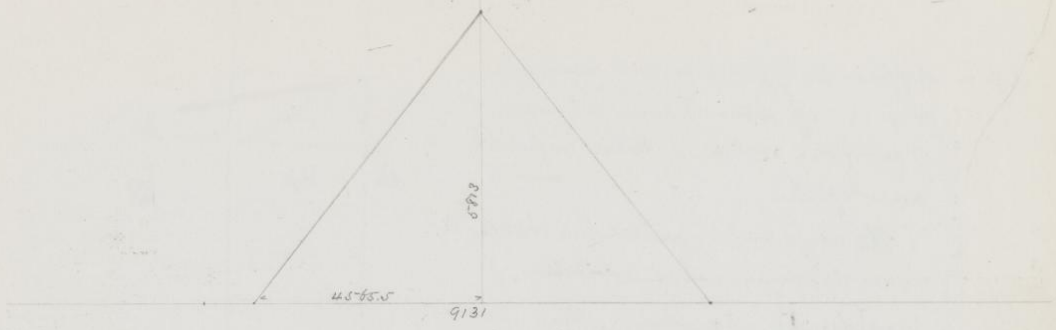
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Semi Polar diameter of the Earth = 20853654 ft. = 250243848 in.

Polar Diam. " " = = 500487696 in. = log. 8.699 3934

500000000 " = " 8.698 9700

Number of Pyramidal inches in 1 in. = " 9.999 5766 0.0004234

Height of Pyramid in English inches = 9140 . = . 3.960 9462

" " " . Pyramidal inches = 9131.998 = 3.960 5228

4. = 0.602 0600

3.14159 = 4.862 5828

0.497 1499

11626.1 = 4.065 4329

Height taken as $\frac{9131 \times 2}{3.141593}$ Pyr. inches = 5813.

9131.098 = 3.960 5228

Inclination of side = 51° 51' 14".3 = log tan 0.104 9101

Length of Diagonal of Base = $\sqrt{9131.^2 + 9131^2} = 9131\sqrt{2}$ pyr. in.

2 = log 0.301 0300

$\sqrt{2}$ = " 0.150 5150

9131.1 = " 3.960 5228

Diagonal of Base in pyr. in = 12913.3 = " 4.111 0378

Half do = 6457.

2(5813) = 4.065 4329

Rise of Edge per units of Diagonal = .900316 = 9.954 3951

Length of Edge. = $\sqrt{6457^2 + 5813^2} = \frac{1}{2}\sqrt{12913.3^2 + 11626.1^2}$

166754000. = 12913.3^2 = log 8.222 0756

135765000 = 11626.1^2 = " 8.130 8658

301919000 = = " 8.479 8905

Length of Edge in pyr. in = 8688. = $\frac{1}{2}$(17375.8) = " 4.239 9452

" " " Eng " = 8696. = $\frac{1}{2}$(17392.8) 0.000 4234

4.240 3686

12 = 1.079 1812

5280 = 3.722 6839

4.801 8151

" " " in miles .274507 = 9.438 5535

one ten millionth of circum of earth at 90 000 000 miles

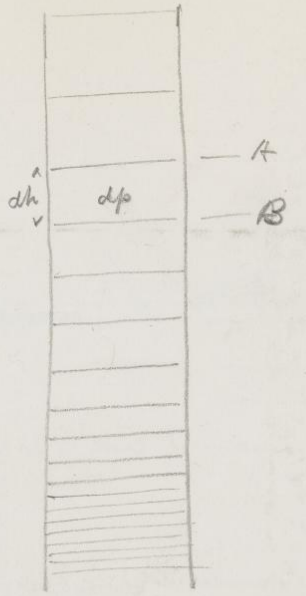
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Formulae for the Barometric measurement of heights.

dp = difference of pressures at sections A + B, of Atmospheric columns of uniform section - taken infinitely near together.
(The weight of the air between A. + B, makes this difference of pressure,)
consider dp as uniform. then

dh = the varying thickness of the infinitely thin layer of air of constant weight dp. as the pressure upon it varys



As the pressure upon the layer dp varies, its thickness dh varies inversely as the total pressure, or the sum of the weights of all the layers above it.

total pressure $= \int dp = p.$

c = some constant quantity

$$\frac{dh}{dp} = \frac{c}{p}$$

$$dh = c \cdot \frac{dp}{p}$$

$$\int_{H_2}^{H_1} dh = c \int_{P_2}^{P_1} \frac{dp}{p}$$

$$H_1 - H_2 = C\left(\log_e P_1 - \log_e P_2\right) \qquad \text{Napierian log.}$$

$$= ce\left(\operatorname{com}\log P_1 - \operatorname{com}\log P_2\right) \qquad ce = \text{constant } C$$

$$= C\left(\log P_1 - \log P_2\right)$$

Let h_1' h_2' = the height of the barometer, in inches of mercury and they are proportional to the Pressure. P_1 + P_2

$$H_1 - H_2 = C\left(\log h_1' - \log h_2'\right)$$

C depends upon the wt. of the air. temperature, gravity, humidity - (expansive force of Vapor)

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Weight of 1 cc in air = $n g p$

Weight of a layer, dx thick = $n g p dx$

$= dp$.

$\therefore dx = \frac{1}{n g} \cdot \frac{dp}{p}$ $\quad dx = \frac{dp}{n g p}$

	B	R
A n	0.1930965	0.1965204
	0.1965204	
	2 | 0.3896169	
	0.1948084	
n'	0.2084406	0.2135485
	0.2135485	
	0.4219891	
	0.2109945	

$6772.3 = n \log \frac{22.054}{\left(1 + \frac{\quad}{1000}\right)}$

$28.630 = \log 1.45682$

$22.054 = \frac{1.343549}{0.11323}$

13.39
14.83
28.22
64.
35.78 .196422

$6772.3 = n \times 0.11323 \left(1 - .003578\right)$

$x_1 - x_2 = \frac{1}{n}\left(\log p_1 - \log p_2\right)$

$= \frac{1}{n}\left(\log \frac{p_1}{p_2}\right)$

Height of Barometer being proportional to the pressure, $\frac{h_1}{h_2} = \frac{p_1}{p_2}$

$x_1 - x_2 = \frac{1}{n}\left(\log \frac{h_1}{h_2}\right)$ for constant temperature, gravity & force of vapour

$H_1 - H_2 = \frac{1}{n}\left(\log h_1 - \log h_2\right)$

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Weight of 1 cu in air = ngp

Weight of a layer 1 sq in, dx thick = $ngp\,dx$

$= dp$.

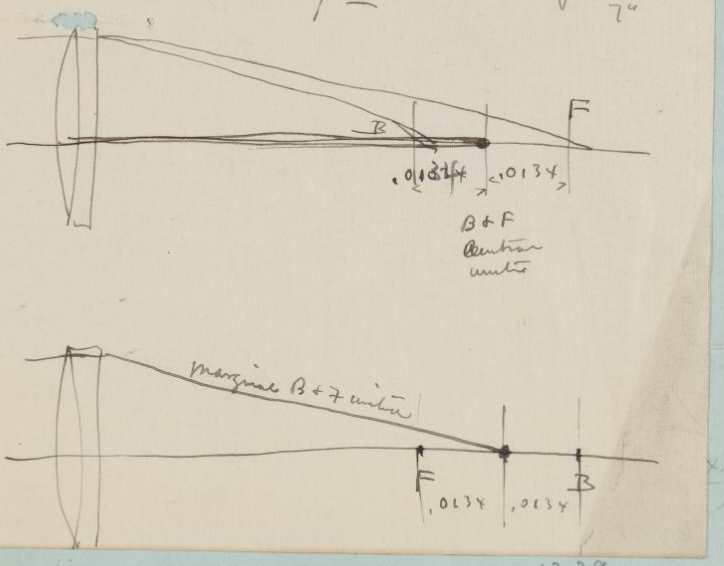
$\therefore dx = \frac{1}{ng} \cdot \frac{dp}{p}$ $\quad dx = \frac{dp}{ngp}$

$x_1 - x_2 = \frac{1}{ng}(\log p_1 - \log p_2)$

B B′

A

7th ed p. 102 74



28.630 = log 1.45882

22.054 = 1.34359

0.11323

13.39
14.83
28.22
64.
− 35.78 .196422

$6772.3 = n \times 0.11323(1 - .003578)$

$x_1 - x_2 = \frac{1}{n}(\log p_1 - \log p_2)$

$= \frac{1}{n}\left(\log \frac{p_1}{p_2}\right)$

Height of Barometer being proportional to the pressure, $\frac{h_1}{h_2} = \frac{p_1}{p_2}$

$x_1 - x_2 = \frac{1}{n}\left(\log \frac{h_1}{h_2}\right)$ for constant temperature, gravity & form of vapour

$H_1 - H_2 = \frac{1}{n}(\log h_1 - \log h_2)$

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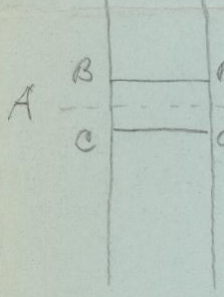
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Weight of 1 cu in air $= n g p$

Weight of a layer 1 sq in, dx thick $= n g p dx$

$= dp$.

$\therefore dx = \frac{1}{n g} \cdot \frac{dp}{p}$



$x_1 - x_2 = \frac{1}{ng}(\log p_1 - \log p_2)$

$= \frac{1}{ng} \cdot \log \frac{p_1}{p_2}$

$\frac{H_1}{H_2} = \frac{p_1}{p_2}$ { height of barometer being proportional to the pressure

since $x_1 - x_2 = \frac{1}{ng} \log \frac{H_1}{H_2}$

$\frac{6791.5}{19.2}$

$\frac{6772.3}{} = n \log \frac{28.630}{22.059}\left(1 + \frac{13.39 + 14.83 - 6x}{1000}\right)$

$28.630 = \log 1.45682$

$22.059 = \underline{1.34359}$

0.11323

$\begin{array}{r} 13.39 \\ 14.83 \\ \hline 28.22 \\ 64. \\ \hline -35.78 \end{array}$ .196422

$6772.3 = n \times 0.11323\left(1 - .003578\right)$

$x_1 - x_2 = \frac{1}{n}(\log p_1 - \log p_2)$

$= \frac{1}{n}\left(\log \frac{p_1}{p_2}\right)$

Height of Barometer being proportional to the pressure, $\frac{h_1}{h_2} = \frac{p_1}{p_2}$

$x_1 - x_2 = \frac{1}{n}\left(\log \frac{h_1}{h_2}\right)$ for constant temperature, gravity & form of vapour

$H_1 - H_2 = \frac{1}{n}(\log h_1 - \log h_2)$

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From THE HARTFORD CITY MISSION RECORD,

An Illustrated Bi-Monthly Magazine, Devoted to General Literature and Philanthropic Work.

EDITED BY FLORINE THAYER McCRAY, PUBLISHED BY KATE E. GRISWOLD, HARTFORD, CONN.

TO nearly every one who receives this open letter, we have mailed, from time to time, copies of the RECORD.

It is now our earnest wish that for one year, at least, you may become a regular subscriber to this magazine, and to this end WE MAKE IT EASY FOR YOU TO DO SO. You have only to add the silver half-dollar and your address to the enclosed card and mail to us.

The RECORD begins its fifth year with the May issue, and will appear every other month instead of quarterly as heretofore. A decided change and improvement is made in the size and shape of the publication. It will be largely increased in size and issued in regular two column magazine form, printed from clearer type, in handsomest style.

Each number will contain matter of excellent literary merit, and every effort will be made to make the magazine bright, interesting and valuable.

The work of the City Mission, which it represents, will be fully set forth; every issue containing one or more phases of its work, together with a general showing of charitable effort throughout the State and the Union.

In no way can a knowledge of this work, with its far-reaching influences, be more effectively brought to the minds and hearts of the people than through this medium. We aim to help the work. For this reason we wish to send the RECORD to every town in the State. Will you help to do it? The subscription price is small. THE OBJECT IS TO OUR MUTUAL ADVANTAGE.

We will gladly send sample copies of the RECORD to your friends if you will furnish us their addresses.

Yours sincerely,

Kate E. Griswold,

Publisher.

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$$n = \frac{6772.3}{0.11323 \times .99642}$$

9.05397	log 3.83074
9.9984x	9.05241
9.05241	4.77833

60024 ←

$$El = 60000 \cdot \log \frac{H_1}{H_2}\left(1 + \frac{t_1 + t_2 - 64^\circ}{1000}\right)$$

28.650 = 1.45712
22.378 = 1.34983
0.10729

60, cm
6437.4000 = 3.80871
= 0.00190
3.81061

1.0044

6465.6
19.2
6485

65.31
42.71
108.06
64.
1.0044.06

Weight of

A B C

np
pressure.

$$x_1 - x_2 = n(\log p_1 - \log p_2)$$

$$= \frac{1}{n}\left(\log \frac{p_1}{p_2}\right)$$

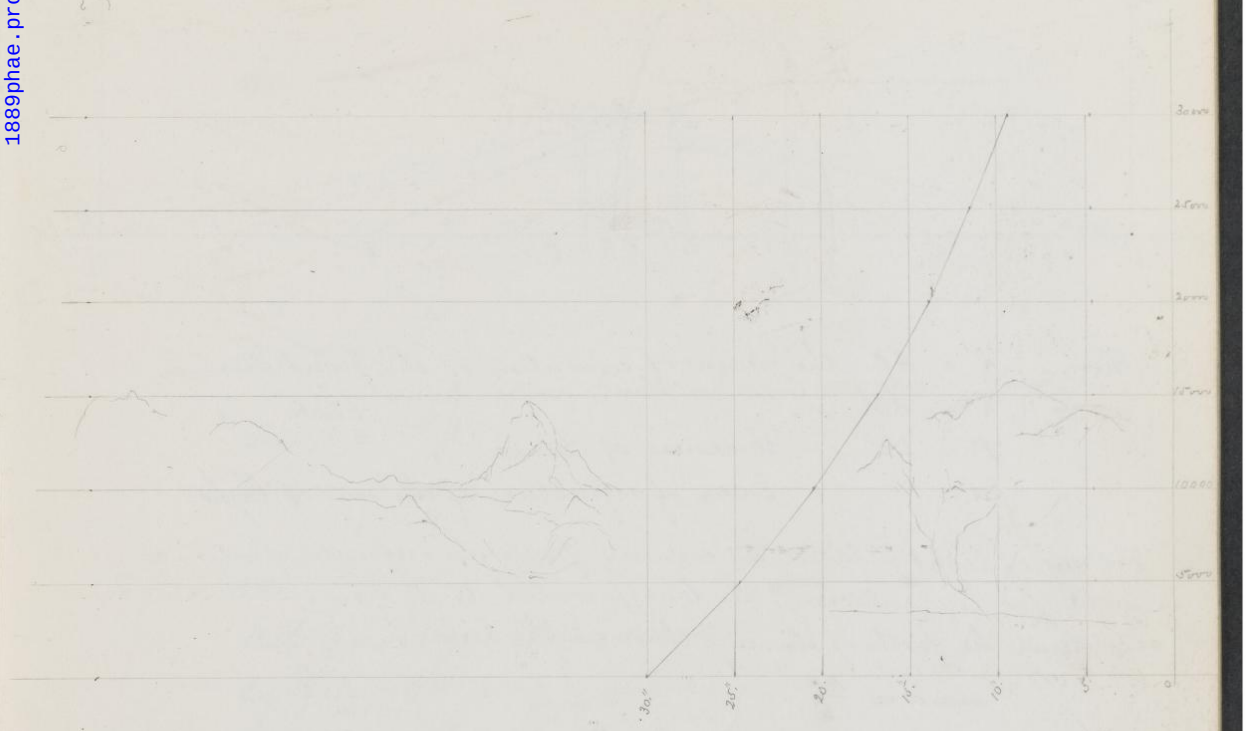
Height of Barometer being proportional to the pressure, $\frac{h_1}{h_2} = \frac{p_1}{p_2}$

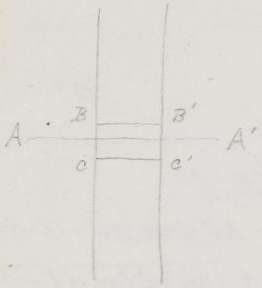
$$x_1 - x_2 = \frac{1}{n}\left(\log \frac{h_1}{h_2}\right)$$ for constant temperature, gravity & form of Vapor

$$H_1 - H_2 = \frac{1}{n}(\log h_1 - \log h_2)$$

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At A A', weight of 1 cu ft. of air = $n\rho$

n = density or weight of cu ft at standard pressure.

Force of gravity & temperature constant =

ρ = pressure at A A'

Weight of layer 1 ft sq. dx thick = $n \cdot \rho \cdot dx = d\rho$

$$dx = \frac{1}{n} \cdot \frac{d\rho}{\rho}$$

$$x_1 - x_2 = \frac{1}{n} (\log \rho_1 - \log \rho_2)$$

$$= \frac{1}{n} \left(\log \frac{\rho_1}{\rho_2} \right)$$

Height of Barometer being proportional to the pressure, $\frac{h_1}{h_2} = \frac{\rho_1}{\rho_2}$

$$x_1 - x_2 = \frac{1}{n} \left(\log \frac{h_1}{h_2} \right)$$ for constant temperature, gravity & force of vapour

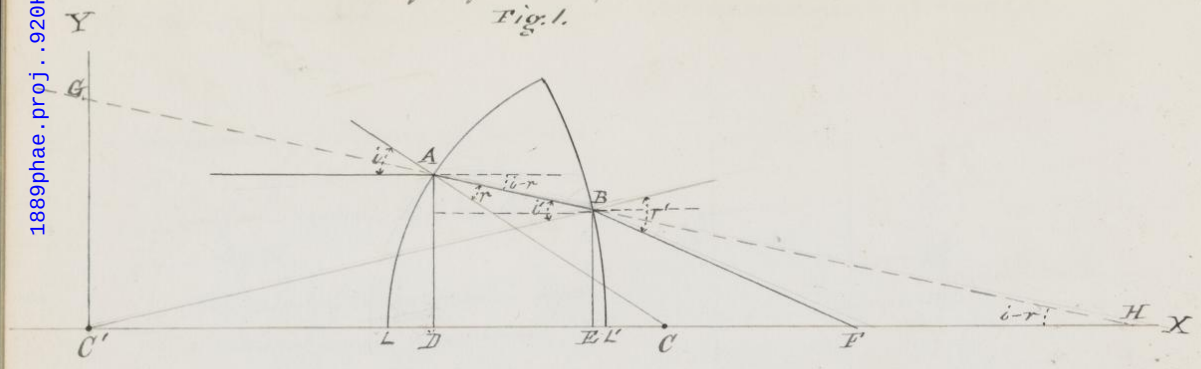
$$H_1 - H_2 = \frac{1}{n} (\log h_1 - \log h_2)$$

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Path of Light through a Lens.

Fig. 1.



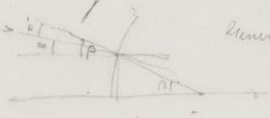
Given – $R = AC$. the radius of curvature of the front surface.
$R' = BC'$ " " " " back "
$T = LL'$ " thickness of Lens
n " Index of refraction of the ray of light.

The ray of light is taken as coming from an infinite distance and therefore as entering the lens parallel to its axis.

To find the path of the ray through the lens.

$$\sin i = \frac{AD}{R}$$

$$\sin r = \frac{\sin i}{n}$$



Generally – $i = B - \alpha$ $\sin B = \frac{AD}{R}$ when R is in this case R is minus

To find the point B, where the ray passes out of the back surface that is, where the line AB. produced to GH. intersects the circle $L'B$ whose centre is at C'.

With C' as origin of coordinates –

Eq. of GH is $y = mx + c$
" " $L'B$ " $x^2 + y^2 = R'^2$

where $m = \tan(i-r)$
$c = C'G$.

$$C'G = C'H \tan(i-r) - \left[R + R' - T - R\cos i\right] = \frac{C'H \times AD}{DH}$$
$$C'H = C'D + DH = R' - T + R - R\cos i \quad + AD \tan\{90° - (i-r)\}$$

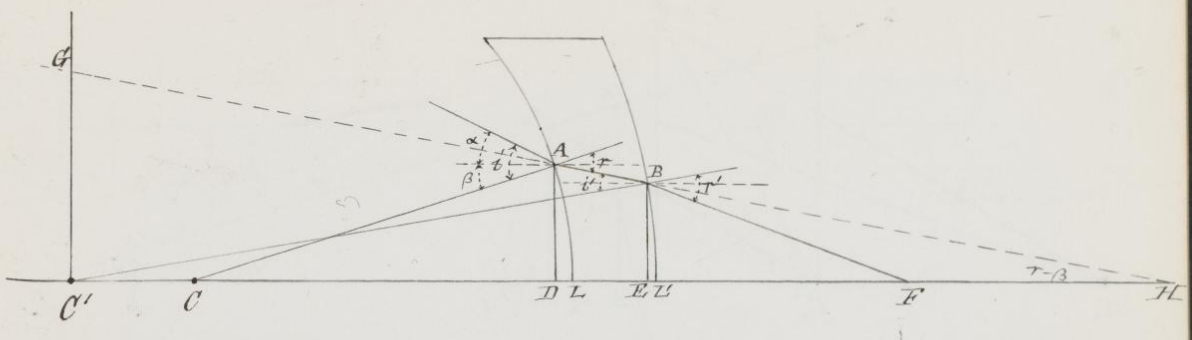
$$BE = y = \frac{c}{m^2+1} \pm \sqrt{\frac{m^2\{R'^2(m^2+1) - c^2\}}{(m^2+1)^2}} = \frac{c \pm \sqrt{m^2\{R'^2(m^2+1) - c^2\}}}{m^2+1}$$

To find the distance $L'F$ at which the ray crosses the axis of the lens from the back surface of the lens.

$$i' = (i-r) + BC'L'$$
$$\sin BC'L' = \frac{BE}{R'}$$
$$\sin r' = n \sin i'$$
$$FBE = 90° - (r' - BC'L') \qquad 90° + BC'L' - r'$$
$$L'F = EF - EL' = BE \tan\{90° - (r' - BC'L')\} - R'(1 - \cos BC'L') \qquad - R' + R'\cos BC'L'$$

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$i = \alpha + \beta$.

α = angle between incident ray and axis of lens.

$\sin \beta = \frac{AD}{R}$.

$\sin r = \frac{\sin i}{n}$

To find BE.

With C' as origin of coordinates

Eq of line GH is $y = mx + c$

" " circle LB. $x^2 + y^2 = R'^2$

where $m = \tan(r - \beta)$

$c = C'G$.

$C'G = C'H \tan(r - \beta)$.

$C'H = C'D + DH = R' - I' - R(1 - \cos\beta) + AD \tan\{90° - (r - \beta)\}$

$$BE = y = \frac{c}{m^2+1} \pm \sqrt{\frac{m^2\{R'^2(m^2+1) - c^2\}}{(m^2+1)^2}} = \frac{c - \sqrt{m^2\{R'^2(m^2+1) - c^2\}}}{m^2+1}$$

To find L'F.

$i' = r - \beta + BC'L'$

$\sin BC'L' = \frac{BE}{R'}$

$\sin r' = n \sin i'$

$FBE = 90° - (r' - BC'L')$

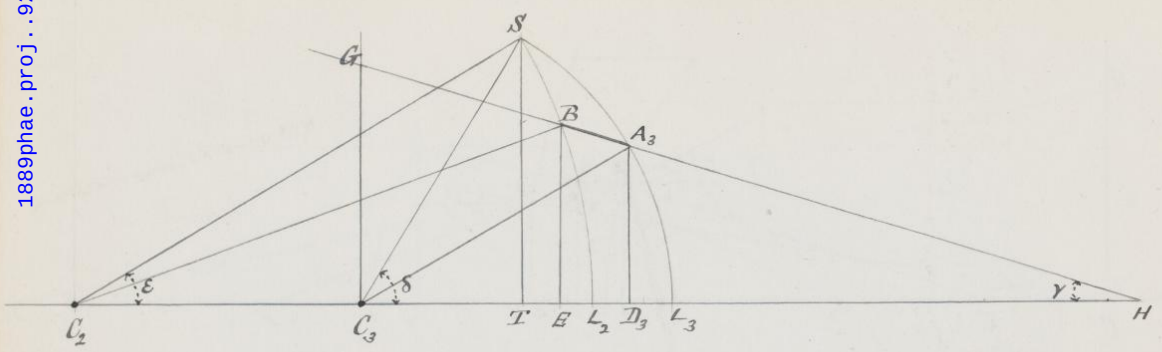
$L'F = EF - EL'$

$= BE \tan\{90° - (r' - BC'L')\} - R'(1 - \cos BC'L')$

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Path of Light between two Lenses -



Given - BE, found from Fig. 1.
" EH = EF of Fig 1.
" R_2 = C_2S
" R_3 = C_3S
" ST = Diam. of Lens.
" L_2H = $L'F$ of Fig 1.

$\sin\delta = \frac{ST}{R_3}$ $\quad \tan\gamma = \frac{BE}{EH}$.

$\sin\varepsilon = \frac{ST}{R_2}$

$TL_3 = R_3(1-\cos\delta) = R_3 - R_3\cos\delta$

$TL_2 = R_2(1-\cos\varepsilon) = R_2 - R_2\cos\varepsilon$

$L_2L_3 = TL_3 - TL_2$

$C_3H = R_3 + L_2H - L_2L_3$

$C_3G = C_3H \tan\gamma$.

To find where the ray BH intersects the spherical surface SL_3

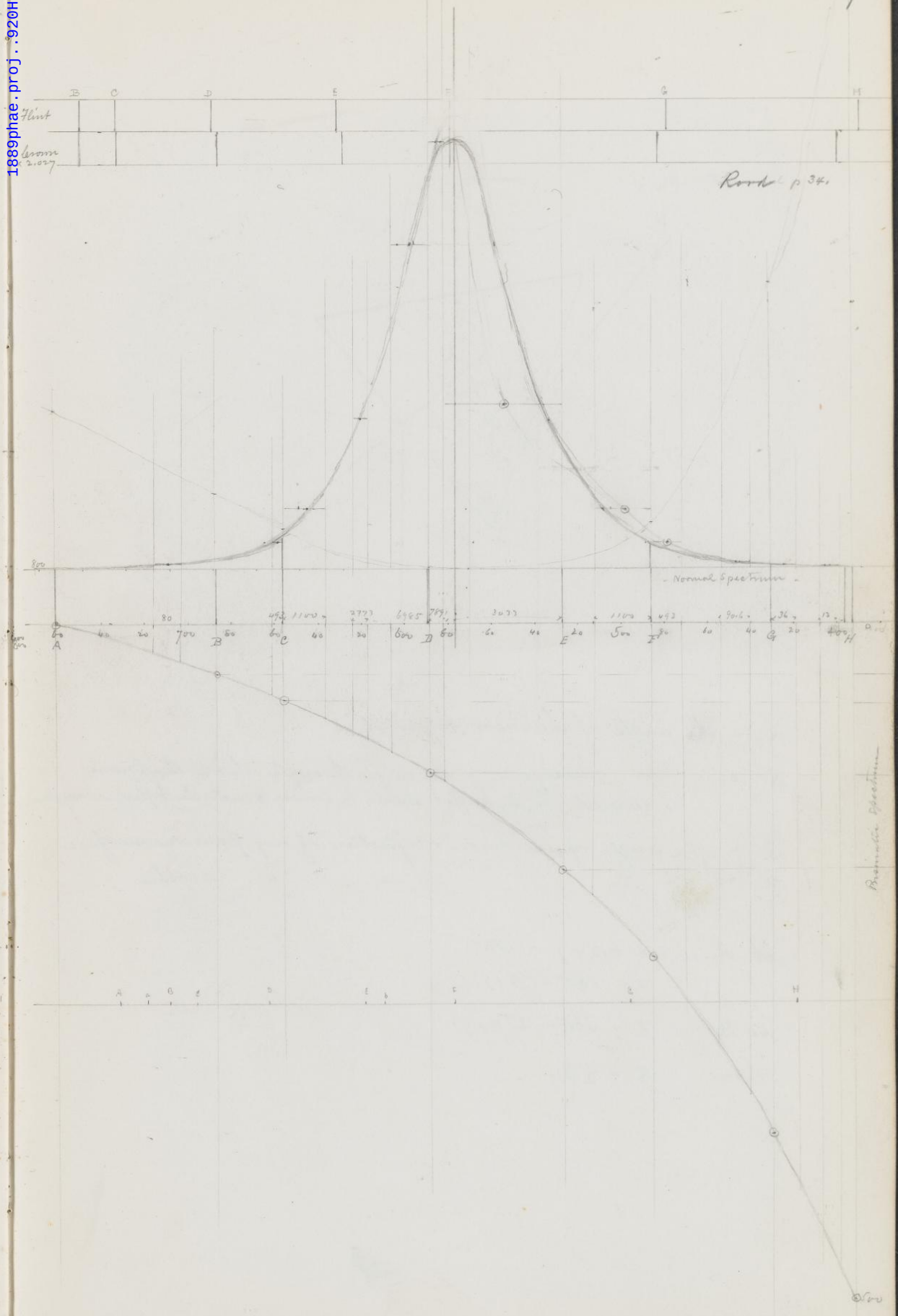
Eq. of line GH is $y = mx + c$
Eq. of circle SL_3 is $x^2+y^2 = R_3$

where $m = \tan\gamma$
$c = C_3G$.

$$AD = y = \frac{c}{m^2+1} \pm \sqrt{\frac{m^2\{R_3^2(m^2+1) - c^2\}}{(m^2+1)^2}} = \frac{c - \sqrt{m^2\{R_3^2(m^2+1) - c^2\}}}{m^2+1}$$

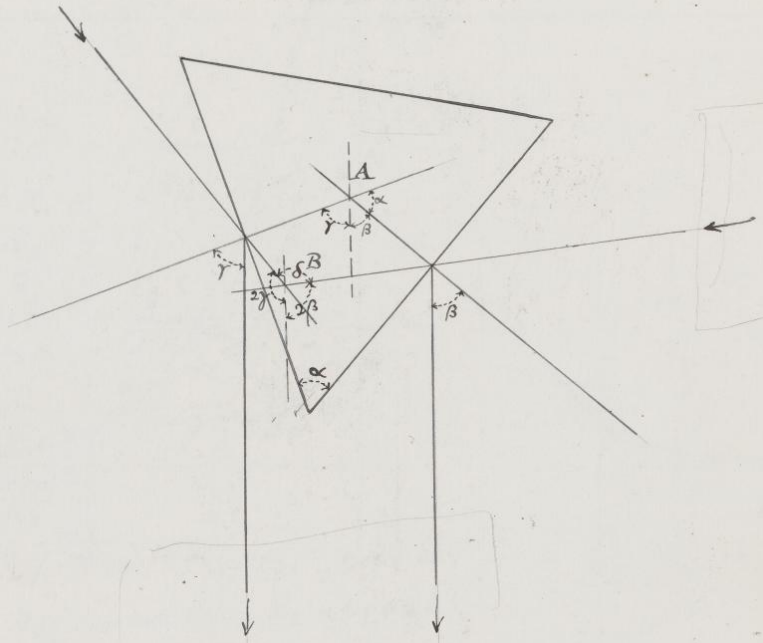
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α = the angle of the Prism required.

δ = " " measured, = the angle through which the prism is turned, or that the Bright should be swung to make the reflected ray pass

β = the angle of incidence + reflection of ray from one surface

γ = " " " " " " other "

At A. $\alpha + \beta + \gamma = 180°$

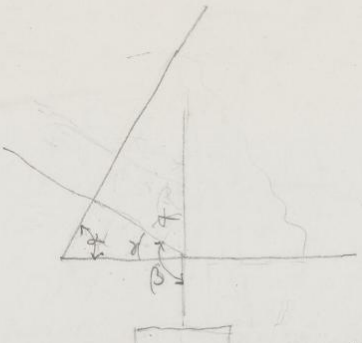
$\alpha = 180° - (\beta + \gamma)$

At B. $\delta = 360° - 2(\beta + \gamma)$

Hence $\alpha = \frac{1}{2}\delta$.

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$\gamma = 90 - \alpha$.

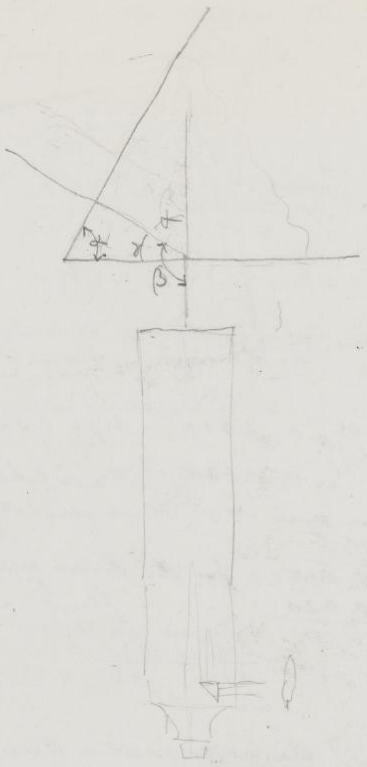
Charles P Howard
of Hartford conn.

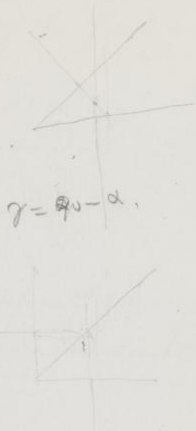
Optics

measured

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β = Angle through which the prism is revolved and is the angle measured;
α = " of Prism, required

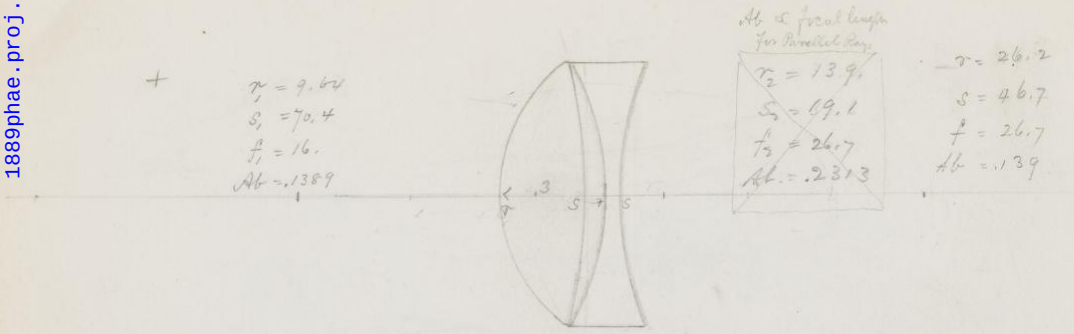
γ = 90 − ½α
β = 90 − ½α
180 − α

Angle of Prism = 180° − β.

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Achromatic Lens.



Given, for crown glass - $n_C = 1.527$ $n_f = 1.53$ $n_A = 1.542$

" " Flint " $= 1.625$ $n_2 = 1.63$ $= 1.655$

Ency. Brit. Vol. XVI. p. 590. Crown glass № 9 Flint glass № 30.

$\Delta n_1 = n_A - n_C = 0.015$ for the crown glass

$\Delta n_2 = n_A - n_C = 0.030$ " " Flint.

$\therefore$ The ratio of dispersion $= \frac{.015}{.53} \div \frac{.030}{.63}$ Parkinson p. 164.

Given - The focal length f of the achromatic lens $= 40$ ins.

The diameter " " " " $= 3$ ins.

To find the ratio between the focal length f_1 of the crown glass lens and the focal length f_2 of the Flint glass lens.

The condition of achromatism is

$$\frac{\Delta n_1}{n_1 - 1} \cdot \frac{1}{f_1} + \frac{\Delta n_2}{n_2 - 1} \cdot \frac{1}{f_2} = 0$$ Parkinson. p. 170. " " 164

$$\therefore \quad \frac{.015}{.53} \cdot \frac{1}{f_1} = -\frac{.030}{.63} \cdot \frac{1}{f_2}$$

$$f_1 = -.6 f_2$$

$$-a = \frac{f_1}{f_2} = -\frac{\frac{\Delta n_1}{n_1 - 1}}{\frac{\Delta n_2}{n_2 - 1}}$$

To find the focal lengths f_1 and f_2

$$\frac{1}{f_1} + \frac{1}{f_2} = \frac{1}{f}$$ Parkinson p. 103.

$$f_2 = \frac{f_1 f}{f_1 - f}$$

$f_1 = (a+1)f$

$f_2 = \frac{(a+1)f}{a} \cdot \frac{f_1}{a}$

~~$f_1 = (a+1)f$~~

substituting $f_2 = \frac{-.6 f_2 \times 40}{-.6 f_2 - 40}$

$\therefore \quad f_2 = -26.7$ inches ✓

$\therefore \quad f_1 = 16$ " ✓

These values of f_1 and f_2 fulfil the conditions of achromatism

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To find the radius of curvature of the surfaces of the crown glass lens so that the spherical aberration may be the minimum,

The condition is that the ratio between the radius of the first surface r_1, and of the second surface s_1, shall be

$$\frac{s_1}{r_1} = \frac{n_1(2n_1+1)}{2n_1^2 - n_1 - 4} \qquad \text{Parkinson p. 122.}$$

$$= \frac{1.53(3.06+1)}{2\times 2.34 - 1.53 - 4} = \frac{6.21}{-.85}$$

$$\therefore \quad \frac{s_1}{r_1} = -7.3 \qquad \therefore \; r_1 \text{ and } s_1 \text{ have opposite signs and are measured in opposite directions, and the lens is double convex.}$$

$\therefore$ f_1 is negative and r is negative also.

To find the radii of curvatures r_1 and s_1

$$\frac{1}{f_1} = (n_1 - 1)\left(\frac{1}{r_1} - \frac{1}{s_1}\right) \qquad \text{Parkinson p. 92.}$$

$$-\frac{1}{16} = .53\left(\frac{1}{-r_1} - \frac{1}{+7.3r_1}\right)$$

$$-r_1 = -9.64 \text{ inches.}$$

$$s_1 = +70.4 \text{ "}$$

To find the aberration, that is the difference of focal distance between the central and the marginal rays. For parallel rays—

$$\text{The aberration} = -\frac{n_1 - 1}{n_1^2}\left\{\frac{1}{r_1^3} - \left(\frac{1}{s_1} - \frac{1}{f_1}\right)^2\left(\frac{1}{s_1} - \frac{n_1+1}{f_1}\right)\right\}\frac{f_1^2 y^2}{2}.$$

Parkinson p. 121,

$$= -\frac{.53}{2.34}\left\{.001116 - \left(\frac{1}{+70.4} - \frac{1}{-16}\right)^2\left(\frac{1}{+70.4} + .1581\right)\right\}\frac{256\times 2.25}{2}$$

$$= -\frac{.53\times 128\times 2.25}{2.34}\left\{.001116 - (.005893\times +.1723)\right\}$$

$$= -\frac{.53\times 128\times 2.25}{2.34}\times -.00213$$

$$= +0.1389 \text{ inch.}$$

In the flint glass lens — $\frac{s_2}{r_2} = \frac{n_2(2n_2+1)}{2n_2^2 - n_2 - 4} = \frac{1.63(3.26+1)}{2\times 2.66 - 1.63 - 4} = \frac{6.94}{-.32} = -21.8$

$$\frac{1}{f_2} = (n_2 - 1)\left(\frac{1}{r_2} - \frac{1}{s_2}\right) \quad \therefore \; \frac{1}{+26.7} = .63\left(\frac{1}{r_2} - \frac{1}{-21.8r_2}\right) \quad \therefore \; r_2 = 16.82 + \frac{16.82}{21.8}$$

$$r_2 = 17.6 \text{ inches} \quad \therefore \; s_2 = 384 \text{ inches}$$

The Aberration where f_2 is positive r_2 is positive and s_2 negative —

$$= -\frac{.63}{2.657}\left\{.0001834 - (.0016\times -.1011)\right\}\frac{26.7^2\times 2.25}{2}$$

$$= -\frac{.63\times .000345\times 26.7^2\times 1.125}{2.657} =$$

$$= -0.0656 \text{ inch.} \quad \text{which is the minimum possible.}$$

This Aberration should be -0.2315 in. to correct that of the crown glass.

If proportion to focal lengths, which is an erroneous supposition.

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The spherical aberration of the flint glass lens so calculated above being less than that required to neutralize that of the crown glass lens. Try. $r_2 = s_2$

$$\therefore \quad \frac{1}{26.7} = .63\left(\frac{2}{r_2}\right)$$

$$r_2 = s_2 = 33.64.$$

which makes r_2 about one half s_1.

$$Ab = -\frac{.63}{1.63^2}\left\{\frac{1}{33.64^3} - \left(\frac{1}{-33.64} - \frac{1}{26.7}\right)^2\left(\frac{1}{-33.64} - \frac{2.63}{26.7}\right)\right\}\frac{26.7^2 \times 2.25}{2}$$

$$= -\frac{.63}{1.63^2}\left\{.00002626 - (-.02972 - .03745)^2(-.02972 - .09852)\right\}A$$

$$= -\frac{.63}{1.63^2}\left\{.00002626 - (-.06717)^2(-.1282)\right\}\frac{26.7^2 \times 2.25}{2}$$

$$= -\frac{.63}{1.63^2}\left\{.00002626 - (-.0005785)\right\}\frac{26.7^2 \times 2.25}{2}$$

$$= -\frac{.63 \times .0006048 \times 26.7^2 \times 2.25}{1.63^2 \times 2}$$

$$= -.1150 \text{ inches}.$$

Try $r_2 = \infty$.

$$\frac{1}{26.7} = .63\left(-\frac{1}{s_2}\right)$$

$$s_2 = 14.82 \text{ inches}$$

$$Ab = -\frac{.63}{1.63^2}\left\{0 - \left(\frac{1}{-1482} - \frac{1}{26.7}\right)^2\left(\frac{1}{14.82} - \frac{2.63}{26.7}\right)\right\}\frac{26.7^2 \times 2.25}{2}$$

$$= -\frac{.63}{1.63^2}\left\{-(-.06749 - .03745)^2(-.06749 - .09852)\right\}A.$$

$$= -0.3475 \text{ inches}.$$

Try. $r_2 = 70 \quad \therefore \quad s_2 = 22.13$

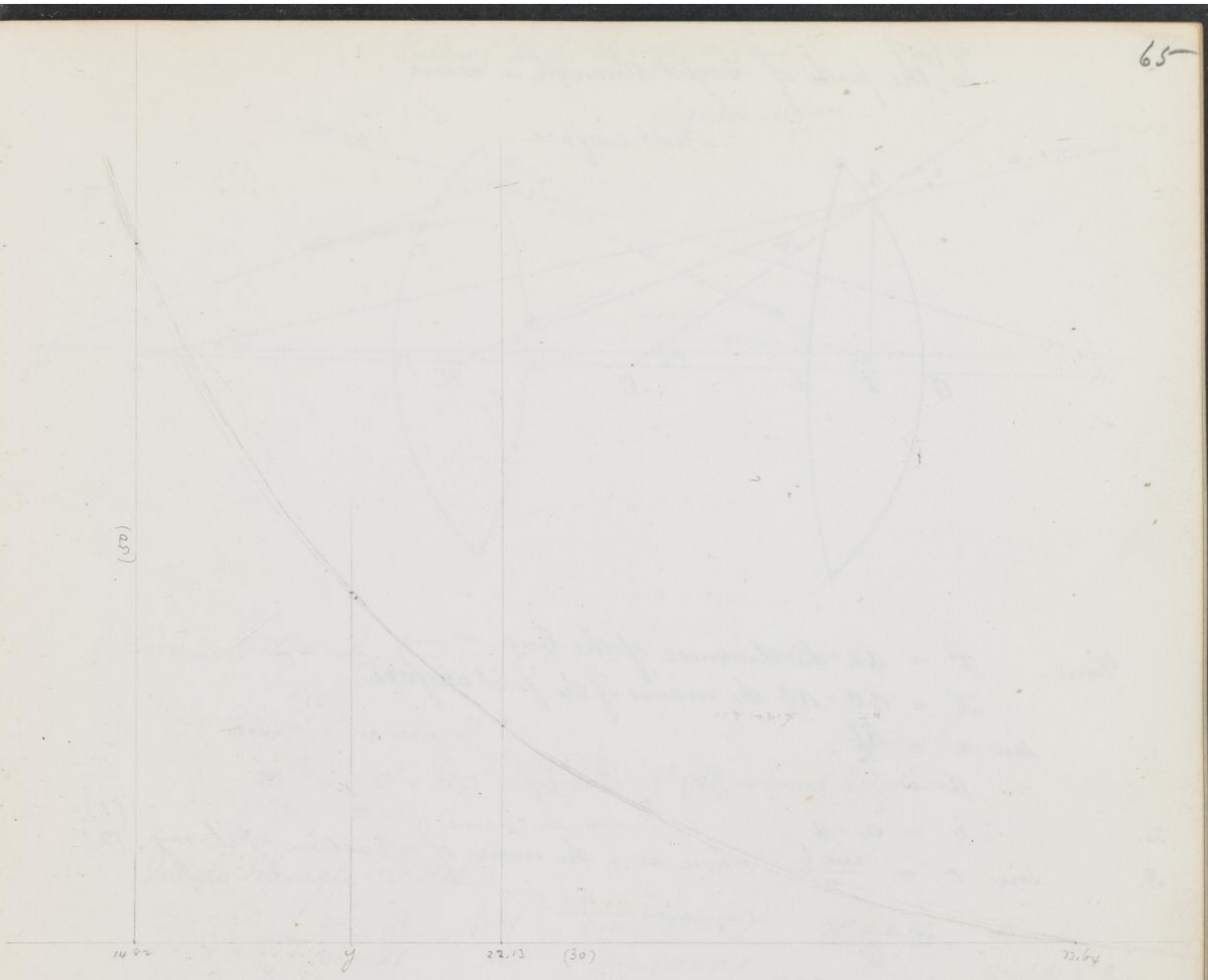
$$Ab = -\frac{.63}{1.63^2}\left\{.00000291 - (-.05129 - .03745)^2(-.05129 - .09851)\right\}A$$

$$= -\frac{.63 \times .001183 \times 26.7^2 \times 2.25}{1.63^2 \times 2}$$

$$= -0.1872 \text{ inches}.$$

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$r_2 = 17.6$ $\therefore$ $S_2 = 384$ Ab. $= .0656$ minimum

$= 33.64$ $= 33.64$ 18.82 $= .1150$ 0

$= 70.$ $= 22.13$ 7.31 $= .1872$ 722

$= {}^{13}\!/_{4}$ $= 19\,{}^{3}\!/_{4}$ 4.31 $= .2315$ 1165

$= \text{Inf.}$ $= 14.82$ 0 $= .3475$ 2325

Try $r_2 = 139$ $S_2 = 19.1$

$$Ab = -\frac{.63}{1.63^2}\left\{\frac{1}{139^3} - \left(\frac{1}{-19.1} - \frac{1}{26.7}\right)^2\left(\frac{1}{-19.1} - \frac{2.63}{26.7}\right)\right\}\frac{26.7^2 \times 2.25}{2}$$

$$= -\frac{.63}{1.63^2}\left\{.0000004 - (-.05236 - .03745)^2(.05236 - .09857)\right\}\frac{26.7^2 \times 2.25}{2}$$

$$= -\frac{.63}{1.63^2}\left\{.0000004 - (-.001217)\right\}\frac{26.7^2 \times 2.25}{2}$$

$$= -\frac{.63}{1.63^2}\left\{.001217\right\}\frac{26.7^2 \times 2.25}{2}$$

$$= -0.2313 \text{ inch}$$

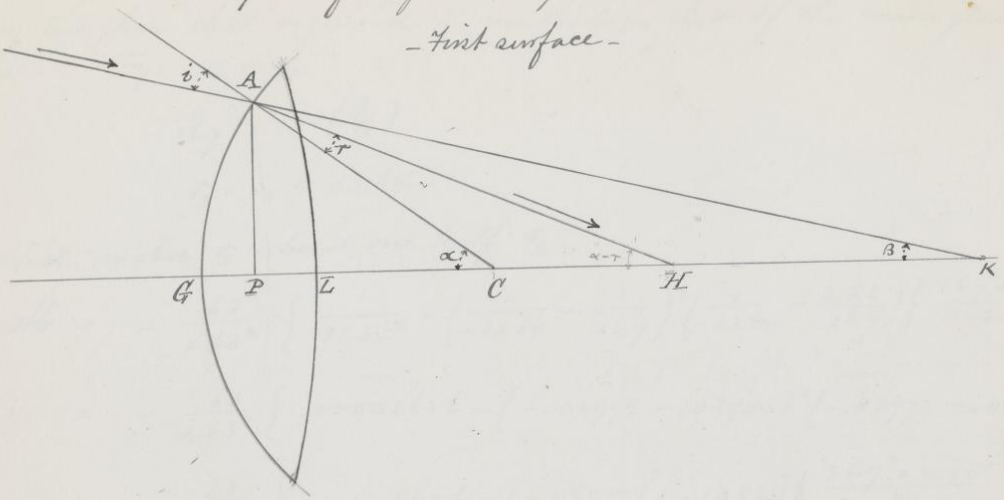
This value of the aberration of the flint lens does not correct that of the crown lens. The supposition that the aberration for parallel rays should be proportional to the focal distances being entirely wrong.

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To trace the path of Light through a Lens -

- first surface -



Given - I = GL the thickness of the lens -

R = GC = AC the radius of the first surface.

1. $\sin \alpha = \frac{AP}{R}$ (0)

$\tan \beta = \frac{AP}{PK}$ = 0 for parallel rays

2. $\therefore i = \alpha - \beta$ (1), (2).

3. $\sin r = \frac{\sin i}{n}$, where n = the index of refraction of the ray.

In the triangle ACH,

$$H = \alpha - r$$

$$\frac{CH}{AC} = \frac{\sin r}{\sin H}$$

$$\frac{CH}{R} = \frac{\sin r}{\sin(\alpha - r)}$$

$$CH = R \cdot \frac{\sin r}{\sin(\alpha - r)}$$

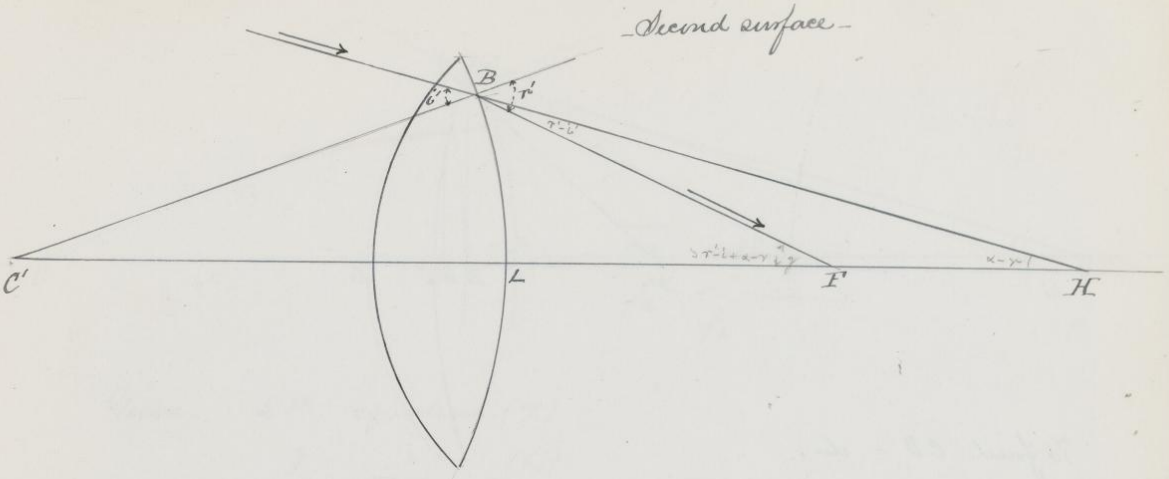
$$LH = R \cdot \frac{\sin r}{\sin(\alpha - r)} + R - I. \qquad (3).$$

$$GH = R + R \frac{\sin r}{\sin(\alpha - r)}$$

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Path of Light through a Lens.



Given $LH = R.\frac{\sin r}{\sin(\alpha - r)} + R - I'$ as above.

$\sin r' = n \sin i'$

$R' = \angle C' = BC' =$ radius of the second surface

$C'HB = \alpha - r$

In the triangle $C'BH$.

$$\frac{\sin B}{\sin H} = \frac{C'H}{R'} \therefore \frac{\sin(180° - i')}{\sin(\alpha - r)} = \frac{R' + LH}{R'} = \frac{\sin i'}{\sin(\alpha - r)}$$

$$\sin i' = \frac{(R' + LH)\sin(\alpha - r)}{R'} \quad (4.)$$

$$\sin r' = n \sin i' = \frac{n(R' + LH)\sin(\alpha - r)}{R'} \quad (5.)$$

In the triangle $BC'F$.

$$\gamma = FHB + FBH = (\alpha - r) + (r' - i') \quad (6.)$$

$$\frac{C'F}{C'B} = \frac{\sin(180° - r')}{\sin \gamma}$$

$$\therefore C'F = R'.\frac{\sin r'}{\sin \gamma} = \frac{R'.n(R' + LH)\sin(\alpha - r)}{R'\sin\{(\alpha - r) + (r' - i')\}}$$

$$LF = C'F - R + I'$$

$$= \frac{R'.n\left\{R' + R\frac{\sin r}{\sin(\alpha - r)} + R - I'\right\}\sin(\alpha - r)}{\sin\{(\alpha - r) + (r' - i')\}} - R + I'$$

or $$LF = C'F - R' = R'.\frac{\sin r'}{\sin \gamma} - R' \quad (7.)$$

$$= \frac{n\left\{R' + \frac{R.\sin r}{\sin(\alpha - r)} + R - I'\right\}\sin(\alpha - r)}{\sin\{(\alpha - r) + (r' - i')\}} - R'$$

$$\therefore LF = \frac{n\left\{\frac{R.\sin r}{\sin(\alpha - r)} + R + R' - I'\right\}\sin(\alpha - r)}{\sin\{(\alpha - r) + (r' - i')\}} - R'$$

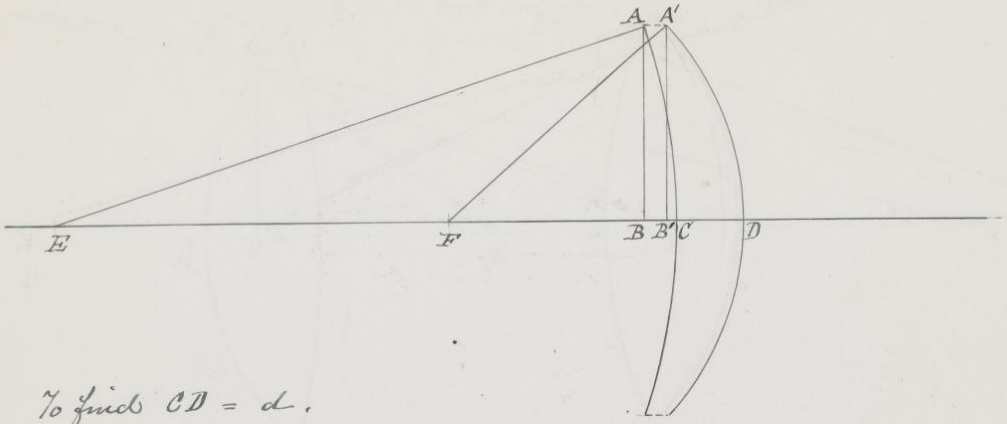
which is the distance from the second surface at which the ray crosses the axis.

$$LF = \frac{n\{R.\sin r + (R + R' - I')\sin(\alpha - r)\}}{\sin\{(\alpha - r) + (r' - i')\}} - R'.$$

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Distance between the Lenses.



To find $CD = d$.

Given - $R' = AE = EC$

$R = A'F = FD$

$AB = A'B$ the distance of edge of lens from its axis

$AA' = BB' =$ " " between the edges of the lenses -

or the thickness of the separating ring -

In the triangle AEB -

$$\sin E = \frac{AB}{R'} \qquad \text{---------- (8.)}$$

$$EB = R' \cos E \quad \therefore \quad BC = R' - R' \cos E.$$

In the triangle A'FC -

$$\sin F = \frac{AB}{R} \qquad \text{---------- (9.)}$$

$$FB' = R \cos F \quad \therefore \quad B'D = R - R \cos F$$

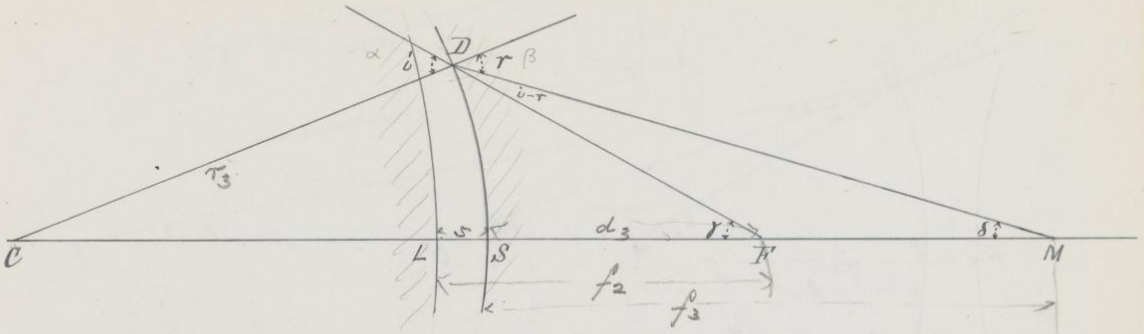
$$d = CD = B'D - BC + AA'$$

$$= R - R' + R' \cos E - R \cos F + AA'. \qquad \text{---- (10.)}$$

$$= R(1 - \cos F) - R'(1 - \cos E) + AA'$$

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Given- LF, equation (7.)

γ, " (6.)

$d_1 = LS$ " (10.)

$R_1 = CS = CD$ the radius of the first surface

In the triangle CDF,

$$\frac{\sin D}{\sin F} = \frac{CF}{R} \quad \therefore \quad \frac{\sin i}{\sin \gamma} = \frac{R + LF - LS}{R}.$$

$$\sin i = \frac{R + LF - d_1}{R} \cdot \sin \gamma \qquad (11.)$$

$$\sin r = \frac{\sin i}{n} \qquad (12.)$$

In the triangle CDM.

$$\delta = \gamma + r - i \qquad (13.)$$

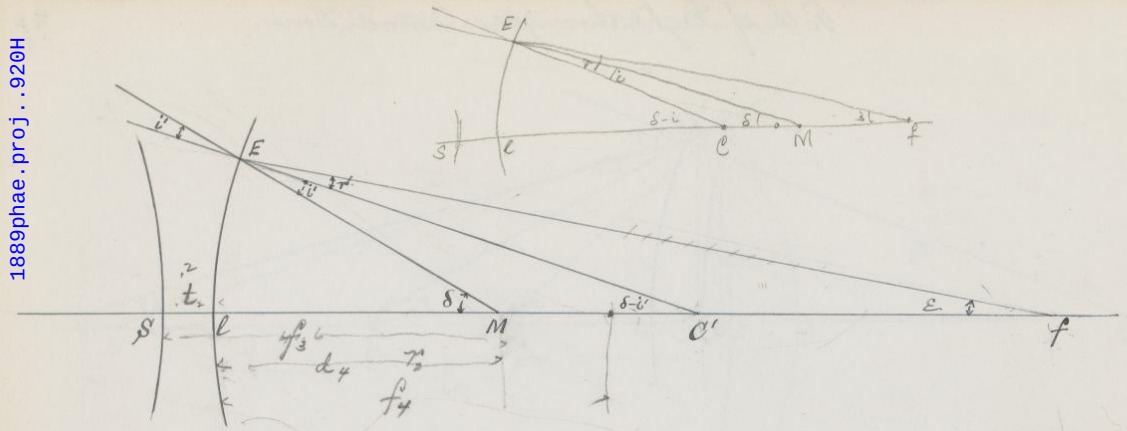
$$\frac{\sin D}{\sin M} = \frac{CM}{R} \quad \therefore \quad \frac{\sin r}{\sin \delta} = \frac{SM + R}{R}$$

$$SM = \frac{R(\sin r - \sin \delta)}{\sin \delta}$$

$$SM = R \cdot \frac{\sin r}{\sin \delta} - R \qquad (14.)$$

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Given - SM, equation (14.)

δ, " (13.)

$t_1 = Sl$ the thickness of the lens.

$R' = C'l = C'E$. the radius of the second surface.

In the triangle EMC'.

$$\frac{\sin i'}{\sin \delta} = \frac{MC'}{R'}$$

$$\sin i' = \frac{(R' + t - SM)\sin \delta}{R'} \qquad (15.)$$

$$\sin r' = \frac{\sin i'}{n} \qquad (16.)$$

In the triangle $C'Ef$.

$$\varepsilon = \delta - (i' - r') \qquad (17.)$$

$$\frac{C'f}{R'} = \frac{\sin r'}{\sin \varepsilon}$$

$$C'f = R' \cdot \frac{\sin r'}{\sin \varepsilon}$$

$$lf = +R' \cdot \frac{\sin r'}{\sin \varepsilon} + R' \qquad (18.)$$

$$lf = \frac{(R + R' + t)\sin \delta - R \sin r}{n \sin \varepsilon} + R' \qquad (19.)$$

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$4\frac{1}{2}$ in

Crown

Angle of Prism = 60° 0' 30" see about 60 leaves over —

Hastings measurements below

A

$2\delta = 75° 38' 15"$

$\frac{1}{2}\delta = 18\ 54\ 34$

$\frac{1}{2}P = 30\ 0\ 15"$ ✓

$48\ 54\ 49 = \sin$ 9.8772097 ✓

$\sin \frac{1}{2}P =$ 9.6990247 ✓

$= 0.1781850$ ✓

$n =$ 1.5072497 ✓ — .001873

B

$2\delta = 75\ 57\ 53.2$

$\frac{1}{2}\delta = 18\ 59\ 28$ ✓

$30\ 0\ 15"$

$48\ 59\ 43 - \sin$ 9.8777488 ✓

$\frac{1}{2}P = \sin$ 9.6990247

$= 0.1787241$ ✓

$n =$ 1.5091222 ✓ .000000

C

$2\delta = 76\ 7\ 24$

$\frac{1}{2}\delta = 19\ 1\ 51$ ✓

$30\ 0\ 15"$

$49\ 2\ 6 = \sin$ 9.8788100 ✓

9.6990247

$= 0.1798353$ ✓

$n =$ 1.5100299 ✓ .000907

λ 5614

$2\delta = 76\ 48\ 18$

$19\ 12\ 4\frac{1}{2}$ ✓

~~96 0 22½~~

$30\ 0\ 15"$

$49\ 12\ 19\frac{1}{2} = \sin$ 9.8791285 ✓

9.6990247

$= 0.1801038$

$n =$ 1.5113923 ✓ .004801 ✓ 477°

F

$2\delta = 77\ 38\ 18$

$19\ 24\ 34\frac{1}{2}$ ✓

$30\ 0\ 15"$

$49\ 24\ 49\frac{1}{2} = \sin$ 9.8804864

9.6990247

$= 0.1814617$

1.5118664 ✓ .009542 ✓

G

$2\delta = 78\ 33\ 31$

$19\ 38\ 23$

$30\ 0\ 15"$

$49\ 38\ 38 = \sin$ 9.8819745 ✓

9.6990247

$= 0.1829498$

1.5123876 ✓ .014754 ✓

H

$2\delta = 79\ 21\ 8\frac{1}{2}$

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Flint

Angle of Prism = 60° 0' 34"

A

	°	'	"
2δ =	94	5	49
½δ =	23	31	27
½P =	30	0	17
	53	31	44

sin 9.9053406 ✓
½P = sin 9.6990320 ✓
= 0.2063086

n = 1.608083 — .003354

B

2δ =	94	44	40
	23	41	10
	30	0	17
	53	41	27

sin 9.9062453 ✓ .000000
9.6990320
= 0.2072133

n = 1.611437 ✓

C

2δ =	95	4	36
	23	46	14
	30	0	17
	53	46	31

sin 9.9067149 ✓ .001743 ✓
9.6990320
0.2076829

n = 1.613180

λ-5461 2δ =

	96	30	38½
	24	7	39½
	30	0	17
	54	7	56½

sin 9.9086848 ✓
9.6990320
= 0.2096528

n = 1.620514 ✓ .009077
9276

F

2δ =	98	22	27
	24	35	37
	30	0	17
	54	35	54

sin 9.9112167 ✓
9.6990320
= 0.2121847

n = 1.629989 ✓ .018552

G

2δ =	100	34	54½
	25	18	43½
	30	0	17
	55	9	0½

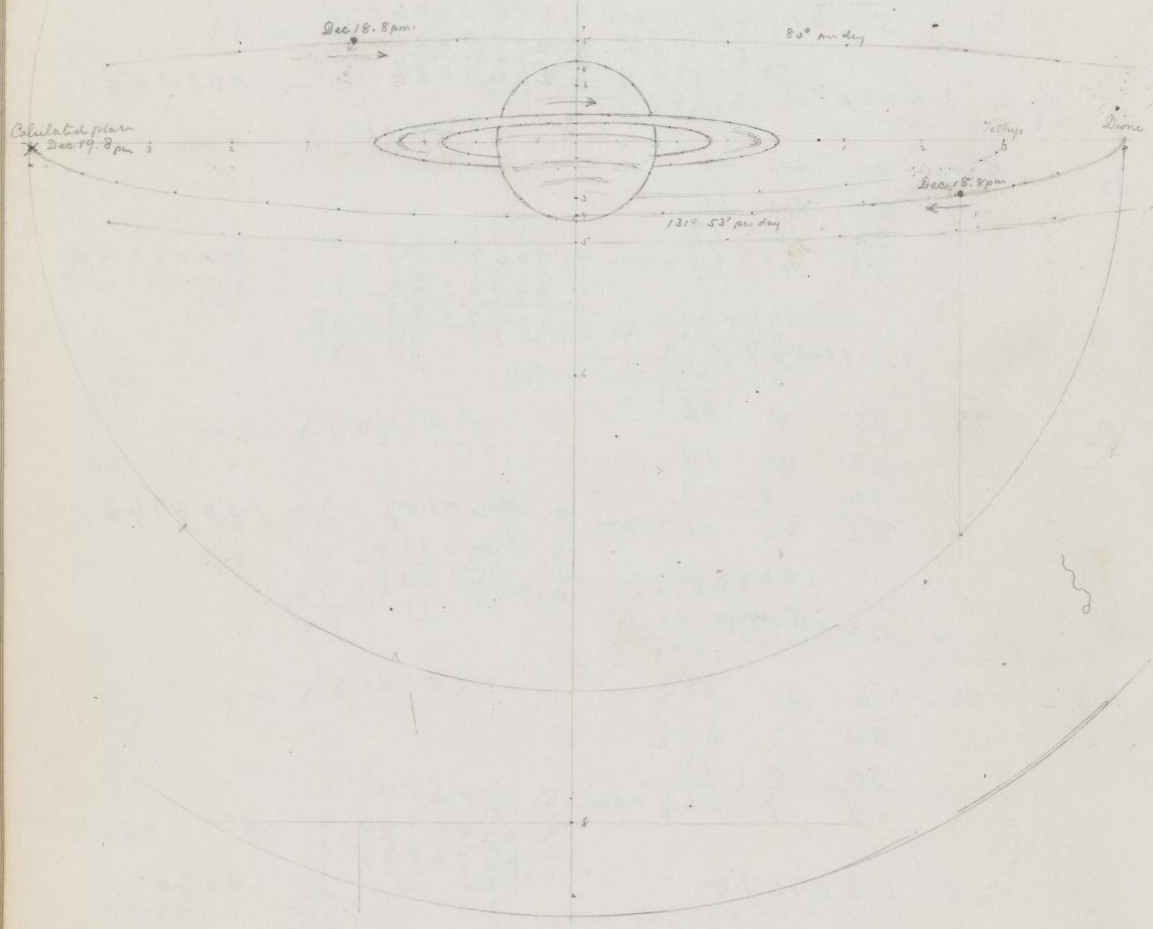
sin 9.9141591 ✓
9.6990320
0.2151271

n = 1.641070 ✓ .029633

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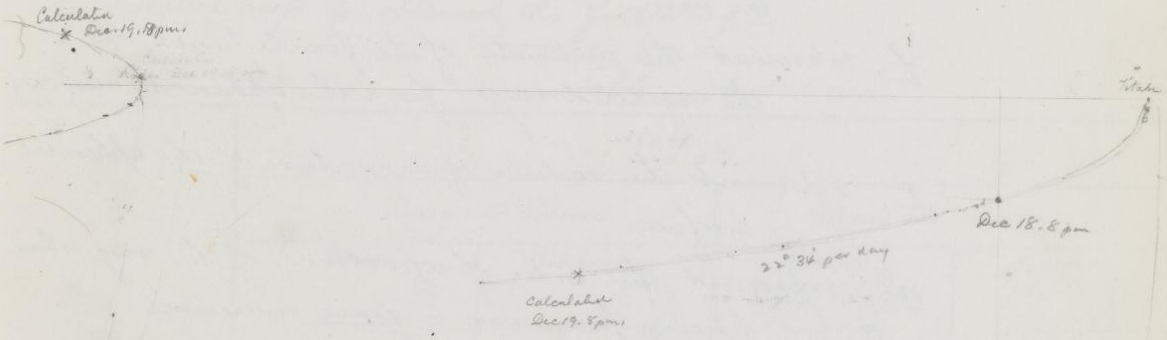
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Appearance of Saturn Rng.-
Dec. 26. 1879;



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Optics -

To find the focus of a cone of rays radiating from a given point after refraction at a spherical surface whose centre is in the axis of the cone.

Let d, represent the distance of the radiant point from the spherical surface measured along the axis.

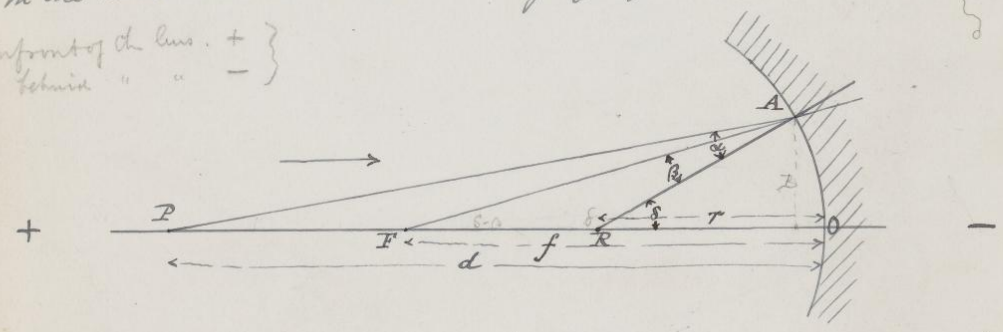
f, represent the distance of the focal point of the refracted rays from the spherical surface

r, represent the radius of curvature of the spherical surface

n, represent the index of refraction of the ray when passing from rare to dense medium.

d, f, and r, are positive when measured in the direction contrary to that of the ray of light. and minus when measured in the same direction with the ray of light.

Inference of the law. + }
Reference " " − }



$$n = \frac{\sin \alpha}{\sin \beta}.$$

$$\frac{AF}{FR} = \frac{\sin \delta}{\sin \beta}$$

$$\frac{AP}{PR} = \frac{\sin \delta}{\sin \alpha}$$

$$\frac{AF \times PR}{FR \times AP} = \frac{\sin \alpha}{\sin \beta} = n$$

$$\frac{AF \times (d-r)}{AP \times (f-r)} = n$$

For central rays - $AF = f$, $AP = d$

$$\frac{f(d-r)}{d(f-r)} = n$$

Hence $$f = \frac{ndr}{r + d(n-1)}$$ for central rays. (1.)

from rare to dense.

P +
d +
f +

$fd - fr = ndf - ndr$
$f(d - r - nd) = -ndr$
$f(r + nd - d) = ndr$
$f = \frac{ndr}{r + d(n-1)}$

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From dense to rare,

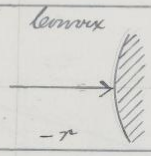
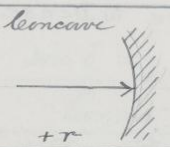
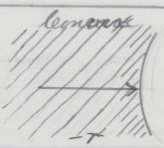
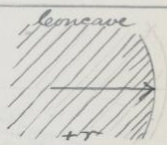
$$\frac{f(d-r)}{d(f-r)} = \frac{1}{n}$$

$$nfd - nfr = df - dr$$
$$ndf - nrf + df = -dr$$
$$f(nr - nd + d) = dr$$
$$f = \frac{dr}{nr - d(n-1)}$$

Hence $$f = \frac{dr}{nr - d(n-1)}$$ for central rays from dense to rare. (2.)

From the above general formulae for the value of f by substituting the proper signs of d and r in the various cases, and putting $d = \infty$ for parallel rays is obtained the following -

— Table — (Central Rays)

	$f =$			
	Rare to Dense		Dense to Rare.	
Rays -	convex  $-r$	concave  $+r$	convex  $-r$	concave  $+r$
Parallel $d=\infty$	$-\frac{nr}{n-1}$	$\frac{nr}{n-1}$	$\frac{r}{n-1}$	$-\frac{r}{n-1}$
Diverging $+d$	$\frac{ndr}{r-d(n-1)}$	$\frac{ndr}{r+d(n-1)}$	$-\frac{dr}{nr+d(n-1)}$	$\frac{dr}{-nr+d(n-1)}$
Converging $-d$	$-\frac{ndr}{r+d(n-1)}$	$\frac{ndr}{d(n-1)-r}$	$\frac{dr}{d(n-1)-nr}$	$-\frac{dr}{nr+d(n-1)}$
$r=\infty$	nd		$\frac{d}{n}$	

To find the focus of the Central Rays - after passing through a lens - of thickness t. d_1, f_1, and r_1 refer to the first surface and d_2 f_2 and r_2 to the second.

From (1.) $$f_1 = \frac{nd_1r_1}{r_1 + d_1(n-1)}$$

For the second surface in (2.) $d_2 = f_1 + t$

$\therefore$ from (2.) $$f_2 = \frac{r_2\left(\frac{nd_1r_1}{r_1+d_1(n-1)} + t\right)}{nr_2 - (n-1)\left(\frac{nd_1r_1}{r_1+d_1(n-1)} + t\right)} = \frac{r_2}{\frac{nr_2}{\frac{nd_1r_1}{r_1+d_1(n-1)} + t} - (n-1)}$$

$$\therefore \quad f_2 = \frac{1}{\frac{1}{\frac{1}{\frac{1}{d_1} + \frac{n-1}{r_1}} + \frac{t}{n}} - \frac{n-1}{r_2}}$$

When $d_1 = \infty$ and $t = 0$. that is, the principal focus of a lens of no thickness is

$$f = \frac{1}{\frac{n-1}{r_1} - \frac{n-1}{r_2}} = \frac{1}{(n-1)\left(\frac{1}{r_1} - \frac{1}{r_2}\right)}$$

or $$\frac{1}{f} = (n-1)\left(\frac{1}{r_1} - \frac{1}{r_2}\right)$$

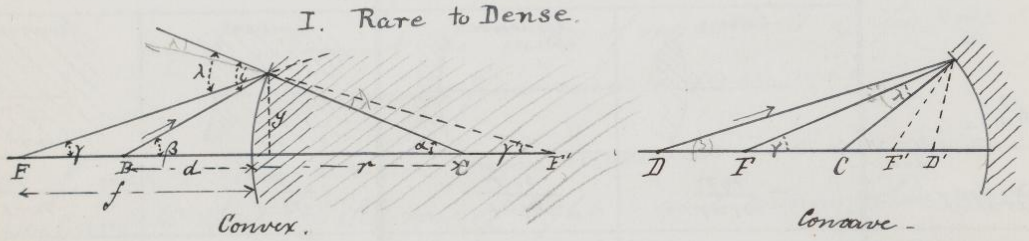
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Marginal Rays.

Let r = the radius of the spherical surface
d = the distance of the radiant point from the surface.
f = " " " " focal point of the refracted rays from the surface
y = " " from the axis of the point in the spherical surface intersected by the ray.
i = the angle of incidence
λ = " " " refraction
α = the "
β = " " Incident ray makes with axis, 2nd line = δ of first line.
γ = " " Refracted " " " "
δ =
t = thickness of the lens. n = index of refraction

I. Rare to Dense.



Convex. Concave.

(1.) $\sin\alpha = \frac{y}{r}$ $\left(\tan\beta = \frac{y}{d + r - \sqrt{r^2 - y^2}}\right)$

(2.) $i = \alpha$ for parallel rays

$\sin i =$

Parallel =		Convex − r	Concave + r	Flat r = ∞
Diverging	$d > r$	$\frac{(d+r)\sin\beta}{r}$	$\frac{(d-r)\sin\beta}{r}$	$\tan i = \frac{y}{d}$
"	$d < r$	do.	$\frac{(r-d)\sin\beta}{r}$	
Converging	$d > r$	$\frac{(d-r)\sin\beta}{r}$	$\frac{(d+r)\sin\beta}{r}$	$\tan i = \frac{y}{d}$
	$d < r$	$\frac{(r-d)\sin\beta}{r}$	do.	

(3.) $\sin\lambda = \frac{\sin i}{n}$

(4.) $\gamma =$

		Convex	Concave
Diverging	$d > r$	$\beta - (i - \lambda)$	$\beta + (i - \lambda)$
	$d < r$	do.	$\beta - (i - \lambda)$
Converging	$d > r$	$\beta + (i - \lambda)$	$\beta - (i - \lambda)$
	$d < r$	$\beta - (i - \lambda)$	do.
Parallel		$\alpha + \lambda$	$\alpha + \lambda$
$\lambda < \alpha$		$-\beta + (i - \lambda)$	

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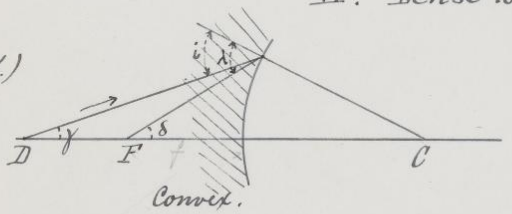
(5.) $f = r \frac{\sin\lambda}{\sin\gamma} - r \begin{cases} d>r \\ d<r \end{cases}$ Convex. Converging: $(d<r)\ r - r\frac{\sin\lambda}{\sin\gamma}$ $\left.\begin{matrix}\\\\\end{matrix}\right\}(d>r)\ r + r\frac{\sin\lambda}{\sin\gamma}$

$= \pm r \frac{\sin\lambda}{\sin\gamma} + r \begin{cases} d>r \\ d<r \end{cases}$ Concave. $\left.\begin{matrix} d>r \\ d<r \end{matrix}\right\}\ r\frac{\sin\lambda}{\sin\gamma} - r$

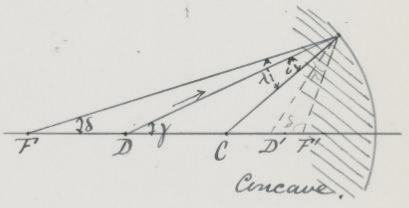
(6.) $d_2 = f_1 \pm t$

II. Dense to Rare.

(7.)



Convex.



Concave.

(7.) $\sin i =$

		Convex	Concave
Diverging	$d > r$	$\frac{(d+r)\sin\gamma}{r}$	$\frac{(d-r)\sin\gamma}{r}$
	$d < r$	do.	$\frac{(r-d)\sin\gamma}{r}$
Converging	$d > r$	$\frac{(d-r)\sin\gamma}{r}$	$\frac{(d+r)\sin\gamma}{r}$
	$d < r$	$\frac{(r-d)\sin\gamma}{r}$	do.
	$r = \inf$	γ	

(8.) $\sin\lambda = n \sin i$

(9.) $\delta =$

		Convex	Concave
Diverging	$d > r$	$\gamma + (\lambda - i)$	$\gamma - (\lambda - i)$
	$d < r$ $r = \text{Inf}$	$\gamma + \frac{}{\lambda}(\lambda - i)$	$\gamma + (\lambda - i)$
Converging	$d > r$	$\gamma - (\lambda - i)$	$\gamma + (\lambda - i)$
	$d < r$ $r = \text{Inf}$	$\gamma + \frac{}{\lambda}(\lambda - i)$	$\gamma + (\lambda - i)$

(10.) $f =$

		Convex	Concave
Diverging	$d > r$	$r\frac{\sin\lambda}{\sin\delta} - r$	$r + r\frac{\sin\lambda}{\sin\delta}$
	$d < r$		$r - r\frac{\sin\lambda}{\sin\delta}$
	$r = \inf$	$d\frac{\tan i}{\tan\lambda}$	
Converging	$d > r$	$r + r\frac{\sin\lambda}{\sin\delta}$	$r\frac{\sin\lambda}{\sin\delta} - r$
	$d > r$	$r - r\frac{\sin\lambda}{\sin\delta}$	
	$r = \inf$	$d\frac{\tan i}{\tan\lambda}$	

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- Achromatic Lens -

June 1883.

Crown Glass Prism

28

Date	Angle of Prism	C	λ = 5614	F
Mch 1880	59° 57′ 18″	76° 07′ 14″	77° 29′ 7″	78° 28′ 37″
June 16th 1881	—	45	15	37
		22	3	43
	60° 5′ 24″			

Flint Glass Prism

28

Date	Angle of Prism	C	λ = 5614	F
Mch. 1880	59° 57′ 35″			
Sept. 21. 1880	59 57 37	—	90° 5′ 26″	91° 43′ 43″
" 22. "	—			
" 23 "	—	89° 5′ 15″	90 5 16	91 43 55
	60° 4′ 48″			

Crown Glass. $n =$

C	1.51483	= log. 0.180363	0.360726
λ 5614	1.51840	" 0.181389	.362778
7	1.52404	" 0.182996	.365992
7 − C	.00921	= log 7.96426	

$$\frac{f_c}{f_F} = .65645 = \begin{array}{r} 7.96426 \\ 8.14706 \\ \hline 9.81720 \end{array}$$

Flint Glass $n' =$

C	1.58237	= log 0.199310
λ 5614	1.58770	" 0.200773
7	1.59640	" 0.203144
7 − C	.01403	= log 8.14706

dispersion = $\frac{.00921}{1.51840}$ Crown

$\frac{.01403}{1.58772}$ Flint

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Hartmann color correction see page 46,

$$n' = \alpha + \beta n + \gamma n^2$$

(1). $1.58238 = \alpha + \beta\, 1.51483 + \gamma\, 2.29471$ ✓

(2). $1.58772 = \alpha + \beta\, 1.51840 + \gamma\, 2.30557$ ✓

(3). $1.59640 = \alpha + \beta\, 1.52404 + \gamma\, 2.32270$ ✓

(3) − (2) $.00870 = \beta\ .00564 + \gamma\ .01716$ ✓

(2) − (1) $.00539 = \beta\ .00357 + \gamma\ .01083$ ✓

$\times \frac{564}{357}$ $.00885 = \beta\ .00564 + \gamma\ .01696$

$.000185 = \gamma\ .000209$

$\gamma = .9$

$.00539 = \beta\ .00357 + .00966$

$-.00427 = \beta\ .00357$

$\beta = -1.19$

$1.58238 = \alpha + 1.80261 + 2.06524$

$\alpha = -2.28554$

$\frac{1}{F} = .51840\,A + .58877\,B$

$A = -B(-1.19 + 2 \times .9 \times 1.51840)$

$A = -3.923\,B$

$\frac{1}{F} = -3.029\,B + .58877\,B$

$\frac{1}{F} = -1.4413\,B$

$\varphi = \frac{1}{F} = (n-1)A + (n'-1)B$

$\frac{d\varphi}{dn} = A + \beta B + 2\gamma n B = 0$

$A = \left(\frac{1}{r_1} + \frac{1}{r_2}\right)$ for Crown Glass Lens

$B = \left(\frac{1}{r_1} + \frac{1}{r_2}\right)$ " Flint " "

When $F = 1$ { $B = -.6938$, $A = +2.7218$

$F = 50^{in}$

$r_1 = r_2$ $\quad \frac{2}{r} \times 50 = +2.722$ } Crown Glass Lens.

$r_1 = r_2 = 36.74^{in}$

$r_2 = \infty$ $\quad \frac{1}{r_1} \times 50 = -.6938$ } Flint Glass Lens.

$r_1 = -72.08^{in}$

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Achromatic Lens continued -

Central Ray $\lambda = 5614.$

$r_1 = r_2 = 36.74$ inches	$t_1 = .3$ inches	$n = 1.51840$
$r_3 = 72.08$ "	$t_2 = .25$ "	$n' = 1.58770$
$r_4 = \text{inf.}$	$D = .25$ "	

Rare to dense $f_1 = -\frac{nr_1}{n-1}$

$n = 1.51840 = \log 0.18139$ ✓

$r_1 = 36.74 = \log \frac{1.56514}{1.74653}$

$n-1 = .51840 = \log \frac{9.71466}{2.03187}$

$f_1 = 107.615 = \log 2.03308$

$d = \frac{.3}{107.915} = \log \frac{1.56514}{3.59822}$

$r_2 = 36.74 =$

Dense to rare $f_2 = -\frac{dr_2}{nr_2 + d(n-1)}$

$n = \log. 0.18139$

$r_2 = \log \frac{1.56514}{1.74653} = nr_2 = 55.787$

$d = \log 2.03308$

$n-1 = \log \frac{9.71466}{1.74774} = d(n-1) = 55.942$

$111.729 = \log \frac{2.04817}{1.55005}$

$f_2 = 35.486 =$

$D = \frac{.25}{35.736} = \log 1.55311$

Rare to Dense $f_3 = \frac{n'dr}{d(n'-1) - r}$

$n' = 1.58770 = \log 0.20077$

$r_3 = 72.08 = \log \frac{1.85781}{3.61169}$

$d = \log 1.55311$

$n'-1 = \log \frac{9.74281}{1.29592}$

$= 19.766$

$-52.214 = \log \frac{1.71779}{1.89390}$

$f_3 = 78.325$

$t_2 = \frac{.25}{78.575} = \log 1.89528$

$d =$

Dense to rare $f_4 = \frac{d}{n'}$

$n' = 1.58770 = \log \frac{0.20077}{1.69451}$

$f_4 = 49.489$

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Central Ray C $n = 1.51483$
$n' = 1.58231$

$n = 1.57483 = \log 0.18036$
$r_1 = \quad = \quad 1.56514$
1.74550
$n-1 = .57483 = 9.71166$
2.03384
$f_1 = 108.104 =$
$d = \frac{3}{108.404} = \log 2.03504$
$r_2 = \quad = \quad 1.56514$
3.60018

$n = \log 0.18036$
$r_2 = \quad 1.56514$
$1.74550 = 55.655 = rf_2$

$d = \log 2.03504$
$n-1 = \quad 9.71166$
$1.74670 = d(n-1) = \frac{56.808}{111.463} = \log 2.04713$
1.55305
$f_2 = 35.731 =$
$D = \frac{.25}{35.981} = \log 1.55607$
$n' = 1.58231 = \quad 0.19929$
$r_3 = 72.08 = \quad 1.85781$
3.61317

$d = \log 1.55607$
$n'-1 = \quad 9.78515$
$1.32122 = \frac{20.952}{51.028} = \log 1.70866$
1.90451
$f_3 = 80.262 =$
$t_2 = \frac{.25}{80.012} = \log 1.90315$
$n' = \quad 0.19929$
$f_4 = 50.566 = \quad 1.70386$

Central Ray F $n = 1.52404$
$n' = 1.59640$

$n = 1.52404 = \log 0.18300$
$r = 36.74 = \quad 1.56514$
1.74814
$n-1 = .52404 = \quad 9.71936$
2.02878
$f_1 = 106.852$
$d = \frac{.3}{107.152} = \log 2.03000$
$r_2 = \quad 1.56514$
3.59514
$112.145 = \log 2.04978$
$f_2 = 35.104 = \quad 1.54536$
$D = \frac{.25}{35.354} = \log 1.54844$
$n' = 1.59640 = \quad 0.20314$
$r_3 = 72.08 = \quad 1.85781$
3.60939
$\frac{24.085}{50.995} = \log 1.70753$
$f_3 = 79.774 = \quad 1.90186$
$t_2 = \frac{.25}{79.524} = \quad 1.90050$
$n' = \quad 0.20314$
$f_4 = 49.815 = \log 1.69736$

$n = \log 0.18300$
$r_2 = \quad 1.56514$
$1.74814 = 55.994$
$d = \quad 2.03000$
$n-1 = \quad 9.71936$
$1.74936 = \frac{56.151}{112.145}$

$d = \log 1.54844$
$n'-1 = \quad 9.77554$
$1.32398 =$

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$$\frac{1}{p} = \varphi = (n-1)A + (\alpha - 1 + \beta n + \gamma n^2)B \qquad (1')$$

$$\varphi = .51483 \times 2.722 + \left(-2.28554 - 1 + \left(-\frac{1.19}{.6938} \times 1.51483\right) + .9 \times 2.29471\right)(-.6938)$$

$$= 1.40014 + \left[-3.28554 + (-1.80026) + 2.06524\right](-.6938)$$

$$= 1.40014 + (-3.0229 \times -.6938)$$

$$= 3.4987$$

$$3.4987 = nA - A + \cancel{\alpha B} - 3.2855B + \beta Bn + \gamma Bn^2$$

$$= 2.722n - 2.722 + 3.2855 \times .6938 + 1.19 \times .6938n - .9 \times .6938n^2$$

$$.62442n^2 - 3.5476n = 2.2795 - 3.4987 = -1.2192$$

$$n^2 - \frac{3.5476}{.62442}n = -\frac{1.2192}{.62442}$$

$$n^2 - 5.6813n = -1.9525$$

$$n^2 - 5.6813n + (2.84065)^2 = (2.84065)^2 - 1.9525$$

$$n^2 - 5.6813n + 8.0694 = 6.1169$$

$$n - 2.8406 = \pm 2.4732$$

$n = 5.3138$ or 0.3674 which is absurd.

The remainders in solving eq. (1) (2) (3). are so small that their ratios are of no value.

$$\frac{1}{F} = (n-1)\left(\frac{1}{r_1} + \frac{1}{r_2}\right) + (n'-1)\left(\frac{1}{r_3} + \frac{1}{r_4}\right)$$

Assume on Abbe Clarks. curves. $r_1 = r_2 = r_3$ $\quad r_4 = \text{Inf.}$

$$\frac{1}{F} = .5184\left(\frac{2}{r_1}\right) - .5877\left(\frac{1}{r_1}\right)$$

$$\frac{1}{F} = \frac{1.0368}{r_1} - \frac{.5877}{r_1}$$

$$\frac{1}{F} = \frac{.4491}{r_1}$$

$$\frac{1}{50} = \frac{.4491}{r_1}$$

$$r_1 = 22.455 \text{ inches}$$

$\frac{1}{f_1} = 21.658$ in. Crown. $\quad r_1 = r_2 = 22.455$

$\frac{1}{f_2} = 38.209$ in Flint, $\quad r_1 = r_2 = 44.910$

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.5483 = 9.71166
2.722 = 0.43489
1.4014 0.14655

1.5483 = 0.18036
.6938 = 9.84123
1.0510 0.02159
1.8026

0.18036 =
1.19 0.07555
0.25591

2.29471
.9
2.065239

.6938 = 9.84123 87
3.0229 = 0.48042
0.32165
2.0973
1.4014
3.4987

(38)

− 3.28554
− 1.8026
− 5.08814
+ 2.06524
− 3.0229

1.19 = 0.07555
.6938 = 9.84123
+ .82562 9.91678
2.722
3.54756n

.6938
.9
.62442

Leandre p. 160

$\frac{1}{f} = (n-1)\frac{2}{r_1} + (n'-1)\frac{2}{r_3}$

3.2855 = 0.51660
.6938 = 9.84123
2.2795 0.35783

3.4987
2.2795
1.2192

3.5476 = 0.54993
.62442 = 9.79548
5.6813 0.75445

1.2192 = 0.08607
= 9.79548
1.9525 0.29059

2.84065 = 1. 0.45342
2
8.0694 = 0.90684
1.9525
6.1169 = 0.78653
2.4732 0.39326
2.8406
5.3138
0.3674

$r_1 = .727\, r_3$ env.

$\frac{1}{f} = (n-1)\frac{2}{r_1} - (n'-1)\frac{2}{.727\, r_1}$

$\frac{1}{f} = \frac{.5784 \times 2}{r_1} - \frac{.5877 \times 2}{.727\, r_1}$

$\frac{1}{f} = \frac{.5784 \times 2}{r_1} - \frac{.8084 \times 2}{r_1}$

$= \frac{1.0368}{r_1} - \frac{1.6168}{r_1}$

$\frac{1}{f} = -\frac{.58}{r_1}$

$\frac{1}{50} = -\frac{.58}{r_1}$

$r_1 = .50 \times .58$

$r_1 = -29.00$ inches

$r_3 = 40-$

Recalculation of 1881. Compare p. 30, bottom.

$r_1 = r_2 = 24.13$
$r_3 = 25.57$
$r_4 = \text{Inf.}$

	Central C	Central 561μ	Central F	Marginal 561μ
f_1 =	70.98	70.67	70.18	70.58
f_2 =	23.38	23.22	22.97	23.00
f_3 =	77.26	77.26	77.07	77.09
f_4 =	48.67	48.50	48.76	48.87

Color – over corrected .09
Sphm. Abb. under " .13

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Central Rays. $\lambda = 5614$

$r_1 = r_2 = 22.45$ | $t_1 = .3$ | $n = 1.51840$

$r_3 = r_4 = 44.95$ | $t_2 = .25$ | $n' = 1.58772$

$D = .25$

Rare to dense $f_1 = -\frac{nr_1}{n-1}$

$n = 1.51840 = \log 0.18639$

$r_1 = 22.45 = \log 1.35122$

1.53161

$n-1 = \quad = 9.71466$

1.51695

$f_1 = 65.607$

$-.3$

$d = 65.307 = \log 1.81496$

Dense to rare $f_2 = -\frac{dr_2}{nr_2 + d(n-1)}$ $\quad r_2 = \quad = 1.35122$

3.16618

$n = \log 0.18039$

$r_2 = 1.35122 = 34.010$

1.53161

$d = 1.81496$

$n-1 = 9.71466$

1.52962

33.855

$67.865 = \log 1.83164$

1.33454

$f_2 = 21.604$

$D = .25$

$d = 21.354 = \log 1.32948$

0.20077

Rare to dense $f_3 = \frac{n'dr_2}{d(n'-1) - r_2}$ $\quad n' =$

$r_3 = 44.95 = 1.65273$

3.18298

$d = \log 1.32948$

$n'-1 = 9.76917$

1.09865

12.55

$32.40 = 1.51054$

1.67244

$f_3 = 47.037$

Dense to rare $f_4 = \frac{dr_4}{d(n'-1) - nr_4}$ $\quad .25$

$d = 46.787 = 1.67012$

$r_4 =$ $\quad 1.65273$

3.32285

$d = 1.67012$

$n'-1 = 9.76917$

$1.43929 = 27.497$

$n' = 0.20077$

$r_4 = 1.65273$

1.85350

-71.368

$43.871 = \log 1.64218$

1.68067

$f_4 = 47.937$

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Ratio of radii for achromatic combination by formulae in Sq Lardners Optics p. 160. Double convex - double concave.

$$\frac{n'-m'}{n''-m''} = \frac{(r_1+r_2)R_1R_2}{(R_1+R_2)r_1r_2} \qquad \frac{2rR^2}{2Rr^2}$$

$$= \frac{R}{r} \text{ where } +R_1 = -R_2 \text{ and } r_1 = r_2$$

$n' = 1.52404$ $\quad n'' = 1.59641$

$m' = 1.51483$ $\quad m'' = 1.58238$

$n'-m' = .00921$ $\quad n''-m'' = .01403$

Dispersive Power of glass $= \frac{n_v - n_r}{n_d - 1}$ Parkinson p 164.

$$\frac{.00921}{.01403} = \frac{R}{r}$$

$$r = \frac{1403}{921} R$$

$$= 1.523\,R$$

$\frac{f_1}{f_2} = -$

$$\frac{1}{F} = (n-1)\left(\frac{1}{r_1}+\frac{1}{r_2}\right) + (n'-1)\left(\frac{1}{r_3}+\frac{1}{r_4}\right) \qquad \frac{1}{F} = \frac{1}{f_1} + \frac{1}{f_2}$$

Lardners notation

$$\frac{1}{50} = .5784\,\frac{2}{R_1} - .5877\,\frac{2}{r_1}$$

$$= \frac{1.0368}{R} - \frac{1.1754}{r}$$

$$= \frac{1.0368}{R} - \frac{1.1754}{1.523\,R}$$

$$= \frac{1.0368}{R} - \frac{.7717}{R}$$

$$\frac{1}{50} = \frac{.2651}{R}$$

$$R = 50 \times .2651$$

$$= 13.255 \text{ inches}$$

These values of R + r are nearly correct see p. 14 for correct formulae

They under correct for Color - see p. 10. $\frac{1}{50} = 0.142$

$$r = 13.255 \times 1.523$$

$$= 20.19 \text{ inches}$$

The condition of achromatism is

$$\frac{\Delta n_1}{n_1 - 1} \cdot \frac{1}{f_1} + \frac{\Delta n_2}{n_2 - 1} \cdot \frac{1}{f_2} = 0$$ Parkinson p. 164 170

$$\frac{.00921}{.5184} \cdot \frac{1}{f_1} + \frac{.01403}{.58772} \cdot \frac{1}{f_2} = 0$$

$$\frac{.00921}{.5784}(n_1-1)\left(\frac{1}{r_1}+\frac{1}{r_2}\right) + \frac{.01403}{.58772}(n_2-1)\left(\frac{1}{R_1}+\frac{1}{R_2}\right) = 0$$

$$.00921\left(\frac{1}{r_1}+\frac{1}{r_2}\right) + .01403\left(\frac{1}{R_1}+\frac{1}{R_2}\right) = 0$$

$$\frac{R_1+R_2}{R_1R_2} + \frac{r_1+r_2}{r_1r_2} = 0$$

this reduces to same as above)

focal lengths are proportional to dispersive power of each glass

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Central Ray. C. line

$r_1 = r_2 = 13.255$ in
$r_3 = r_4 = 20.19$ "

$t_1 = .3$
$t_2 = .25$
$D = .25$

$n = 1.51483$
$n' = 1.58238$

Rays to dense $f_1 = -\frac{nr}{n-1}$

$n = 1.51483$ = log 0.18036
$r = 13.255$ = " 1.12238 ✓
1.30274
$n-1 = .51483$ = " 9.71166
$f_1 = 39.002$ = " 1.59108
$d = \frac{.3}{38.701}$ = " 1.58772
" 1.12238
$r_2 =$ 2.71010

Dense to rare.

$f_2 = -\frac{dr_2}{nr_2 + d(n-1)}$

$n =$ log 0.18036
$r =$ " 1.12238
1.30274 = 20.079

$d =$ 1.58772
$n-1 =$ 9.71166
1.29938 = $\frac{19.924}{40.003}$ = log 1.60209
1.10801
$f_2 = 12.823$ =
$D = \frac{.25}{12.573}$ = 1.09944
$d_3 =$
$n' = 1.58238$ = 0.19931
$r_3 = 20.19$ = 1.30514 ✓
2.60389

Rare to dense

$f_3 = \frac{n'dr}{d(n-1) - r}$

$d =$ log 1.09944
$n'-1 =$ " 9.76521
0.86465 = $\frac{7.3223}{12.8677}$ = log 1.10950
1.49439
$f_3 = 31.217$ = "
$d_4 = \frac{.25}{30.967}$ = " 1.49090
$r_4 =$ 1.30514
2.79604

Dense to rare

$f_4 = \frac{dr_4}{d(n-1) - nr_4}$

$d =$ log 1.49090
$n'-1 =$ 9.76521
1.25611 = 18.035

$n' =$ 0.19931
$r_4 =$ 1.30514
1.50445 = $\frac{31.948}{13.913}$ = log 1.14342
1.65262
$f_4 = 44.939$ = "

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Central Ray F. line

$n = 1.52404$

$n' = 1.59641$

$n = 1.52404 = \log 0.18300$

$r = 13.255 = \quad 1.12238$

1.30538

$n-1 = .52404 = \quad 9.71936$

1.58602

$f = 38.550$ (.3)

$d = 38.250 = \quad 1.58263$

$r_2 = \quad 1.12238$

2.70501

$n = \log 0.18300$

$r_2 = \quad 1.12238$

$1.30538 = 20.201$

$d = \quad 1.58263$

$n-1 = \quad 9.71936$

$1.30199 = 20.045$

$40.246 = \log 1.60472$

1.10029

$f_2 = 12.598$ (.25)

$d = 12.348 = \quad 1.09160$

$n' = 1.59641 = \quad 0.20314$

$r_3 = 20.19 = \quad 1.30514$

2.59988

$d = 1.09160$

$n'-1 = 9.77554$

$0.86714 = \quad 7.3644$

$12.8256 = \quad 1.10808$

1.49180

$f_3 = 31.031 = \quad$

$d = 30.781$ (.25) $= \quad 1.48828$

$r_4 = \quad 1.30514$

2.79342

$d = 1.48828$

$n'-1 = 9.77554$

$1.26382 = 18.358$

$n' = 0.20314$

$r_4 = 1.30514$

$1.50828 = \quad 32.231$

$13.873 = \quad 1.14217$

$f_4 = 44.797 = \quad 1.65125$

Red Cline $f = 44.939$

Blue F " $f = 44.797$

.142 under corrected.

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Central Ray. C. line.

Change $r_3 = r_4$ by 1/2 in. to 19.69

$f_2 =$

$d = 12.573$

Rear distance $f = \frac{n' dr}{d(n-1) - r}$

$d = 12.573 = \log 1.09944$

$n' = 1.58238 = \log 0.19931$

$r_3 = 19.69 = \log \frac{1.29424}{2.59299}$

$d = 1.09944$

$n - 1 = \frac{9.76521}{0.86465}$

$= \frac{7.3223}{12.3677} = \log \frac{1.09229}{1.50070}$

$f_3 = 31.674$

$d = 31.424 = \log 1.49726$

$r_4 = = \frac{1.29424}{2.79150}$

Dense Crown

$f_4 = \frac{dr}{d(n-1) - nr}$

$d = 1.49726$

$n - 1 = \frac{9.76521}{1.26247} = 18.301$

$n = 0.19931$

$r = \frac{1.29424}{1.49350} = \frac{31.156}{12.855} = \log \frac{1.10907}{1.68243}$

$f_4 = 48.132$

F line.

$d = 12.348 = \log 1.09160$

$n' = 1.599641 = \log 0.20314$

$r_3 = 19.69 = \log \frac{1.29424}{2.58898}$

$d = 1.09160$

$n - 1 = \frac{9.77554}{1.86714} = \frac{7.3644}{12.3256} = \log \frac{1.09080}{1.49818}$

$f_3 = 31.491$

$d = 31.241 = \log 1.49472$

$r_4 = = \frac{1.29424}{2.78896}$

$d = 31.241 = 1.49472$

$n - 1 = 9.77554 = \frac{9.77554}{1.27026} = 18.632$

$n = 0.20314$

$r = \frac{1.29424}{1.49738} = \frac{31.432}{12.800} = \log \frac{1.10721}{1.68175}$

$f_4 = 48.056$

Red C. line $f = 48.132$

Blue F. " $f = \frac{48.056}{.076}$ under corrected.

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Central Rays.

Change. $r_3 = r_4$ again by $\frac{1}{2}$ in. to 19.19. ~~$d_3 = 12.673$~~

" Thickness of Crown Glass Lenses, to .35 in

$r_1 = r_2 = 13.255$. $r_3 = r_4 = 19.19$.

$\lambda = 5614$. $n = 1.51840$

$n' = 1.58772$

$f_1 = -\frac{nr}{n-1}$

$n =$ = log 0.18139

$r = 13.255$ = 1.12238 / 1.30377

$n-1 = .51840$ = 9.71466

$f_1 = 38.825$ = 1.58911

$d_2 = \frac{.35}{38.475}$ = log 1.58518 / 1.12238 / 2.70756

$r_2 =$ =

$f_2 = -\frac{dr}{nr + d(n-1)}$

$nr = 1.30377$ = 20.127

$d = 1.58518$

$n-1 = 9.71466$ / 1.29984 = 19.945 / 40.072 = log 1.60284 / 1.10472

$f_2 = 12.727$ = "

$d_3 = \frac{25}{12.477}$ = 1.09611

$n' = 1.58772$ = 0.20077

$r_3 = 19.19$ = 1.28307 / 2.57995

$f_3 = \frac{n' dr}{d(n-1) - r}$

$d = 1.09611$

$n-1 = 9.76917$

0.86528 = 7.3380 / 11.857 = log 1.07397 / 1.50598

$f_3 = 32.061$ =

$d_4 = \frac{.25}{31.811}$ = 1.50258

$r = 19.19$ 1.28307 / 2.78565

$f_4 = \frac{dr}{d(n-1) - nr}$

$d = 1.50258$

$n-1 = 9.76917$ / 1.27175 = 18.696

$n = 0.20077$

$r = 1.28307$ / 1.48384 = 30.468 / 11.772 = log 1.07085 / 1.71480

$f_4 = 51.856$ = "

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13

Central Rays -

Thickness of Crown Glass Lens. changed to .35 in. = t_1

$r_1 = r_2 = 13.253$

$r_3 = r_4 = 19.19$

---

b. line $n = 1.51483$

$n' = 1.58238$

Rare to dense $f_1 = -\frac{nr}{n-1}$ $\quad n =$ $\quad = \log 0.18036$

$r =$ $\quad =$

$n-1 =$

$f_1 = 39.001$

$d_2 = \frac{39.001}{38.651} = \log 1.58716$

Dense to rare $f_2 = -\frac{dr}{nr + d(n-1)}$ $\quad r_2 =$ $\quad = \frac{1.22238}{2.70954}$

$= 20.079$

nr

$d = l.\ 1.58716$

$n-1 = \frac{9.71166}{1.29882} = \frac{19.899}{39.978} = \log \frac{1.60182}{1.10772}$

$f_2 = 12.815 =$ "

$d_3 = \frac{.25}{12.565} =$ " 1.09916

$n' =$ $\quad =$ 0.19931

Rare to dense $f_3 = \frac{n'dr}{d(n-1) - r}$ $\quad r_3 = 19.19$ $\quad = \frac{1.28307}{2.58154}$

$d = l.\ 1.09916$

$n-1 = \frac{9.76521}{0.86437} = \frac{7.3176}{11.8724} = \frac{1.07454}{1.50700}$

$f_3 = 32.137 =$

$d_4 = \frac{.25}{31.887} = 1.50361$

$r_4 = 19.19 = \frac{1.28307}{2.78668}$

Dense to rare $f_4 = \frac{dr}{d(n-1) - nr}$

$d = l.\ 1.50361$

$n-1 = \frac{9.76521}{1.26882} = 18.570$

$n = 0.19931$

$r = \frac{1.28307}{1.48238} = \frac{30.365}{11.795} = \frac{1.07170}{1.71498}$

$f_4 = 51.878 =$

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Central Rays.

Data same as on opposite page

---

7 line. $n = 1.52404$

$n' = 1.59641$

$r_1 =$ $= \log 0.18300$

$\gamma =$

$f_1 = 38.550$

$d_2 = \frac{.35}{38.200} = \log 1.58206$

$\gamma_2 =$ $\frac{1.12238}{2.70444}$

$n\gamma_2 = 20.201$

$d = l.\ 1.58206$

$n-1 = \frac{9.71936}{1.30142} = \frac{20.018}{40.219} = \log \frac{1.60443}{1.10001}$

$f_2 = 12.589 =$ "

$d_3 = \frac{.25}{12.339} =$ " 1.09128

$n' =$ " 0.20314

$r_3 = 19.19$ " $\frac{1.28307}{2.57749}$

$d = l.\ 1.09128$

$n'-1 = \frac{9.77554}{0.86682} = \frac{7.3591}{11.8309} = \frac{1.07302}{1.50447}$

$f_3 = 31.950$

$d_4 = \frac{.25}{31.700} = \log 1.50106$

$r_4 =$ $= \frac{1.28307}{2.78413}$

$d = l.\ 1.50106$

$n'-1 = \frac{9.77554}{1.27660} = 18.906$

$n' = 0.20314$

$r = \frac{1.28307}{1.48621} = \frac{30.634}{11.728} = \frac{1.06922}{1.71491}$

$f_4 = 51.869$

Red. C line $f = 51.878$

Blue 7 " $f = 51.869$ } 51.873

.009 under corrected.

$\frac{51.856}{.017}$

$\lambda = 5614$ $f = 51.856$

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15.

Marginal Rays.

$\lambda = 5614.$

$r_1 = r_2 = 13.255$ in. $\quad t_1 = .35$ in. $\quad n = 1.51840$

$y = 1.75$ "

$d_1 = \text{Inf.}$ $\quad n' = 1.58772$

Crown Glass

1. $\sin \alpha = \frac{y}{r}$ $\quad y = 1.75 = \log 0.24304$

$r = 13.255 = \log \frac{1.12238}{9.12066}$ $\quad \frac{66}{63}$ $\frac{300}{}$

2. $i = \alpha$ $\quad \alpha = i = 7° 35' 12" = \log \sin$

3. $\sin \lambda = \frac{\sin i}{n}$ $\quad n = 1.51840 = \frac{0.18139}{8.93927}$

$\lambda = 4° 59' 17"$ $= \log \sin$

4. $\gamma = \alpha - \lambda$ $\quad \gamma = 2° 35' 55"$

5. $f = r \frac{\sin \lambda}{\sin \gamma} + r$ $\quad \gamma = \log \frac{1.12238}{0.06165}$

$\gamma = \log \sin \frac{8.65647}{1.40518}$

25.420

$r = 13.255$

$f_1 = 38.675$

6. $D = f_1 - t_1$ $\quad .35$

$D_2 = 38.325$

7. $\sin I = \frac{(D + R_2) \sin \gamma}{R}$ $\quad R = 13.255$

$51.580 = \log 1.71248$

$= \log \sin \frac{8.65647}{0.36895}$

$R = 13.255 = \log \frac{1.12238}{9.24657}$ $\quad \frac{57}{54}$ $\frac{300}{}$

$I = 10° 9' 42".5 = \log \sin$

$= \log \frac{0.18139}{9.42796}$

8. $\sin \Lambda = n \sin I$ $\quad n =$

$\Lambda = 15° 32' 20" = \sin \frac{1.12238}{0.53034} = R$

$15° 22' 37".5$

9. $\delta = \gamma + (\Lambda - I)$ $\quad \gamma = 2\ 35\ 55.$

$\delta = 15° 58' 32".5 = \sin 9.14224$

10. $\gamma = R \frac{\sin \Lambda}{\sin \delta} - R$ $\quad$ ~~$R = 13.255$~~ $\quad$ ~~0.12238~~

~~9.26462~~

$= 1.40810$

2048 $\quad 310$ $\quad 7$ $\quad 42$

25.592

$R = 13.255$

~~$\gamma = 38.847$~~

$\gamma_2 = 12.337$

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Marginal Rays. continued

— Flint Glass —

$r_3 = r_4 = 19.19$

1. $d = 7 - S$

$r_2 = 12.337$
$.25$
$d = 12.087$

2. $\sin i = \frac{(d + r)\sin\beta}{r}$

$r = \frac{19.19}{31.277} =$ log. 1.49522

$\beta = \delta_1$ = angle of incident ray with axis. $= 7^\circ 58' 32''.5$ = log sin. 9.14224
0.63746

$r = 19.19$ = 1.28307
= sin 9.35439

$i = 13^\circ 4' 13''.3$

3. $\sin\lambda = \frac{\sin i}{n}$

n = 0.20077
$\lambda = 8^\circ 11' 20''$ = sin 9.15362
1.28307
0.43669

4. $\gamma = \beta - (i - \lambda)$

$\gamma = 3^\circ 5' 39''.2$ = sin 8.73222
1.70447

5. $f = r\frac{\sin\lambda}{\sin\gamma} - r$

$r = 50.637$
$\frac{19.19}{31.447}$
$f_3 =$

6. $d = f - t$

$\frac{25}{31.197}$
d_4

7. $\sin i = \frac{(d - r)\sin\gamma}{r}$

r $\frac{19.19}{12.007}$ = log. 1.07943
= sin. 8.73222
γ 9.81165
= 1.28307
$i = 1^\circ 56' 7''.7$ = sin 8.52858
= 0.20077

8. $\sin\lambda = n\sin i$

n
$\lambda = 3^\circ 4' 26''$ = sin 8.72935
$1^\circ 8' 18''.3$ 1.28307 = γ
0.01242

9. $\delta = \gamma - (\lambda - i)$

$\gamma = 3\ 5' 39''.2$
$\delta = 1^\circ 57' 21''$ = sin 8.53312
1.47930
=

10. $f = \gamma + r\frac{\sin\lambda}{\sin\delta}$

$r = 30.151$
19.19
$f_4 = 49.341$

central ray $\lambda = 5^\circ 614$ $f = 51.856$

Marginal " " " $f = \frac{49.341}{2.515}$ under corrected.

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Flint Glass Lenses

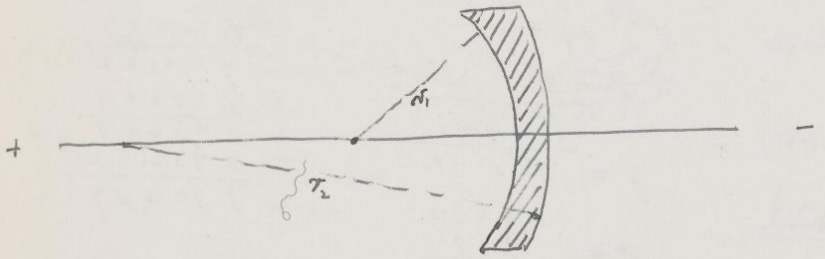
$$f = \frac{r_1 r_2}{(n-1)(r_1 + r_2)} = \frac{19.19 \times 19.19}{.58772 \times 38.38} =$$

$19.19 =$ log 1.28307_2 / 2.56614

$.58772 =$ 9.76917

$38.38 =$ 1.58410 / 1.35327

$f = 16.326' =$ 1.21287



$$r_1 = \frac{r_2}{\frac{r_2}{f(n-1)} + 1}$$ from $\frac{1}{f} = (n-1)\left(\frac{1}{r_1} - \frac{1}{r_2}\right)$

make $r_2 = 100$ inches -

$$r_1 = \frac{100}{100}$$

$f =$ l. $1.21287'$

$n-1 =$ 9.76917 / 0.98204

$r_2 =$ 2.00000 / $1.01796 =$ 10.422 / $1.$ / $11.422 =$ log $2.00000 = r_2$ / 1.05774 / 0.94226

$r_1 = 8.7551$ in.

---

make $r_2 = 250$ inches -

$r_2 =$ 2.39794 / 0.98204 / $1.41590 =$ 26.055 / 1 / $27.055 =$ log 2.39794 / 1.43225 / 0.96569

$r_1 = 9.2404$ in

when $r_2 = \infty$. $r_1 = (n-1) f$

$= 9.5949$ in

$r_2 = 400 =$ 2.60206 / 9.76917 / 0.98204 / $1.62002 =$ 41.689 / $42.689 =$ log 2.60206 / 1.63032 / 0.97174

$r_1 = 9.3709$

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Flint Glass Lens - 2nd trial. $\lambda = 5614.$

$r_3 = 9.3700$ $\quad d_3 = 12.477 =$

$r_4 = 4.00.$

$f_3 = \dfrac{n' d r_3}{d(n'-1) - r_3}$

$d_3 =$ $\quad = \log 1.09611$

$n' =$ $\quad = \; " \; 0.20077$

$r_3 = 9.3700$ $\quad = \; " \; 0.97174$

$d(n-1) = \dfrac{7.3330}{2.03777} = \dfrac{0.30914}{1.95948}$

$f_3 = 91.092$ $\quad = \dfrac{2.68622}{}$

$\overset{.25}{90.842}$

$f_4 = \dfrac{dr}{nr + d(n-1)}$

$d_4 = 90.842 = 1.958229$

$r_4 = 400 = \dfrac{2.60206}{4.56038}$

$n = l.\ 0.20077$

$r = \; " \; \dfrac{2.60206}{2.80283} = 63.508$

$d = l\ 1.958229$

$n-1 = \; " \; \dfrac{9.76917}{1.72746} = \dfrac{53.390}{119.898} = \dfrac{2.06781}{2.49264}$

$f_4 = \cancel{31.034} = 310.84$

$r_4 = \text{Inf}$

$d_4 = l.\ 1.958229$

$n = 0.20077$

$f_4 \quad 57.216 = 1.75752$

---

make $r_3 = 11.$ $\quad$ other data same as before -

$r_4 = 400,$ $\quad d_3 = 12.477$

$d_3 = 12.477 = \log 1.09611$

$n' = \quad = \; " \; 0.20077$

$r_3 = 11.000 = \; " \; \dfrac{1.04139}{2.33827}$

$d(n-1) = \dfrac{7.333}{3.667} = \; " \; \dfrac{0.56431}{1.77396}$

$f_3 = 59.424 = \; "$

$\overset{.25}{59.174} = \; " \; 1.77213$

$r_4 = 400 = \; " \; \dfrac{2.60206}{4.37419}$

$nr + d(n-1) = 98.286 = \; " \; \dfrac{1.99249}{2.38170}$

$f_4 = 240.82 = \; "$

$d_4 = l.\ 1.77213$

$n-1 = \dfrac{9.76917}{1.54130} = \dfrac{63.508}{34.778}$

98.286

$r_4 = \text{Inf} \quad 1.77213$

0.20077

$f_4 = 37.270 = 1.57136$

---

make $r_3 = 8.00$

$r_4 = 400$

$d_3 = 12.477 = \log 1.09611$

$n' = \quad = \quad 0.20077$

$r_3 = 8. \quad = \dfrac{9.90309}{2.19997}$

$d(n-1) = \dfrac{7.333}{0.667} = \log \dfrac{9.82413}{2.37584}$

$f_3 = 237.60 = \quad \dfrac{2.37539}{2.60206}$

$\overset{.25}{237.35} = \quad \dfrac{4.97745}{}$

$r_4 = 400. \quad = \log 2.30750$

$nr + d(n-1) = 203.00 = \; " \; 2.56995$

$f_4 = 371.49 = \; "$

$d_4 = 2.37539$

$n-1 = \dfrac{9.76917}{2.14456} = \dfrac{63.50}{139.50}$

203.00

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make $r_3 = 8.55$
$r_4 = 400.$

$d_3 = 12.477 = \log 1.09611$
$n' = \quad = \quad 0.20077$
$r_3 = 8.55 = \quad 0.93197$
$\quad 2.22885$
$\frac{7.333}{1.217} = \quad 0.08529$
$\quad 2.14356$
$139.174 =$
$\frac{.25}{138.924} = \log 2.14277$
$r_4 = 400 = \quad 2.60206$
$\quad 4.74483$

$f_4 = \frac{d_3 r_3}{n r_4 + d_4(n-1)}$

$d_4 = l.\ 2.14277$
$r_4 = \frac{2.60206}{4.74483} =$

$d_4 = l.\ 2.14277 \qquad n r_4 = 63.508$
$(n-1) = \frac{9.76917}{1.91194} = \frac{81.647}{145.155} = \frac{2.16183}{2.58300}$
$f_4 \ 382.83 =$

---

make $r_3 = 20.$
$r_4 = 400.$

$d_3 = 12.477 = \log 1.09611$
$n' = \quad 0.20077$
$r_3 = 20.000 \quad 1.30103$
$\quad 2.59791$
$d_3(n-1) = \frac{7.333}{12.667} = \quad 1.10267$
$\quad 1.49524$
$f_3 = 31.278 =$
$d_4 = \frac{.25}{31.028} = \quad 1.49175$
$r_4 = 400 = \quad 2.60206$
$\quad 4.09381$

$n r_4 = 63.508$

$d_4 = 1.49175$
$n-1 = \frac{9.76917}{1.26092} = \frac{18.236}{81.744}$

$= \log 1.91246$
$f_4 = 151.83 = \quad 2.18135$

$r_3 = 36.$
$r_4 = 400$

$d_3 = 12.477 = \log 1.09611$
$\quad 0.20077$
$n \quad = \quad 1.55630$
$r_3 = \frac{36}{7.333} = \quad 2.85318$
$28.667 = \quad 1.45738$
$\quad 1.39580$
$f_3 = 24.877 =$
$d_4 = \frac{.25}{24.627} = \quad 1.39141$
$r_4 = 400 = \quad 2.60206$
$\quad 3.99347$
$n r_4 = 63.508$

$d_4 = 1.39141$
$n-1 = \frac{9.76917}{1.16058} = \frac{14.474}{77.982} = \frac{1.89199}{2.10148}$
$f_4 = 12.632 =$

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make $r_3 = 31.65$
$r_4 = 400$

$f_3 = \frac{n' dr}{d(n-1) - r}$

$f_4 = \frac{dr}{nr + d(n-1)}$

$d_3 = 12.477 =$ log 1.09611
0.20077
$r_3 = 31.65$ 1.50037
$d(n-1) = 7.333$ 2.79725
$24.317 =$ 1.38591
1.41134
$f_3 = 25.783$
$d_4 = 25.833 =$ 1.40710
$r_4 = 400 =$ 2.60206
4.00916
$nr_4 = 63.508$

$d_4 = 1.40710$
$n-1 = 9.76917$
1.17627

$= \frac{15.006}{78.514} =$ 1.89495
2.11421
$f_4 = 13.508 =$

---

make $r_3 = 115$
$r_4 = 400$

$d = 12.477 =$ log 1.09611
0.20077
$r = 115 =$ 2.06070
7.333
$107.667 =$ 2.03209
f_3 21.159 = 1.32549
d_4 20.909 = 1.32033
400 = 2.60206
3.92239

$d = 1.32033$
$n-1 = \frac{9.76917}{1.08950} =$

nr_4 63.508
12.288
$75.796 =$ 1.87965
2.04274
f_4 110.34 =

Formulae used evidently wrong / Checked & found correct

$r_3 = 400$
$r_4 = 400$

$d = 12.477 =$ log 1.09611
0.20077
$r_3 = 400 =$ 2.60206
3.89894
$d(n-1) = \frac{7.33}{392.67} =$ 2.59403
1.30491
$f_3 = 20.180 =$
$d_4 = 19.930 =$ 1.29951 1.
$r_4 = 400 =$ 2.60206
3.90157

$d = 1.29951$
$n-1 = \frac{9.76917}{1.06868} =$

63.508
11.713
$75.221 =$ 1.87634
2.02523
$f_4 = 105.98 =$

---

r_4 Impl.

$f_4 = \frac{d_4}{n}$

$d_4 = 19.93 =$ 1.29951
$n =$ 0.20077
$f_4 = 12.553 =$ 1.09874

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Flint Glass lens continued

make $r_3 = 9.96$
$r_4 = \text{Inf.}$

$r_3 = 11.00 \quad f_4 = 37.270$
$r_3 = 9.96 \quad f_4 = 47.149$
$r_3 = 9.37 \quad f_4 = 57.216$

$d = 12.477 = \log 1.09611$
$n' = \quad = 0.20077$
$r_3 = 9.96 \quad = 0.99826$
$\quad 7.333 \quad 2.29514$
$\quad 2.627 = 0.41946$
$f_3 = 75.107 = 1.87568$
$\quad 25$
$d_4 = 74.857 = 1.87423$
$n' \quad = 0.20077$
$f_4 = 47.149 = 1.67346$

Changing the fourth surface, alters the focal length of the lens very rapidly - when 4th surface is flat - or nearly so.

λ 5610 A.

$\frac{5}{31}$

$f = (n-1)\left(\frac{1}{r_3} + \frac{1}{r_4}\right) \quad \therefore \quad r_4 = \frac{r_3}{\frac{r_3}{f(n-1)} - 1}$

$r_3 = 19.19$
$r_3 = 9.96$
$2) \overline{29.15}$
14.58



Assume $r_3 = 14.60$

$f = 16.50$

$r_3 = \log 1.16435$
$f = \quad 1.21748$
$n-1 = \quad 9.76917$
$\quad 0.98665$
$1.5056 = 0.17770$
$1. \quad = \log 9.70381$
$0.5056 = 1.46054$
$r_4 = 28.876$

Assume. $r_3 = 13.255$

$r_3 = \log 1.12238$
$f = \quad 1.21748$
$n-1 = \quad 9.76917$
$\quad 0.98665$
$1.3669 \quad 0.13573$
$1. \quad = \log 9.58455$
$0.3669 = 1.55783$
$r_4 = 36.127$

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Flint Glass Lens

Marginal Rays. $\lambda = 5614$

$r_3 = 9.96$
$r_4 = \text{inf.}$

$d_3 = 12.087$
$t_3 = \dfrac{9.96}{22.047} = \log.$ 1.34335

2. $\sin i = \dfrac{(d+r)\sin\beta}{r}$

$\beta = 7^\circ 58' 82.5'' = \log\sin.$ 9.14224
$r_3 = 9.96 =$ 0.48355-9
$i = 17^\circ 53' 12'' = \sin$ 0.99826
9.48733

3. $\sin\lambda = \dfrac{\sin i}{n}$

$\lambda = \dfrac{11^\circ 9' 14''}{6^\circ 43' 58''} = \sin$ 0.20077
$n =$ 9.28656
$r =$ 0.99826
0.28482

4 $\gamma = \beta - (i - \lambda)$

$\gamma = 1^\circ 14' 34.5'' = \sin$ 8.33628
1.94835-4

5 $f = r\dfrac{\sin\lambda}{\sin\gamma} - r$

$r = \dfrac{88.826}{9.960} =$
$f_3 = \dfrac{78.866}{.250} =$
$d_4 = 78.616$

6. $d_4 = f_3 - t_2$

7. $\sin i = \dfrac{(d-r)\sin\gamma}{r}$

$r = \text{inf.}$
$\sin i = \sin\gamma \quad i = \gamma.$

$i = 1^\circ 14' 34.5'' = \sin.$ 8.33628
$n =$ 0.20077
$\lambda = \dfrac{1^\circ 58' 25''}{0^\circ 43' 51''.5} = \sin$ 8.53705-5

8. $\sin\lambda = n\sin i$

$(\delta = 0^\circ 20' 43'')$

9 $\boxed{\delta = \gamma - (\lambda - i)}$

10. $f = \dfrac{d.\ 1\tan i}{1\tan\lambda}$

$d_4 = 78.616 = \log$ 1.89555-1
$i = 1^\circ 14' 34.5 = \log 1\tan$ 8.33639
0.23194

$\lambda = 1^\circ 58' 25'' = \log 1\tan$ 8.53731
1.69459

$f_4 = 49.498$

Central ray " $= \dfrac{47.149}{2.349}$ over corrected

see 6 p. previous.

under

Recapitulation — $r_3 = r_4 = 19.19$ in. under corrected 2.575 in.
$r_3 = 9.96$ $r_4 = \text{Inf}$ over " 2.349 in.

over

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23

Flint Glass Lens.

make $r_3 = 13.255 = \log 1.12238$
$r_4 = 36.127 = \quad " \quad 1.55783$

Central Ray $\lambda = 5614.$

$f_3 = \dfrac{n' d r_3}{d_3(n-1) - r_3}$

$d_3 = 12.477 = \log 1.09611$
$n' = \quad = \quad " \quad 0.20077$
$r_3 = 13.255 = \quad " \quad 1.12238$
$\qquad\qquad\qquad\qquad 2.41926$

$d = l.\ 1.09611$
$n-1 = \dfrac{9.76917}{0.86528} = \dfrac{7.383}{5.922} = " \dfrac{0.77247}{1.64679}$

$f_3 = 44.339$
$d_4 = \dfrac{.25}{44.089} = " \ 1.64433$
$r_4 = \quad = " \ \dfrac{1.55783}{3.20216}$

$f_4 = \dfrac{d r_4}{d_4(n-1) - n r_4}$

$d_4 = 1.64433$
$n-1 = \dfrac{9.76917}{1.41350} = 25.912$

$n' = 0.20077$
$r_4 = \dfrac{1.55783}{1.75860}$

$\dfrac{57.359}{31.447} = \log \dfrac{1.49758}{1.70458}$

$f_4 = 50.650 = \quad "$

Central Rays l. & 7.

C.

$d_3 = 12.585 = l.\ 1.09916$
$n = \quad = \quad 0.19931$
$r = 13.255 = \quad 1.12238$
$\qquad\qquad\qquad\qquad 2.42085$

$d = l.\ 1.09916$
$n-1 = \dfrac{9.76521}{0.86437} = \dfrac{7.3176}{5.9378} = \dfrac{0.77360}{1.64725}$

$f_3 = 44.386 = \quad "$
$d_4 = \dfrac{.25}{44.136} = 1.64479$
$r_4 = \quad = \dfrac{1.55783}{3.20262}$

$d_4 = 1.64479$
$n-1 = \dfrac{9.76521}{1.41000} = 25.704$

$n = 0.19931$
$r = \dfrac{1.55783}{1.76714} = \dfrac{57.166}{31.462} = \dfrac{1.49779}{1.70483}$

$f_4 = 50.679 = \quad "$

F.

$d_3 = 12.339 = l.\ 1.09128$
$n = \quad = \quad 0.20314$
$r_3 = 13.255 = \quad 1.12238$
$\qquad\qquad\qquad\qquad 2.41680$

$d_3(n-1) = \dfrac{7.3591}{5.8959} = \dfrac{0.77055}{1.64625}$

$f_3 = 44.284$
$d_4 = \dfrac{.25}{44.034} = 1.64379$
$r_4 = \quad = \dfrac{1.55783}{3.20162}$

$d_4 = 1.64379$
$n-1 = \dfrac{9.77554}{1.41933} = 26.262$

$n = 0.20314$
$r = \dfrac{1.55783}{1.76097} = \dfrac{57.673}{31.411} = \dfrac{1.49708}{1.70454}$

$f_4 = 50.645 = \quad "$

Red 6 lens $f = 50.679$
Blue 7 " $f = \dfrac{50.645}{.034}$ under corrected

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Flint Glass Lens.

Data same as on opposite page.

Marginal Rays. $\lambda = 5614$

$d_2 = 12.087$

$r_3 = \frac{13.255}{25.342}$ = log 1.103 84

2. $\sin i = \frac{(d+r)\sin\beta}{r}$ $\beta = 7^\circ 58' 32''.5$ = sin $\frac{9.14224}{0.54608}$

r_3 = $\frac{1.12238}{9.42370}$

$i = 15^\circ 23' 0''$ = sin

3. $\sin\lambda = \frac{\sin i}{n}$ n = log $\frac{0.20077}{9.22293}$

$\lambda = 9^\circ 37' 6''$ r = $\frac{1.12238}{0.34531}$

4. $\gamma = \beta - (\lambda - \lambda_0)$ $-5^\circ 48' 54''$ = sin $\frac{8.58629}{1.75902}$

$\gamma = 2^\circ 12' 38''.5$ =

5. $f = r\frac{\sin\lambda}{\sin\gamma} - r$ $r_3 = \frac{57.414}{13.255}$

$f_3 = \frac{44.159}{25}$

$d_4 = 43.909$

$r_4 = \frac{36.127}{7.782}$ = log 0.89109

= sin $\frac{8.58629}{9.47738}$

r_4 = $\frac{1.55783}{7.91955}$

$i = 0^\circ 28' 33''.9$ = sin

n = $\frac{0.20077}{8.12032}$

6. $\sin\lambda = n\sin i$ $\lambda = 0^\circ 45' 21''.2$ = sin

$16' 47''.3$ r = $\frac{1.55783}{9.67815}$

7 $\delta = \gamma - (\lambda - i)$ $\gamma = 2^\circ 12' 38''.5$

$\delta = 1^\circ 55' 51''.2$ = sin $\frac{8.52758}{1.15057}$

10 $f = d + r\frac{\sin\lambda}{\sin\delta}$ 14.144

36.127

$f_4 = 50.271$

$\frac{20''}{22} = 10''$

16

Central Ray $f = 50.650$

Marginal " $f = 50.271$

.379 under corrected.



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25

Flint Glass Lens

make $r_3 = 12.755$ = log 1.10568
$r_4 = 36.127$ = " 1.55783

C.

$f_3 = \frac{n' d_3 r_3}{d_3(n-1) - r_3}$

$d_3 = 12.566$ = 1.09916 ✓
n = 0.19931 ✓
$r_3 = 12.755$ = $\frac{1.10568}{2.40415}$ ✓

$d_3 = 1.09916$
$n-1 =$ } = $\frac{7.3176}{5.43745}$ ✓ = $\frac{0.73539}{1.66876}$ ✓

$f_3 = 46.640$ ✓
$d_4 = \frac{25}{46.3901}$ = 1.66642 ✓
r_4 = $\frac{1.55783}{3.22425}$ ✓

$f_4 = \frac{d_4 r_4}{d_4(n-1) - n r_4}$

$d_4 = 1.66642$ ✓
$n\#1 = \frac{9.76521}{1.43163}$ ✓ = 27.016

$n = 0.19931$
$r_4 = \frac{1.55783}{1.75714} = \frac{57.166}{30.160} = \frac{1.47929}{1.74494}$

$f_4 = 55.583$ = log

7

$d_3 = 12.339$ = log 1.09128
n = 0.20314
$r_3 = 12.755$ = " 1.10568
2.40010

$d_3(n-1)$ = $\frac{7.3591}{5.39589}$ = " 0.73206
1.66804

$f_3 = 46.563$ = "
$d_4 = \frac{.25}{46.313}$ = " 1.66570
r_4 = " 1.55783
3.22353

$d_4 = 1.66570$
$n-1 = \frac{9.77554}{1.44124} = 27.621$

$n = 0.20314$
$r_4 = \frac{1.55783}{1.76097} = \frac{57.673}{30.052} = \frac{1.47787}{1.74566}$

$f_4 = 55.675$ = log

Red, blue $f = 55.583$
Blue 7 " $f = \frac{55.675}{.092}$ over corrected.

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Flint Glass Lens

$r_3 = 13.705$ $r_4 = 36.127$

C

$d_3 =$ 1.09916
0.19931
13.705 $r_3 =$ 1.13847
7.3176 2.43694
6.4374 = 0.80871
$f_3 = 42.484$ = 1.62823
$d_4 = \frac{25}{42.234}$ = 1.62566
r_4 = 1.55783
= 3.18349

$d_4 = 1.62566$
$n-1 = 9.76521$
1.43163 = 27.106
1.39087 = 24.596
$n = 0.19931$
$r_4 = \frac{1.55783}{1.75714} = \frac{57.166}{32.570}$
= 1.51282
$f_4 = 46.846$ = 1.67067

7

$d_3 =$ 1.09128
0.20314
$r_3 = 13.705$ = 1.13847
7.3591 2.43289
6.3959 = 0.80590
$f_3 = 42.363$ = 1.62699
$d_4 = \frac{25}{42.113}$ = 1.62442
r_4 = 1.55783
3.18225

$d_4 = 1.62442$
$n-1 = \frac{9.77584}{1.39996} = 25.117$

$n = 0.20314$
$r_4 = \frac{1.55783}{1.76097} = \frac{57.673}{32.556} = 1.51263$
1.66962

f_4 46.733

blue $f =$ $\frac{46.846}{.113}$ under corrected

$r_3 = 13.085$ $r_4 = 36.127$ as above. (from curve graphic)

C

$d_3 =$ 1.09916
$n =$ 0.19931
13.085 $r_3 =$ 1.11677
7.3176 2.41524
5.7674 = 0.76098
f_3 45.109 = 1.65426
$d_4 = \frac{25}{44.859}$ = 1.65185
r_4 = 1.55783
3.20968

$d_4 = 1.65185$
$n-1 = 9.76521$
1.41706 = 26.125

$n r$ = 57.166
31.041 = 1.49195
$f_4 = 52.208$ = 1.71774

7

$d_3 =$ 1.09128
$n =$ 0.20314
13.085 = $r_3 =$ 1.11677
7.3591 2.41119
5.7259 = 0.75784
$f_3 = 45.014$ = 1.65335
$d_4 = \frac{25}{44.764}$ = 1.65093
r_4 = 1.55783
3.20876

$d_4 = 1.65093$
$n-1 = \frac{9.77554}{1.42647} = 26.697$

nr = 57.673
30.976 = 1.49102
$f_4 = 52.208$ = 1.71774

Red - b. line $f_4 = 52.208$
Blue 7. " $f_4 = \frac{52.208}{0}$ exact.

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27

Central Rays Flint

$\lambda = 5614$

$r_3 = 13.085 = \log 1.11677$

$r_4 = 36.127 = \text{"} 1.55783$

$(n = \log. 0.18939)$

$n' = \text{"} 0.20077$

$f_3 = \dfrac{n' dr_3}{d_3(n-1) - r_3}$

$n' = \log. 0.20077$

$d_3 = \text{"} 1.09611$

$13.085 = r_3 = \text{"} \dfrac{1.11677}{2.41365}$

$d_3(n-1) = \dfrac{7.333}{5.782} = \text{"} \dfrac{0.75982}{1.65383}$

$45.064 = f_3 = -$

$d_4 = \dfrac{.25}{44814} =$

$\log 1.65141$

$f_4 = \dfrac{dr_4}{d_4(n-1) - nr_4}$

$r_4 = \dfrac{1.55783}{3.20924}$

$d_4 = \log 1.65141$

$n-1 = \dfrac{9.76917}{1.42058} = 26.338$

$n' = 0.20077$

$r_4 = \dfrac{1.55783}{1.75860} = \dfrac{57.359}{31.021} = \dfrac{1.49166}{1.71758}$

$f_4 = 52.189$

C. & F. Red & Blue - $f_4 = 52.208$

$\lambda = 5614$ " $= 52.189$

$.019$

see foot of p. 14.

P. 26. 17.

$f = \dfrac{r_1 r_2}{(n-1)(r_1 + r_2)}$

13.085

36.127

$49.21.2$

$r_1 = \log. 1.11677$

$r_2 = \text{"} 1.55783$

2.67460

$= 1.69207$

$(n-1) = 9.76917$

$1.66124 = \dfrac{1.46124}{1.21336}$

$f = 16.344 =$

Crown Glass Lens p. 15.

$r_1 = r_2 = 13.255$

1.12238

2.24476

1.18807

1.06669

$26.510 = 1.42341$

$n-1 = 9.71466$

1.13807

$f_c = \log 1.06669$

$f_F = \dfrac{1.21336}{9.89333} f_c = 12.785$

$\dfrac{f_c}{f_F} = .78222 =$

$\dfrac{1}{F} = \cancel{(n-1)}$

$f_2 = \dfrac{f_2 F}{f_2 - F} = \dfrac{.65645 f_2 \times 50.}{.65645 f_2 - 50}$

$f_2 = \dfrac{50 f_2}{f_2 - 50}$

best color correction is when $\dfrac{f_{Hr}}{f_{Pl}} = .65645$?

p. 1

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Marginal Rays.

$\lambda = 5614$

Data same as on opposite page.

$d_2 = 12.087$

$r_3 = 13.085^-$

25.172^- = log. 1.400 97

$\beta = 7^\circ 58' 32''.5$ = sin. 9.14224

0.54316

r = 1.11677

$i = 15^\circ 28' 53''$ = sin 9.426.39

n = 0.20077

= sin 9.225.67

$\lambda = 9^\circ 40' 47''$ r = 1.11677

$5^\circ 48' 11''$ 0.34239

$\gamma = 2^\circ 10' 21''.5$ = sin 8.578 75

1.763.64

$\delta = 8.028$ =

r = 13.085

f_3 = 44.943

d_4 = 44.693^- =

r_4 = 36.127 / 8.566 = 0.93278

sin γ = 8.57875^-

9.51153

r = 1.55783

$i = 0^\circ 30' 54''.1$ = sin 7.953.70

0.20077

$\lambda = 0\ 49\ 3.8$ = sin 8.15447 (12/14)

$18'\ 9''.7$ r = 1.55783

$\gamma = 2^\circ 10' 21''.5$ sin 9.71230 (3.9/27)

$1^\circ 52' 11''.8$ 8.51363

1.198.67

15.800 = log

36.127

$f_4 = 51.987$

1. $\sin i = \frac{(d-r)\sin\gamma}{r}$

2. $\sin i = \frac{(d+r)\sin\beta}{r}$

3. $\sin\lambda = \frac{\sin i}{n}$

4. $\gamma = \beta - (\lambda - i)$

5. $f = r\frac{\sin\lambda}{\sin\gamma} - r$

7. $\sin i = \frac{(d-r)\sin\gamma}{r}$

8. $\sin\lambda = n\sin i$

9. $\delta = \gamma - (\lambda - i)$

10. $f = r + r\frac{\sin\lambda}{\sin\delta}$

Central Rays $f = 52.189$

Marginal " $f = 51.987$

.202 under corrected.

$r_3 = 13.205^-$ Spher. Abb. = 0.379 under corrected

$= 13.085^-$ " = 0.202 "

.170 .177

28.3 29.5

.198.3 206.5

13.085 170 177

196 26 25

12.889 196 202

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29

Proportion of focal length of crown and flint glass lens to obtain best color correction, focal length proportional to dispersion powers.

$\frac{f_1}{f_2} = a$

$f_1 = a f_2$

$f_2 = \frac{f_1 7}{f_1 + 7}$

$f_1 = \frac{a f_2 7}{a f_2 + 7}$

$1 = \frac{a 7}{a f_2 + 7}$

$a f_2^2 + f_2 7 = a f_2 + 7$

$a f_2^2 + a f_2 7 =$

$a f_2 + 7 = a 7$

$a f_2 = a 7$

$f_2 = \frac{7}{a} + 7.$

$\frac{1}{7} = \frac{1}{f_1} + \frac{1}{f_2}$

$\frac{1}{7} = \frac{1}{f_1} + \frac{1}{f_2}$

$f_1 f_2 = 7 (f_2 + f_1)$

$(f_1 + 7) f_2 = -7 f_1$

$f_2 = -\frac{7 f_1}{f_1 + 7}$

$f_1 = \frac{7_2 f_2}{f_2 + 7}$

$7 = 50 = \log. 1.69897$

$a = .65645 = 9.81720$

$76.168 \quad 1.88177$

$\frac{50}{26.168}$

$f_2 =$

$\frac{1}{7} = (n-1)\frac{1}{f_1} + (n'-1)\frac{1}{f_2}$

$\frac{1}{50} = \frac{1}{26} + \frac{1}{\cancel{54}}$

$.20 \quad .42 - 18$

$\frac{1}{50} = \frac{1}{26} + \frac{1}{17}$

$42 - 6$

26

$24 \overline{)} \begin{array}{r} 26. \\ 50 \\ \hline 300 \\ 120 \\ \hline 1 \end{array} (54.$

$26 \overline{)} \begin{array}{r} 1.00 \\ 96 \\ \hline 40 \end{array} (42$

$54 \overline{)} \begin{array}{r} 1.00 \\ 54 \\ \hline 460 \end{array} (18$

$f_2 = 26.168 = \log 1.41777 \quad .\cancel{018129} = \cancel{8.118223}$

$a = \quad = \frac{98172}{1.23497} \quad .038215 = 8.582235$

$f_1 = 17.178 = \quad .058215 = 8.765035$

$.02$

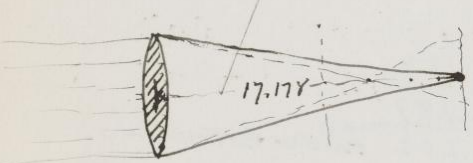
$\frac{1}{f} = (n-1)\left(\frac{1}{r_1} + \frac{1}{r_2}\right) \quad \therefore r_1 = r_2 \quad \frac{1}{f} = (n-1)\frac{2}{r} \quad r = 2f(n-1)$

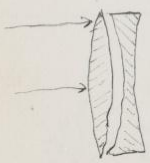
$r = \begin{cases} 17.178 = \log 1.23497 \\ 2 = 0.30103 \\ n-1 = \frac{9.76917}{1.30517} \end{cases}$ $\lambda = 5614$ Crown $n-1 = \log 9.71466$ Flint

$r_1 = r_2 = 20.192$

Crown Lens. $r_1 = r_2 = 20.192 \quad f_1 = 17.178$

see page 8 compare why any diff.





$f_2 = 26.168$

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Flint Glass Lens -

$r_4 = 36.127$

When $r_3 = 12.89$ Spk. Att = 0 Letrov. Att = +.067 from graphic curve

" $r_3 = 13.085$ " = -.202 " = 0

$r_3 = 12.95$ $f = 16.344$ as on p. 27.

$$r_4 = \frac{r_3}{\frac{r_3}{f(n-1)} - 1}$$

$r_3 = \log 1,11227$ $n-1 = \frac{9.76917}{0.98253}$ $f = \log 1.21336$

$\frac{1.3.482}{1} = 0.12974$

~~$\frac{1}{12.482} = \frac{1.11227}{0.99628}$~~

~~1.01599~~

$\frac{1.3482}{1} = \frac{1.11227}{9.54183}$

$\frac{1}{.3482} = 1.57044$

$r_4 = 37.191$

$$\frac{1}{f} = (n-1)\left(\frac{1}{r_1} + \frac{1}{r_2}\right)$$

Eno. Brit. Optics p. 581

Dispersion

Crown $= \frac{.00921}{1.51840} = \log 7.78287$

Flint $= \frac{.01403}{1.58772} = " \ 7.94629$

$= " \ 0.16342$

Relative $\frac{\text{Flint}}{\text{Crown}} = 1.4589$

$\frac{f_2}{f_3} = 1.4589 \quad \therefore f_2 = 1.4589 f_1$

$f_3 = + \frac{7 f_2}{f_2 + 7} = \frac{50 \times 1.4589 f_1}{1.4589 f_1 + 50} = f_1$

$1.4589 f_1 + 50 = 72.8450$

$1.4589 f_1 = 22.8450$

$f_1 = 15.681$

$r_1 = r_2 = 2 f_1 (n-1) = 25.767$

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31

Central Rays. $\lambda = 5614$

Flint

$r_3 = 12.95 = \log 1.11227$ $\quad n' = \log 0.20077$

$r_4 = 37.191 = \quad 1.570444$ $\quad n'-1 = \quad 9.76917$

$f_3 = \dfrac{n' d r_3}{d_3(n-1) - r_3}$

$n' = \log 0.20077$

$d_3 = \quad 1.09611$

$r_3 = \quad 1.11227$

2.40915

$d_3(n-1) \quad 12.95 = 7.333 \quad 5.617 = 0.74950$

$45.672 = f_3 = 1.65596$

$d_4 = \dfrac{.285}{45.422}$ $\quad = \log 1.65727$

r_4 $\quad = \quad 1.570444$

3.22771

$f_4 = \dfrac{d_4 r_4}{d_4(n-1) - n r_4}$

$d_4 = \log 1.65727$

$n-1 = \dfrac{9.76917}{1.42644} = 26.696$

$n = 0.20077$

$r_4 = \dfrac{1.570744}{1.77121} = \dfrac{59.049}{32.353} = \dfrac{1.50991}{1.71780}$

$f_4 = 52.216$

$r_3 = 13.085$

$r_3' = 12.950$

$.135$ diff.

20

2.270

$r_3' = 10.715$

$r_4 = \dfrac{r_3}{\dfrac{r_3}{f(n-1)} - 1}$

Aphn. Abb = 0.202

0.192

$.010$ diff.

20

$.200$ "

$r_4 = 36.127$

$r_4 = 37.191$

1.064 diff

20

21.28

r_4 57.40

$f = 1.21336$

$n-1 = \dfrac{9.76917}{0.98253}$

10.715 $\quad r_3 = \dfrac{1.02999}{0.04746}$

$\dfrac{1.115}{1} = \dfrac{9.06258}{1.96741}$

$r_4 = 92.771$

$\phi = 11$ $\quad 0.98253$

1.14541 $\quad 1.04139$

$\dfrac{1}{0.14541} = \dfrac{9.16167}{1.87972}$

75.80

$r = 12.66 = 1.10243$

$f(n-1) = 0.98253$

$1.3180 = 0.88990$

$\dfrac{1}{.3180} = 9.50243$

39.811 $\quad 1.60000$

$\phi = 11.3$ $\quad \phi = 1.05308$

$= 0.98253$

$f(n-1)$ $\quad 0.07055$

$\dfrac{1.1764}{.1764} = 9.24650$

$r_4 = 64.06 = 1.80658$

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Marginal Rays

Flint

$\lambda = 5614$

Data same as on opposite page.

2. $\sin i = \frac{(d+r)\sin\beta}{r}$

3 $\sin\lambda = \frac{\sin i}{n}$

4 $\gamma = \beta(i-\lambda)$

5 $f = r\frac{\sin\lambda}{\sin\gamma} - r$

$d_2 = 12.087$
$r_3 = 12.950$
$25.037 = \log 1.39858$

$\beta = 7^\circ\ 5'\ 8''.5$ $= \sin 9.14224$
0.54082
$= 1.11227$
$= \sin 9.428.55$ 49
$n = 0.20077$ 600
$= \sin 9.22778$ 64
$r = 1.112249$
$= \sin 0.340055$
8.57266
1.76739

$i = 15^\circ\ 33'\ 38''$ r_3

$\lambda = 9^\circ\ 43'\ 38$
$5^\circ\ 50'\ 0''$
$\gamma = 2^\circ\ 8'\ 32''.5$

$5.58.532$
$r = 12.950$
$f_3 = 45.582$
$.25$
$d_4 = 45.332$
$r_4 = 37.191$
8.141 $= 0.91068$

$\sin\gamma = 8.57266$
9.48334
$r = 1.57044$
$\sin = 9.91290$ 64
$n = 0.20077$ 2200 24
$\sin = 8.11367$ 53 144 16
$r = 1.57044$
9.68411
$= \sin 8.57289$
1.17122

7. $\sin i = \frac{(d-r)\sin\gamma}{r}$

8. $\sin\lambda = n\sin i$

9. $\delta = \gamma - (\lambda - i)$

10 $f = r + r\frac{\sin\lambda}{\sin\delta}$

$\delta = 0^\circ\ 28'\ 17''.9$

$\lambda = 0^\circ\ 44'\ 39''.9$
$16'\ 32''.0$
$\delta = 1^\circ\ 5'\ 2''.5$

14.833
37.191
$f_4 = 52.024$

Central Rays $f = 52.216$
Marginal " $f = 52.024$
$.192$ under corrected

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1889phae.proj..920H

33

Flint Glass Lens

make $\nu_3 = 12.66. = \log 1.10243$ $\quad n' = \log 0.20077$

$\nu_4 = 39.811 = \text{“} 1.60000$ $\quad (n'-1) = 9.76917$

$\lambda = 5614$

$$f_3 = \frac{n' d_3}{d_3(n-1) - \nu_3}$$

$n' = \log 0.20077$

$d_3 = 1.09611$

$\nu_3 = 12.66 \quad 1.10243$

2.39931

$= \frac{7.333}{5.327} = 0.72648$

1.67283

$d_3(n-1) = l.$

$f_3 = 47.079 = \log 1.67283$

$\frac{.25}{46.829}$

$d_4 = \log 1.67081$

$\nu_4 = 1.60000$

3.27051

$$f_4 = \frac{d_3 \nu_4}{d_3(n-1) - n\nu_4}$$

$d_4 = \log 1.67081$

$n-1 = \frac{9.76917}{1.43968} = 27.522$

$n = 0.20077$

$\nu = 1.60000$

$1.80077 = \frac{63.208}{35.068} = \log \frac{1.55260}{1.71801}$

$f_4 = 52.241$

C.

$d_3 = 12.555 = l. \; 1.09916$

$n = 0.19931$

$\nu = 12.66 = 1.10243$

$d(n-1) = \frac{7.3176}{5.3424} = \frac{2.40090}{0.72774}$

1.67316

$f = 47.115 = 1.67316$

$\frac{.25}{46.863}$

$d = 1.67083$

$\nu = \frac{1.60000}{3.27083}$

$d_4 = l. \; 1.67083$

$n-1 = \frac{9.76521}{1.43604} = 27.292$

$n = 0.19931$

$\nu = \frac{1.60000}{1.79931} = 62.996$

$35.704 \quad 1.55272$

$52.253 = 1.71811$

7.

$d_3 = 12.339 \quad l. \; 1.09128$

$n = 0.20314$

$\nu_3 = 12.66 \quad 1.10243$

$d(n-1) = \frac{7.3591}{5.3009} = \frac{2.39685}{0.72435}$

1.67250

$f = 47.044 = 1.67250$

$\frac{.25}{46.794}$

$d_4 = 1.67019$

$\nu = \frac{1.60000}{3.27019}$

$d_4 = l. \; 1.67019$

$n-1 = \frac{9.77574}{1.44573} = 27.908$

$n = 0.20314$

$\nu = \frac{1.60000}{1.80314} = \frac{63.554}{35.646} = \frac{1.55201}{1.71818}$

$f_4 = 52.261$

$52.261 \quad 52.253$

$.241 \quad .241$

$.020 \quad .012$

Blue – Flint $f_4 = 52.261$

Red C – $f_4 = 52.253$

$.008$ over corrected

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1009phae.proj..920H

Marginal Rays

$\lambda = 5761\text{A}$

Data same as on opposite page

2. $\sin i = \dfrac{(d+r)\sin\beta}{r}$

3 $\sin\lambda = \dfrac{\sin i}{n}$

4 $\gamma = \beta - (i - \lambda)$

5 $f = r\dfrac{\sin\lambda}{\sin\gamma} - r$

$\alpha_3 = 12.087$

$r_3 = \dfrac{12.660}{24.747}$ = log 1.393-52

$\beta = 7^\circ\ 5'\ 8''.5$ = log $\dfrac{9.14224}{0.55576}$

r_3 = $\dfrac{1.10243}{\sin 9.43333}$

$i = 15^\circ\ 44'\ 14''$ = $\dfrac{0.20077}{}$

n = $\sin 9.23256$

$\lambda = \dfrac{9^\circ\ 50'\ 10''}{5^\circ\ 5'\ 4''}$ r = $\dfrac{1.10243}{0.33499}$

$\gamma = 2^\circ\ 4'\ 28''.5$ = $\sin \dfrac{8.55871}{1.77628}$

59.742

$r = 12.660$

$f_3 = 47.082$

.25

$d_4 = 46.832$

$r_4 = \dfrac{39.811}{7.021}$ = log 0.84640

7 $\sin i = \dfrac{(d-r)\sin\gamma}{r}$

$\gamma = 2^\circ\ 4'\ 28''.5$ = $\sin \dfrac{8.55871}{9.40511}$

r = log $\dfrac{1.60000}{7.80511}$

$i = 0^\circ\ 21'\ 56''.8$ = $\sin$

8 $\sin\lambda = n\sin i$

n = $\dfrac{0.20077}{\sin 8.00588}$

$\lambda = \dfrac{0^\circ\ 34'\ 50''.8}{12'\ 54''.0}$ # r = $\dfrac{1.60000}{9.60588}$

9 $\delta = \gamma - (\lambda - i)$

$\delta = 1^\circ\ 51'\ 34''.5$ = $\sin \dfrac{8.51121}{1.09467}$

12.436

39.811

10 $f = r + r\dfrac{\sin\lambda}{\sin\delta}$

$f_4 = 52.247$

Marginal Rays $f_4 = 52.247$

central " $f_4 = \dfrac{52.241}{.006}$ over corrected.

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35

Flint Glass Lens.

Correct for color by changing radius of last surface

$\nu_4 = 40.25 = \log 1.60476$ other data as on p 33.

C

$d_4 = 46.863 - \log 1.67083$

$\nu = \quad = \dfrac{1.60476}{3.27559}$

$d_4 = 1.67083$

$n-1 = \dfrac{9.76521}{1.43604} = 27.292$

$n = 0.13931$

$\nu = \dfrac{1.60476}{1.80407} = \dfrac{63.690}{36.398} = \dfrac{1.56108}{1.71451}$

$f_4 = 51.822 =$

7

$d_4 = \quad \log 1.67019$

$\nu = \quad \dfrac{1.60476}{3.27495}$

$d_4 = 1.67019$

$n-1 = \dfrac{9.77534}{1.44573} = 27.908$

$n = 0.20314$

$\nu = \dfrac{1.60476}{1.80790} = \dfrac{64.257}{36.346} = \dfrac{1.56046}{1.71449}$

$f_4 = 51.819 =$

Red. Clim $f = 51.822$

Blue Z. $f = \dfrac{51.819}{.003}$ under corrected.

$\therefore$ Change of +.439 in ν_4 changed color abb. .44

$\therefore$ $\nu_4 = 40.131$ would correct for color.

$\dfrac{39.811}{.32}$

$\dfrac{}{40.131}$

$\lambda = 5614$. Central Rays

$\nu_4 = 40.11 = \log 1.60825$

$d_4 \quad " \quad = \dfrac{1.67051}{3.27376}$

$d_4 = 1.67051$

$n-1 = \dfrac{9.76917}{1.43968} = 27.522$

$n = 0.20877$

$\nu = \dfrac{1.60825}{1.80402} = \dfrac{63.683}{36.161} = \dfrac{1.55824}{1.71552}$

$f_4 = 51.942$

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Marginal Rays

$r_4 = 40.11$. other data same as on p. 34.

$d_4 = 46.832$
$r_4 = 40.110$
$6.722 = \log 0.82780$

7. $\sin i = \frac{(d-r)\sin\gamma}{r}$ $\quad \gamma = 2^\circ\ 4'\ 28.''8 = \sin 8.53871$
9.38621
1.60325
$r =$
$i = 0^\circ\ 20'\ 51.''4 \quad \sin 7.78296$
0.20071

8. $\sin\lambda = n\sin i$ $\quad \lambda = \frac{0^\circ\ 33'\ 6.''9}{0^\circ\ 12'\ 15.''8} = \sin 7.98375$ $\quad r = 1.60325$
9.58700

9 $\delta = \gamma - (\lambda - i)$ $\quad \delta = 1^\circ\ 52'\ 13.''0 = \sin 8.51371$
1.07329

10 $f = r + r\frac{\sin\lambda}{\sin\delta}$ $\quad r = \frac{11.838}{40.11}$
$f_4 = 51.948$

Marginal Rays. $f_4 = 51.948$
Central " $f_4 = \frac{51.942}{.006}$ over corrected

a change of .0,300 inch in r_4 does not affect the Spherical Abb.

Changing r_3 to 12.668 corrects spherical Abb, and also changes color abb. .001 about. making .007 the abb to be corrected by changing r_4

∴ make $r_3 = 12.668$
$r_4 = 40.09$
} see next page

40.09
39.811
.279 =013
changed .0215 .001
.1075 .005

40.09
.107
39.983

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37

Flint Glass Lens.

make $\nu_3 = 12.668 = \log 1.10271$

$\nu_4 = 40.09 = \log 1.60304$

$\lambda = 5614$

$n' = \log 0.20077$

$(n-1) = 9.76917$

$\lambda = 5614$ / n'

$$f_3 = \frac{n' d_{33}}{d_3 (n-1) - \nu_3}$$

$$f_4 = \frac{d_4 \nu_4}{d_4 (n-1) - n \nu_4}$$

C.

$d_3 = \log 1.09916$

$n = " \ 0.19931$

$\nu_3 = " \ \frac{1.10271}{2.40118}$

$12.668 = " \ 0.72839$

$\frac{7.3176}{5.3504} = " \ \frac{1.67279}{}$

$\frac{f}{13} = 47.075 = " \ \frac{0.725}{46.825} = \log 1.67048$

$\nu_4 = " \ \frac{1.60304}{3.27352}$

$d_4 = l. \ 1.67048$

$n-1 = \frac{9.76521}{1.43569} = 27.270$

$n = 0.19931$

$\nu_4 = \frac{1.60304}{1.80235} = \frac{63.438}{36.168} = \frac{1.55832}{1.71520}$

$f_4 = 57.904 =$

F.

$d_3 = 1.09128$

$n = 0.20314$

$12.668 = \nu_3 = \frac{1.10271}{2.39713}$

$\frac{7.3591}{5.3089} = \frac{0.725500}{1.67213}$

$47.004 = f_3 = 1.66982$

$\frac{.25}{46.754} \quad d_4 = \nu_4 = \frac{1.60304}{3.27286}$

$d_4 = l. \ 1.66982$

$n-1 = \frac{9.77354}{1.44536} = 27.884$

$n = 0.20314$

$\nu_4 = \frac{1.60304}{1.80618} = \frac{64.000}{36.116} = \frac{1.55770}{1.71516}$

$f_4 = 57.899$

Red. C. line $f_4 = 57.904$

Blue F. " $f_4 = \frac{57.899}{.005}$ under corrected

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C.

$d_4 = 46.825 = \log 1.67048$
$\gamma_4 = 39.915 = \text{“} \ 1.60113$
3.27161

$n = 0.19931$
$\gamma_4 = \frac{1.60113}{1.80044} = 63.160$
27.270
$35.890 = 1.55497$
$f_4 = 52.076 = 1.71664$

7.

$d_4 = 46.754 = \log 1.66982$
$\gamma_4 = 39.915 = \text{“} \ 1.60113$
3.27095

$n = 0.20314$
$\gamma_4 = \frac{1.60113}{1.80427} = 63.719$
27.884
$35.838 = 1.55431$
$f_4 = 52.076 = 1.71664$

C

$d_4 = 46.825 = \log. 1.67048$
$\gamma_4 = 39.983 = \text{“} \ 1.60187$
3.27235

$d_4 = \text{l. } 1.67048$
$n-1 = \text{“} \ 9.76521$
$1.43569 = 27.270$

$n = 0.19931$
$\gamma_4 = \frac{1.60187}{1.80118} = 63.267$
$35.997 = 1.55627$
$f_4 = 52.009$ $\quad 1.71608$

7.

$d_4 = 46.754 = \log 1.66982$
$\gamma_4 = 39.983 = \text{“} \ 1.60187$
3.27169

27.884

$n = 0.20314$
$\gamma_4 = \frac{1.60187}{1.80501} = 63.828$
$35.944 = 1.55363$
$f_4 = 52.004 = 1.71606$

$C - f_4 = 52.009$
$7 - f_4 = 52.004$
$.002$ under corrected

40.09
39.983
$.107 = .003$
$.036 = .001$
$.072 = .002$

39.983
$.072$
39.911

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Flint Glass Lens

$\lambda = 5614$

$\nu_3 = 12.668 = \log 1.10271$ $\quad n' = \log 0.20077$

$\nu_4 = 39.915 = \text{"} 1.60113$ $\quad n'-1 = \text{"} 9.76917$

Central Rays.

$$f_3 = \frac{n' d_3 \nu_3}{d_3(n'-1) - \nu_3}$$

$n' = \log 0.20077$

$d_3 = \text{"} 1.09611$

$12.668 = \nu_3 = \text{"} \frac{1.10271}{2.39959}$

$\frac{7.333}{5.335} = \text{"} \frac{0.72713}{1.67246}$

$f_3 = 47.039 =$

$\frac{.250}{46.789}$

$d_4 = \text{"} 1.67014$

$$f_4 = \frac{d_4 \nu_4}{d_4(n'-1) - n' \nu_4}$$

$\nu_4 = \text{"} \frac{1.60113}{3.27127}$

$d_4 = 1.67014$

$n-1 = \frac{9.76917}{1.43931} = 27.499$

$n = 0.20077$

$\nu_4 = \frac{1.60113}{1.80190} = \frac{63.373}{35.874} = \frac{1.55478}{1.71649}$

$f_4 = 52.058$

Red + Blue. C. + F. lines $f_4 = 52.076$

$\lambda = 5614$ $\quad \text{"} = \frac{52.058}{.018}$ see p. 27 compare.

Changing Radius of third surface

ν_3	Chrom. Abb.	Sph. Abb.
+ 1.	.205	1.04

Changing Radius of fourth surface

ν_4		
+ 1.	.025	0.000

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Marginal Rays.

Data same as on opposite page.

2. $\sin \delta = \frac{(d+r)\sin\beta}{r}$

3. $\sin\lambda = \frac{\sin i}{n}$

4. $\gamma = \beta - (i - \lambda)$

5. $f_3 = r\frac{\sin\lambda}{\sin\gamma} - r$

7. $\sin i = \frac{(d-r)\sin\gamma}{r}$

8. $\sin\lambda = n\sin i$

9. $\delta = \gamma - (\lambda - i)$

10 $f = r + r\frac{\sin\lambda}{\sin\delta}$

$d_3 = 12.087$

$r_3 = 12.668$

$24.755 = \log 1.39366$

$\beta = 7^\circ\ 58'\ 32''.8 = \sin 9.14224$ / 0.535590

$r_3 = 1.10271$ / $= \sin 9.433.19$

$i = 15^\circ\ 43'\ 55''.4$

$n = 0.20077$ / $= \sin 9.232.42$

$\lambda = 9^\circ\ 49\ 58''.4$ / $5^\circ\ 53'\ 57''$

$r = 1.60271$ / 033613

$\gamma = 2^\circ\ 4'\ 35''.8 = \sin 8.55912$ / 1776.01

59.705
$r = 12.668$
$f_3 = 47.037$
$.25$
$d_4 = 46.787$

$r_4 = \frac{39.915}{6.872} = \log 0.83708$

$\gamma = 2^\circ\ 4'\ 35''.8 = \sin \frac{8.55912}{9.39620}$

$\gamma_4 = \log 1.60113$ / $= \sin 7.99507$

$n = 0.20077$ / $= \sin 7.99584$

$\lambda = 0^\circ\ 34'\ 3''.0$ / $0^\circ\ 12'\ 36''.8$

$r = 1.60113$ / 9.59697

$\delta = 1^\circ 51'\ 59''.0$ / 139

$= \sin 8.57280$ / $= 1.08417$

12.139
$r = 39.915$
$f_4 = 52.054$
52.054

Central Ray $f_4 = 52.058$

Marginal " $f_4 = 52.054$

$.004$ under corrected

---

r_3 $+.008$ Sphr. Abb. $-.010$

$r_3 = 12.660$ Sphr. Abb. $= +.006$

" $= 12.668$ " " $= -.004$

$+.008$ $-.010$

$.0008$ $-.001$

$.0032$ $-.004$

To correct Spherical Abb. try $r_3 = 12.665$

Changing r_3 .003 changes Colr correction, .0006

" " " Sphr. " .003

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Result of calculation

Feb. 5th 1883

Crown Glass Lens - $r_1 = 13.255$ in. $r_2 = 13.255$

Flint Glass Lens $r_3 = 12.665$ $r_4 = 39.915$

Focal Distance - from back surface of Object glass -

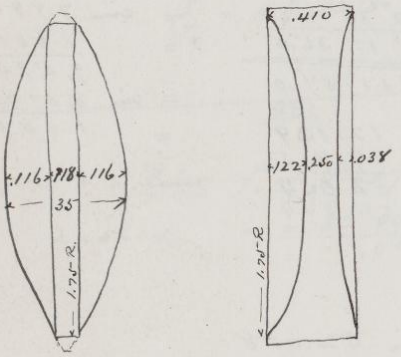
f_4 = for $\lambda = 5614$, C + F. lines plus 52.06 in. .018.

Thickness of Crown Glass Lens = 0.35 in.

" " Flint " " = .25

Distance apart of inner surfaces = .25

.85



Marginal λ. $\gamma_1 = 12.331$ Crown, } diff = 0.39 inch

Central λ " = 12.727 "

" C = 12.815 C - λ = .088

" F = 12.589 λ - F = .138 } Central

C - F = 0.226

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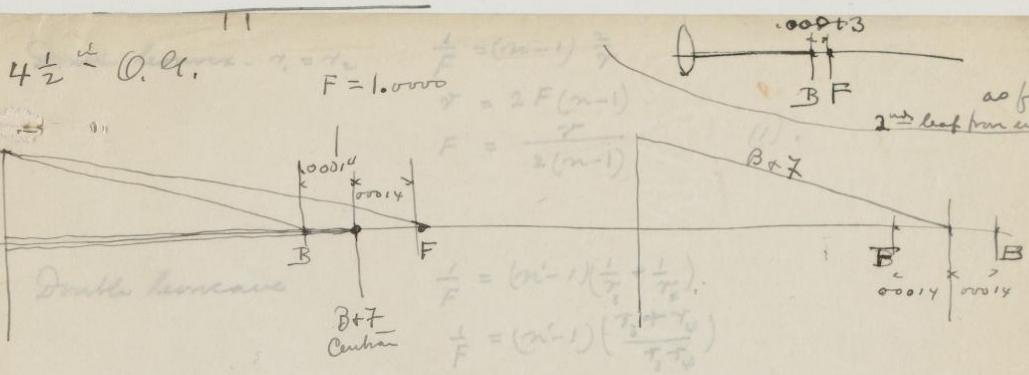
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$$\frac{1}{F} = (n-1)\left(\frac{1}{r_1} - \frac{1}{r_2}\right)$$

11

$4\frac{1}{2}$ in O. G.

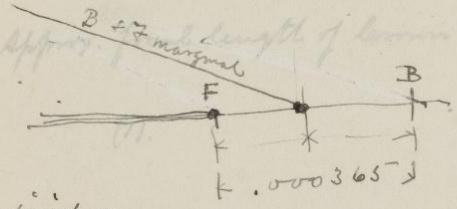
F = 1.0000



$F_B - F_A = .00065$ see diagram (cells Cemented no 7. O.) 12th Pk.

F = 1

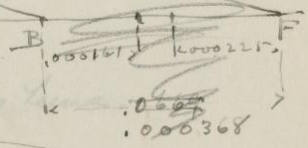
7th



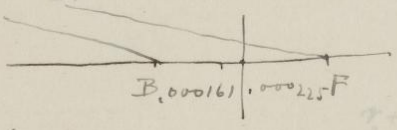
$F_{B+F} - F_{B+7} = .0009$

F = 1

12th As finished cemented in front

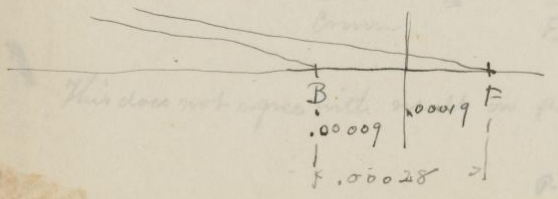


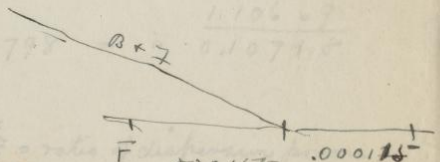
Flint in front





12th lenses in front





$F_B - F_A = .000625$ Marginal writer
.00061 central "

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$$\frac{1}{F} = (n-1)\left(\frac{1}{r_1} - \frac{1}{r_2}\right)$$

Double Convex - $r_1 = r_2$

$$\frac{1}{F} = (n-1)\frac{2}{r}$$

$$r = 2F(n-1)$$

$$F = \frac{r}{2(n-1)} \qquad (1).$$

Double Concave

$$\frac{1}{F} = (n'-1)\left(\frac{1}{r_3} + \frac{1}{r_4}\right)$$

$$\frac{1}{F} = (n'-1)\left(\frac{r_3 + r_4}{r_3 r_4}\right)$$

$$r_3 r_4 = F(r_3 + r_4)(n'-1)$$

$$F = \frac{r_3 r_4}{(n'-1)(r_3 + r_4)} \qquad (2.)$$

Approx. focal length of Crown Glass Lens -

(1).

$r = 13.255^{-} = \log 1.122384$

$2 = \quad " \ 0.301030$

$n-1 = .57840 = " \ 9.761466$

0.015569

$F_1 = 12.786^{-} = " \ 1.106469$

Approx. focal length of Flint Glass Lens.

2.

$r_3 = 12.665^{-} = \log 1.102600$

$r_4 = 39.915^{-} = " \ 1.601013$

2.703613

$r_3 + r_4 = 52.580 = " \ 1.720882$

$n'-1 = \quad = " \ 9.769917$

1.489995

$F_2 = 16.362 = " \ 1.213884$

1.106469

Flint / Crown $= \frac{F_2}{F_1} = 1.2798 = " \ 0.107155$

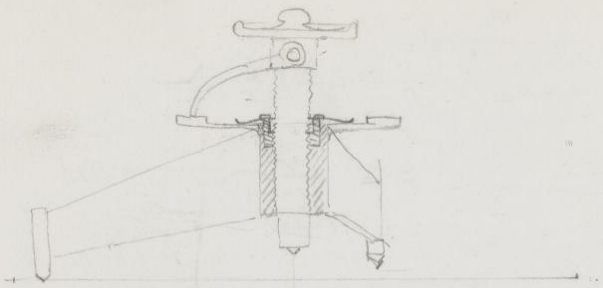
This does not agree with result on p. 80 $\frac{F_2}{F_1}$ = ratio of dispersive powers.

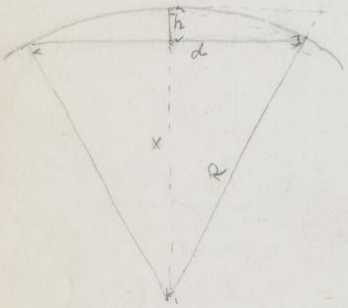
p. 8

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1889phae.proj..920H

– Spherometer – Jan. 19th 1884.







$\frac{D}{d} = \text{cvs } 30°$ $\quad l\text{-}9.93753$

$d = \frac{D}{\text{cvs } 30°} = \frac{D}{.86602}$

$x = \sqrt{R^2 - \frac{d^2}{4}}$

$h = R - \sqrt{R^2 - \frac{d^2}{4}}$

$h - R = -\sqrt{R^2 - \frac{d^2}{4}}$

$h^2 - 2hR + R^2 = R^2 - \frac{d^2}{4}$

$-2hR = -h^2 - \frac{d^2}{4}$

$R = \frac{h}{2} + \frac{d^2}{8h}$ ✓

$8hR = 4h^2 + d^2$

$4h^2 + 8hR = -d^2$

$h^2 + 2hR = -\frac{d^2}{4}$

$h^2 + 2hR + R^2 = R^2 - \frac{d^2}{4}$

$h - R = \pm\sqrt{R^2 - \frac{d^2}{4}}$

$h = R \pm \sqrt{R^2 - \frac{d^2}{4}}$

Error in $R = -\left(\frac{d^2}{8h^2} - \frac{1}{2}\right)$ times error in h.

$d = 3.$
$h = 0.1$

$R = \frac{0.1}{2} + \frac{9}{8 \times 0.1}$
$= 0.05 + \frac{9}{0.8}$
$= 0.05 + 11.25$
$= -11.3$

½d = 1.5	log	0.17609
R = 11.3	"	1.05308
sin 7° 37' 40"	"	9.12301
cvs	"	9.99614
R	=	1.05308
r = 11.200	=	1.04922
h = .100		

$R = \frac{h}{2} + \frac{d^2}{8h}$ to find $\frac{\delta R}{\delta h}$

$R = \frac{h}{2} + \left(\frac{d^2}{8}\right) h^{-1}$

$\delta R = \frac{\delta h}{2} + \left(\frac{d^2}{8}\right)\left(-1 h^{-2} \delta h\right)$
$= \frac{\delta h}{2} - \frac{d^2}{8} \times \frac{\delta h}{h^2}$
$= \left(\frac{1}{2} - \frac{d^2}{8h^2}\right) \delta h$

$\frac{\delta R}{\delta h} = \frac{1}{2} - \frac{d^2}{8h^2} = -\left(\frac{d^2}{8h^2} - \frac{1}{2}\right)$

$= \frac{1}{2} - \frac{9}{.08} = .5 - 112.5 = 112.$

$h = R - \sqrt{R^2 - \frac{d^2}{4}}$

$\delta h = \delta R - \left(R^2 - \frac{d^2}{4}\right)^{\frac{1}{2}}$

$\delta h = \delta R - \frac{1}{2}\left(R^2 - \frac{d^2}{4}\right)^{-\frac{1}{2}} (2R\,\delta R)$

$\frac{\delta h}{\delta R} = 1 - \frac{R}{\sqrt{R^2 - \frac{d^2}{4}}}$

$= 1 - \frac{11.3}{11.2} = -\frac{1}{112}$

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Best lens correction. substitute for page 2.

n' = for Flint glass. n for Crown glass.

$$n' = \alpha + \beta n + \gamma n^2$$

(1) $1.58238 = \alpha + 1.51483\beta + 2.29471\gamma$

(2) $1.58772 = \alpha + 1.51840\beta + 2.30554\gamma$

(3) $1.59640 = \alpha + 1.52404\beta + 2.32270\gamma$

(3)-(2) $.00870 = .00564\beta + .01716\gamma$

(2)-(1) $.00534 = .00357\beta + .01083\gamma$

$.008436 = .00564\beta + .01711\gamma$

$.000264 = .00005\gamma$

$\gamma = 5.3$

subt. in (2)-(1) $.00534 = .00357\beta + .05740$

$-.00357\beta = .05206$

$\beta = -14.6$

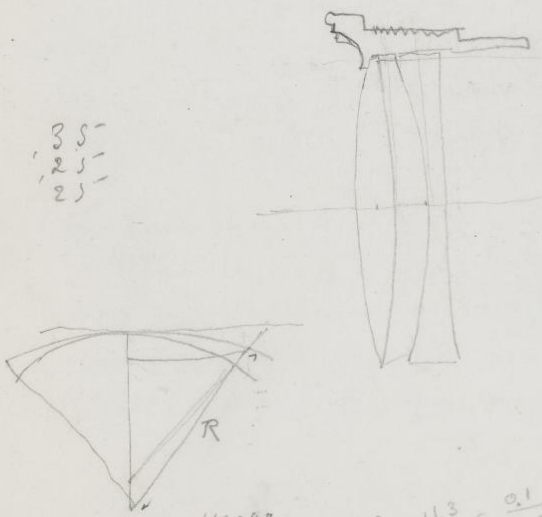
subt. in (1) $1.58238 = \alpha - 22.11652 + 12.1620$

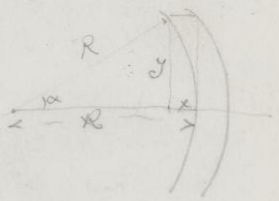
$-\alpha = -22.11652 - 1.58238 + 12.1620$

$\alpha = +11.5369$

$$\frac{1}{F} = (n_{5614} - 1)A + (n'_{5614} - 1)B$$

$d = 3.5$
$h = .038$ } 1065 times





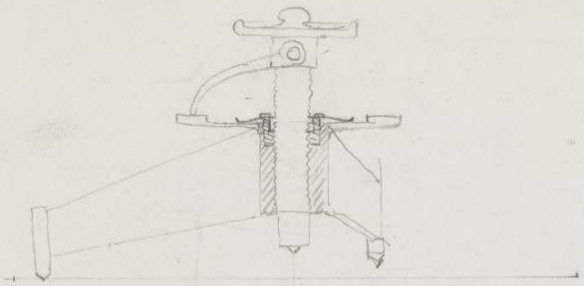
$\sin\alpha = \frac{y}{R}$

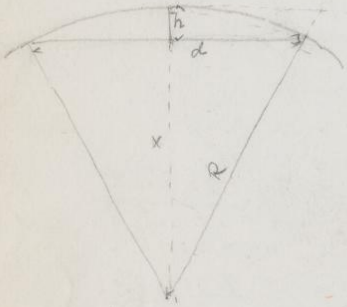
$x = R - R\cos\alpha$

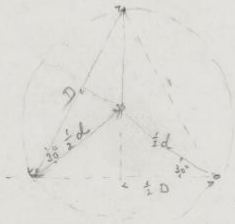
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– Spherometer – June 19 1887.







$\frac{D}{d} = \cos 30°$ $\quad \log 9.937\,53$

$d = \frac{D}{\cos 30°} = \frac{D}{.8660}$

$x = \sqrt{R^2 - \frac{d^2}{4}}$

$h = R - \sqrt{R^2 - \frac{d^2}{4}}$

$h - R = -\sqrt{R^2 - \frac{d^2}{4}}$

$h^2 - 2hR + R^2 = R^2 - \frac{d^2}{4}$

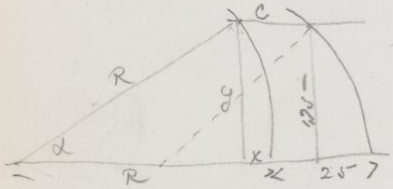
$8hR = 4h^2 + d^2$

$4h^2 + 8hR = -d^2$

$h^2 + 2hR = -\frac{d^2}{4}$

$h^2 + 2hR + R^2 = R^2 - \frac{d^2}{4}$

$h - R = \pm\sqrt{R^2 - \frac{d^2}{4}}$



$\sin \alpha = \frac{y}{R}$

$x = R - R\cos\alpha$

$y = 1.75 = \log 0.24304 \quad = \log .24304$

$R = 13.255 = \text{“} \frac{1.12238}{9.12066} \quad = 12.665 = \frac{1.10260}{9.14044}$

$\cos\alpha \quad = \log 9.99618$

$R \quad = \text{“} \frac{1.12238}{1.11856}$

$x_1 = \frac{13.139}{0.116}$

$= \log \frac{9.99581}{1.10260}$

$x_2 = \frac{12.543}{0.102} = \text{“} \frac{1.09841}{}$

$C = .25 - x_2 + x_1 = \begin{array}{r} .250 \\ .116 \\ \hline .366 \\ .122 \\ \hline .244 \end{array}$

$C = 0.244$ which is the width of the collar separating edges of the two lenses, to give $\frac{1}{4}$" between centers of surfaces

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Best levlos correction. substitute for page 2.

n' = for Flint glass. n for Crown glass.

$$n' = \alpha + \beta n + \gamma n^2$$

C (1) $1.58238 = \alpha + 1.51483\beta + 2.29471\gamma$

5614 (2) $1.58772 = \alpha + 1.51840\beta + 2.30554\gamma$

F (3) $1.59640 = \alpha + 1.52404\beta + 2.32270\gamma$

(3)-(2) $.00870 = .00564\beta + .01716\gamma$

(2)-(1) $.00534 = .00357\beta + .01083\gamma$

$.008436 = .00564\beta + .01711\gamma$

$.000264 = .00005\gamma$

$\gamma = 5.3$

subt. in (2)-(1) $.00534 = .00357\beta + .05740$

$-.00357\beta = .05206$

$\beta = -14.6$

subt. in (1) $1.58238 = \alpha - 22.11652 + 12.1620$

$-\alpha = -22.11652 - 1.58238 + 12.1620$

$\alpha = +11.5369$

$$\frac{1}{F} = (n_{5614} - 1)A + (n'_{5614} - 1)B$$

$$A = -B(\beta + 2\gamma n_{5614})$$

When $F = 1$. $1 = .51840A + .58772B$

10.6
5.3
107.8
14.

$A = -B(-14.6 + 2 \times 5.3 \times 1.5184)$

$A = -1.5B$

$1 = -.7776B + .58772B$

$B = -\frac{1}{.1899} = -5.26$

$A = +7.89$

For Crown Glass. $A = \frac{1}{r_1} + \frac{1}{r_2} = 7.89$ when $F = 1$

" Flint " $B = \frac{1}{r_1} + \frac{1}{r_2} = -5.26$ " " "

Crown, $r_1 = r_2$ $A = \frac{2}{r} = 7.89$ $\therefore r = .253$ when $F = 1$

Flint $r_2 =$ Inf. $B = \frac{1}{r_1} = -5.26$ $\therefore r_1 = .190$ " " "

When $F = 52\frac{1}{3}$" For Crown, $r = 13.24$" when $r_1 = r_2$

" Flint $r_1 = 9.94$" when $r_2 =$ Inf.

See 2 leaves over

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A1

Feb. 26th 1884. Discovered that in calculating the angle of the glass prisms from the angle through which the prism was turned, to reflect light normally from each face, I used wrong formulae

α = angle of prism (refracting)
β = observed angle through which prism was turned

$\alpha = 180° - \beta$

Hence. Angle of Iceroon Glass prism = 60° 5' 24"
" " Flint " " = 60° 4' 48"

n = Index of Refraction
δ = Minimum Deviation of Ray,

$$n = \frac{\sin \frac{1}{2}(\alpha+\delta)}{\sin \frac{1}{2}\alpha}$$

D line. δ = 38 39 58 ?

Iceroon Glass.

δ 38 25 43

C line, 2δ = 76° 51' 27"
δ = 38 25 43
α = 60 5 24
2) 98 31 7
$\frac{1}{2}(\alpha+\delta)$ = 49 15 34 = log sin. 9.8794815−
$\frac{1}{2}\alpha$ = 30 2 42 = " " 9.6995603
n_c = 1.513287 = log — 0.1799212
8963
249

2.29004 36 0.35984424
358
69
57
120

D line — 14 15
δ = 38 39 58
α = 60 5 24
2) 98 45 22
49 22 41

= sin 9.8802574
9.699560
0.1806974
7 30

n = 1.515798

0.5160 = 9.7126½
.00917 = 7.9623½
V = 56.27 = 1.7503

λ = 5614. line.
2δ = 77° 29' 8"
δ = 38 44 34
α = 60 5 24
2) 98 49 58
$\frac{1}{2}(\alpha+\delta)$ = 49 24 59 = log sin. 9.8804034
= " " 9.6995603
0.1809431
283
148

$n_{\lambda=5614}$ = 1.516852 = log — 0.3618862
789
73
57
160

2.30084 38

F line.
39 14 20
6 48 37

2δ = 78° 28' 39"
δ = 39 14 20
α = 60 5 24
2) 99 19 44
$\frac{1}{2}(\alpha+\delta)$ = 49 39 52 = log sin. 9.8821070
9.6995603
0.1825467
288
179

n_F = 1.522463 = log
1.513287

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Flint Glass,

C line,

$2\delta = 89^\circ\ 5'\ 15''$

$\delta = 44\ 32\ 38$

$\alpha = 60\ 4\ 48$

$2)\ 104\ 37\ 26$

$\frac{1}{2}(\alpha+\delta) = 52\ 18\ 43$ = log sin 9.8983692

$\frac{1}{2}\alpha = 30\ 2\ 24$ = " 9.6994948

0.1988744

$n'_C = 1.5\bar{8}079$ = log 49 5- 249

$\lambda = 5614$

$2\delta = 90^\circ\ 5'\ 20''$

$\delta = 45\ 2\ 40$

$60\ 4\ 48$

$2)\ 105\ 7\ 28$

$52\ 33\ 44$ = log sin 9.8998281

9.6994948

$n'_{\lambda=5614} = 1.5\bar{8}611$ = log. 0.2003333

582 06 27

1.5-8611
174
D = 1.5-8437

F line

$2\delta = 91^\circ\ 43'\ 49''$

$\delta = 45\ 51\ 55$

$60\ 4\ 48$

$2)\ 105\ 56\ 43$

$52\ 58\ 21$ = log sin 9.9021915

9.6994948

865

$n'_F = 1.5\bar{9}476$ = log 0.2026967

790 177

$1.5\bar{8}079$

$n'_F - n'_C = .01397$

3-C 0.5844 = 9.7667
F-C .01397 = 8.1452
V = 41.83 = 1.6215

$\delta =$ 39 14 20 / 38 25 43 / 48' 37" = 2917"

45 51 55 / 44 32 38 / 1 19 17" = 4757"

38° 44' 34" / 60 / 2324 60 / 139.4774) 2917.00 (.0209 / 2790 / 1270 / 1256

45° 2 40 / 60 / 2702 60 / 162160) 4755.00 (.0293 / 3240 / 1515 / 1458 / 5580

209) 293 (1.402 / 209 / 840 / 836 / 40

$\frac{1}{\sqrt{2}} = 1.402$

$\frac{f_2}{f_1}$

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A3

Condition of Achromatism. Best color correction.

$$n' = \alpha + \beta n + \gamma n^2$$

(1) $1.58079 = \alpha + 1.51328\beta + 2.29004\gamma$ ✓ C

(2) $1.58611 = \alpha + 1.51685\beta + 2.30084\gamma$ ✓ 5614

(3) $1.59476 = \alpha + 1.52246\beta + 2.31789\gamma$ ✓ F

(3)−(2) $.00865 = 0 + .00561\beta + .01705\gamma$ ✓ 7.74904 − 7.55206 = 0.19698

(2)−(1) $.00532 = 0 + .00357\beta + .01080\gamma$ ✓ 8.03382 − 8.23048

$.00836 = + .00561\beta + .01699\gamma$ ✓

$.00029 = + .00056\gamma$ 6.4624 − 5.7482 = 0.7142

$\gamma = \frac{3.625}{5.2}$

$.00532 = + .00357\beta + .03915$

$-.00357\beta = +.03383$

$\beta = -9.4761$ 1.0584 → 8.0334 + 0.1963 = 8.2297

Sub. in (1) $1.58079 = \alpha - 14.3400 + 8.3014$

$-\alpha = -7.61939$

$\alpha = 7.61939$

C − 7 .00917 = 9624

F − 7 .00661 = 8202

7208 .8578

$$\frac{1}{F} = (n_{5614} - 1)A + (n'_{5614} - 1)B$$

$$A = -B(\beta + 2\gamma n_{5614})$$

When $F = 1$.

$$1 = 0.51685\,A + 0.58611\,B$$

$$A = -B(-9.4761 + 2 \times 3.625 \times 1.51685)$$

$A = -1.5211\,B$

$1 = -.78618\,B + .58611\,B$

$1 = -.20007\,B$

$B = -4.9983$

$A = +7.6029$

A = 7.60, B = −5.00 } is correct

For the Lerebour Glass lens $\frac{1}{f_1} + \frac{1}{f_2} = \frac{7.6029}{53.75}$ $f_1 = f_2 = \frac{1}{\frac{7.6029}{107.50}} = 14.139$

" " Flint " " $\frac{1}{R_1} - \frac{1}{R_2} = \frac{4.9983}{53.75}$ $R_2 = \infty$ $R_1 = \frac{1}{\frac{4.9983}{53.75}} = 10.754$

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Focal length = 50.36,

$\gamma_1 = \gamma_2 = 13.255$

$R_2 = \infty \qquad R_1 = 10.72$

		R_1	R_2
$R_1 = 12.665$	$R_2 = 49.184$,	12.665	49.184
$R_2 = 39.915$	$R_1 = 13.471$	13.000	44.716
$R_1 = 13.000$	$R_2 = 44.716$	13.471	39.915
$R_1 = 14.000$	$R_2 = 35.896$	13.595	38.905
$R_1 = 13.590$	$R_2 = 38.905$	14.000	35.896

$Q_c = \varphi_c = 0.57328\,A + 0.58079\,B$

$\frac{1}{f_c} = \varphi_c = 0.99945$

which checks the values of A & B.

3.9024 ✓

-2.90295 ✓
$.99945$

$Q_{d=587.6} = 0.9996$

0.57328 = 9.71036 ✓
A = 0.85098 ✓
= 0.57438 ✓

0.58079 = 9.76402 ✓
B = −0.69882 ✓
= 0.46284

To find what ray is to be combined with the C ray for best color cor.

$$Q_c = n^2\gamma B + n(A + \beta B) + B(\alpha - 1) - A$$

$$0.99945 = n^2(-18.119) + n(7.6029 + 47.36x) - 33.086 - 7.6029$$

$$18.119\,n^2 - 54.967\,n = -41.68835$$

$$n^2 - 3.033707n = -2.300801$$

$$n^2 - 3.0337n + (1.51685)^2 = -2.3008 + 2.3008$$

$n - 1.51685 = \pm 0$ this should come ± 00357 to give n_d

$n =$

$n'_7 - n'_d = n_7 - n_d(\beta + 2\gamma n) + (n_7 - n_d)^2\gamma$ ✓

$n'_d - n'_c = (n_d - n_c) \;\; " \;\; + (n_d - n_c)^2\gamma$ ✓

.00865 = .00561 + 00003148 ✓

.00532 = .00356 + ——

.00836 = .00561 + 00001997 ✓

.00029 .00001151 ✓

n'_7 =	1.59476 ✓	1.58611 ✓
n'_d =	1.58811 ✓	1.58079 ✓
	.00865 ✓	.00532 ✓

1.52246 ✓	1.51685 ✓	1.51685 ✓
1.51685 ✓	1.51328 ✓	
.00561 ✓	.00357 ✓	

5611 = 7.74904 × 2 = 5.49808 ✓

3565 = 7.55296 × 2 = 5.10592 ✓

x = 0.1963 ✓ 0.1963 ✓

532 = 7.72589 ✓ 5.30.04 ✓

7.92222 ✓

	6.46824	6.46824
	5.05588	5.71119
γ =	1.40236	0.75705
B = 4.990 =	0.69881	0.69881
δn^2 =	5.44980	5.64044
	7.81818	7.08900
$\delta\varphi$ =	7.89997	0.55863
	.00123	6.33385
		= 6.89248

13. 1.471 .590 .00008014

.01397 = 8.14552

.00918 = 7.96280

x = 0.18248

(n'−)5168 = 9.71330

.7865 = 9.89557

.5861 = 9.30194

.2004 = 9.30194 = 4.990 = B

0.6981
0.1824
0.8805 = 7.594 = A

n_d = 1.52246
1.51685
.00661 = 7.82052
5 .6404

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15 Feb. 27th 1884.

Crown Glass -

$r_1 = r_2 = 13.253$, $r_3 = 12.665$, $r_4 = 49.184$

$t_1 = 0.375$, $t_2 = 0.22$, $D = 0.25$

$\lambda = 5614$. Central Ray. $n'_{\lambda=5614} = 1.51685 = \log 0.18094$

$f_1 = -\frac{nr}{n-1}$

$r = \quad = \quad = " \ 1.12238$

$n-1 = \quad = \quad = " \ \frac{9.71336}{1.30332}$

$f_1 = 38.901 \quad = " \ 1.58996$

$t = .375$

$d_2 = 38.526 \quad = " \ 1.58575$

$r \quad = " \ 1.12238$

$f_2 = \frac{dr}{nr + d(n-1)}$ $\qquad 2.70813$

$n = l. \ 0.18094$

$r = \ 1.12238 / 1.30332 = 20.106$

$d = 1.58575$

$n-1 = 9.71836 / 1.29911 = 19.912 / 40.018 = \log 1.60226 / 1.10587$

$f_2 = 12.761 \quad = "$

Flint Glass.

$\lambda = 5614$. Central Ray.

$D = .250 / 12.511 = \log 1.09729$

$d_3 = 1.58611 \quad = " \ 0.20033$

$n'_\lambda = 12.665 \quad = " \ \frac{1.10260}{2.40022}$

r_3

$f_3 = \frac{n' d_3 r_3}{d_3(n'-1) - r_3}$

$d_3 = l. \ 1.09729$

$n'-1 = 9.76798 / 0.86527 = 7.3328 / 12.6650 = " \ 0.72691$

$r \quad = 5.3322 \quad = " \ \frac{1.67331}{}$

$f_3 = 47.131 \quad =$

$t_2 = .220$

$d_4 = 46.911 \quad = \log 1.67127$

$r_4 = 49.184 \quad = " \ \frac{1.69182}{3.36309}$

$f_4 = \frac{d_4 r_4}{d_4(n'-1) - n' r_4}$

$d_4 = l. \ 1.67127$

$n-1 = 9.76798 / 1.43925 = 27.495$

$n' = 0.20033$

$r_4 = 1.69182 / 1.89215 = 78.010 / 50.515 = \log 1.70342 / 1.65967$

$f_4 = 45.674 \quad = "$

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A 6
133

– Marginal Ray –

$\lambda = 56.4$. Lenses Glass.

1. $\sin\alpha = \frac{y}{r}$
2. $i = \alpha$
3. $\sin\lambda = \frac{\sin i}{n}$
4. $\gamma = \alpha - \lambda$
5. $f_1 = r\frac{\sin\lambda}{\sin\gamma} + r$
6. $D = f_1 - t_1$
7. $\sin I = \frac{(D + R_2)\sin\gamma}{R_2}$
8. $\sin\Lambda = n\sin I$
9. $\delta = \gamma + (\Lambda - I)$
10. $Z = R\frac{\sin\Lambda}{\sin\delta} - R$

$y = 1.75$ = log. 0.24304
$r = 13.255$ = " 1.12238
$\alpha = i = 7° 35' 12''$ = log sin 9.12066
$n = 1.57685$ = " 0.18094
$\lambda = 4° 59' 36''$ = log sin 8.93972
$\gamma = 2° 35' 36''$

$r =$ = log 1.12238
0.06210
$y =$ = log sin 8.65359
25.498 = 1.40607
$r = 13.255$
$f_1 = 38.753$
.375
$D = 38.378$
$R_2 = 13.255$ = log 1.71293
51.633 = log sin 8.65359
0.36852
$R_2 =$ = 1.12238
$\sin I = 10° 9' 6''$ = log sin 9.24614
n = 0.18094
$\Lambda = 15° 30' 24''$ = log sin 9.42708
$5° 21' 18''$ $R =$ log 1.12238
$\gamma = 2\ 35\ 36$ 0.54946
$\delta = 7° 56' 54''$ = log sin 9.14076
25.627 = 1.40870
$R = 13.225$
$f_2 = 12.402$

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Marginal Ray.

— Flint Glass.

$f_2 = 12.402$
$.250$
$d_3 = 12.152$
$r_3 = 12.665$

2. $\sin i = \frac{(d+r)\sin\beta}{r}$ $\qquad 24.817 =$ log 1.39475

$\beta = \delta = 7^\circ 56' 54''$ = log sin 9.14076
$\qquad 0.53551$
$r_3 = 12.665$ = log 1.10260
$i = 15^\circ 43' 18''$ = log sin 9.43291 $\quad 75)600(8$
$n' =$ = 0.20033

3. $\sin\lambda = \frac{\sin i}{n}$ $\qquad 9.23258$ $\quad 100)200$

$\lambda = 9^\circ 50' 12''$ = log sin
$\qquad 5^\circ 53' 6''$ $\quad r_3 =$ 1.10260
$\qquad 0.33518$

4. $\gamma = \beta - (i - \lambda)$ $\qquad \gamma = 2^\circ 3' 48''$ = log sin 8.55635

60.094 = 1.77883
$r = 12.665$

5. $f = \frac{r \sin\lambda}{\sin\gamma} - r$ $\qquad f_3 = 47.429$
$\qquad .220$

6. $d = f - t$ $\qquad d_4 = 47.209$
$r_4 = 49.184$

7. $\sin i = \frac{(d - r_4)\sin\gamma}{r_4}$ [above: $(r-d)$] $\qquad 1.975$ = log 0.29557

γ = log sin 8.55635
$\qquad 8.85192$
$r_4 \quad 49.184$ = log 1.69182
$i = 0^\circ 4' 58''$ = log sin 7.16010
n' = 0.20033

8. $\sin\lambda = n \sin i$ $\qquad \lambda = 0^\circ 7' 53''$ = 7.36043

$\qquad 0^\circ 2' 55''$ $\quad r_4 =$ 1.69182
$\qquad 9.05225$

9. $\delta = \gamma + (\lambda - i)$ $\qquad \delta = 2^\circ 0' 53''$ = log sin 8.54600

3.2081 = 0.50625

10. $f_4 = r - \frac{r \sin\lambda}{\sin\delta}$ $\qquad r_4 = 49.184$

$f_4 = 45.976$

Flint Glass $\left.\begin{array}{l} r_3 = 12.665 \\ r_4 = 49.184 \end{array}\right\}$ $t_2 = .22$

Marginal Ray $f_4 = 45.976$
Central " $f_4 = 45.674$
$\qquad .302$ over corrected.

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Marginal Ray.

Flint Glass

$r_3 = 13.000$
$r_4 = 44.716$

$d_3 = 12.152$

$r_3 = \frac{13.000}{25.152} = \log 1.400057$

$\beta = \delta = 7° 56' 54'' = \log\sin \frac{9.14076}{0.541133}$

$r_3 = 13.000 = \frac{1.11394}{9.42739}$ 76/500(

$i = 15° 31' 7'' = \log\sin$

$n' = \log \frac{0.20033}{9.22706}$

$\lambda = \frac{9° 42' 40''}{5° 48' 27''} = \log\sin r = \frac{1.11394}{0.34100}$

$\gamma = 2° 8' 27'' = \log\sin \frac{8.57236}{1.76864}$

$58.701 =$

$r_3 = 13.000$
$f_3 = 45.701$
$\quad\ ,220$
$d_4 = 45.481$

$D_4 > R_4$

$r_4 = \frac{44.716}{0.765} = \log 9.88366$
$\quad = \log\sin \frac{8.57236}{8.45602}$
γ

$r = 44.716 = \log \frac{1.65046}{6.80556}$

$i = 0° 2' 12'' = \log\sin$

$n' = \frac{0.20033}{7.00589}$

$\lambda = \frac{0° 3' 29''}{0° 1' 17''} \quad r = \frac{1.65046}{8.65635}$

$\delta = 2° 7' 10'' = \sin \frac{8.56800}{0.08835}$

$\delta = \gamma - (\lambda - I)$

$1.2256 =$

$f_4 = r + \frac{r\sin\lambda}{\sin\delta}$

$r_4 = 44.716$
$f_4 = 45.942$

Central Ray

$d_3 n' = 1.29762$
$r_3 = 13.000 \quad = 1.11394$
$\quad 7.333 \quad = 2.41156$
$d_3 = 1.0 \quad 5.667 \quad = 0.75335$
$f_3 = 45.521 \quad = 1.65821$
$\quad\ ,220$
$d_4 = 45.301 \quad = 1.65611$
$r_4 = 44.716 \quad = 1.65046$
$\quad 3.30657$

$d_4 = 1.65611$
$n'-1 = \frac{9.76798}{1.42409} = 26.552$

$n' = 0.20033$
$r_4 = \frac{1.65046}{1.85079} = \frac{70.923}{44.371} = \frac{1.64710}{1.65947}$

$f_4 = 45.653$

.289 over corrected

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Marginal Ray
Flint Glass.

$r_3 = 14.000$
$r_4 = 35.896$

$d_3 = 12.152$

$r_3 = 14.000$
$26.152 = \log\ 1.41750$

2. $\sin i = \frac{(d+r)\sin\beta}{r}$

$\beta = \delta = 7^\circ\ 56'\ 57'' = \log\sin\ 9.14076$
0.55826

$r_3 = 14.000 = 1.14613$
$i = 14^\circ\ 58'\ 10'' = \log\sin\ 9.41213$
0.20033

3. $\sin\lambda = \frac{\sin i}{n}$

$n' = 9^\circ\ 22'\ 22'' = \sin\ 9.21180$
$5^\circ\ 35'\ 48'' \quad r = 1.14613$
0.36793

4 $\gamma = \beta - (i - \lambda)$

$\gamma = 2^\circ\ 21'\ 6'' = \sin\ 8.61813$
1.74480

55.565

$f_3 = \frac{14.}{41.565}$

$d_4 = \frac{.220}{41.345}$

5. $f = \frac{r\sin\lambda}{\sin\gamma} - r$

$r_4 = \frac{35.896}{5.449} = 0.73632$

6. $d = f - t$

$\gamma = \sin\ 8.61813$
9.34945

7. $\sin i = \frac{(d - r_4)\sin\gamma}{r_4}$

$r_4 = 1.55505$
$i = 0^\circ\ 21'\ 25'' = \sin\ 7.79440$
0.20033

8 $\sin\lambda = n\sin i$

$n = \sin\ 7.99473$
$\lambda = 0\ 33\ 58 \quad r = 1.55505$
$0^\circ\ 12'\ 33''$
9.54978

9 $\delta = \gamma - (\lambda - i)$

$\delta = 2^\circ\ 8'\ 33'' = \sin\ 8.57270$
0.94708

10 $f_4 = r + \frac{r\sin\lambda}{\sin\delta}$

9.486
$f_4 = \frac{35.896}{45.382}$

Central Ray.

$f_3 = \frac{n' d_3 r_3}{d_3(n'-1) - r_3}$

$d_3 n' = \log\ 1.29762$
$r_3 = 14.000 = 1.14613$
2.44375
$\frac{7.333}{6.667} = 0.82393$
$= 1.61982$

$f_3 = 41.670$

$d_4 = \frac{.220}{41.450} = 1.61752$

$r_4 = 35.896 = 1.55305$
3.17257

$f_4 = \frac{d_4 r_4}{d_4(n'-1) - n' r_4}$

$d_4 = \log\ 1.61752$
$n'-1 = \frac{9.76798}{1.38505} = 24.294$

$n' = 0.20033$
$r_4 = \frac{1.55505}{1.75538} = \frac{56.935}{32.641} = 1.57376$
$= 1.65581$

$f_4 = 45.584$

$.202$ under corrected

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Marginal Ray Flint Glass.

$r_3 = 13.590. = \log 1.13322$
$r_4 = 38.905 = \;\; 1.59001$

$d_3 = 12.152$

$r_3 = \frac{13.590}{25.742} = \log 1.41064$

$\beta = 7^\circ\ 56'\ 54'' = \sin \frac{9.14076}{0.55140}$

$r_3 = \frac{1.13322}{}$

$i = 15^\circ\ 11'\ 4'' = \sin \frac{9.41818}{}$ 78|300(4

$n = \frac{0.20033}{}$

$\lambda = 9^\circ\ 30'\ 19'' \quad \sin \frac{9.21785}{}$

$\frac{5\ 40\ 45}{} \quad r = \frac{1.13322}{0.35107}$

$\gamma = 2^\circ\ 16'\ 9'' = \sin \frac{8.59763}{}$

$56.681 = \frac{1.75344}{}$

$f_3 = \frac{13.590}{43.091}$
$\quad\ \ .220$

$d_4 = 42.871$

$r_4 = \frac{38.905}{3.966} = 0.59835$

$\gamma = \frac{8.59763}{9.19598}$

$r_4 = \frac{1.59001}{}$

$i = 0^\circ\ 13'\ 52'' = \sin \frac{7.60597}{}$

$n = \frac{0.20033}{}$

$\lambda = \frac{0^\circ\ 2'\ 1''}{0^\circ\ 8'\ 9''} = \sin \frac{7.80630}{} \quad r = \frac{1.59001}{9.39631}$

$\delta = 2^\circ\ 8'\ 0'' = \sin \frac{8.57083}{0.82548}$

$66.908 =$
$f_4 = \frac{38.905}{45.596}$

Central Ray

$d_3 n' = \quad = 1.29762$

$r_3 = 13.590 \quad = \frac{1.13322}{2.43084}$
$\quad 7.333$
$\quad 6.257 = \frac{0.79637}{}$

$= 1.63447$

$f_3 = 43.099$
$\quad\ \ .220$

$d_4 = 42.879 = 1.63224$

$r_4 = \frac{1.59001}{3.22225}$

$d_4 = \log 1.63224$
$n'-1 = \frac{9.76798}{1.40022} = 25.132$

$n' = 0.20033$

$r_4 = \frac{1.59001}{1.79034} = 61.708$
$\quad 36.576 = 1.56320$
$\quad\ \ 1.65905$

$f_4 = 45.609 =$

.013 under corrected.

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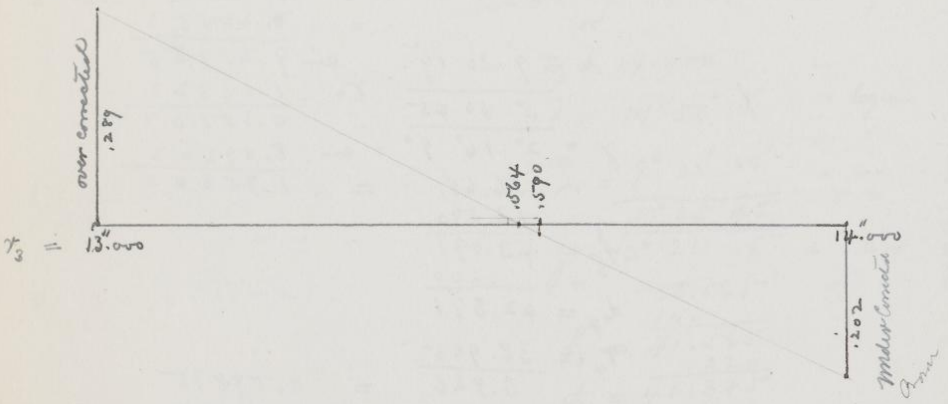
A11

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r_3	Sph. Abb.
13.000	.289 over
13.590	.013 under
14.000	.202 under.

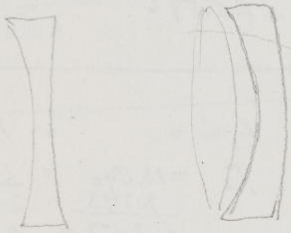
In each case r_4 was calculated by the formula

$$\frac{1}{r_3} + \frac{1}{r_4} = 5 \quad \text{when } F = 1$$



This diagram indicates that the Spherical Abberation = 0 when

$r_3 = 13.564$. $r_4 = 39.150$ by diagram p. —

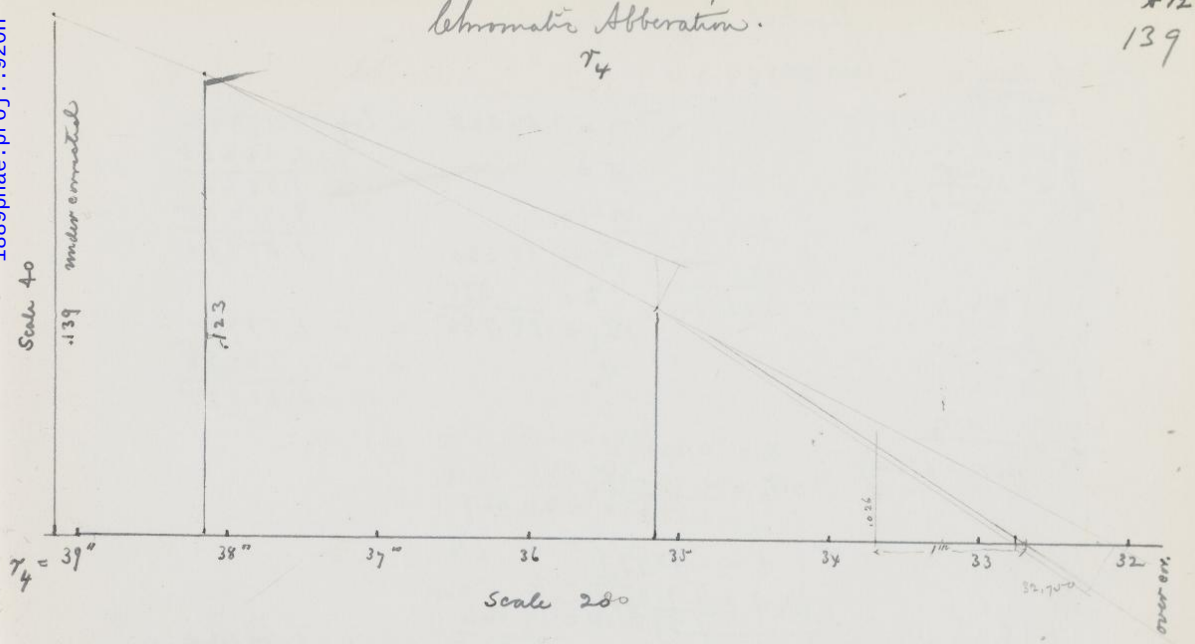


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Chromatic Abberation.

r_4



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Central Ray

6. lens - lenses.

$$f_1 = -\frac{n r_1}{n-1}$$

$n = 1.51328 = \log\ 0.17992$

$r = \quad\quad\quad\quad\quad\quad\quad\quad 1.12238$

$\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad 1.30230$

$n-1 = \quad\quad\quad\quad\quad\quad\quad\quad 9.71035-$

$f_1 = 39.080 \quad\quad\quad\quad\quad\quad\quad\quad 1.59195-$

$t = \underline{.375-}$

$d_2 = 38.705- = \quad\quad\quad\quad\quad\quad\quad\quad 1.58777$

$r_2 = \quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad 1.12238$

$\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad 2.71015-$

$$f_2 = \frac{d r_2}{n r_2 + d(n-1)}$$

$n = 0.17992$

$r_2 = \frac{1.12238}{1.30230} = 20.059$

$d = 1.58777$

$n-1 = \frac{9.71035-}{1.29812} = \frac{19.866}{39.925-} = \quad\quad\quad\quad\quad\quad\quad\quad 1.60124$

$\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad 1.10891$

$f_2 = 12.850 =$

Flint.

(6. lens. central Ray)

$$f_3 = \frac{n' d_3 r_3}{d_3(n'-1) - r_3}$$

$D = \underline{.250}$

$d_3 = 12.600 = \log\ 1.10037$

$n' = 1.58079 = \quad\quad\quad\quad 0.19887$

$r_3 = 13.564 = \quad\quad\quad\quad 1.13239$

$\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad 2.43163$

$d_3 = 1.10037$

$n-1 = \frac{9.76402}{0.86439} = \frac{7.3180}{6.246} = \quad\quad\quad\quad\quad\quad\quad\quad 0.79560$

$\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad 1.63603$

$f_3 = 43.254 =$

$d_4 = \underline{.220} = 43.034 = \quad\quad\quad\quad\quad\quad\quad\quad 1.63381$

$r_4 = 39.150 = \quad\quad\quad\quad\quad\quad\quad\quad 1.59273$

$\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad 3.22654$

$$f_4 = \frac{d_4 r_4}{d_4(n'-1) - n' r_4}$$

$d_4 = 1.63381$

$n'-1 = \frac{9.76402}{1.39783} = 24.994$

$n = 0.19887$

$r = \frac{1.59273}{1.79160} = \frac{61.887}{36.893} = \quad\quad\quad\quad\quad\quad\quad\quad 1.56694$

$\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad 1.65960$

$f_4 = 45.667 =$

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Central Ray

7 line lenses

$n = 1.52246 = \log 0.18253-$

$r = \quad 1.12238$

$\quad\quad 1.30493$

$n-1 = \quad 9.71805-$

$f_1 = 38.626 = \quad 1.58688$

$t = \frac{.375}{}$

$d_2 = 38.251 = \quad 1.58264$

$r = \quad 1.12238$

$\quad\quad 2.70502$

$n = 0.18253-$

$r = \frac{1.12238}{1.30493} = 20.180$

$d = 1.58264$

$n-1 = \frac{9.71805-}{1.30069} = \frac{19.984}{40.164} = \frac{1.6038.4}{1.10118}$

$f_2 = 12.624 = \quad 1.10118$

12.850
12.624
.226

Flint

(Flint lenses Central Ray)

$D = \frac{.250}{}$

$d_3 = 12.374 = \log 1.09251$

$n' = 1.59476 = \quad 0.20270$

$r_3 = 13.584 = \quad 1.13239$

$\quad\quad 2.42760$

$d_3 = 1.09251$

$n-1 = \frac{9.77434}{0.86685-} = \frac{7.3595-}{6.2045-} = \frac{0.79271}{1.63489}$

$f_3 = 43.141 = \quad 1.63489$

$d_4 = \frac{.220}{42.926} = \quad 1.63267$

$r_4 = 39.150 = \quad 1.59273$

$\quad\quad 3.22540$

$d_4 = 1.63267$

$n-1 = \frac{9.77434}{1.40701} = 26.527$

$n = 0.20270$

$r = \frac{1.59273}{1.79543} = \frac{62.435-}{36.908} = \frac{1.56712}{1.63528}$

$f_4 = 45.528 = \quad 1.63528$

---

6 line $f_4 = 45.667$

7 " " $= \frac{45.528}{.139}$ under corrected for color

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- Central Ray -

The d_4 and r_4 are so nearly alike that the spherical abberation probably will not be much affected by a change in r_4.

Change r_4 1.000. making $r_4 = 38.150$.

---

6 lens. Flint - $d_4 = 43.034 = \log 1.63381$

$r_4 = 38.150 = \dfrac{1.58149}{3.21530}$

$f_4 = \dfrac{dr}{d(n-1) - nr}$ $\quad d = 1.63381$

$n-1 = \dfrac{9.76402}{1.39783} = 24.994$

$n = 0.19887$

$r = \dfrac{1.58149}{1.78036} = \dfrac{60.306}{35.312} = \dfrac{1.54792}{1.66738}$

$f_4 = 46.492 =$

Changing r_4 1.000 changed Color abb - .016

Make $r_4 = 38.150$.

$d_4 = 43.034 = \log 1.63381$

$r_4 = \dfrac{1.54592}{3.17973}$

$d(n-1) = 24.994$

$n = 0.19887$

$r = \dfrac{1.54592}{1.74479} = \dfrac{53.564}{30.570} = \dfrac{1.48530}{1.69443}$

$f_4 = 49.480$

Changing r_4 3.000 changed Color Abb. .061

Make $r_4 = 32.750$. see 2 leaves back - diagram.

$d_4 = \log 1.63381$

$r_4 = 32.750 = \dfrac{1.57521}{3.14902}$

$d(n-1) = 24.994$

$n = 0.19887$

$r = \dfrac{1.57521}{1.71408} = \dfrac{51.770}{26.776} = \dfrac{1.42766}{1.72136}$

$f_4 = 52.645$

$r_4 = 32.690$ corrects for color.

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Central Ray

data same as on opposite page

7 lines. 7 limit.

$d_4 = 42.921 = \log 1.63267$

$r_4 = 38.150 = \quad " \quad \frac{1.58149}{3.21416}$

$d(n-1) = 25.527$

$n = 0.20270$

$r = \frac{1.58149}{1.78419} = \frac{60.840}{35.313} = \quad " \quad \frac{1.54793}{1.666.23}$

$f_4 = 46.369 =$

---

6 lines $f = 46.492$

7 " " $= \frac{46.369}{.123}$ under corrected

$d_4 = 42.921 = \log 1.63267$

$r_4 = \quad = \frac{1.54592}{3.17859}$

$d(n-1) = 25.527$

$n = 0.20270$

$r = \frac{1.54592}{1.74862} = \frac{56.056}{30.529} = \frac{1.48471}{1.69388}$

$f_4 = 49.418 =$

---

6 lines $f = 49.480$

7 " " $= \frac{49.418}{.062}$ under corrected

$d_4 = \quad \log 1.63267$

$r_4 = 32.750 = \quad " \quad \frac{1.51521}{3.14788}$

$d(n-1) = 25.527$

$n = 0.20270$

$r = \frac{1.51521}{1.71791} = \frac{52.229}{26.702} = \frac{1.42654}{1.72134}$

$f_4 = 52.643 =$

---

6 lines $f = 52.645$

7 " " $= \frac{52.643}{.002}$ under corrected

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A17

Marginal Ray

$r_3 = 13.590$ as before
$r_4 = 32.690$

$\sin i = \frac{(d-r)\sin\gamma}{r}$

$\sin\lambda = n \sin i$

$\delta = \gamma - (\lambda - i)$

$f_4 = r + \frac{r \sin\lambda}{\sin\delta}$

$d_4 = 42.871$

$r_4 = 32.690$

$10.181 = \log\ 1.00779$

$\gamma \quad 2^\circ\ 16'\ 9'' = \sin\ 8.59763$

9.60542

$\gamma = \quad = \quad 1.51441$

$i = 0^\circ\ 42'\ 24'' = \sin\ 8.09101$

$n \quad = \quad 0.20033$

$\lambda = 1^\circ\ 7'\ 15'' = \sin\ 8.29134$

$0^\circ\ 24'\ 51'' \quad r = \quad 1.51441$

9.80879

$\delta = 1^\circ\ 31'\ 18'' = \sin\ 8.51014$

$19.752 \quad = \quad 1.29561$

32.690

$f_4 = 52.442$

Central Ray

$\lambda = 5614.$ data as above,

$d_4 = \quad = \log\ 1.63224$

$r = 32.690 \quad = \quad 1.51441$

3.14665

$d(n-1) = 25.132$

$f_4 = \frac{dr}{d(n-1) - nr}$

$n = 0.20033$

$r = 1.51441$

$1.71474 = 51.849 \quad = \quad 1.42679$

26.717

$f_4 = 52.464 \quad = \quad 1.71986$

.022 under corrected

$r_3 = 13.548$
$r_4 = 32.693$

{ Color corrected when $r_3 = 13.564$, $r_4 = 32.690$ } +.016

$t_2 = .200$

When focal dist = 45.6

a change of .026 in r_3 changed the abb. .013

So that when the focal dist = 52.88 it is probable that a change of .030 in r_3 will change the abb. .016.

$r_3 = 13.548$
$.030$
probably $r_3 = 13.578$ to make abb = 0
$r_4 = 32.680$

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A 18
IKJ—

Marginal Ray Flint.

$r_3 = 13.548$
$r_4 = 32.693$

2. $\sin i = \frac{(d+r)\sin\beta}{r}$

3 $\sin\lambda = \frac{n\sin i}{n}$

4 $\gamma = \beta - (i - \lambda)$

5 $f = \frac{r\sin\lambda}{\sin\gamma} - r$

6 $d = f - t$

7 $\sin i = \frac{(d-r)\sin\gamma}{r_4}$

8 $\sin\lambda = n\sin i$

9 $\delta = \gamma - (\lambda - i)$

10 $f_4 = r + \frac{r\sin\lambda}{\sin\delta}$

$d_3 = 12.152$

$r_3 = \frac{13.548}{25.700}$ = log 1.40993

$\beta = 7^\circ 56' 54''$ = sin 9.14076
0.550069

r = 1.13187

$i = 15^\circ 12' 27''$ = sin 9.41882 76/5720 (
n = 0.20033

$\lambda = 9^\circ 31' 10''$ = sin 9.21849
$5^\circ 41' 17''$ r = 1.13187

$\gamma = 2^\circ 15' 37''$ = sin 8.59593
56.811 = 1.75443

$r = \frac{13.548}{43.263}$
$t_3 = \frac{.200}{43.063}$
d_4

$r_4 = \frac{32.693}{10.370}$ = 1.01578

γ = sin 8.59593
9.61171

r_4 = 1.51445

$i = 0^\circ 43' 0''$ = sin 8.09726
n = 0.20033

$\lambda = 1^\circ 8' 13''$ = sin 8.29759
0 25 13 r = 1.51445
9.81204

$\delta = 1^\circ 50' 24''$ = sin 8.50662
20.203 = 1.30542

$r_4 = \frac{32.693}{52.896}$

Central Ray.

$f_3 = \frac{n\,dr}{d(n-1) - r}$

dn = log 1.29762

$r_3 = 13.548$ = 1.13187
2.42949

$d(n-1)$ = $\frac{7.333}{6.215}$ = 0.79344
1.63605

$f_3 = 43.256$
.200

$d_4 = 43.056$ = 1.63403

r_4 = 1.51445
3.14848

$f_4 = \frac{dr}{d(n-1) - nr}$

$d = 1.63403$
$n-1 = \frac{9.76798}{1.40201} = 25.235$

$n = 0.20033$
$r = \frac{1.51445}{1.71478} = \frac{51.854}{26.619} = 1.42519$
1.72329

$f_4 = 52.880$

.016 over corrected

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A 19

March 12th 1884

Marginal Ray

$r_3 = 13.578$
$r_4 = 32.680$

2. $\sin i = \frac{(d+r)\sin\beta}{r}$

3 $\sin\lambda = \frac{\sin i}{n}$

4 $\gamma = \beta - (i - \lambda)$

5. $f = \frac{r\sin\lambda}{\sin\gamma} - r$

6. $d = f - t$

7. $\sin i = \frac{(d-r)\sin\gamma}{r}$

8. $\sin\lambda = n\sin i$

9. $\delta = \gamma - (\lambda - i)$

10. $f_4 = r + \frac{r\sin\lambda}{\sin\delta}$

$d_3 = 12.152 = \log$

$r_3 = \frac{13.578}{25.730} = \log 1.41044$

$\beta = 7^\circ\ 56'\ 54'' = \quad \frac{9.14076}{0.55120}$

$r_3 = 13.578 = \quad \frac{1.13284}{9.41836}$ 74/600

$= \sin \quad n = \frac{0.20033}{9.21803}$ 114/400

$i = 15^\circ\ 11'\ 28'' = \sin$

$\lambda = \frac{9\ 30\ 33}{5^\circ 40'\ 55''} \quad r = \frac{1.13284}{0.35087}$

$\gamma = 2\ 16\ 59 = \sin \frac{8.59710}{1.78377}$

$r = \frac{56.724}{13.578}$

$f_3 = 43.146$

$t = \frac{.200}{42.946}$

$r_4 = \frac{32.680}{10.266} = \log 1.01140$

$= \sin \frac{8.59710}{9.60850}$

$\gamma = \log \frac{1.51428}{9.09422}$

$r_4 = \sin \frac{0.20033}{8.29455}$

$i = 0^\circ\ 42'\ 42'' = \frac{1.51428}{9.80883}$

$n = \frac{8.50878}{1.80005}$

$\lambda = 1^\circ\ 7'\ 44''$

$\delta = 0\ 25\ 2$

$\delta = 1\ 50\ 57 =$

$19.955 =$

$f_4 = \frac{32.680}{52.635}$

Central Ray.

$f_3 = \frac{ndr}{d(n-1) - nr}$

$dn = \quad = \log 1.29762$

$r_3 = 13.578 = \quad \frac{1.13284}{2.43046}$

$d(n-1) = \frac{7.333}{6.245} = \quad \frac{0.79553}{1.63493}$

$f_3 = 43.145$

$t = \frac{.200}{42.945} = \log 1.63791$

$d_4 = \quad = \frac{1.57428}{3.14719}$

$r_4 =$

$f_4 = \frac{dr}{d(n-1) - nr}$

$d = 1.63291$

$n-1 = \frac{9.76798}{1.40089} = 25.170$

$n = 0.20033$

$r_4 = \frac{1.51428}{1.71461} = \frac{51.833}{26.663} = \frac{1.42591}{1.72128}$

$f_4 = 52.636$

.001 under corrected

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6. + 7. Central Rays.

6. data same

$dn =$ log 1.29924
$r = 13.578$ = " 1.13284
$d(n-1) = \frac{7.318}{6.260}$ = " $\frac{2.43208}{0.79657}$
$f_3 = 43.203$ = " 1.63550-1
$t = \frac{.200}{}$
$d_4 = 43.003$ = log 1.63350
$r_4 = 32.680$ = " $\frac{1.51428}{3.14778}$

$d =$ 1. 1.63350
$n-1 = \frac{9.76402}{1.39752} = 24.976$

$n = 0.19887$
$r = \frac{1.51428}{1.713.15} = \frac{51.660}{26.684} = \frac{1.42625}{1.721.53}$

$f_4 = 52.666$

---

7. data same.

$dn =$ = log 1.29521
$r = 13.578$ = $\frac{1.13284}{2.42805}$
$d(n-1) = \frac{7.3595}{6.2185}$ = " $\frac{0.79368}{1.63437}$
$f_3 = 43.089$
$t = \frac{.200}{42.889}$ = " 1.63234
$d_4 =$ = $\frac{1.51428}{3.14662}$
r_4

$d = 1.63234$
$n-1 = \frac{9.77434}{1.40.668} = 25.508$

$n = 0.20270$
$r = \frac{1.51428}{1.716.98} = \frac{52.117}{26.609} = \frac{1.42503}{2.721.59}$

$f_4 = 52.673$

.007 over corrected

By diagram to increase r_4 1 in. undercorrects .026 r_3 remaining same.

To correct for color increase r_4 .269 -

$\therefore \quad r_4 = 32.949$

as this makes r_4 nearer = d_4 ray opposite from the spherical abb. will not be effected

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A 21

Hasting by Spherometer.

Result.

Crown $\left.\begin{aligned} r_1 &= 13.253 \\ r_2 &= 13.253 \end{aligned}\right\} t_1 = .375$ $\left\{\begin{aligned} &13.40 \quad \text{diff } +.15 \quad \tfrac{1}{90} \end{aligned}\right.$

Flint. $\left.\begin{aligned} r_3 &= 13.578 \\ r_4 &= 32.949 \end{aligned}\right\} t_2 = .200$ $\begin{aligned} &13.76 \quad +.18 \quad \tfrac{1}{70} \\ &33.64 \quad +.59 \quad \tfrac{1}{57} \end{aligned}$

Distance between Lenses = .250

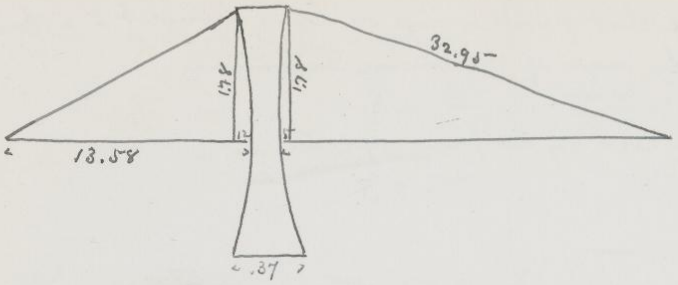
Focal length. $\lambda = 57.14 = 52.635$ See 9 pages on

A.G. worked by brass gauges to the above figures. Hastings measured them by Spherometer as above

		Central.	Marginal
Crown Lens.	b. line f =	12.850	(12.590) est.
	586 " " =	12.761	12.402
	7 " " =	12.624	(12.264) est
diff Central b. + Marginal f =		.586	
Ave Focus =		12.557	

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17.8 = log 0.2504
13.58 = " 1.1329
7° 31' 50" = sin 9.1175

1.1329
cos 9.9962
1.1291

13.46 =

Concavity = .12

17.8 = log 0.2504
32.95 = " 1.5178
3° 5' 49" = sin 8.7326
cos 9.9994
1.5172

32.90 =

.05

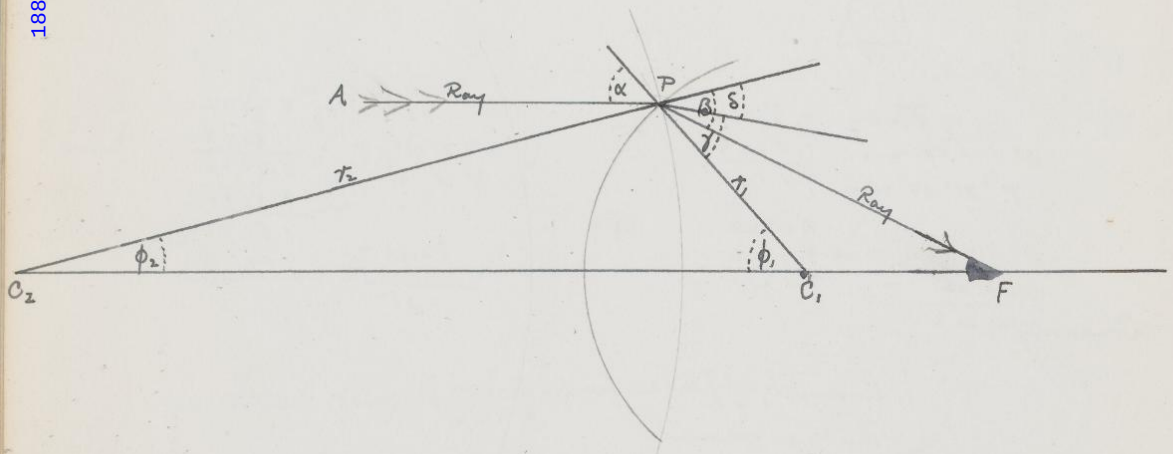
Concavity of first surface = .12
Thickness of centre .20
Concavity of second " = .05
Thickness of Edge = .37

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Form of Lens such that parallel rays on being brought to a focus shall pass through it at the angle of minimum Deviation.

Advantage - Least light lost by surface reflections -



Condition of Minimum Deviation = $\alpha = \beta$

$\sin\gamma = \frac{\sin\alpha}{n}$ and $\sin\beta = n\sin\delta$ also $\phi_1 + \phi_2 = \gamma + \delta$

$\underline{\sin\alpha = n\sin\gamma}$

therefore when $\alpha = \beta$, $\gamma = \delta$ and $\phi_1 + \phi_2 = 2\gamma$

As the angles α and γ are not very different in magnitude - and in an object glass both are small - it will cause but a small error to assume that these angles are proportional to their sines -

hence $\gamma = \frac{\alpha}{n}$ and $\phi_1 + \phi_2 = \frac{2\alpha}{n}$

For parallel rays $\alpha = \phi_1$ and $\phi_1 + \phi_2 = \frac{2\phi_1}{n}$

$$1 + \frac{\phi_2}{\phi_1} = \frac{2}{n}$$

$$\frac{\phi_2}{\phi_1} = \frac{2}{n} - 1$$

$r_1 \sin\phi_1 = r_2 \sin\phi_2$ hence $\frac{\sin\phi_2}{\sin\phi_1} = \frac{r_1}{r_2}$

ϕ_1 and ϕ_2 in an object glass are never large therefore it will not cause a large error to assume $\frac{\sin\phi_2}{\sin\phi_1} = \frac{\phi_2}{\phi_1} = \frac{r_1}{r_2}$

$$\frac{r_2}{r_1} = \frac{2}{n} - 1$$

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Minimum Deviation, of Lenses.

When $n = 1.5$ as in Crown Glass

$$\frac{r_1}{r_2} = \frac{2.0}{1.5} - 1 = \frac{4}{3} - 1 = \frac{1}{3}$$

$$r_2 = 3 r_1$$

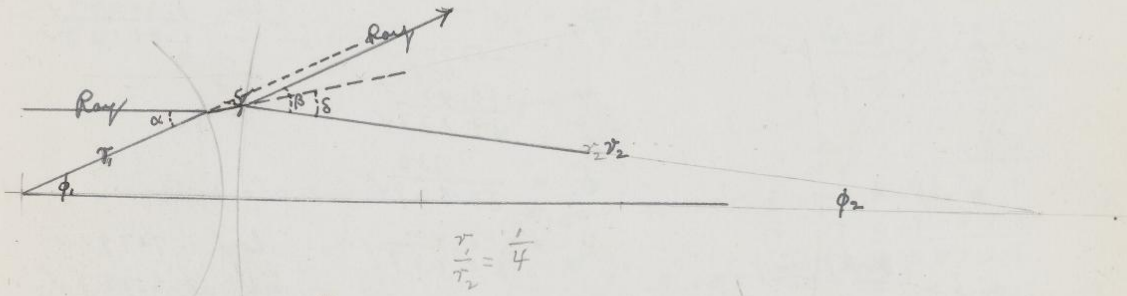
When $n = 1.6$ as in Flint Glass

$$\frac{r_1}{r_2} = \frac{2.0}{1.6} - 1 = \frac{5}{4} - 1 = \frac{1}{4}$$

$$r_2 = 4 r_1$$

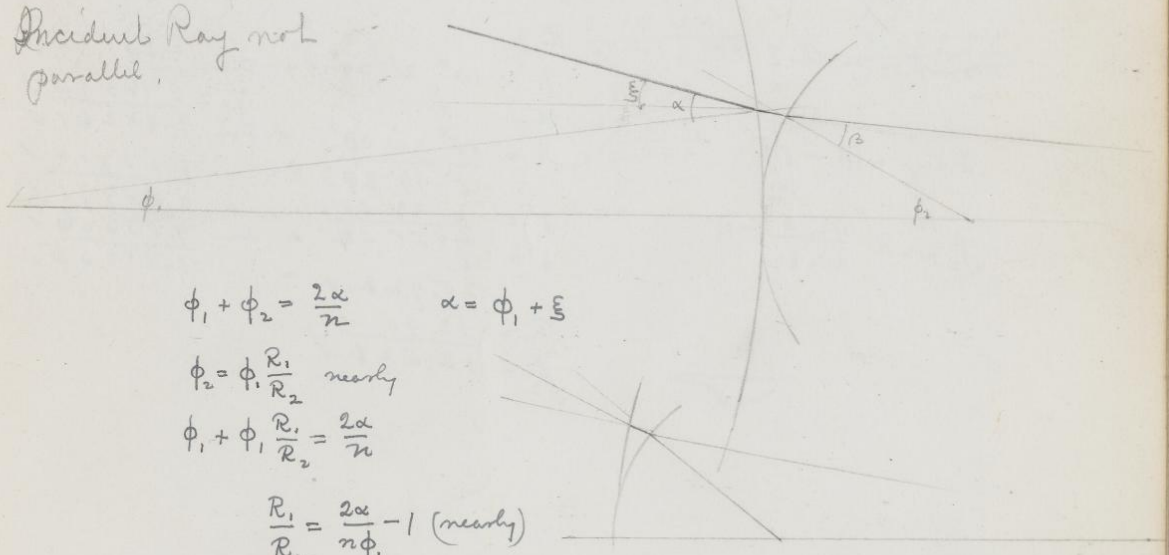
This demonstration is strictly true only at the intersection of the two surfaces of the lens, it would also be true for the central rays of a lens of no thickness

March 16th 1884.



$$\frac{r_1}{r_2} = \frac{1}{4}$$

Incident Ray not parallel.



$$\phi_1 + \phi_2 = \frac{2\alpha}{n} \qquad \alpha = \phi_1 + \xi$$

$$\phi_2 = \phi_1 \frac{R_1}{R_2} \quad \text{nearly}$$

$$\phi_1 + \phi_1 \frac{R_1}{R_2} = \frac{2\alpha}{n}$$

$$\frac{R_1}{R_2} = \frac{2\alpha}{n\phi_1} - 1 \quad \text{(nearly)}$$

This is equally true for a convex lens.

$$\frac{R_1}{R_2} = \frac{2(\phi_1 + \xi)}{n\phi_1} - 1$$

$$= \frac{2}{n} + \frac{2\xi}{n\phi_1} - 1$$

$$= \frac{2}{n}\left(\frac{\xi}{\phi_1} + 1\right) - 1$$

$\xi = 9°$
$\phi_1 = 3°$
$n = 1.6$

$$\frac{R_1}{R_2} = \left(\frac{2}{1.6} \times 4\right) - 1$$

$$= \frac{8}{1.6} - 1$$

$$= 5 - 1$$

$$= 4$$

$$R_2 = 4 R_1$$

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B. 4

Ratio of radii of curvatures, same as on p. A 21. as measured by Hastings Spherometer. + the flint lens was adjust the crown as made.

$r_1 = r_2 = 13.40$
$r_3 = 13.726$
$r_4 = 33.308$

$f = 53.20.$

$t_1 = .350$
$t_2 = .180$

Marginal Ray -- Yellow -- $\lambda = 5614$

1 $\sin\alpha = \frac{y}{r}$

2 $i = \alpha$

3 $\sin\lambda = \frac{\sin i}{n}$

4 $\gamma = \alpha - \lambda$

5 $f_1 = r\frac{\sin\lambda}{\sin\gamma} + r$

6. $D_1 = f_1 - t_1$

7 $\sin I = \frac{(D+R)\sin\gamma}{R}$

$\sin A = n \sin I$

$\delta = \gamma + (A - I)$

$f_2 = R\frac{\sin A}{\sin\delta} - R$

$y = 1.75$ — log. 0.24304 ✓
$r = 13.40$ — " 1.12710 ✓
$\alpha = i = 7° 30' 16"$ ✓ — sin 9.11894 ✓

$n = 1.51685$ — log 0.18094 ✓
$\lambda = 4° 56' 21"$ ✓ — sin 8.93500 ✓
$\gamma = 2° 33' 55"$ ✓

γ — log 1.12710 ✓
— 0.06210
λ — sin 8.65087 ✓
1.41123 ✓

25.777 ✓ =
$r = 13.40$ ✓
$f_1 = 39.177$ ✓
$t_1 = .350$
$d_2 = 38.827$ ✓
$R_2 = 13.40$ / 52.227 ✓ = log 1.71790 ✓
— sin 8.65087 ✓
γ — 0.36879 ✓
R = 1.12710 ✓
$I = 10° 2' 49"$ ✓ — sin 9.24167 ✓
n — 0.18094 ✓
$A = 15° 20' 38"$ ✓ — sin 9.42261 ✓
$5° 17' 49"$ ÷ R = 1.12710 ✓
$\gamma = 2\ 33\ 55$ ✓ 0.54971 ✓
$\delta = 7° 51' 44"$ = sin 9.13606 ✓
1.41364 ✓
25.921 ✓ =
$R = 13.40$
$f_2 = 12.521$ ✓

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Marginal Rays. Flint Glass.

$f_2 = 12.522$
$\quad .280$
$d_3 = 12.242$

12.522
.275
12.247

$r_3 = 13.726$
25.998

2. $\sin i = \frac{(d+r)\sin\beta}{r}$

$\beta = 7^\circ 21' 43''$

$r =$
$i = 15^\circ 0' 53''$

3. $\sin\lambda = \frac{\sin i}{n}$

$n =$
$\lambda = 9^\circ 24' 4''$

4 $\gamma = \beta - (i - \lambda)$

$i - \lambda = 5^\circ 36' 51''$
$\gamma = 2^\circ 14' 52''$

5 $f = \frac{r\sin\lambda}{\sin\gamma} - r$

57.167
13.726
$f_1 = 43.441$

6 $d = f - t$

$t_1 = .180$
$d_4 = 43.261$

7 $\sin i = \frac{(d-r)\sin\gamma}{r_4}$

$r_4 = 33.308$
9.995

8 $\sin\lambda = n\sin i$

$r =$
$r_4 =$
$i = 0^\circ 40' 17.5''$
$n =$
$\lambda = 1^\circ 3' 5\cancel{4}.5''$
$0^\circ 23' 37''$

9. $\delta = \gamma - (\lambda - i)$

$\gamma = 2\ 14\ 52$
$\delta = 1^\circ 5' 1' 15''$
19.136

10. $f_4 = r + \frac{r\sin\lambda}{\sin\delta}$

$r = 33.308$
52.444

$\log 1.414995$
$\sin 9.13604$
0.550099
1.137356
$\sin 9.41343$
0.20033
$\sin 9.21310$
$r = 1.137356$
0.350066
$\sin 8.59352$
$1.757.14$
$=$

$\log 0.999795$
$\sin 8.59352$
9.59147
$= \log 1.522554$
$\sin 8.06893$
0.20033
$\sin 8.26926$
1.522554
9.79180
$\sin 8.50995$
$1.281.85$
$=$

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B 3

$\lambda = 5614.$

Central Ray. Iervoux.

$f_1 = -\frac{nr}{n-1}$

$n = 1.57685$ = log. 0.18094 ✓

$r_1 = 13.40$ = " 1.12710 ✓

1.30804 ✓

$n-1 =$ 9.71336 ✓

$f_1 = 39.326$ ✓ = 1.59468 ✓

$f_2 = \frac{dr}{nr + d(n-1)}$

$t_1 = .350$

$d_1 = 38.976$ ✓ = 1.59079 ✓

$r_2 = 13.40$ = 1.12710 ✓

2.71789 ✓

$n = l.\ 0.18094$ ✓

$r = \cdot \frac{1.12710}{1.30804}$ ✓ $= 20.328-$ ✓

$d = l\ 1.59079$ ✓

$n-1 = \cdot \frac{9.71336}{1.30415-} = \frac{20.144}{40.469}$ ✓ = log 1.60713 ✓

$f_2 = 12.905-$ ✓ = " 1.11076 ✓

12.905
.275-
12.630

Central Ray Flint.

$D_2 = \frac{.250}{12.655-}$ = log 1.10229

$n = 1.58611$ = " 0.20033

$r_3 = 13.726$ = " 1.13756

2.44018

$f_3 = \frac{ndr}{d(n-1) - r}$

$d = l.\ 1.10229$

$n-1 = \cdot \frac{9.76798}{0.87027} = 7.418$

$r = \frac{13.726}{6.308} =$ log 0.79989 / 1.64029

$f_3 = 43.681$

$f_4 = \frac{dr}{d(n-1) - nr}$

$t_2 = .180$

$d_4 = 43.501$ = log 1.63850

$r_4 = 33.308$ = " 1.52254

3.16104

$d =$ log 1.63850

$n-1 = \frac{9.76798}{1.40648} = 25.497$

$n =$ log 0.20033

$r = \frac{1.52254}{1.72287} = \frac{32.828}{27.331} =$ log 1.43666 / 1.72128

Central Ray $f_4 = 52.012 =$

Marginal " $= \frac{52.444}{0.568}$

$=$

Spher

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$r_3 = 13.000$
$r_4 = 38.541$

lemma $R = \frac{r}{2(n-1)}$ $\quad$ limit $F = \frac{r_3 r_4}{(n-1)(r_3 + r_4)}$

$r_3 = 13.786$ - log 1.13756
$r_4 = 33.308$ " 1.52254
$r_3 + r_4 = 47.034$ 2.66010
1.44039
$F = 16.584$ = 1.21971
$(n-1) = 9.76798$
$r + s = 1.67241$ $(n-1) = 9.76798$
1.44039 $F(n-1) = \bar{1}0.98769$

r

$$r_4 = \frac{r_3}{\frac{r_3}{F(n-1)} - 1}$$

make $r_3 = 13.$ = log 1.11394
$F(n-1)$ = " 0.98769
= " 0.12625
1.3373
1.
0.3373 = " 9.52802
$r_4 = 38.541$ = " 1.58592

---

try $r_3 = 12.85$ $r_3 = 12.85$ = log 1.10890
$F(n-1)$ = 0.98769
1.3218 = 0.12121
1.
.3218 = 9.50759
$r_4 = 39.931$ = 1.60131

---

try $r_3 = 12.88$. $r_3 = 12.88$ = log. 1.10992
$F(n-1)$ = " 0.98769
= 0.12223
1.3250
1.
.3250 = 9.51188
$r_4 = 39.632$ = 1.59804

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B 5

Marginal Ray - Flint.

$d_3 = 12.272$

$r_3 = \frac{13.}{25.272}$ = log. 1.40264

$\beta = 7° 57' 43''$ = sin 9.13604 / 0.53868

$r = 13.$ = 1.11394

$i = 15° 25' 17''$ = sin 9.42474 / 0.20033

$n =$ = 9.22441

$\lambda = \frac{9° 39' 5''}{5° 46' 12''}$ = sin r = 1.11394 / 0.33835

$\gamma = 2° 5' 31''$ = sin 8.56233 / 1.77602

59.707

$r = \frac{13.}{46.707}$

$f_3 = \quad .180$

$d_4 = 46.527$

$\frac{38.541}{7.986}$ = log 0.90233 / sin 8.56233 / 9.46466

γ

$r_4 = 38.541$ = log 1.58592 / sin 7.87874 / log 0.20033 / sin 8.07907

$i = 0° 26' 0''$

$n =$

$\lambda = \frac{0° 41' 15''}{0° 15' 15''}$ r_4 = 1.58592 / 9.66499

$\gamma = 2° 5' 31''$

$\delta = 1° 50' 16''$ = sin 8.50609 / 1.15890

14.417

$r = \frac{38.541}{52.958}$

$f_4 =$

Central Ray - Flint.

nd = log 1.30262

$r_3 = \frac{1.11394}{2.41656}$

$d(n-1) = 7.418$

$r = \frac{18.}{5.582}$ = 0.74679 = 1.66977

$f_3 = 46.749$

$.180$

$d_4 = 46.569$ = log 1.66810

$r_4 = 38.541$ 1.58592 / 3.25402

d_4 = log 1.66810

$n-1$ = 9.76798 / 1.43608 = 27.295

n = log 0.20033

r_4 = 1.58592 / 1.78625 = 61.130 / 33.835 = log 1.52936 / 1.72466

central f_4 = 53.047 = "

Marginal " = 52.958 / .089

Spherical Abb. under corrected -

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Marginal Ray Flint.

B6-
157

$r_3 = 12.85-$ } log 1.10890
$r_4 = 39.931$ } " 1.60131

$d_3 = 12.272$
$r_3 = \frac{12.850}{25.122} =$ log 1.40005 ✓
$\beta = 7° 57' 43" =$ sin 9.13604 ✓
0.53609-
r_3 = 1.10890 ✓
$i = 15° 30' 40" ✓ =$ sin 9.42719-
n = 0.20033
$\lambda = 9° 42' 23" ✓ =$ sin 9.22686-
$5° 48' 17" \quad r =$ 1.10890
$\beta = 7\ 51\ 43$ 0.33576-
$\gamma = 2° 3' 26" =$ sin 8.55506 ✓
60.353 ✓ = 1.78070-
$r = 12.850$
$f_3 = 47.503-$
.180
$d_4 = 47.323-$
$r_4 = \frac{39.931}{7.392-} =$ log 0.86876 ✓
γ = sin 8.55506 ✓
9.42382-
r_4 = log 1.60131 ✓
$i = 0° 22' 50.6" ✓ =$ sin 7.82251-
n = 0.20033
$\chi = 0° 36' 14.0" ✓ =$ sin 8.02284-
$0° 13' 23".4 ✓$ r_4 1.60131
9.62415-
$\delta \gamma = 2\ 3\ 26.$
$\delta = 1° 50' 2".6 =$ sin 8.50521 ✓
13.150 ✓ = 1.11894-
39.931
$f_4 = 53.081 ✓$

$T_5 = 13.726$ Spher. Ab. = .568 under
$T_3 = 13.$ Sp. Ab. = .089 under
$r_3 = \frac{12.85-}{.15-}$ " = .033 over
.122

Central Ray. Flint.

$d(n-1) = 7.418$
$r_3 = \frac{12.850}{5.432} ✓ =$
nd = log 1.30262 ✓
r_3 = " 1.10890
2.41152-
" 0.73496 ✓
$f_3 = 47.485 ✓ =$ " 1.67656-
.180
$d_4 = 47.305-$ log 1.67491 ✓
r_4 = 1.60131
3.27622-

d_4 = log 1.67491
$n-1$ = 9.76798
1.44289 = 27.727 ✓

n = " 0.20033
r_4 = $\frac{1.60131}{1.80164} = 63.336$ ✓
95.608- = $\frac{1.55-15-}{1.72469}$

Central Ray f_4 = 53.048 = log 1.72469
Marginal f_4 = 53.081
.033

Spherical Abb. over corrected

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B7

$r_3 = 12.88 = \log 1.10992$
$r_4 = 39.632 = \text{"} 1.59804$
} Approx. correction for Sph. Abb.

---

b line - Central Ray Crown - (p. A13) from n.

$n = 1.51328 = \log 0.17992$ ✓
$r_1 = 13.40 = \text{"} \frac{1.12710}{1.30702}$ ✓
$n-1 = \frac{9.71035-}{1.59667}$ ✓
$f_1 = 39.507$ ✓
$t_1 = .350$
$d_2 = 39.157$ ✓ $= \log 1.59280$ ✓
$r_2 = = \text{"} \frac{1.12710}{2.71990}$ ✓

$n = \log 0.17992$ ✓
$r_2 = \text{"} \frac{1.12710}{1.30702}$ ✓ $= 20.278$ ✓

$d_2 = 1.59280$
$n-1 = \frac{9.71035-}{1.30315-} = 20.097$ ✓
$\frac{}{40.375-} = \log \frac{1.60612}{1.11378}$ ✓
$f_2 = 12.994$ ✓

Lerown b line

Flint.

$d_3 = \frac{.250}{12.744} = \log 1.10532$
$n' = 1.58079 = \text{"} 0.19887$
$r_3 = 12.8800 = \text{"} \frac{1.10992}{2.41411}$

$d_3 = \log 1.10532$
$n-1 = \text{"} \frac{9.76402}{0.86934} = 7.4019$
$\frac{}{5.4781} = \log \frac{0.73863}{1.67548}$
$f_3 = 47.367$
$d_4 = \frac{.180}{47.187} = \log 1.67383$
$r_4 = = \text{"} \frac{1.59804}{3.27187}$

$d_4 = \log 1.67383$
$n-1 = \text{"} \frac{9.76402}{1.43785-} = 27.406$

$n = \log 0.19887$
$r_4 = \frac{1.59804}{1.79691} = \frac{62.649}{35.243} = \log \frac{1.54708}{1.72479}$
$f_4 = 53.062$

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7. line, Lenticular Ray Lenses. (p. 114 [illegible])

$n = 1.52246 = \log 0.18255$ ✓
$r_1 = \quad " \quad \frac{1.12710}{1.30965}$ ✓ ✓
$n-1 = \quad " \quad 9.71805$ ✓
$f_1 = 39.049$ ✓ $= \quad " \quad 1.59160$ ✓
$d_2 = \frac{.350}{38.699}$ ✓ $= \quad " \quad 1.58769$ ✓
$r_2 = \quad = \quad " \quad \frac{1.12710}{2.71479}$ ✓ ✓

Lenses. 6. lin, $f_2 = 12.994 - .092$
k=58.4 " " = 12.902 - .136
7 " " = 12.766

$n = l.\ 0.18255$ ✓
$r_2 = " \ \frac{1.12710}{1.30965} = 20.401$ ✓ ✓
$d_2 = " \ 1.58769$ ✓
$n-1 = " \ \frac{9.71805}{1.30574} = 20.217$ ✓ ✓
$\frac{}{40.618} = \log \frac{1.60872}{1.10607}$ ✓ ✓
$f_2 = 12.766$ ✓ $=$

Flint. $d_3 = \frac{.250}{12.516} = \log 1.09749$
$n' = \quad = " \quad 0.20270$
$r_3 = 12.8800 = " \quad \frac{1.10992}{2.41019}$

$d_3 = \log 1.09749$
$n-1 = \frac{9.77434}{0.87183} = \frac{7.4443}{5.4357} = \log \frac{0.73526}{1.67485}$
$f_3 = 47.299 = " \quad$
$d_4 = \frac{.180}{47.119} = " \quad 1.67319$
$r_4 = \quad = " \quad \frac{1.59804}{3.27123}$

$d_4 = l.\ 1.67319$
$n-1 = " \ \frac{9.77434}{1.44753} = 28.024$

$n = " \ 0.20270$
$r_4 = " \ \frac{1.59804}{1.79074} = \frac{63.208}{35.179} = \log \frac{1.54628}{1.72495}$
Flint $= f_4 = 53.082 = " \quad$
6 " $= f_4 = \frac{53.062}{.020}$

Lens corrected for color.

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B9 $r_3 = 12.880$ = log. 1.10992
$r_4 = 39.632$ = " 1.59804

Marginal Ray. Flint.

$d_3 = 12.272$

$r_3 = \frac{12.880}{25.152}$ = log 1.40057 ✓

$\beta = 7° 51' 43''$ = sin $\frac{9.13604}{0.53661}$ ✓

r_3 = log $\frac{1.10992}{}$ ✓

$i = 15° 29' 38''$ ✓ = sin $\frac{9.42669}{}$ ✓

n = $\frac{0.20033}{}$

$\lambda = \frac{9° 41' 43''}{5° 47' 50''}$ ✓ = sin $\frac{9.22636}{}$ ✓

$\beta = \frac{7\ 51\ 43}{}$ r = $\frac{1.10992}{0.33628}$ ✓

$\gamma = 2° 53' 53''$ ✓ = sin $\frac{8.55664}{1.77964}$ ✓

60.205 ✓ =

$r = \frac{12.880}{}$

$f_3 = \frac{47.325}{.180}$ ✓

$d_4 = 47.145$ ✓

$r_4 = \frac{39.632}{7.513}$ ✓ = log 0.87581 ✓

γ = sin $\frac{8.55664}{9.43245}$ ✓

r_4 = log $\frac{1.59804}{}$ ✓

$i = 0° 23' 29''.8$ = sin $\frac{7.83441}{}$ ✓ 24/31

n = $\frac{0.20033}{}$

$\lambda = \frac{0° 37' 14''.5}{0\ 13\ 45.7}$ r_4 = $\frac{1.59804}{9.63278}$

$\gamma = \frac{2\ 3\ 53.}{1° 50' 7''.8}$ = sin $\frac{8.55055}{1.12724}$ ✓

13.404 ✓ = log

$f_4 = \frac{39.632}{53.036}$ ✓

---

nd = log $\frac{1.30262}{1.10992}$

$r_3 = 12.880$ $\frac{2.41254}{}$

$d(n-1) = \delta$ $\frac{7.418}{5.462}$ = log $\frac{0.73735}{1.67519}$ ✓

$f_3 = 47.336$ =

$d_4 = \frac{.180}{47.156}$ = 1.67353 ✓

r_4 = $\frac{1.59804}{3.27157}$ ✓

$d_4 = \log 1.67353$

$n-1 = \frac{9.76798}{1.44151} = 27.638$ ✓

$n = 0.20033$

$r_4 = \frac{1.59804}{1.79837} = \frac{62.860}{35.222}$ ✓ = log $\frac{1.54681}{1.72476}$ ✓

Central Ray $f_4 = 53.059$ ✓ =

Marginal " Δ = 53.036 ✓

.023 ✓

Sph. Abr. Under corrected

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B10
161

$r_3 = 12.87 = \log 1.10958$
$r_4 = 40.80 = \text{“} \; 1.61066$
$D = .275$

$d_3 = 12.247$
$r_3 = \frac{12.870}{25.117} = \log 1.39997$

$\beta = 7^\circ 51' 43'' = \sin \frac{9.13604}{0.53601}$
$r_3 = \log \frac{1.10958}{9.42643}$
$i = 18^\circ 28' 59'' = \sin \frac{0.20033}{9.22610}$
$n = \text{“} \frac{1.10958}{0.33568}$
$\lambda = \frac{9\ 41\ 22}{5\ 47\ 37} \quad r = \sin \frac{8.55740}{1.77828}$
$\beta = \frac{7\ 51\ 43}{2^\circ\ 4'\ 6''}$
$\gamma = 60.018$

$r_3 = 12.870$
$f_3 = 47.148$
$\quad\quad .180$
$d_4 = 46.968$
$r_4 = \frac{40.800}{6.168} = \log 0.79014$

$\gamma = \sin \frac{8.55740}{9.34754}$
$r_4 = \frac{1.61066}{7.73688}$
$i = 0^\circ 18' 45''.4 = \sin \frac{0.20033}{7.93721}$
$r_4 = \frac{1.61066}{9.54787}$
$\lambda = \frac{0\ 29\ 45.0}{0^\circ\ 10'\ 59''.6}$
$\gamma = \frac{2\ 4\ 6.0}{\delta = 1^\circ\ 53'\ 6''.4} = \frac{8.51714}{1.03073}$
10.733
40.1800
51.533

16/89

$n = \log 0.20033$
$d_3 = 12.630 = \text{“} \; 1.10140$
$r_3 = \text{“} \frac{1.10958}{2.41131}$
$\text{“} \frac{0.73779}{1.67352}$
$f_3 = 47.154 = \text{“} \; 1.67352$
$\quad\quad .180$
$d_4 = 46.974 = \text{“} \; 1.67186$
$r_4 = \frac{1.61066}{3.28252}$

$d = 1.67186$
$n-1 = \frac{9.76798}{.143984} = 27.532$

$n = 0.20033$
$r_4 = \frac{1.61066}{1.81099} = \frac{64.713}{37.181} = \log 1.57032$
$\text{“} \; 1.71220$

central $f_4 = 51.547$
Marginal $= \frac{51.533}{.014}$

Shr. Abb. under corrected.

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B11

Central Ray

$r_3 = 12.87 = \log 1.109\,58$
$r_4 = 40.80 = \;\;\; 1.61066$
$D = .278-$

6. line. Flint.

$f_2 = 12.994$
$d_3 = 12.719 \;\; .278-$
$n =$
$r_3 = 12.870$

$= \log 1.10450$
$= 0.19887$
$= 1.10958$
$= 2.41295-$

$d_3 = l.\ 1.10450$
$n-1 = \frac{9.76402}{0.86852} = \frac{7.3879}{5.4821} = \frac{0.73895-}{1.67400}$

$f_3 = 47.207$
$d_4 = 47.027 \;\; .180$
r_4

$= 1.67234$
$= 1.61066$
$= 3.28300$

$d_4 = l.\ 1.67234$
$n-1 = \frac{9.76402}{1.43636} = 27.312$

$n = 0.19887$
$r_4 = \frac{1.61066}{1.80953} = \frac{64.496}{37.184} = \frac{1.87035-}{1.71265-}$
$f_4 = 51.600$

---

7 line Flint.

$f_2 = 12.766$
$d_3 = 12.491 \;\; .278-$
$n =$
$r_3 = 12.8700$

$= \log. 1.09660$
$= 0.20270$
$= 1.10958$
$= 2.40888$

$d_3 = l.\ 1.09660$
$n-1 = \frac{9.77434}{0.87094} = \frac{7.4291}{5.44.09} = \frac{0.73567}{1.67321}$

$f_3 = 47.120$
$d_4 = 46.940 \;\; .180$
r_4

$= \log 1.67154$
$= 1.61066$
$= 3.28220$

$d_4 = l.\ 1.67154$
$n-1 = \frac{9.77434}{1.44588} = 27.917$

$n = 0.20270$
$r_4 = \frac{1.61066}{1.81336} = \frac{65.067}{37.150} = \frac{1.56996}{1.71224}$
$f_4 = 51.551$

7 line $f_4 = 51.551$
6 " $f_4 = \frac{57.600}{.049}$

$6 = f = 51.600$
$\lambda = 5614$ " $= 51.547$
$7.$ " $= 51.551$

Undercorrected for color

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$v_3 = 12.87$
$v_4 = 38.80 = \log.$ } $D = .275$

6. lum. flint. $d_4 = 47.027 = \log 1.67234$
$r_4 = \quad = \quad " \quad 1.58883 / 3.26117$

$d_4 = l.\ 1.67234$
$n-1 = 9.76402 / 1.43636 = 27.312$

$n = 0.19887$
$r = 1.58883 / 1.78770 = 61.334 / 34.022 = " \ 1.53176 / 1.72941$
$f_4 = 53.630 =$

---

7. lum. flint.

$d_4 = 46.940 = \log 1.67154$
$r_4 = \quad = \quad 1.58883 / 3.26037$

$d_4 = l.\ 1.67154$
$n-1 = 9.77434 / 1.44588 = 27.918$

change of .2.00 in f_4 = .049 in Color correction
" .049 " .016
" .67 "

$n = 0.20270$
$r_4 = 1.58883 / 1.79153 = 61.878 / 33.960 = " \ 1.53097 / 1.72940$
$=$

7 flint $f_4 = 53.629$
6 " $f_4 = 53.630 / .001$

Color correction perfect (under if either way)

$\lambda = 5614$

$f_2 = 12.905$
$d_3 = 12.630 = \log 1.10140$
$n = \quad 0.20033$
$r_3 = 12.870 \quad 1.58883 / 2.89056$
$= 7.4025 / 5.4675 = 0.73779 / 0.49689$
$f_3 = 24.755 / 47.154 = 1.53367 - .15277$
$d_4 = .180 / 46.974 = \log 1.67186$
$r_4 \quad = \quad 1.58883 / 3.26069$

1.10140
0.20033
1.10958
2.41131
0.73779
1.67352

$d_3 = 1.10140$
$n-1 = 9.76798 / 0.86938 =$

$d_4 = 1.67186$
$n-1 = 9.76798 / 1.43984 = 27.532$

$n = 0.20033$
$r = 1.58883 / 1.78916 = 61.540 / 34.008 =$

$1.53158 / 1.72911$

$f_4 = 53.594$

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B13

Marginal Ray -

$\tau_3 = 12.87 = \log 1.10958$
$\tau_4 = \frac{38.80}{51.67} = \text{"} \frac{1.58883}{2.69841}$

$f_2 = 12.521$
$\quad .275$
$d_3 = 12.246$
$\tau_3 = \frac{12.870}{25.116} = \log 1.39995$

$\beta = 7^\circ 51' 44'' = \sin \frac{9.13606}{0.53601}$
$= \frac{1.10958}{}$
$\tau_3 = \frac{}{}$
$i = 15^\circ 28' 58'' = \sin 9.42643$
$\quad 0.20033$
$\lambda = \frac{9^\circ 41' 22''}{5^\circ 47' 36} = \sin 9.22610$
$\tau = \frac{1.10958}{0.33568}$
$\gamma = 2^\circ 4' 8'' = \sin \frac{8.55752}{1.77816}$
$= \quad 60.001$

$\tau = \frac{12.870}{47.131}$
$f_3 = \quad .180$
$d_4 = 46.951 =$

$\tau_4 = \frac{38.800}{8.151} = \log 0.91121$
$= \sin 8.55752$
$\gamma \quad = 9.46873$
$\quad = 1.58883$
$\tau_4 \quad \quad 7.87990$
$i = 0^\circ 26' 4''.3 = \sin 0.20033$
$\quad 8.08023$
$\lambda = \frac{0\ 41\ 21.2}{0^\circ 15' 16''.9} = \sin \frac{1.58883}{9.66906}$
$\gamma = \frac{2\ 4\ 8.0}{\delta = 1^\circ 48' 51''.1} = \sin \frac{8.50049}{1.16857}$
$\quad 14.742$

Marginal
Central

$f_4 = \frac{38.800}{53.542}$
$\text{"} \quad \frac{53.594}{.052}$

2.8
1.7

Sph. Abb, Under corrected

Eq. focal length to correct for collar. $F = \frac{\tau_3 \tau_4}{(n-1)(\tau_3 + \tau_4)}$ $\therefore \tau_4 = \frac{\tau_3}{\frac{\tau_3}{F(n-1)} - 1}$

$\tau_3 \tau_4 = l. 2.69841$
$n-1 = l. 9.76798$
$\tau_3 + \tau_4 = \text{"} \frac{1.71324}{1.48122}$
$F = l 1.21719$
$n-1 = \frac{9.76798}{0.98517}$

$12.80 = \tau_3 = l. 1.10728$ | 1.10721
$F(n-1) = \frac{0.98517}{0.12441}$ | $\frac{0.98517}{0.12204}$
$1.32445 =$ | 9.51114
$.32445 =$ | $\cancel{9.51090}$
$\tau_4 = 39.452 =$ | 1.59607

$\tau_3 = 12.835 = l. 1.10841$
$\quad 0.98517$
$1.3281 = 0.12324$
$.3281 = 9.51601$
$d_4 = 39.120 = 1.59240$

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Marginal Ray.

B 14
165

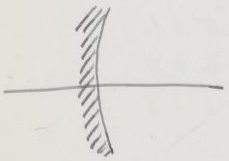
$r_3 = 12.80 = \log 1.10721$
$r_4 = 39.452 = \text{“} \; 1.59607$

$d_3 = 12.246$
$r_3 = 12.800$
$25.046 = \log 1.38104$

$\beta = 7° 51' 44'' = \sin 9.13606$
0.47710
$r_3 = 1.10721$
$i = 14° 53' 26'' = \sin 9.40989$
0.20033
$\lambda = 9° 19' 26'' = \sin 9.20956$
$5\ 34\ 0 = 1.10721$
0.31677
$\gamma = 2° 17' 44'' = \sin 8.60265$
$8\text{-}1.775 = 1.71412$

8/13

12.800
$f_3 = 38.975$
$.180$
$d_4 = 38.795$
$r_4 = 39.452$
$.657 = \log 9.$



$\sin i = \frac{(R-D)\sin\gamma}{R}$

$\sin\lambda = n \sin i$

$\delta = \gamma + (\lambda - i)$

$R' = R - R\frac{\sin\lambda}{\sin\delta}$

~~d less than r_4 - f_2 must be less than $r_4 = 39.452$.~~

~~$r_3 = 12.885 = \log 1.10841$~~
~~$r_4 = 39.120 = \text{“} \; 1.59240$~~

$d_3 = 12.246$
$r_3 = 12.800$
$25.046 = \log 1.39883$
$\beta = 7° 51' 44'' = \sin 9.13606$
0.53479
$r_3 = 1.10721$
$i = 15° 31' 30'' = \sin 9.42758$
0.20033
$\lambda = 9\ 42\ 55 = \sin 9.22725$
$5\text{-}48\ 28\text{-} \quad r_3 = 1.10721$
$\gamma = 2° 3' 9'' = \sin 0.33446$
8.55407
$60.310 = 1.78039$

6/12

12.800
$f_3 = 47.510$
$.180$
$d_4 = 47.330$
$r_4 = 39.452$
$7.878 = \log 0.89642$
$\gamma = 2° 3' 9''.0 \quad \sin 8.55407$
9.45049
$i = 0° 24' 35''.2 \quad r_4 = 1.59607$
$\sin 7.85442$
0.20033
$\lambda = 0\ 38\ 59.8 \quad \sin 8.05475$
$0° 14' 24''.6 \quad r_3 = 1.10721$
$\delta = 1° 48' 44''.4 = \sin 9.65082$
8.50004
$14.157 = 1.15078$

6/29
15-/19

39.452
$f_4 = 53.603$

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B75

Central Ray $\lambda = 5614$,

$f_2 = 12.905^-$

$d_3 = \frac{.275^-}{12.630} = \log 1.10140$

$n = \quad = \quad " \quad 0.20033$

$r_3 = 12.80 \quad = \quad " \quad \frac{1.10721}{2.40894}$

$d = 1.10140$

$n-1 = \frac{9.76798}{0.86938} = \frac{7.4026}{5.3974} = \frac{0.73218}{1.67676}$

$f_3 = 47.5^-08 \quad = \quad 1.67511$

$d_4 = \frac{.180}{47.328} \quad = \quad \frac{1.59607}{3.27118}$

$r_4 \quad 39.452$

$d = 1.67511$

$n-1 = \frac{9.76798}{1.44309} = 27.739$

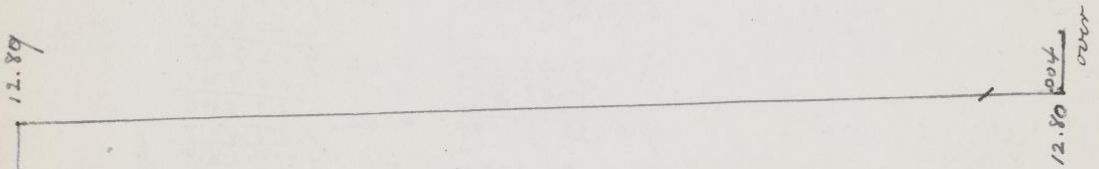
$n = 0.20033$

$r = \frac{1.59607}{1.79640} = \frac{62.5^-75^-}{34.836} = \frac{1.54203}{1.72915^-}$

Central $= f_4 = 53.599$

Marginal $f_4 = \frac{53.603}{.004}$

over corrected –



To correct for sphr. abb. $r_3 = 12.805^-$

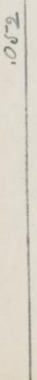
$r_3 = 12.805^- = \log 1.10789$

$F(n-1) = \frac{0.985^-17}{0.12222}$

$1.32250 = \frac{9.5^-1188}{1.595^-51}$

$.32250 =$

$r_4 = 39.401$



Change of .08 in r_3 (r_4 to correspond) changed Sphr. Ab. .056

" .01 " .007

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$\tau_3 = 12.805^- = \log 1.10739$
$\tau_4 = 39.401 = " \ 1.595^-1$
} correct for Sph. Abb.

6. line Flint.
(cont. B7.)

$f_2 = 12.995^-$
$d_3 \ \overset{.275^-}{12.720} = \log 1.10449$
$n = \quad = " \ 0.19887$
$\tau_3 = 12.805^- = " \ 1.10739$
2.41075^-

$d = 1.10449$
$n-1 = \frac{9.76402}{0.8685^-1} = \frac{7.3877}{5^-.4173} = \frac{0.73378}{1.67697}$

$f_3 = 47.5^-30$
$d_4 = \overset{.180}{47.35^-0} = \log 1.675^-32$
$\tau_4 \quad = " \ \frac{1.595^-1}{3.27083}$

$d = 1.675^-32$
$n-1 = \frac{9.76402}{1.43934} = 27.5^-00$

$n = 0.19887$
$\tau = \frac{1.595^-1}{1.79438} = \frac{62.285^-}{34.785^-} = \frac{1.5^-4140}{.72943}$
$f_4 = 5^-3.632$

7. line Flint

$f_2 = 12.766$
$d_3 = \overset{.271^-}{12.491} = 1.09660$
$n \quad = 0.20270$
$\tau_3 = 12.805^- = \frac{1.10739}{2.40669}$

$d = 1.09660$
$n-1 = \frac{9.77434}{0.87094} = \frac{7.4291}{5^-.37^-59} = \frac{0.73048^-}{1.67624}$

$f_3 = 47.45^-0$
$d_4 = \overset{.180}{47.270} = 1.67459$
$\tau_4 \quad = \frac{1.595^-1}{3.27010}$

$d = 1.67459$
$n-1 = \frac{9.77434}{1.44893} = 28.115^-$

$n = 0.20270$
$\tau = \frac{1.595^-1}{1.79821} = \frac{62.835^-}{34.720} = \frac{1.5^-405^-8}{1.7295^-2}$

7 line — $f_4 = 5^-3.644$
6 " — $= \frac{5^-3.632}{.012}$

~~over corrected~~
(Correct) for color.

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B 17

Result of Calculation

$r_1 = 13.40$
$r_2 = 13.40$
$r_3 = 12.805$
$r_4 = 39.401$

$t_1 = .350$
$t_2 = .180$
$d = .275$

$f_4 = 53.63$ in.

Measurement of completed Lens

$r_1 = 13.38$
$r_2 = 13.38$ –
$r_3 = 12.77$
$r_4 = 39.56$

$t_1 =$
$t_2 = .157$
$d =$

$f_4 = 52.56$

3.15) 52.56 (15 diameter
31.5
21.0
15.75
5.25

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B 18
169

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Best color correction – Hastings –

$A = \frac{1}{r_1} + \frac{1}{r_2}$ (Crown)

$B = \frac{1}{r_3} + \frac{1}{r_4}$ (Flint)

n for crown glass
n' " flint "

1. $n' = \alpha + \beta n + \gamma n^2$ $\qquad \varphi = (n-1)A + (n'-1)B$

2. $\frac{1}{F} = \varphi = (n-1)A + (n'-1)B$

$= n(A + \beta B) + n^2 \gamma B + (\alpha - 1)B - A$

$\frac{d\varphi}{dn} = A + \beta B + 2\gamma n B = 0$

3. $B = -\frac{A}{\beta + 2\gamma n}$ is the condition of achromatism cannot be met, best value of B when $n \doteq n_{\lambda 5614}$. { φ does not change for small change in n

To find what ray to combine with C to give the best color correction

$\varphi_c = (n_c - 1)A + (n'_c - 1)B$ ①

$\varphi_c = n(A + \beta B) + n^2 \gamma B + (\alpha - 1)B - A$ ②

~~$+ B(n^2\gamma + \alpha - 1) - A$~~

find φ_c in equation ①, then substituting its value in equation ② find the two values of n satisfying it, viz n_c and n_x.

then, $n'_x = \alpha + \beta n_x + \gamma n_x^2$

$n_c - 1 = .57328 = \log 9.71035$

$A = 1.10852 = \text{"} \; \frac{0.04474}{9.75509}$

$.56897$

$.42320$

$\varphi_c = .99217$

$n'_c - 1 = .58079 = \log 9.76402$

$B = .72865 = \text{"} \; \frac{9.86252}{9.62654}$

$.42320 = \quad\quad$

$.99217 = n\left(1.10852 + (-9.4 \times .72865)\right) + n^2\left(3.6 \times .72865\right) + 6.56148 \times .72865 - A$

$= -n \times 5.74079 + 2.62314\, n^2 + 3.67250$

$2.62314\, n^2 - 5.74079\, n = -3.67250 + .99217 = -2.68033$

$n^2 - 2.18852\, n = -1.02180$

$n^2 - 2.18852\, n + \left(\frac{2.18852}{2}\right)^2 = -1.02180 + 1.19740 = +0.17560$ ~~0.20264~~

$n - 1.09426 = \pm 0.41905$

$n = 1.09426 \pm 0.41905$

$n = 1.51331$ and 0.67521

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see p. 46. forward.

$\alpha = 11.5369$

$\beta = -14.6$

$\gamma = 8.3$

$A = 7.89$ } when $\frac{1}{F} = 1$

$B = -5.26$ }

$n - 1 =$

see p. 43.

$\alpha = 7.56148$

$\beta = \frac{-9.4}{7.4}$ ~~0.72865~~

$\gamma = 3.6$

~~$A = \frac{0.72865}{7.60}$~~

~~$B = -5.00$~~ } when $F = 1$

n_{5614}

$A = 1.10852$

$B = 0.72865$

$n_c - 1 = .51328 = \log 9.71035^-$ } $n'_c - 1 = .58079 = \log 9.76402$

$A = 7.60 = \text{"} \; 0.88081$ $B = -5.00 = \text{"} \; 0.69897$

$3.9009 = \text{"} \; 0.59116$ $- 2.9040 \quad - 0.46299$

$- 2.9040$

$\frac{1}{F_{\&c}} = \varphi_c = 0.9969$

$0.9969 = n(7.60 + 47.) + n^2(-18) + (6.56148 \times -5.) - 7.60$

$= n\,54.6 - n^2 18 - 32.8074 - 7.60$

$18n^2 - 54.6n = -41.4043$

$9n^2 - 27.3n = -20.7021$

$n^2 - 3.03n = -2.3002$

$n^2 - 3.03n + \left(\frac{3.03}{2}\right)^2 = -2.3002 + 2.2952 = \sim\!\sim .0050 \sim\!\sim$

~~$n - 1.515 = \pm 2.1320\ 0.21213$~~

~~$n = 1.515 \pm 2.1320 \pm 0.21213$~~

~~$+1.72713$ or 1.30287~~

$= -$ ~~0.617 or $+ 2.647$~~

$n^2 - 3.03n + \left(\frac{3.03}{2}\right)^2 = -2.3002 + 2.2952 = .0050$

$n - 1.515 = \pm .07071$

$n = 1.515 \pm .07071$

$= \begin{cases} 1.44429 = n_c \\ 1.58571 \end{cases}$

$n_c = 1.51328$

.9969
32.8074
7.60
18) 40.4043

3.03
3.03
909
9090
4) 9.1809
2.2952
2.3002
~~4.5754~~
.0050
log 8.6552
0.32878
9.32660
2.3002
2.2952
.0050

.07
.07
.0049

.0050 .07
07
.0049

$50 = 1.69897$
$7.071 = .84948$

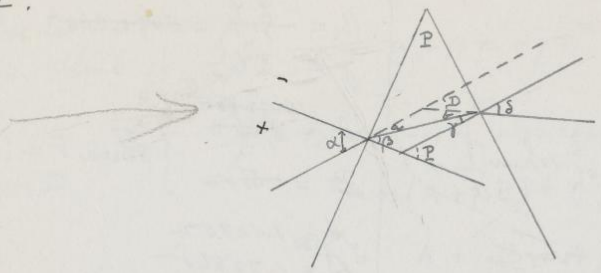
.07071
1.515000
1.44429
1.58571

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Case I.

$+\alpha$



$D = a + b$
$= (\alpha - \beta) + (\delta - \gamma)$
$= \alpha + \delta - (\gamma + \beta)$
$= \alpha + \delta - P$

Deviation of Ray after passing through prism, whose refracting angle P.

$\sin \beta = \frac{\sin \alpha}{n}$

$\gamma = P - \beta$

$\sin \delta = n \sin \gamma$

$D = \delta - (P - \alpha) = \delta + \alpha - P$ ✓

Minimum Deviation, $\sin \alpha = n \sin \frac{1}{2} P$

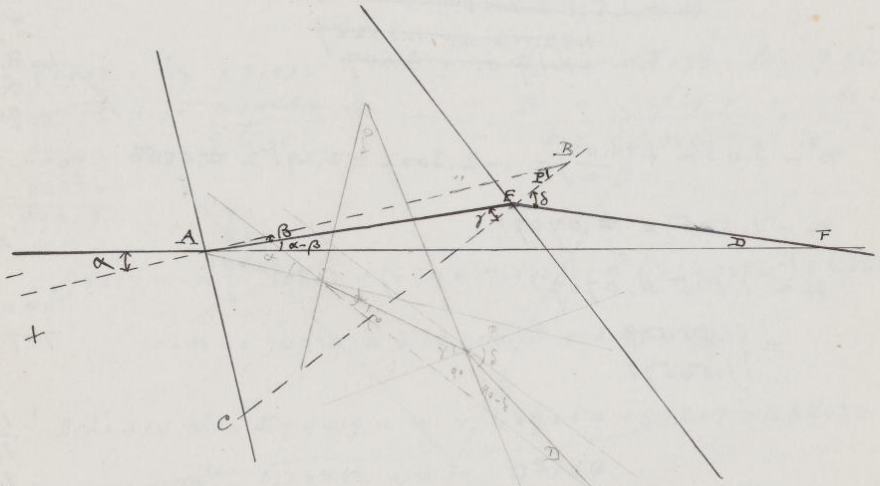
$\beta = \gamma = \frac{1}{2} P$

$\delta = \alpha$

$D = 2\alpha - P$

Case II

$-\alpha$



Triangle ABC.

$P = 90° - C = 90 - [180° - (90° - \beta) - \gamma] = 90° - [180° - 90° + \beta - \gamma] = 90° - 180° + 90° - \beta + \gamma$

$= -\beta + \gamma$

Triangle AEF.

$D = 180° - (A + E) = 180° - (\alpha - \beta) - [360° - (\delta + 180° - \gamma)]$

$= 180° - \alpha + \beta - 180 - \gamma + \delta$

$= \beta - \gamma + \delta - \alpha$

but $-P = \beta - \gamma$

$\therefore D = \delta - \alpha - P$

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Crown Glass Prism 60°.

At minimum deviation for the C ray.

$n = 1.51328 = \log 0.1799212$

$\frac{1}{2}P = 30° = \sin 9.6989700$

$\alpha = 49°10'9'' = \text{“} 9.8788912$ (148, 164)

$P = 60°\ 0\ 0$

$\alpha = 49\ 10\ 9$

$P - \alpha = 10°\ 49'\ 51''$

6.

$2\alpha = 98°\ 20'\ 18''$

$P = 60\ 0\ 0$

$D = 38°\ 20'\ 18''$

$\lambda = 5614.$

$\sin \alpha = 9.8788912$

$n = 1.51685 = 0.1809431$

$\beta = 29°\ 53'\ 20'' = 9.6979481$ (73, 8)

$\gamma = 30°\ 4'\ 40'' = 9.6999895$

$\delta = 49°\ 28'\ 57'' = 9.8809326$ (196, 130)

$P - \alpha = 10\ 49\ 51$

$D = 38°\ 39'\ 6''$

7

$\sin \alpha = 9.8788912$

$n = 1.52246 = 0.1825467$

$\beta = 29°\ 48'\ 3'' = 9.6963445$ (236, 109)

$\gamma = 30°\ 11'\ 57'' = 9.7015743$

$\delta = 49°\ 58'\ 48'' = 9.8847210$ (126, 84)

$P - \alpha = 10\ 49\ 51$

$D = 39°\ 8'\ 54''$

	D =			Dispersion		
C	38°	20'	18"	48' 36"	2916"	10000
λ	38	39	6	29 48	1788	6132
F	39	8	54	0	0	0

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Corom Flass Prism 60°

At Minimum Deviation for the 7 Rays.

$n = 0.1825467$
9.6989700
$\alpha = 49° 34' 22'' = 9.881.5167$ (25, 42)
$P - \alpha = 10° 25' 38''$

C

9.8815167
0.1799212
$\beta = 30° 12' 3'' = \sin 9.701.5955$ (85, 2, 10, 3)
$\gamma = 29° 47' 57'' = \sin 9.6963226$
$\delta = 48° 46' 4'' = \sin 9.8762438$ (361, 77)
$P - \alpha = 10\ 25\ 38$
$D = 38° 20' 26''$

λ

9.8815767
0.1809431
$\beta = 30° 7' 21'' = \sin 9.7005736$
$\gamma = 29° 52' 39'' = \sin 9.6973577$
$\delta = 49° 4' 45'' = \sin 9.8783008$ (2916, 92)
$10\ 25\ 38$
$D = 38° 39' 7''$

F

$\alpha = 49° 34' 22''$
$2\alpha = 99\ 8\ 44$
$D = 39° 8' 44''$

	$D =$			Dispersion		
C	38°	20′	26″	48′ 18″	2898″	10000
λ	38	39	7	29 37	1777	6132
F	39	8	44	0	0	0

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Lerroux Glass Prism at 15° less than min. dev. for C line, 175

$\alpha = 34^\circ\ 10'\ 9''$ ✓ = sin. 9.74942 87 ✓

$49^\circ\ 10'\ 9''$
$15^\circ\ 0'\ 0''$

$n =$ 0.17992 12 ✓
9.56950 75 ✓

$P - \alpha = 28^\circ\ 49'\ 51''$ ✓
$25\ 50\ 0$

$\beta = 21^\circ\ 47'\ 4''$ ✓ =
$38^\circ\ 12'\ 56''$ ✓ =

9.79142 51 ✓
0.17992 12 ✓
9.97134 63 ✓

C

$\delta = 69^\circ\ 24'\ 54''$ ✓ =
$25\ 49\ 00$
$D = 43^\circ\ 34'\ 54''$
$43\ 34\ 54$ ✓

9.74942 87 ✓
0.18094 31 ✓
9.56848 56 ✓

$\beta = 21^\circ\ 43'\ 50''$ ✓ =
$38^\circ\ 16'\ 10''$ ✓ =

9.79194 35 ✓
0.18094 31 ✓
9.97288 66 ✓

$\delta = 69^\circ\ 57'\ 58''$ ✓ =
$25\ 49\ 00$
$D = 44^\circ\ 7'\ 58''$ ✓
$44\ 7\ 57$

λ

9.74942 87 ✓
0.18254 67 ✓
9.56688 20 ✓

$\beta = 21^\circ\ 38'\ 47''$ ✓ =
$38^\circ\ 21'\ 13''$ ✓ =

9.79275 09 ✓
0.18254 67 ✓
9.97529 76 ✓

$\delta = 70^\circ\ 51'\ 28''$ ✓ =
$25\ 49\ 00$
$D = 45^\circ\ 1'\ 28''$ ✓

Z.

	D					
C	43°	35′	3″	1° 26′ 34″	5194	10000
λ	44	8	0	53 37	3217	6194 ✓
F	45	1	37	0	0	0

43	34	54	1 26 34	5194	
44	7	57	53 37	3217	
45	1	28	0	0	

5194) 32170 (6194
31164
10060
5194
48660
46746
1914 0

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Flint Glass Prism, 60°

At Minimum Deviation for the C ray.

$n = 1.58079 = \log 0.1988744$

$\frac{1}{2}P = \sin 9.6989700$

$\alpha = 52° 13' 21'' = \sin 9.8978444$

$P - \alpha = 7° 46' 39''$

$2\alpha = 104\ 26\ 42''$

$D = 44° 26' 42''$

6

$\alpha = \log 9.8978444$

$n = \text{"} 0.2003333$

$\beta = 29° 53' 21'' = \sin 9.6975111$

$\gamma = 30° 6' 39'' = \text{"} 9.7004219$

$\delta = 52° 43' 21'' = \text{"} 9.9007552$

$P - \alpha = 7\ 46\ 39$

$D = 44° 56' 42''$

$\lambda = 5614$

$\alpha = \log 9.8978444$

$n = \text{"} 0.2026967$

$\beta = 29° 42' 38'' = \sin 9.6951477$

$\gamma = 30° 17' 22'' = \text{"} 9.7027480$

$\delta = 53° 32' 51'' = \text{"} 9.9054447$

$P - \alpha = 7\ 46\ 39$

$D = 45° 46' 12''$

7.

	D =		Dispersion		
C	44°	26' 42"	1° 19' 30"	477"	10000
λ	44	56 42	49 30	297"	6226
7	45	46 12	0	6	0

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Flint Glass Prism, 60°

At Minimum Deviation for the F ray.

n = log 0.2026967

$\frac{1}{2}P$ = sin. 9.6989700

$\alpha = 52^\circ\ 52'\ 51''$ = sin 9.9016667

$P - \alpha = 7^\circ\ 7'\ 9''$

C

α = Sin. 9.9016667

n = 0.1988744

$\beta = 30^\circ\ 17'\ 34''$ = Sin 9.7027923

$\gamma = 29\ 42\ 26$ = " 9.6955034

$\delta = 57^\circ\ 34'\ 19''$ = " 9.8939778

$D = 44\ 27\ 10$

λ

α = Sin 9.9016667

n = 0.2003333

$\beta = 30^\circ\ 10'\ 50''$ = Sin 9.7013334

$\gamma = 29^\circ\ 49'\ 10''$ = " 9.6965909

$\delta = 52^\circ\ 3'\ 59''$ = " 9.8969242

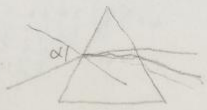
$D = 44\ 56\ 50$

$\alpha = 52^\circ\ 52'\ 51''$

$2\alpha = 105^\circ\ 45'\ 42''$

$D = 45^\circ\ 45'\ 42''$

	D =	Dispersion		
C	44° 27′ 10″	1° 18′ 32″	4712″	10000
λ	44 56 50	48 52	2932	6222
F	45 45 42	00	0	0



α for flint increased

Flint 6222 / borrow 6132 / 90°

4/90 = 1/22

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Flint glass prism 60°.

At 10° beyond minimum deviation for 7 ray.

C.

$\alpha = 62° 52' 51''$ ✓ = sin. 9.949.4195 ✓

n = 0.1988744 ✓

$\beta = 34° 16' 0''\frac{1}{2}$ ✓ = sin 9.75-05-45-1 ✓

$\gamma = 25° 43' 59\frac{1}{2}''$ ✓ = sin 9.6376709 ✓

$\delta = 43° 20' 31''$ ✓ = sin 9.836.5-45-3 ✓

$\alpha = 62\ 52\ 51$

$106° 13' 22''$ ✓

$P = 60$

$D = 46° 13' 22''$ ✓

λ =

α = sin. 9.949 4195 ✓

n = 0.200 3333 ✓

$\beta = 34° 8' 10''$ ✓ = sin 9.749.0862 ✓

$\gamma = P - \beta = 25° 51' 50''$ ✓ = sin 9.639.7203 ✓

$\delta = 43° 46' 55''$ ✓ = sin 9.840 05-36 ✓

$62\ 52\ 51$

$106\ 39\ 46$

$D = \frac{60}{46° 39' 46''}$ ✓

7.

α = sin 9.949.4195 ✓

n = 0.202 6967 ✓

$\beta = 33° 53' 32''$ ✓ = sin. 9.7467228 ✓

$\gamma = 26° 4' 28''$ ✓ = sin 9.6429991 ✓

$\delta = 44° 30' 15''$ ✓ = sin 9.845-6938 ✓

$2\ 52\ 51$

$D = 47° 23' 6''$ ✓

	D		
C	46° 13' 22" ✓	1° 9' 44" ✓	4184" ✓	10000
λ	46 39 46 ✓	43 20 ✓	2600 ✓	6214
7	47 23 6 ✓	40 20	0	0

4184) 2600.0 (6214
25104
8960
8368
5921
4184
17370

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Flint glass prism 60°

At 15° beyond minimum deviation for F ray.

$\alpha = 67^\circ\ 52'\ 51''$ = sin 9.9667999

$R =$ $n =$ 0.1988744

$P - \alpha = -7^\circ\ 52'\ 51''$

$\beta = 35^\circ\ 52'\ 35''$ = sin 9.7679256 (1 3 9)

$\gamma = 24^\circ\ 7'\ 25''$ = sin 9.6114116

0.1988744

$\delta = 40^\circ\ 14'\ 48''$ = sin 9.8102860 (6 6 1 / 1 9 9)

$7\ 52\ 51$

C. $D = 48^\circ\ 7'\ 39''$

α = sin 9.9667999

$n =$ 0.2003333

$\beta = 35^\circ\ 44'\ 15''$ = sin 9.7664666 (1 2 2 / 1 4 4)

$\gamma = 24^\circ\ 15'\ 45''$ = sin 9.6137549

0.2003333

$\delta = 40^\circ\ 40'\ 28''$ = sin 9.8140882 (6 8 2 / 2 0 0)

$7\ 52\ 51$

λ. $D = 48^\circ\ 33'\ 19''$

α = sin 9.9667999

$n =$ 0.2026967

$\beta = 35^\circ\ 30'\ 50''$ = sin 9.7641032 (1 6 / 1 6)

$\gamma = 24^\circ\ 29'\ 10''$ = sin 9.6174959

0.2026967

$\delta = 41^\circ\ 22'\ 31''$ = sin 9.8201926 (1 3 / 1 3)

$7\ 52\ 57$

7. $D = 49^\circ\ 15'\ 22''$

	D			
C	48° 7′ 39″	1° 7′ 43″	4063″	10000
λ	48 33 19	42 3	2523	6209
7	49 15 22	0	0	0

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Crown Glass Prism,

turned so that α = 30° less than for min dev. for C ray.

α = 20° less than for M.D. Cray

$= 29^\circ\ 10'\ 9'' = \sin$ 9.6878764
0.1799212
$18^\circ\ 47'\ 18'' =$ 9.5079552
047
505
$41^\circ\ 12'\ 42'' =$ 9.8187817
0.1799212
$=$ 9.9987029

$\alpha = 19^\circ\ 10'\ 9'' = \sin$ 9.5162936
$n =$ 0.1799212
$12^\circ\ 31'\ 49'' =$ 9.3363724
2854
0870
$y =$ $47^\circ\ 28'\ 11'' =$ 9.8674204
0.1799212
total reflection 0.0473416

7769
48
7817

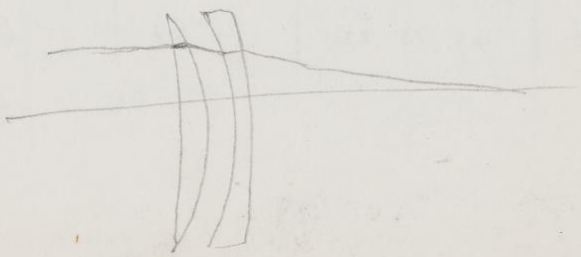
9.6878764
0.1809431
$=$ 9.5069333

$12^\circ\ 30'\ 1'' =$ 9.5162936
0.1809431
9.3353505
368
137
$47^\circ\ 29'\ 59'' =$ 9.8676290

9.6878764
$18^\circ\ 40'\ 16''$ 0.1825467
$41^\circ\ 19'\ 44''$ 9.8053297
963
334

9.8197942
0.1825467
total reflection 9.0023409

$12^\circ\ 27'\ 13'' =$ 9.5162936
0.1825467
9.3337469
190
279
$47^\circ\ 32'\ 47'' =$ 9.8679527



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Flint Glass Prism -

turned so that $\alpha = 30°$ more than for min dev for F ray

$\alpha = 82° 52' 54''$ = sin 9.9966389

$n =$ 0.1988744

$38° 52' 55''$ = sin 9.7977645

$21° 7' 8''$ = sin 9.5566532

0.1988744

$\delta =$ $34° 43' 7''$ = 9.7555276

P − α 22 52 51

$D =$ $57° 35' 58''$ =

$\alpha =$ sin 9.9966389

$n =$ 0.2003333

$38° 43' 38''$ = 9.7963056

$21° 16' 22''$ = 9.5596775

0.2003333

$35° 7' 53''$ = 9.7600108

22 52 51

$D =$ $57° 0' 44''$

$\alpha =$ sin 9.9966389

$n =$ 0.2026967

$38° 28' 43''$ = 9.7939422

$21° 31' 17''$ = 9.5644867

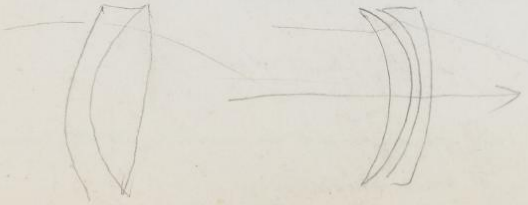
0.2026967

$35° 48' 20''$ = 9.7671834

22 52 51

$D =$ $58° 41' 11''$

	D			Dispersion		
C	57°	35'	58''	1° 5' 13''	3913	10000
x	58	0	44	40 27	2427	6202
F	58	41	11	0	0	0



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$4\frac{1}{2}$ inch Objective.

Focal length = $4\frac{1}{2} \times 12 = 54$ in
= $4\frac{1}{2} \times 13\frac{1}{2} = 60$

To find what ray must unite at the same focus with C to obtain the best color correction. "Hastings"

Measure Index of Refraction of $\lambda = C$.
$\lambda = 5614$. the brightest ray.
$\lambda = F$.

n = Index of refraction of Crown Glass
n' = " " " " Flint "

$A = \frac{1}{r_1} + \frac{1}{r_2}$, $B = \frac{1}{r_3} + \frac{1}{r_4}$ $\varphi = \frac{1}{F}$

(1) $\varphi = (n-1)A + (n'-1)B$

(2) $n' = \alpha + \beta n + \gamma n^2$

(3) $1 = (n_{5614} - 1)A + (n'_{5614} - 1)B$ when $F_{5614} = 1$

$\varphi = nA - A + \alpha B + \beta n B + \gamma n^2 B - B$

(4) $\varphi = n(A + \beta B) + \gamma n^2 \beta - A - B + \alpha B = n(A + \beta B) + (\gamma n^2 + \alpha - 1)B - A$

put $\frac{d\varphi}{dn} = A + \beta B + 2\gamma n B = 0$ when a small change in n produces no change in φ or $\frac{1}{F}$ φ at maximum

(5) $A = -B(\beta + 2\gamma n)$

(6) when $A = -B(\beta + 2\gamma n_{5614})$ the ~~greatest~~ brightest rays of the spectrum are bunched together at the focus of λ_{5614} the brightest ray and is the condition of best color correction for telescope O.G. $A = -B(\beta + 2\gamma n_G)$ for Photographic

First find the values of α, β and γ in equation (2)
then " " " " A and B " " (3) and (6)

then introducing the values of n_c and n'_c in equations (1) and (4)

(7). we have $\varphi_c = (n_c - 1)A + (n'_c - 1)B$

(8) ~~$\varphi_c = n(A + \beta B) + n^2 \gamma B + B(\alpha - 1) - A$~~

$\varphi_c = n^2 \gamma B + n(A + \beta B) + B(\alpha - 1) - A$.

then find φ_c in equations (7) and substituting its value in equation (8) find the two values of n which satisfy it. namely n_c and n_x

then $n'_x = \alpha + \beta n_x + \gamma n_x^2$ for the flint glass.

n_x therefore is the index of refraction of the ray which must be united at the same focus with the C ray. to obtain the most perfect color correction

This of course is true only for infinitely thin lenses. Oct 24 86.

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4½.

Oct. 25. 86. Sawed the corners off the squares of Crown + Flint glass on a hand milling machine, using a sheet brass disc. the section of glass sawed through was 11/16 x 1 17/16 on the average. Sawed one corner off in 9 minutes. the others took rather longer say from 10 to 12 minutes, as did not crowd them quite so hard.

Nov. 6 to 10. 87 Roughed out the Crown lens on milling mach. very close to the proper curve and thickness -

Nov 14 - 87. Roughed out Flint lens -

Finished about Sept 1st 1889.

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4½

Angle of Prisms = α

Crown

Vernier A. B	Vernier B. B
119 59 30	119 59 30
119 59 30	119 59 30
119 59 22	119 59 15
119 59 23	119 59 58

Ave. β = 119° 59′ 30″

α = 60° 0′ 30″

Flint

Vernier A	Vernier B
119 59 18	119 59 15
119 59 0	119 59 45
119 59 45	119 59 30
119 59 15	119 59 38

Ave. β = 119° 59′ 26″

α = 60° 0′ 34″

Double Deviation = 2δ

see check measurement 27 pages over

Crown

b. line

[76° 7′ 45″	[76° 7′ 37″
76 7 15]	76 7 53]
76 7 0	76 7 0
76 7 15	76 7 8 } 12″
76 7 23	76 7 23

Ave 2δ = 76° 7′ 15″ (−9″ Hastings)

λ = 5614 line

76° 42′ 53″	76° 42′ 45″
76 43 22	76 43 37

Ave. 2δ = 76° 43′ 9″ (−5′ 9″ Hastings)
76 43 52 remeasurement

7 line

77° 38′ 7″	77° 38′ 0″
77 38 7	77 38 30

Ave 2δ = 77° 38′ 11″ (−7″ Hastings)

Flint

b. line

95° 5′ 22″	95° 5′ 45″
95 5 30	95 5 30

Ave 2δ = 95° 5′ 32″ (+46″ Hastings)

λ = 5614 line

96° 21′ 15″	96° 20′ 15″
96 20 53	96 20 30
96 21 0	96 20 52

Ave. 2δ = 96° 20′ 47″ (−9′ 51″ Hastings)
96 21 18 remeasurement

7 line.

98° 23′ 37″	98° 23′ 30″
98 23 45	98 44 0

Ave 2δ = 98° 23′ 43″ (+1′ 16″ Hastings)
98 23 58 remeasurement

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4½

– Index of Refraction –

$$n = \frac{\sin \frac{1}{2}(\alpha+\delta)}{\sin \frac{1}{2}\alpha}$$

Lesovoe

C line –

$2\delta = 76^\circ\ 7'\ 15''$
$\frac{1}{2}\delta = 19\ 1\ 49$ ✓
$\frac{1}{2}\alpha = 30\ 0\ 15$ ✓
$\frac{1}{2}(\alpha+\delta) = 49^\circ\ 2'\ 4''$ ✓ = log sin 9.8780067 ✓
$\frac{1}{2}\alpha$ = " 9.6990247 ✓
$n = 1.5100018$ ✓ = log 0.1789820 ✓
$n-1 = 0.510018$ = " 9.7075856

λ = 5614 line

76 43 9
19 10 58
30 0 15
49 11 13 =
9.8790076
9.6990247
0.1799829

$2\delta = 76^\circ\ 43'\ 9''$
$\frac{1}{2}\delta = 19\ 10\ 47$
$\frac{1}{2}\alpha = 30\ 0\ 15$
$\frac{1}{2}(\alpha+\delta) = 49\ 11\ 2$ = log sin 9.8789876
$\frac{1}{2}\alpha$ = " 9.6990247
$n = 1.5134332$ = 0.1799629
$n-1 = 0.513432$ = 9.7104829

7 line

$2\delta = 77^\circ\ 38'\ 11''$
$\frac{1}{2}\delta = 19\ 24\ 33$
$\frac{1}{2}\alpha = 30\ 0\ 15$
$\frac{1}{2}(\alpha+\delta) = 49^\circ\ 24'\ 48''$ = log sin 9.8804836
$\frac{1}{2}\alpha$ = " 9.6990247
$n = 1.5186554$ = 0.1814589
$n-1 = 0.518654$ = 9.7148777

(4) line – (line towards H from group ·) = g

$\delta = 39^\circ\ 22'\ 11''$
$\frac{1}{2}\delta = 19\ 41\ 5$ ✓
$\frac{1}{2}\alpha = 30\ 0\ 15$
$\frac{1}{2}(\alpha+\delta) = 49\ 41\ 20$ = log sin 9.882264 ✓
$\frac{1}{2}\alpha$ = " 9.6990025 ✓
$n = 1.52489$ ✓ = 0.183239 ✓
$n-1 = .52489$ ✓ = 9.720068 ✓

If for C line 2δ had uncertainty of 10"

2δ might = $76^\circ\ 7'\ 25''$
$\frac{1}{2}\delta = 19\ 1\ 51$
$\frac{1}{2}\alpha = 30\ 0\ 15$
$49\ 2\ 6$ = log sin 9.87800104
$\frac{1}{2}\alpha$ = " 9.6990247
= 0.1789857

1.5100306
177
.0000129

Hence there is an uncertainty of 1 unit in the fifth place

Flint

C line –

$2\delta = 95^\circ\ 5'\ 32''$
$\frac{1}{2}\delta = 23\ 46\ 23$
$\frac{1}{2}\alpha = 30\ 0\ 17$
$53^\circ\ 46'\ 40''$ = log sin 9.9067288
$\frac{1}{2}\alpha$ = " 9.6990320
$n' = 1.6132232$ = log 0.2076968
$n'-1 = 0.6132232$ = " 9.7876248

λ = 5614 line

96° 21' 18"
24 5' 19½
30 0 17
54 5' 36½ = 9.908472
9.699032
0.209440

$2\delta = 96^\circ\ 20'\ 47''$
$\frac{1}{2}\delta = 24\ 5'\ 12$ = 1.619720
$\frac{1}{2}\alpha = 30\ 0\ 17$
$54^\circ\ 5'\ 29''$ = log sin 9.9084601
$\frac{1}{2}\alpha$ = " 9.6990320
$n' = 1.619676$ = log 0.2094281
$n'-1 = 0.619676$ = " 9.7921647

7 line

$2\delta = 98^\circ\ 23'\ 43''$
$\frac{1}{2}\delta = 24\ 35\ 56$
$\frac{1}{2}\alpha = 30\ 0\ 17$
$54\ 36\ 13$ = log sin 9.9112452
$\frac{1}{2}\alpha$ = " 9.6990320
$n' = 1.630097$ = log 0.2122132
$n'-1 = 0.630097$ = " 9.7994074

(4) line – = g

$2\delta = 50^\circ\ 30'\ 33''$ correct, see 27 lines over
$\frac{1}{2}\delta = 25\ 15\ 16$ ✓
$\frac{1}{2}\alpha = 30\ 0\ 17$
$55\ 15\ 33$ ✓ = log sin 9.9147331 ✓
$\frac{1}{2}\alpha$ = " 9.699032 ✓
$n' = 1.6432444$ ✓ = 0.2157701 ✓
$n'-1 = .6432444$ ✓ = 9.808376 ✓

~~If 2δ had uncertainty of 15" = δ uncertainty of 7"~~
~~call $2\delta = 50^\circ\ 30'\ 40''$~~
~~$\frac{1}{2}\delta = 25\ 15\ 20$~~

D line –

$n' = 1.61807$

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Best color correction.

Eq. 2. $n' = \alpha + \beta n + \gamma n^2$.

(1)	$1.613232 =$	$\alpha +$	$\beta\ 1.5710018 +$	$\gamma\ 2.280153$ ✓
(2)	$1.619676 =$	$\alpha +$	$\beta\ 1.513432 +$	$\gamma\ 2.290477$ ✓
(3)	$1.630097 =$	$\alpha +$	$\beta\ 1.518654 +$	$\gamma\ 2.306310$ ✓
(3)-(2)	$.010421 =$		$\beta\ .005222 +$	$\gamma\ 0.015833$ ✓
(2)-(1)	$.006444 =$		$\beta\ .003414 +$	$\gamma\ .010324$ ✓
	$.00985641 =$		$\beta\ .005222 +$	$\gamma\ .015791143$ ✓
(4)	$.0005 64359 =$			$\gamma\ .00004157$

.020036

$n_2 = 1.518654$
$n_3 = 1.513237$
$.005417$

$7.788 / 2 / 5.576 / 1.545 / 7.121$

$\gamma = 13.57611 = \log. 1.1327754$

$\beta y = .00132$

	$.006444 =$	$\beta\ .003414 +$	$.1401598$
$-$	$.003414\beta =$		$.1337158$
	$\beta = -39.16690 = \log 1.5929192$		
sub. in (1)	$1.613232 = \alpha$	$- 59.14270 +$	$30.955-62$
	$\alpha = 29.80081$		

$\delta p = \beta_p \delta n^2$

$2.7 / 13 / 81 / 27 / 351$

Eq. 3 $\quad 1 = (n_\lambda - 1) A + (n'_\lambda - 1) B$

6 $\quad A = -B(\beta + 2\gamma n_\lambda)$

$\lambda = 0.513432\ A + 0.619676\ B$

$A = -B[-39.733 + 2 \times 13.763 \times 1.513432.]$

$A = -1.925\ B$

$1 = -0.988835\ B + 0.619676\ B$

$1 = -0.369159\ B$

$B = -2.7124$

$A = +5.2214$

see next page

Eq. 7. $\varphi_c = (n_c - 1) A + (n'_c - 1) B$

$= 0.510018 \times 5.2214 + 0.613232 \times (-2.7124)$

$= 2.66305 - 1.66334$

$= 0.99971$

see next page

Eq. 8. $\varphi_c = n^2 \gamma B + n(A + \beta B) + B(\alpha - 1) - A$ $\quad [\times 29.229 - 5.2214$

$0.99971 = n^2\ 13.763 \times (-2.7124) + n(5.2214 + 39.733 \times 2.7124) - 2.7124 \times$

$= -n^2\ 37.331 + n\ 112.994 - 84.502$

$37.331\ n^2 - 112.994\ n = -86.502$

$n^2 - 3.0268\ n = -2.2904$

$n^2 - 3.0268\ n + 2.2904 = 0$ $\qquad 1.5134^2 = 2.2904$

$n - 1.5134 = 0$

$n = 1.5134 \pm 0$

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As a check on the foregoing values of α β and γ - substitute their values in eq. (3) opposite -

$$1.630097 = 29.80031 - 59.48097 + 31.31073$$
$$= 1.63007$$

Error = .000027 which is within the limit of error of the measurement of the Index of Refraction.

Eq. 5. $\quad 1 = 0.513432\,A + 0.619676\,B$

$$A = -B(-39.16690 + 2 \times 13.57611 \times 1.513432)$$
$$A = -1.92615\,B$$
$$1 = -.988947\,B + 0.619676\,B$$
$$1 = -.369271\,B$$
$$B = -2.708038 \quad = \log 0.4326548$$
$$A = +5.216082 \quad = \text{"} \; 0.7173448$$

Eq. 7. $\quad \varphi_c = (n_c - 1)A + (n'_c - 1)B.$

$$= 2.660299 - 1.660656$$
$$= 0.999643$$

29.
217
203
5-8
5.13
5.17
83.5

Eq. 8. $\quad \varphi_c = n^2\gamma B + n(A + \beta B) + B(\alpha - 1) - A$

$$0.999643 = -36.76463\,n^2 + 111.2816\,n - 83.20841$$
$$36.76463\,n^2 - 111.2816\,n = -84.20805$$
$$n^2 - 3.026866\,n = -2.290465$$
$$n^2 - 3.026866\,n + \left(\frac{3.026866}{2}\right)^2 = -2.290465 + 2.290479$$
$$n - 1.513433 = \sqrt{.000014} = \pm .003742$$
$$n = 1.513433 \pm .003742$$
$$n = 1.509691 \text{ or } 1.517175$$

If $-2.290465 + 2.290479$ had equaled .00001172 instead of as above which might equally be as the last figure of each number is uncertain by at least 1 or 2 units - we would have $\sqrt{.00001172} = \pm .003424$

hence

$$n = 1.513433 \pm .003424$$
$$n = \begin{cases} 1.510018 = n_c \\ 1.516856 \end{cases}$$

but $1.513433 = n_{\lambda = 5614}$ Therefore the Index of Refraction of the ray to unite with C is as much greater than $n_{\lambda = 5614}$ as n_c is less - (Eq. 8 by $(\delta n)^2$ same number)

and this simple assumption would seem to be a more accurate method than solving the above equation

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$$n' = \alpha + \beta n + \gamma n^2$$

$n_x = 1.516856 = \log. 0.1809444$ ✓

$n_x^2 = \quad = \quad " \quad 0.3618888$ ✓

$$n'_x = 29.80031 - 59.41054 + 31.23663$$ ✓

$$n'_x = 1.62640$$ ✓

$n'_{\lambda = 5614} = 1.619676$

$n'_C = 1.613232$

$.006444$

$n'_{\lambda = 5614} = 1.619676$

1.626120 which does not agree exactly with

the above value $n'_x = 1.62640$ by .00028 but there is ~~no~~ reason to believe that it should not, on account of the irrationality of the two spectra.

Therefore the best color correction is obtained when the ray which is combined with C has for its Index of Refraction

$n_x = 1.516856 = \log. 0.1809444$

$n'_x = 1.62640 = " \quad 0.2112274$

$n_x - 1 = 0.516856 = " \quad 9.7133695$

$n'_x - 1 = 0.62640 = \quad 9.7968517$

X = wave length 509.2 about. from plotted curve.

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By a preliminary calculation, the Spherical Abberation is corrected and the C and F rays united at the same focus

when $\vartheta_1 = \vartheta_4 = 49.210 = \log 1.69205$

$\vartheta_2 = 15.453 = \text{“} 1.18900$

$\vartheta_3 = 15.701 = \text{“} 1.19592$

$t_1 = .360$

$t_2 = .200$

$d = .010$

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$y = 2.5^s = \log 0.39794$

$\eta = 49.21 = \quad 1.69205^s$

$\lambda = 2^\circ\ 54'\ 43.5^s = \sin\ 8.70589$

$n_c = \quad 0.17898$

$\lambda = 1^\circ\ 55'\ 41.0 = \sin\ 8.52691$

$\gamma = 0^\circ\ 59'\ 2.5'' \quad \gamma_1 = \quad 1.69205^s$

$\quad 0.21896$

$= \sin\ 8.23486$

$96.405^s \quad = 1.98410$

49.21

$f_1 = 146.615^s$

$t_1 = \quad .40$

$d_2 = 146.215^s$

$\gamma_2 = \frac{15.453}{160.668} = 2.20593$

$\quad 8.23486$

$\quad 0.44079$

$\eta_2 = 15.453 = \quad 1.18990$

$i = 10^\circ 17' 10'' = \sin\ 9.25179$

$n = 0.17898$

$\lambda = 15^\circ\ 38'\ 33.'' \quad \sin\ 9.43077$

$5^\circ\ 21\ 23'' \quad \gamma_2 = \quad 1.18900$

$\quad 0.61977$

$5^\circ\ 2.5^s$

$\delta = 6^\circ\ 20'\ 25.5^s = \sin\ 9.04311$

$37.728 \quad = 1.57666$

$\gamma_2 = 15.453$

$f_2 = 22.275^s$

$d = \quad 0.$

$d_3 = 22.275^s$

$\gamma_3 = \frac{15.701}{37.976} = 1.57951$

$\quad 9.04311$

$\quad 0.62262$

$\eta_3 = 15.701 = \quad 1.19592$

$i = 15^\circ 29' 34'' = \sin\ 9.42670$

$n' \quad 0.20770$

$\lambda = 9^\circ\ 31'\ 51'' = \sin\ 9.21900$

$5^\circ\ 57'\ 43'' \quad \gamma = \quad 1.19592$

$\quad 0.41492$

$\beta = 6\ 20\ 25.5^s$

$\gamma = 0\ 22\ 42.5^s \quad = \quad 7.81990$

$\quad = \quad 2.59502$

393.57

$\gamma_3 = 15.70$

$f_3 = 377.87$

$\quad .20$

$d_4 = 377.67$

$\gamma_4 = \frac{49.21}{426.88} = 2.63031$

$\quad 7.81990$

$\quad 0.45021$

$\gamma_4 = \quad 1.69205^s$

$i = 3^\circ\ 17'\ 5.7 = \sin\ 8.75816$

$\quad 0.20770$

$\lambda = 5^\circ\ 18'\ 14.5^s = \sin\ 8.96586$

$2^\circ\ 1'\ 8.8 \quad \gamma_4 = \quad 1.69205^s$

$\quad 0.65791$

$\delta = 2^\circ\ 23'\ 51.3 = \sin\ 8.62153$

$22\ 42.5^s \quad \quad 2.03638$

108.738

$\eta_4 = 49.210$

$f_4 = 59.528$

59.513

$.015^s$ under

X

$i = 2^\circ\ 54'\ 43.5^s = \sin\ 8.70589$

$\quad = \quad 0.18094$

$n_x \quad \quad \sin\ 8.52495$

$\lambda = 1^\circ\ 55'\ 9.6 \quad \eta_1 = \quad 1.69205$

$\gamma = 0^\circ\ 59'\ 33.9 \quad \quad 0.21700$

$= \quad 8.23869$

$95.128^s \quad = 1.97831$

49.21

$f_1 = 144.338^s$

$\quad .40$

143.938^s

$\gamma_2 = \frac{15.453}{159.391^s} = 2.20246$

$\quad 8.23869$

$\quad 0.44115^s$

$= \quad 1.18900$

$\gamma_2 \quad \quad 9.25215^s$

$i = 10^\circ\ 17'\ 40.8 = \sin\ 0.18094$

$\lambda = 15^\circ\ 43\ 41.8 \quad \sin\ 9.43309$

$5^\circ\ 26'\ 1'' \quad \gamma_2 = \quad 1.18900$

$0\ 59\ 33.9 \quad \quad 0.62209$

$\delta = 6\ 25\ 34.9 = \quad 9.04892$

$37.426 \quad = \quad 1.57317$

$\gamma_2 = 15.453$

$f_2 = 21.973$

$d_3 = 21.973$

$\gamma_3 = \frac{15.701}{37.674} = 1.57604$

$\quad 9.04892$

$\quad 0.62496$

$i = 15^\circ\ 34'\ 42.7 = \sin\ 1.19592$

$\quad 9.42904$

$n' \quad 0.21123$

$\lambda = 9\ 30\ 16.0 \quad \sin\ 9.21781$

$6\ 4\ 26.7 \quad \quad 1.19592$

$\quad 0.41373$

$\beta = 6\ 25\ 34.9$

$\gamma = 0\ 21'\ 8.2 = \quad 7.78876$

$\quad = \quad 2.62497$

421.67

15.70

$f_3 = 405.97$

$\quad .20$

$d_4 = 405.77$

$\gamma_4 = \frac{49.21}{454.98} = 2.65799$

$\quad 7.78876$

$\quad 0.44675^s$

$\quad 1.69205^s$

$i = 3^\circ\ 15'\ 31.6 = \sin\ 8.75470$

$\quad 0.21123$

$\lambda = 5\ 18\ 17.5^s = \sin\ 8.96593$

$2\ 2\ 45.9 \quad \quad 1.69205^s$

$\quad 0.65798$

$\delta = 2^\circ\ 23'\ 54.1 = \quad 8.62166$

$21\ 8.2 \quad \quad 2.03632$

$108.723 \quad =$

49.210

$f_4 = 59.513$

$\gamma_4 = 49.21$

$.79$

$50.-$

γ_4

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C

$d_4 = 377.67$

$r_4 = \frac{50.00}{427.67}$ = log. 2.63111 − ar. 7.81990 = 0.45101

r_4 = 1.69897 − sin 8.75204 = i = 3° 14′ 20″

r' = 0.20770 − sin 8.95974 = λ = 5° 13′ 46.5″

r_4 = 1.69897 − 0.65871 = γ = 0 22 42.5″

= 8.61635 − 2.04236 = δ = 2° 22′ 9″

110.245″

$r_4 = \frac{50.}{60.245}$

$\frac{60.243}{.002}$ under.

∴ a change of +.79 in r_4 produced the change of −.013 in the color correction

13.) .790 (.0608 ; $\frac{78}{100}$ $\frac{2}{.1216}$ to be added to r_4 = 50.

Hmae color correction is perfect when

$r_1 = 49.210$
$r_2 = 15.453$
$r_3 = 15.701$
$r_4 = 50.121$

$A = \frac{1}{r_1} + \frac{1}{r_2}$ $B = \frac{1}{r_3} - \frac{1}{r_4}$

$r_1 = 49.210$ = log. 1.69205

$\frac{1}{r_1}$ = .0.20321 = " 8.30795

$r_2 = 15.453$ = " 1.18900

$\frac{1}{r_2}$ = .0.64714 = " 8.81100

(A) = .0.85035 ✓

$r_3 = 15.701$ = log 1.19592 ✓

$\frac{1}{r_3}$ = .063691 ✓ = 8.80408 ✓

$r_4 = 50.121$ = 1.70002 ✓

$\frac{1}{r_4}$ = .019952 ✓ = 8.29998

(B) = .043739 ✓

The above values make the focal length 60.243 inches.

To reduce it to 59.341 deduct 1½% from r_1 r_2 r_3 & r_4.

X

$d_4 = 405.77$

$r_4 = \frac{50.00}{455.77}$ = log 2.65875 − 7.78876 = 0.44751

r_4 = 1.69897 − sin 8.74854 = i = 3° 12′ 46.2″

r' = 0.21123 − sin 8.95977 = λ = 5° 13 47.8

r_4 = 1.69897 − 0.65874 = γ = 2° 1′ 1.6

= 8.61639 − 2.04235 = δ = 21 8.2

2° 22 9.8

110.243

50.

60.243

Focal length = 60.244

less 1½ percent − .904

59.341

r_1 = 49.210

less 1½% = .738

48.472 ✓

r_2 = 15.453

less 1½% = .232 ✓

15.221 ✓

r_3 = 15.701

1½% = .235

15.466 ✓

r_4 = 50.121

1½% = .752

49.369 ✓

r_1 = 48.472 = log. 1.68549

.0206305 = 8.31451

r_2 = 15.221 = 1.18244

= 8.81756

.0656995

known A = .0863300 ✓

r_3 = 15.466 = 1.18938

.064658 = 8.81062

r_4 = 49.369 = 1.69345

.0202556 = 8.30655

Hint B = .0444402 ✓

Try $r_1 = r_4$ = 48.503 = log 1.68577

r_2 = 15.218 = 1.18235

r_3 = 15.380 = 1.18696

for Sph. Abb.

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5614

$y = 2.5^-$ = log 0.397900

$r = 48.503$ = " 1.685769

$i = 2° 57' 15.''27$ = sin 8.712131

n = 0.179963

$\lambda = 1\ 57\ 5.50$ = sin 8.532168

$\gamma = 1° 0' 9.77$ r_1 = 1.685769

0.217937

sin 9.243032

94.3854 = 1.974905

$f_1 = \frac{r_1 = 48.503}{142.8884}$

$t_1 = .40$

$d_2 = 142.4884$

$r_2 = \frac{15.218}{157.7064}$ = 2.197849

γ = sin 8.243032

0.440881

r_2 = 1.182358

$i = 10° 26' 54.''74$ = sin 9.258523

0.179963

$\lambda = \frac{15^- 53^- 48.34}{5^- 28 53.60}$ = sin 9.438486

r_2 = 1.182358

$\gamma = \frac{1\ 0\ 9.77}{6° 29' 3.''37}$ = sin 9.052811

= 1.568033

36.9856

$r_2 = \frac{15.2180}{21.7676}$

f_2

$D = \frac{0.}{21.7676}$

d_3

$r_3 = \frac{15.380}{37.1476}$ = 1.569931

$\beta = \delta$ = sin 9.052811

0.622742

r_3 = 1.186956

$i = 15° 49' 43.''57$ = sin 9.435786

n' = 0.209428

$\lambda = \frac{9\ 41\ 42.6.}{6° 8' 0.''97}$ sin 9.226358

r_3 = 1.186956

$\beta = \frac{6\ 29\ 3.37}{0° 21' 2.''40}$ = 7.786769

= 2.626.5445

423.199

$r_3 = \frac{15.380}{407.819}$

f_3

$t_4 = \frac{.200}{407.619}$

d_4

$r_4 = \frac{48.503}{456.122}$ = 2.659081

γ = sin 7.786769

0.445850

r_4 = 1.685769

$i = 3° 17' 58.''08$ = sin 8.760081

n' = 0.209428

$\lambda = \frac{5^- 20 55.96}{2° 2' 57.''88}$ = sin 8.969509

r_4 = 1.685769

$\gamma = \frac{0\ 21\ 2.40}{2° 24' 0.''28}$ = sin 8.621976

2.033302

107.9697

$r_4 = \frac{48.503}{59.4667}$

f_4

59.3798

.0869 over corrected (4)

5614 central

n = 0.179963

r_1 = 1.685769

1.865732

$n-1$ = 9.710483

f_1 = 142.9714 = 2.155.2490

$\frac{.40}{142.5714}$ = 2.154032

d_2

r_2 = 1.182358

3.336390

$d_2 = 2.154032$

$n-1 = \frac{9.710483}{1.864515} = 73.20067$

n = 0.179963

$r_2 = \frac{1.182358}{1.362321} = \frac{23.03143}{96.23216} = 1.983320$

f_2 = 22.54605 = 1.353070

d_3 = 22.54605 = 1.353070

n' = 0.209428

r_3 = 1.186956

2.749454

$d_3 = 1.353070$

$n-1 = \frac{9.792165}{1.145235} = \frac{15.38000}{13.97124} = 1.40876 = 0.148837$

= 2.600.617

f_3 = 398.673

$d_4 = \frac{.20}{398.473}$ = 2.600399

r_4 = 1.685769

2.286168

$d_4 = 2.600399$

$n-1 = \frac{9.792165}{2.392564} = 246.9244$

$n' = 0.209428$

$r_4 = \frac{1.685769}{1.895197} = \frac{78.5392}{325.4836} = 2.512.529$

= 1.773.639

f_4 = 59.3798

---

try $r_1 = r_4$ = 49.370 = log 1.693463

8.306537

$\frac{1}{r_1}$ = .0202555 =

$A = \frac{.086330}{.066075}$ = 8.820037

$\frac{1}{r_2}$ = 1.179963

r_2 = 15.1343 =

$\frac{1}{r_4}$ = .0202555

$B = \frac{.044402}{.064657}$ = 8.810616

r_3 = 15.4662 = 1.189384

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5614 7.14 p.m.

$y = 2.5$ = log 0.397900

$r_1 = 49.370$ = 1.693463

$i = 2° 54' 8.''11$ = sin 8.704437

$n = 0.179963$

$\lambda = 1° 53' 2.''08$ = sin 8.524474

$\gamma = 0° 59' 6.''03$ $r_1 = 1.693463$

0.217937

= sin 8.235296

= 1.982641

$r_1 = 49.370$ 96.0818

$f_1 =$ 145.4518

$t_1 = .40$

$d_2 =$ 145.0518

$r_2 =$ 15.1343 / 160.1861 = 2.204625

γ = sin 8.235296 / 0.439921

$r_2 = 1.179963$

$i = 10° 29' 0.''63$ = sin 9.259958

$n = 0.179963$

$\lambda = 15° 59' 3.''21$ = sin 9.439921

$5° 30' 2.''58$ $r_2 = 1.179963$

$\gamma = 0° 59' 6.''03$ 0.619884

$\delta = 6° 29' 8.''61$ = sin 9.052908

= 1.566976

36.8957

$r_2 =$ 15.1343

$f_2 =$ 21.7614

$d_3 =$ 21.7614

$r_3 =$ 15.4662 / 37.2276 = 1.570865

$\beta = \delta$ = sin 9.052802 / 0.623667

$r_3 = 1.189384$

$i = 15° 46' 21.''57$ = sin 9.434283

$n' = 0.209428$

$\lambda = 9° 39' 40.''85$ = sin 9.224855

$6° 6' 40.''72$ $r_3 = 1.189384$

$\beta = 6° 29' 8.''61$ 0.414239

$\gamma = 0° 22' 27.''89$ = sin 7.815224 / 2.599015 / 0092

= 397.205

$r_3 =$ 15.466

$f_3 =$ 381.739

.200

$d_4 =$ 381.539

$r_4 =$ 49.370 / 430.909 = 2.634386

γ = sin 7.815224 / 0.449610

$r_4 = 1.693463$

$i = 3° 16' 10.''86$ = sin 8.756147

$n' = 0.209428$

$\lambda = 5° 18' 1.''82$ = sin 8.965575

$2° 1' 50.''96$ $r_4 = 1.693463$

$\gamma = 0° 22' 27.''89$ 0.659038

$\delta = 2° 24' 18.''85$ = sin 8.622907

108.6753 = 2.036131

$r_4 =$ 49.3700

8.17 $f_4 =$ 59.3053

59.3998

.0745 under (2)

There is probably a mistake in this calculation see diagram 8/5

5614 central

$n = 0.179963$

$r_1 =$ 1.693463 / 1.873426

$n-1 =$ 9.710483 = 2.162943

$t_1 = 145.5268$ = 2.161748

.40

$d_2 = 145.1268$

r_2 = 1.179963 / 3.341711

$d_2 = 2.161748$

$n-1 =$ 9.710483 / 1.872231 = 74.5128

$n = 0.179963$

$r_2 =$ 1.179963 / 1.359926 = 22.9048 / 97.4176 = 1.988637

$f_2 = 22.5462$ = 1.353074

$d_3 = 22.5462$ = 1.353074

n' = 0.209428

r_3 = 1.189384 / 2.751886

$d_3 = 1.353074$

$n'-1 =$ 9.792165 / 1.145239 = 15.4662 / 13.97137 / 1.49483 = 0.174592

= 2.577294

$f_3 = 377.828$

.20

$d_4 = 377.628$ = 2.577064

r_4 = 1.693463 / 4.270527

$d_4 = 2.577064$

$n'-1 =$ 9.792165 / 2.369229 = 234.007

$n' = 0.209428$

$r_4 =$ 1.693463 / 1.902891 = 79.963 / 313.970 = 2.496888 / 1.773639 29/61

$f_4 = 59.3798$

8.55

$r_1 = r_4$	Abb.
48.503	.0869 over
49.370	.0219 over
Increase = 0.867	.0650 decrease
0.292	.0219
49.370	
49.662	.0000

$r_1 = r_4$

$r_1 = 49.663$ = log 1.696033

$\frac{1}{r_1} = .020135$ = 8.303967

$A = .0863300$

$\frac{1}{r_2} = .0661943$ = 8.820821

$r_2 = 15.1070$ = log 1.179179

$\frac{1}{r_4} = .020135$

$B = .0444020$

$\frac{1}{r_3} = .0646377$ = 8.809813

$r_3 = 15.4948$ = log 1.190187

9.25 p.m.

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5614

$y = 2.5 = \log 0.397900$

$r_1 = 49.663 = \quad 1.696033$

$i = 2°\,53'\,6''.65 = \sin 8.701867$

$n = 0.179963$

$\lambda = 1°\,54'\,21''.34 = \sin 8.521904$

$\gamma = 0°\,58'\,45''.31 \quad r_1 = 1.696033$

0.217937

$\sin 8.232751$

$= 1.985186$

$r_3 = 96.6465$

49.663

$f_1 = 146.3095$

$.40$

$d_2 = 145.9096$

$r_2 = 15.1070$

$161.0165 = 2.206871$

8.232751

0.439622

$r_2 = 1.179179$

$i = 10°\,29'\,43''.26 = \sin 9.260443$

$n = 0.179963$

$\lambda = 16\ 0\ 9.26 = \sin 9.440406$

$r_2 = 1.179179$

0.619585

$\gamma = 0\ 58\ 45.31$

$\delta = 6°\,29'\,11''.31 = \sin 9.058958$

1.566627

36.8661

$r_2 = 15.1070$

$f_2 = 21.7591$

$d_3 = 21.7591$

$r_3 = 15.4948 = 1.571172$

37.2539

$\sin 9.058958$

$\beta = \delta \quad 0.624130$

$r_2 = 1.190187$

$i = 15°\,45'\,35''.98 = \sin 9.433943$

$n' = 0.209428$

$\lambda = 9°\,39'\,13''.37 = \sin 9.224515$

$r_3 = 1.190187$

0.414702

$\beta = 6\ 29\ 11.31$

$\gamma = 0°\,22'\,48''.70 = \sin 7.821880$

$= 2.592822$

391.5813

$r_3 = 15.4948$

$\rho = 376.0865$

$f_3 \quad .20$

$d_4 = 375.8865$

$r_4 = 49.6630$

$425.5495 = 2.628950$

$\gamma \quad \sin 7.821880$

0.450830

$r_4 = 1.696033$

$3°\,15'\,34''.28 \quad \sin 8.784797$

$n = 0.209428$

$5\ 17\ 2,43 \quad \sin 8.964225$

$2°\,1'\,28''.15 \quad r_4 = 1.696033$

0.660258

$\gamma = 0\ 22\ 48.70$

$\delta = 2°\,24'\,16''.85 = \sin 8.622807$

$= 2.037451$

$109,0062$

49.6630

$\rho = 59.3432$

$f_4 \quad 59.3810$

$.0378$ under (3)

$y = 2.5 \quad 1.696033$

$n = \quad 0.179963$

1.875996

$n-1 = \quad 9.710483$

$r_1 = 146.3905 = 2.165513$

$.40$

$d_2 = 145.9905 = 2.164325$

$r_2 = 1.179179$

3.345504

$d_2 = 2.164325$

9.710483

$1.874808 = 74.9563$

$n = 0.179963$

$r_2 = 1.179179$

$1.359142 = 22.8635 = 1.990427$

$97.8198 = 1.359307$

$d_3 = f_2 = 22.5464 \quad 0.209428$

$n' = \quad 1.190187$

$r_3 = \quad 2.785269$

$d_3 = 1.359307$

$n-1 = 9.792165 \quad 15.4948$

$1.145242 = 13.97147 \quad 0.182794$

$1.523337 \quad 2.569898$

$f_{13} = 371.448$

$.20$

$d_4 = 371.248 = 2.569664$

$r_4 = 1.696033$

4.265697

$d_4 = 2.569664$

$n-1 = 9.792165$

$2.361829 = 230.054$

$n' = 0.209428$

$r_4 = 1.696033$

$1.905461 = 80.438 = 2.492050$

$310.492 \quad 1.773647$

$f_4 = 59.3810$

$r_1 = r_4 = 48.700 = 1.687529$

$\frac{1}{r_4} = .0205339 = 8.312471$

$A = .0863300$

$.0657961 = 8.818200$

1.181800

$r_2 = 15.19848$

$\frac{1}{r_4} = .0205339$

$B = .0444020$

$.0649359 = 8.812484$

$r_3 = 15.39984 = 1.187516$

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$y = 2.50 = \log 0.397900$

$\gamma_1 = 48.700 = 1.687529$

$i = 2^\circ 56' 32''.22 = \sin 8.710371$

$n = 0.179963$

$\lambda = 1^\circ 56' 37''.07 = \sin 8.530408$

$\gamma = 0^\circ 59' 55''.15 \quad \gamma_1 = 1.687529$

0.217937

$= \sin 8.241270$

$94.7692 = 1.976667$ (63/7)

$\gamma_1 = 48.7000$

$f_1 = 143.4692$

$.40$

$d_2 = 143.0692$

$r_2 = \frac{15.1985}{158.2677} = 2.199392$

8.241270

0.440662

$r_2 = 1.181800$

$i = 10^\circ 27' 24''.44 = \sin 9.258862$

0.179963

$\lambda = 15^\circ 56' 34''.34 = \sin 9.438825$

$5^\circ 29' 9''.90 \quad r_2 = 1.181800$

$\gamma = 0^\circ 59' 55''.15$

$\delta = 6^\circ 29' 5''.05 = \sin 9.052842$

0.620625

$= 1.567783$ (790/40)

36.9643

$r_2 = \frac{15.1985}{21.7658}$

$f_2 = d_3 = 15.3998$

$r_3 = \frac{15.3998}{37.1656} = 1.570141$

$\delta = \sin 9.052842$

0.622983

$r_3 = 1.187516$

$i = 15^\circ 49' 0''.63 = \sin 9.435467$

$n' = 0.209428$

$\lambda = 9^\circ 41' 16''.73 = \sin 9.226039$

$6^\circ 7' 43''.90 \quad r_3 = 1.187516$

$\beta = 6\ 29\ 5.05$

0.413555

$\gamma = 0^\circ 21' 21''.15 = \sin 7.793172$

$= 2.620383$ (755/75)

417.237

$r_3 = 15.3998$

$f_3 = \frac{401.837}{20}$

$d_4 = 401.637$

$r_4 = \frac{48.700}{450.337} = 2.653537$

$\gamma = 7.793172$

0.446710

$r_4 = 1.687529$

$i = 3^\circ 17' 33''.46 = \sin 8.759181$

$n' = 0.209428$

$\lambda = 5^\circ 20' 15''.99 - \sin 8.968609$

$2^\circ 2' 42''.53 \quad r_4 = 1.687529$

$\gamma_\delta = 0\ 21\ 21.15$

0.656138

$2^\circ 24' 3''.68 = \sin 8.622146$

$108.1414 \quad 2.033992$ (864/556/40/760)

$\gamma_4 = 48.700$

$f_{14} = 59.4414$

59.3778

$.0636$ over ④

$r_1 = 1.687529$

$n = \frac{0.179963}{1.867492}$

$n-1 = 9.710483$

$f_1 = 143.5520 = 2.157009$ (32/5-8)

$.40$

$d_2 = 143.1520 = 2.155797$

$r_2 = 1.181800$

3.337597

$d_2 = 2.155797$

$n-1 = \frac{9.710483}{1.866280} = 73.4988$

$n = 0.179963$

$r_2 = \frac{1.181800}{1.361763} = \frac{23.0018}{96.5006} = \frac{1.984530}{1.353067}$ (467/163) (5-102/168)

$f_2 = 22.5459$

$d_3 = 1.353067$

$n' = 0.209428$

$r_3 = 1.187516$

2.750011

$d = 1.353067$

$n-1 = \frac{9.792165}{1.145232} = \frac{15.39984}{13.97115} = \frac{0.154938}{1.42869} = 2.898073$ (274/45) (661/69)

$f_3 = 393.616$

$.20$

$d_4 = 393.416 = 2.594852$

$r_4 = 1.687529$

4.282381

$d_4 = 2.594852$

$n-1 = \frac{9.792165}{2.387017} = 243.791$

$n = 0.209428$

$\gamma = \frac{1.687529}{1.896957} = \frac{78.8782}{32.2.669} = \frac{2.508757}{1.773624}$ (183/5-7)

$f_4 = 59.3778$

$\gamma_1 = \gamma_4 = 49.310 = 1.692935$

$= 8.307065$ (465/195)

$\frac{1}{\gamma_1} = .0202799$

$A = \frac{.0863300}{.0660501} = 8.819873$

$= 1.180127$

$r_2 = 15.14004$

$\frac{1}{\gamma_4} = .0202799$

$B = \frac{.0444020}{.0646819} = 8.810783$

$= 1.189217$ (495/75/86/190)

$r_3 = 15.46027$

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$y = 2.5^{-}$ = log 0.397900

$r_1 = 49.310$ = $\frac{1.692935^{-}}{}$

$i = 2^\circ\ 54'\ 21.''08$ = sin 8.704965^{-}

$n = \frac{0.179963}{}$

$\lambda = 1^\circ\ 55'\ 10.''48$ = sin 8.525002

$\gamma = 0^\circ\ 59'\ 10.''60$ $r_1 = \frac{1.692935^{-}}{0.217937}$

sin $\frac{8.235855^{-}}{}$

95.9582 = 1.982082_{2}

$r_1 = 49.310$

$f_1 = 145.2682$

$\frac{.40}{}$

$d_2 = 144.8682$

$r_2 = \frac{15.1400}{160.0082}$ = 2.204142

sin $\frac{8.235855^{-}}{0.439997}$

$r_2 = 1.180127$

$i = 10^\circ\ 28'\ 52.''89$ = sin 9.259870

$n = 0.179963$

$\lambda = \frac{15\ 58\ 57.26}{5^\circ\ 29'\ 58.''37}$ = sin 9.439833

$r_2 = 1.180127$

$\gamma = 0\ 59\ 10.60$

$\delta = 6^\circ\ 29'\ 8.''97$ = sin $\frac{9.052914}{1.567046}$ $\frac{381}{79}$

36.9017

$r_2 = 15.1400$

$f_2 = 21.7617$

$d_3 = r_3 = 15.4603$

37.2220 = 1.570800

= 9.052914

0.623714

$r_3 = 1.189217$

$\delta =$

$i = 15^\circ\ 46'\ 55.''28$ = sin 9.434497

$n' = 0.209428$

$\lambda = \frac{9\ 39\ 58.13}{6^\circ\ 6'\ 52.''15}$ = sin 9.223069

$r_3 = 1.189217$

0.414286

$\delta = \frac{6\ 29\ 8.97}{\gamma = 0^\circ\ 22'\ 16.''82}$ = sin $\frac{7.811645^{-}}{2.602641}$ $\frac{351}{59}$

400.535^{-}

$r_3 = 15.460$

$f_3 = 385.075^{-}$

$\frac{.20}{}$

$d_4 = 384.875^{-}$

$r_4 = \frac{49.310}{434.185^{-}}$ = 2.637675^{-}

γ = sin $\frac{7.811645^{-}}{0.449320}$

$r_4 = 1.692935^{-}$

$i = 3^\circ\ 16'\ 17.''31$ = sin $8.756.385^{-}$

0.209428

$\lambda = \frac{5^\circ\ 18'\ 12.''31}{2^\circ\ 1'\ 55.''00}$ = sin 8.965813

$r_4 = 1.692935^{-}$

$\gamma_\delta = \frac{0\ 22\ 16.82}{2^\circ\ 24'\ 11.''82}$ = sin $\frac{8.622.555^{-}}{2.036.193}$ $\frac{896}{340}$

108.6908 = $\frac{49.310}{59.3808}$

r_4

f_4

59.3801

$.0007$ over

$n = 0.179963$

$r_1 = \frac{1.692935^{-}}{1.872898}$

$n-1 = 9.710483$

$\frac{1}{r_1} = 145.3500$ = 2.162415^{-}

$\frac{.40}{}$

$d_2 = 144.950$ = 2.161218

r_2 = $\frac{2.180127}{3.341345^{-}}$

$d_2 = 2.161218$

$n-1 = \frac{9.710483}{1.871.701} = 74.4220$

$n = 0.179963$

$r_2 = \frac{1.180127}{1.360.090} = \frac{22.9134}{97.3354} = \frac{1.988271}{1.353074}$ $\frac{6\ 95^{-}}{4\ 35^{-}}$

$f_2 = 22.5462$

$d_3 =$ = 1.353074

n' = 0.209428

r_3 = $\frac{1.189217}{2.751719}$

$d_3 = 1.3530074$

$n-1 = \frac{9.792165^{-}}{1.145239}$ $\frac{22\ 74^{-}}{1\ 14^{-}}$ $\frac{54}{27}$ $= \frac{15.46027}{13.97137}$ $\frac{1.48890}{}$ = $\frac{0.172865^{-}}{2.578854^{-}}$ $\frac{4\ 5^{-}\times}{8\ 6}$

$f_3 = 379.1875^{-}$

$\frac{.20}{}$

$d_4 = 378.9875^{-}$ = 2.578625^{-}

r_4 = $\frac{1.692935^{-}}{4.271560}$

$d_4 = 2.578625^{-}$

$n-1 = \frac{9.792165^{-}}{2.370790} = 234.850$

$n' = 0.209428$

$r_4 = \frac{1.692935^{-}}{1.902363} = \frac{79.8662}{314.7162} = 2.497919$ $\frac{1.773641}{}$

$f_4 = 379.3801$

$\frac{49.3100}{.0064506}$ from triangle on opp. page.

$r_1 = r_4 = 49.31645^{-} =$ ✓ 1.692992 ✓

$\frac{1}{r_1} = .0202772$ = 8.307008 ✓ $\frac{37}{43}$

$A = \frac{.0863300}{.0660528}$ = 8.819891

$r_2 = 15.1394$ ✓ = 1.180109 ✓ $\frac{972}{118}$

$\frac{1}{r_4} = .0202772$ ✓

$B = \frac{.0444020}{.0646792}$ = 8.810765^{-}

= 1.189235^{-} $\frac{2095^{-}}{2\ 5^{-}5^{-}}$

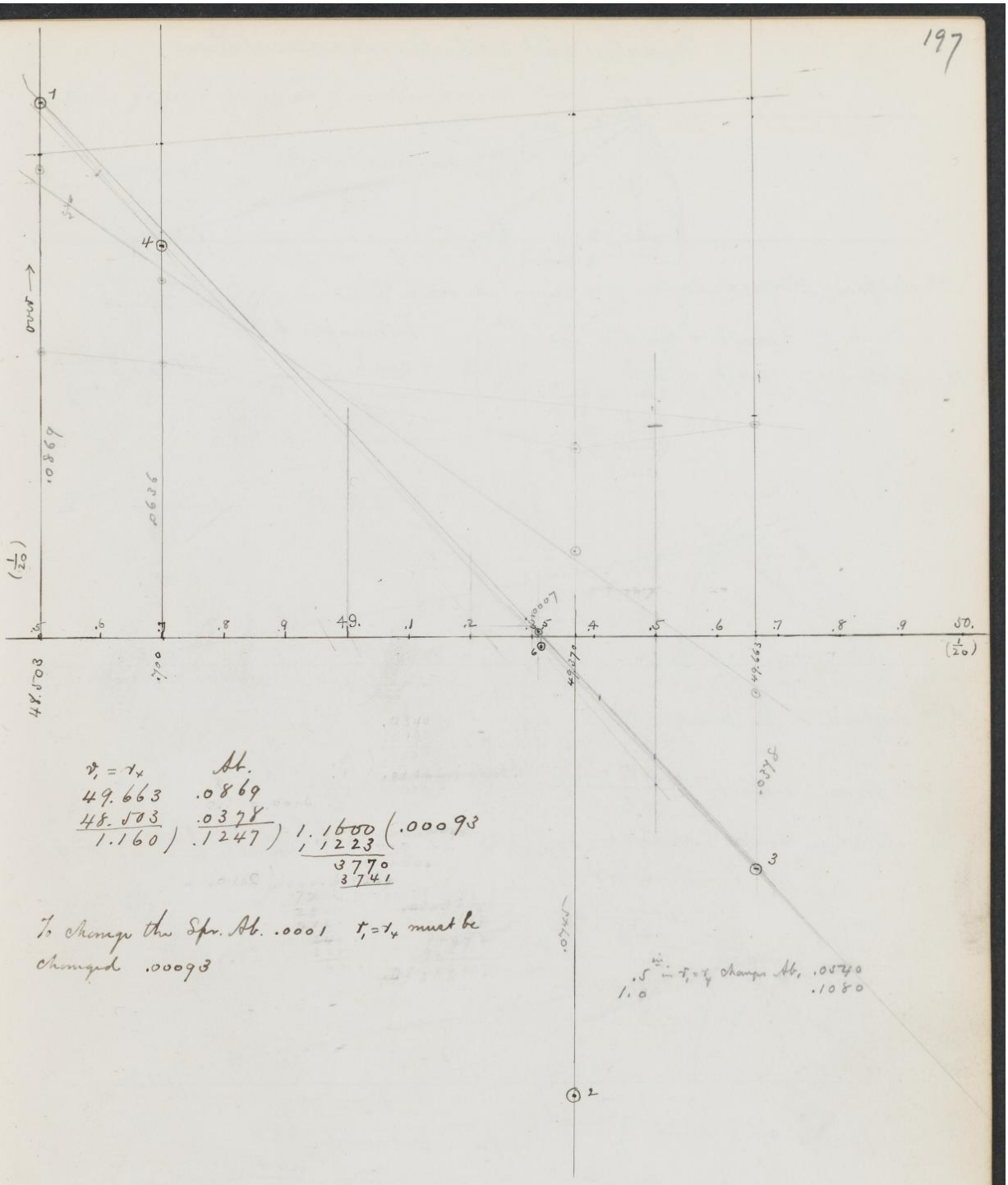
$r_3 = 15.4609$

this corrects for both Spherical Abberation and Color.

~~D = .004 instead of 0 as in the calculation~~

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$r_1 = r_4$	$\Delta t.$
49.663	.0869
48.503	.0378
1.160	.1247

1.1600 (.00093
1223
3770
3741

To change the Spr. Ab. .0001 $r_1 = r_4$ must be changed .00093

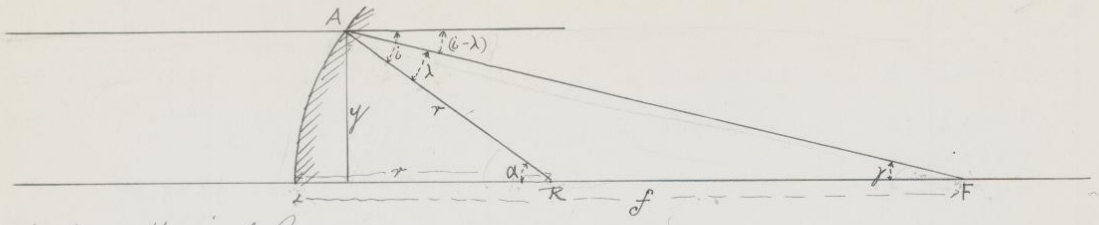
.5 in $r_1 = r_4$ change Ab, .0540
1.0 .1080

Distance apart of inner surfaces at margin = .0040 inches - when the vertices are in contact.

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Formulae used in the foregoing calculations.



1st Surface, Marginal Ray.

$\sin i = \sin \alpha = \frac{y}{r_1}$

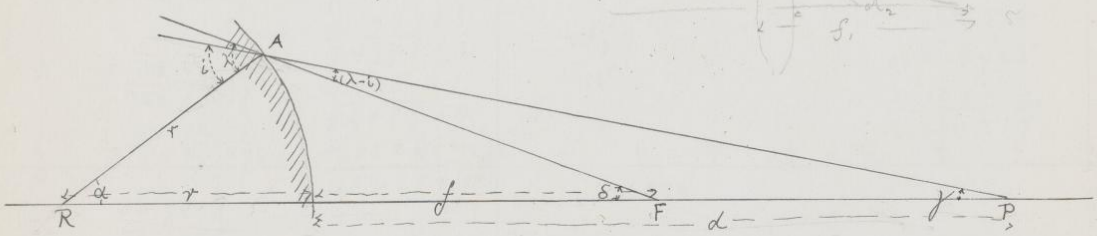
By refraction $\sin \lambda = \frac{\sin i}{n}$

$\gamma = i - \lambda$

$f_1 = \frac{r_1 \sin \lambda}{\sin \gamma} + r_1$

In triangle ARF

$\frac{\sin \lambda}{\sin \gamma} = \frac{f - r}{r} \quad \therefore f - r = \frac{r \sin \lambda}{\sin \gamma}$



2nd Surface. In triangle ARP $\frac{\sin i}{\sin \gamma} = \frac{d + r}{r}$

Hence $\sin i = \frac{(d_2 + r_2) \sin \gamma}{r_2}$

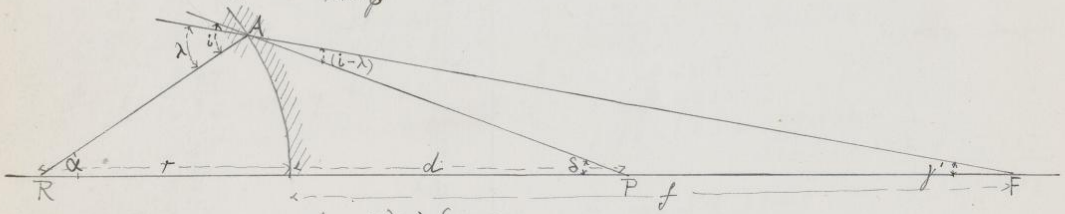
By refraction $\sin \lambda = n \sin i'$

$\delta = (\lambda - i') + \gamma$

$f_2 = \frac{r_2 \sin \lambda}{\sin \delta} - r_2$

In triangle ARF

$\frac{\sin \lambda}{\sin \delta} = \frac{f + r}{r} \quad \therefore f + r = \frac{r \sin \lambda}{\sin \delta}$



3rd Surface. $\sin i = \frac{(d_3 + r_3) \sin \delta}{r_3}$

By refraction $\sin \lambda = \frac{\sin i}{n'}$

$\gamma = \delta - (i - \lambda)$ in this case the calculation shows that $(i - \lambda)$ is less than δ and that therefore the focus falls as in the figure behind the surface. If $(i - \lambda) = \delta$ the refracted ray is parallel to the axis. and if $(i - \lambda)$ is greater than δ the focus falls in front of the surface.

$f_3 = \frac{r_3 \sin \lambda}{\sin \gamma} - r_2$

for In triangle ARP.

$\frac{\sin i'}{\sin \delta} = \frac{d + r}{r} \quad \therefore$

for In triangle ARF

$\frac{\sin \lambda}{\sin \gamma} = \frac{f + r}{r} \quad \therefore f + r = \frac{r \sin \lambda}{\sin \gamma}$

4th Surface. The figure is the same as for the 2nd Surface with δ' and γ' substituted for δ and γ.

$\sin i = \frac{(d_4 + r_4) \sin \gamma'}{r_4}$

$\sin \lambda = n' \sin i$

$\delta' = (\lambda - i) + \gamma'$

$f_4 = \frac{r_4 \sin \lambda}{\sin \gamma'} - r_4$

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Formulae for Central Ray -

Same figures used as for Marginal Ray -

1st Surface - By refraction $\frac{\sin i'}{\sin \lambda} = n$

$i = \alpha$

$$\frac{AF}{FR} = \frac{\sin \alpha}{\sin \lambda} = \frac{\sin i'}{\sin \lambda} = n$$

When the point of refraction A is on the axis $AF = f$ and $FR = f - r$

$$\frac{f}{f-r} = n \quad \therefore f = fn - nr \quad \therefore fn - f = nr$$

$$(1.) \qquad f_1 = \frac{nr_1}{n-1}$$

2nd Surface. By refraction $\frac{\sin i'}{\sin \lambda} = \frac{1}{n}$

$$\frac{AF}{FR} = \frac{\sin \alpha}{\sin \lambda} \text{ and } \frac{AP}{PR} = \frac{\sin \alpha}{\sin i}$$

$$\frac{AF \times PR}{FR \times AP} = \frac{\sin i'}{\sin \lambda} = \frac{1}{n}$$

A. on axis - $AF = f$ + $AP = d$ $\therefore \frac{f(d+r)}{(f+r)d} = \frac{1}{n}$ $\therefore nfd + nfr = fd + dr$

$$f[(dn - d) + nr] = dr$$

$$(2.) \qquad f_2 = \frac{d_2 r_2}{d_2(n-1) + nr_2}$$

3rd Surface. By refraction $\frac{\sin i'}{\sin \lambda} = n'$

$$\frac{AF \times PR}{FR \times AP} = n'$$

$$\frac{f(d+r)}{(f+r)d} = n' \quad \therefore \quad fd + fr = fnd + ndr$$

$$(3.) \qquad f_3 = \frac{n' d_3 r_3}{r_3 - d_3(n-1)}$$

4th surface - Same construction as 2nd

$$(4.) \qquad f_4 = \frac{d_4 r_4}{d_4(n'-1) + n' r_4}$$

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Flint glass lens placed in front using same curves as before

viz $r_1 = 49.3164$, $r_2 = 15.4609$ } flint thickness = .200

distance between = 0

$r_3 = 15.1394$, $r_4 = 49.3164$ } crown thickness = .400

5614

$i = 2° 54' 19."7$

$\lambda = 1\ 47\ 36.2$

$\gamma = 1° 6' 43."5$

$y = 2.5$ = log 0.39790

r_1 = 1.69299

= sin 8.70491

n' = 0.20943

= sin 8.49548

r_1 = 1.69299

i 0.18847

sin 8.28799

= 7.90048

79.521

r_1 = 49.316

f_1 = 128.837

.200

d_2 = 128.637

r_2 = 15.4609

113.176 =

y =

$i = 8° 10' 4."1$

$\lambda = 13\ 18\ 18.4$

$5\ 8\ 9.3$

$\gamma = 1\ 6\ 43.5$

$\delta = 4° 1' 25."8$

50.7002

r_2 = 15.4609

f_2 = 35.2393

r_3 = 15.1394

50.3787 =

d_3 =

$i = 13° 30' 13."4$ = sin

$\lambda = 8° 53' 32.4$

$i - \lambda = 4° 37' 41."0$

$\gamma = 4\ 1\ 25.8$

$\beta = \delta$ $0° 36' 15."2$ = sin

221.503

r_3 = 15.139

f_3 = 236.642

.400

d_4 = 236.242

r_4 = 49.316

285.558 =

$i = 3° 30' 2."6$ = sin

$\lambda = 5\ 18\ 8.6$

$\gamma = 0\ 36\ 15.2$

$2\ 24\ 21.2$ = sin

108.568 =

r_4 = 49.316

f_4 = 59.252

2.05375

8.28799

0.34174

r_2 = 1.18923

sin 9.15251

n' = 0.20943

sin 9.36194

r_2 = 1.18923

0.55117

= sin 8.84616

= 1.70501

1.70225

sin 8.84616

0.85841

r_3 = 1.18011

9.36830

n = 0.17996

sin 9.18834

r_3 = 1.18011

0.36845

sin 8.02307

2.34538

2.45569

sin 8.02307

0.47876

r_4 = 1.69299

8.78577

n = 0.17996

sin 8.96573

r_4 = 1.69299

0.65872

sin 8.62302

= 2.03570

n' = 0.20943

r_1 = 1.69299

1.90242

$n'-1$ = 9.79216

= 2.11026

f_1 = 128.903

.200

d_2 = 128.703

r_2

= 2.10959

= 1.18923

3.29882

d_2 = 2.10959

$n'-1$ = 9.79216

1.90175 = 79.754

n' = 0.20943

r_2 = 1.18923

1.39866 = 25.0415

54.7125 =

$d_3 = \frac{y}{r_2}$ = 36.369

= 1.73809

1.56073

n = 0.17996 ✓

r_3 = 1.18011 ✓

2.92080 ✓

d_3 = 1.56073 ✓

$n-1$ = 9.71048 ✓

1.27121 = 18.6729

r_3 = 15.1394 ✓

3.53355 = 0.54821

f_3 = 235.825 = 2.37285

17.600

d_4 = 235.425 ✓ = 2.37285

r_4 = 1.69299

4.06784

n = 0.17996

r_4 = 1.69299

1.87295 = 74.636

d = 2.37285

$n-1$ = 9.71048

2.08238 = 120.874

195.510 = 2.29147

1.77367

.403
.384
.019
Change r_2 .2 in
Thickness of crown
Change f_4 −.019

f_4 = 59.384

.252

.132 flint over corrected

try $r_1 = r_4$ = 50.000 = log

$\frac{1}{r_1}$ = .020000

B = .044402

.064402 = log 8.80890

1.19110 flint

r_2 = 15.5274 =

$\frac{1}{r_4}$ = .020000

A = .086330

.066330 =

8.82171

1.17829 crown

r_3 = 15.0761

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$y = 2.5^{-}$ = log. 0.39790

$r_1 = 50.$ = 1.69897

$i = 2° 51' 56.6$ = sin 8.69893

$n' = 0.20943$

$\lambda = 1\ 46\ 7.9$ = sin 8.48950

$\gamma = 1° 5' 48.7$ $r_1 = 1.69897$

0.18847

sin 8.28200

80.625^{-} = 1.90647

$r_1 = 50.$

$f_1 = 130.625^{-}$

$.200$

$d_2 = 130.425^{-}$

$r_2 = \frac{15.527}{114.898}$ = 2.06031

γ = sin 8.28200

0.34231

$r_2 = 1.19110$

$i = 8° 8' 35.5^{-}$ = sin 9.15121

$n' = 0.20943$

$\lambda = 13\ 15\ 47.5^{-}$ = sin 9.36064

$5° 7' 12.0$ $r_2 = 1.19110$

$\gamma = 1\ 5\ 48.7$ 0.55174

$\delta = 4° 1' 23.3$ = sin 8.84609

1.70565^{-}

50.778^{-}

$r_2 = 15.527$

$d_3 = f_2 = 35.248$

$r_3 = 15.076$

50.324 = 1.70177

β = sin 8.84609

0.54786

$r_3 = 1.17829$

$i = 13° 32' 38.1$ = sin 9.36957

$n = 0.17996$

$\lambda = 8° 57' 6.7$ = sin 9.18961

$4° 38' 31.4$ $r_3 = 1.17829$

$\beta = \delta = 4\ 1\ 23.3$ 0.36790

$\gamma = 0° 37' 8.1$ = sin 8.03350

2.33440

215.973

$r_3 = 15.076$

$f_4 = 231.049$

$.400$

$d_4 = 230.649$

$r_4 = \frac{50.000}{230.649}$ = 2.44816

γ = sin 8.03350

0.48168

$r_4 = 1.69897$

$3° 28' 33.6$ = sin 8.78269

$n = 0.17996$

$5° 15' 58.4$ = sin 8.96265

$1\ 47\ 19.8$ $r_4 = 1.69897$

$\gamma = 0\ 37\ 8.1$ 0.66162

$2\ 24\ 27.9$ = sin 8.62336

2.03826

109.210

$50.$

$f_4 = 59.210$

$r_4 = r_1 = 47.114$ = log 1.67315

8.32685

$B = \frac{.021225^{-}}{.044402}$ =

$.065627$ = 8.81708

$r_2 = 15.238$ = 1.18292

$A = \frac{.021225^{-}}{.086330}$

$.065105^{-}$ = 8.81361

$r_3 = 15.360$ = 1.18639

distance between lenses = 230

$n' = 0.20943$

$r_1 = 1.69897$

1.90840

10.25^{-}

$n' - 1 = 9.79216$

$f_1 = 130.69$ = 2.11624

$.2$

$d_2 = 130.49$ = 2.11558

r_2 = 1.19110

3.30668

$d = 2.11558$

$n' - 1 = \frac{9.79216}{1.90774} = 80.861$

$n' = 0.20943$

$r_2 = \frac{1.19110}{1.40053} = \frac{25.1496}{55.7114} = \frac{1.74594}{1.56074}$

$d_3 = f_2 = 36.370$ = $n = 0.17996$ ✓

$r_3 = 1.17829$ ✓

2.91899 ✓

$d = 1.56074$ ✓

$n - 1 = 9.71048$ ✓

1.27122 ✓ = 18.6732

$r_3 = \frac{15.0761}{3.59711} = 0.53896$ ✓

= 2.36304 ✓

$f_3 = 230.696$

$.4$

$d_4 = 230.296$ = 2.36229

r_4 = 1.69897

4.06126

$n = 0.17996$

$r_4 = \frac{1.69897}{1.87893} = 75.671$

$d = 2.36229$

$n - 1 = \frac{9.71048}{2.07277} = 118.241$

$193.912 = 2.28760$

$59.383 = 1.77366$

$.210$

$.173$ flint one corrected

10.49

.24 min.

when $r_1 = r_4 = 50.$ Ab = .173

" " 49.316 " = .132

Change of .684 " = .041

" = .132

Try $r_1 = r_4$ = 47.114 = log 1.67315 = 8.32650

$\frac{1}{r_1}$ = .021208

B = .044402 .065610 = 8.81697

r_2 = 15.242 = 1.18303

15.242

$\frac{1}{r_4}$ = .021208

A = .086330 .065122 = 8.81373

r_3 = 15.356 = 1.18627

15.356

$r_1 = r_4$ Abb.

49.316 = .132

Change 2.202 = −.132

47.114 = 0

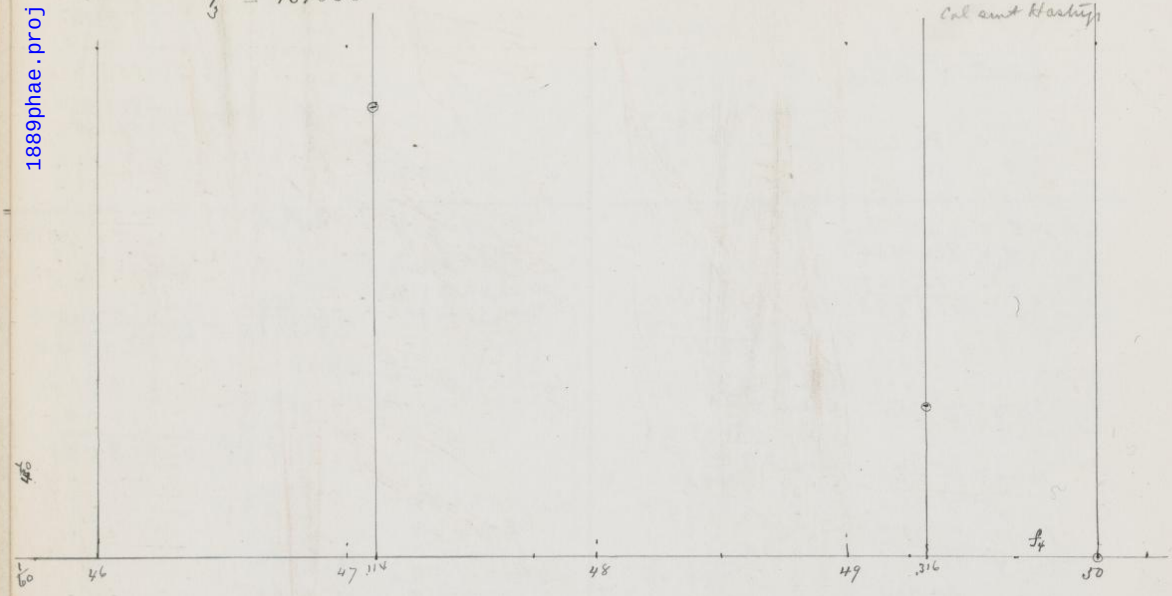
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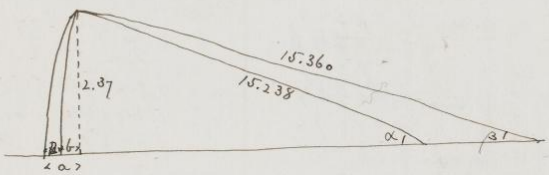
When $\tau_1 = \tau_4 = 47.114$
$\tau_2 = 15.238$
$\tau_3 = 15.360$

$D = .02$

Centesul = .327
Marginal = 59.330
.003 flint under corrected
Cal and Hastings



To find D.



$D = a - b$

2.37 = log 0.374748
15.238 = 1.182928
$8°\,52'\,57''.6$ = sin 9.191820
= cos 9.994682
1.182928
1.177610

15.2380
15.0526
.1854 = a

2.37 = 0.374748
15.360 = 1.186391
$8°\,52'\,33''.7$ = sin 9.188357
= cos 9.994767
1.186391
1.181158

15.3600
15.1761
.1839 = b

D = .0015

$\tau_1 = \tau_4 = 49.3164$
$\tau_1 = \tau_4 = 47.1140$
2.2024
Changing $\frac{1}{45}$ " .0489
47.1140
47.1629

Abb = .132 over -
= .003 under
change Abb .135
= 003

45) 2.2024 (0489
180
402
360
424

$\tau_1 = \tau_4$ 47.163 = l. 1.673601
.0212031 = 8.326399

B = .044402 / .065605 = 8.81694
= 1.18306

τ_2 = 15.243

.021203

A = .086330 / .065127 = 8.81376
= 1.18624

τ_3 = 15.355

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Color correction

Flint $\begin{cases} r_1 = 47.163 \\ r_2 = 15.243 \end{cases}$ Crown $\begin{cases} r_3 = 15.353 \\ r_4 = 47.163 \end{cases}$ $t_1 = .20$ $t_2 = .40$ $D = .0015$

C

$y = 2.5$ = log 0.39794
r_1 = 1.67360
$i = 3° 2' 19''$ = sin 8.72434
= 0.20770
n' 8.51664
$\lambda = 1° 52' 58.7$ = sin 1.67360
$\gamma = 1° 9' 20.3$ 0.19024
sin 8.30467
= 1.88557

76.837
r_1 = 47.163
f_1 = 124.000
t_2 = − .200
d_2 = 123.800
r_2 = 15.243 / 108.557 = 2.03565
r_2 ----- γ = sin 8.30467
0.34032
= 1.18306
$i = 8° 15' 30''$ = sin 9.15726
n' = 0.20770
$\lambda = 13° 23 53''.7$ = sin 9.36496
$\lambda - i$ = $5° 8' 23''.7$ r_2 = 1.18306
γ = 1 9 20.3 0.54802
δ = $3° 59' 3''.4$ = sin 8.84187
= 1.70615

50.834
r_2 = 15.243
f_2 = 35.591
D = +.001
d_3 = 35.592
r_3 = 15.353 / 50.947 = 1.70712
$\beta = \delta$ = sin 8.84187
0.54899
r_3 = 1.18624
$i = 13° 19' 44''.5$ = sin 9.36278
= 0.17898
n 9.18377
λ = 8 46 52.2 = sin r_3 = 1.18624
4 32 49.3 0.37001
β = 3 59 3.4
γ = $0° 33' 45''.9$ = sin 7.99218
2.37783

238.69
r_3 = 15.353
f_3 = 254.045
− .400
d_4 = 253.645
r_4 = 47.163 / 300.808 = 2.47829
γ = sin 7.99218
0.47047
r_4 = 1.67360
$i = 3° 35' 29''.5$ = sin 8.79687
= 0.17898
n = sin 8.97585
λ = 5° 25' 40.
1 50 10.5 r_4 = 1.67360
γ = 0 33 45.9 0.64945
δ = 2 23 56.4 = sin 8.62178
= 2.02767

106.580
r_4 = 47.163
f_4 = 59.417

X

$y = 2.5$ = log 0.39794
r_1 = 1.67360
$i = 3° 2' 19''$ = sin 8.72434
n' = 0.21123
λ = 1 52 3.8 = sin 8.51311
γ = 1 10 15.2 r_1 = 1.67360
0.18671
sin 8.31036
= 1.87635

75.223
r_1 = 47.163
f_1 = 122.386
t_2 = − .200
d_2 = 122.186
r_2 = 15.243 / 106.943 = 2.02918
γ = sin 8.31036
0.33951
r_2 = 1.18306
$i = 8° 14' 34''$ sin 9.15645 (45 927 563)
n' = 0.21123
$\lambda = 13° 29' 2''$ ----- sin 9.36768
5 14 28 r_2 = 1.18306
γ = 1 10 15.2 0.55074
δ = 4 4 12.8 = sin 8.85113
= 1.69961

50.074
r_2 = 15.243
f_2 = 34.831
0.001
d_3 = 34.832
r_3 = 15.353 / 50.187 = 1.70059
$\beta = \delta$ = sin 8.85113
0.55172
r_3 = 1.18624
$i = 13° 24' 52''$ = sin 9.36548
n = 0.18094
λ = 8 47 52 = sin 9.18454
4 37 0 r_3 = 1.18624
β = 4 4 15.2 0.37078
γ = 0 32 45.8 = sin 7.97911
2.39167

246.42
r_3 = 15.353
f_3 = 261.775
− .400
d_4 = 261.375
r_4 = 47.163 / 308.538 = 2.48931
γ = sin 7.97911
0.46842
r_4 = 1.67360
$i = 3° 34' 28''.5$ = sin 8.79482
n = 0.18094
λ = 5° 25 36.0 = sin 8.97576
1 51 7.5 r_4 = 1.67360
γ = 0 32 45.8 0.64936
δ = 2 23 53.3 = sin 8.62162
= 2.02774 (165 235)
106.596
r_4 = 47.163
f_4 = 59.433 − blue
.417 − red
.016 flint under corrected

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Color Correction

$r_4 = 47.163$
-1.000
Try ------ 46.163

C

$d_4 = 253.645$
$r_4 = \frac{46.163}{299.808} =$ 2.476 84 / 7.99218 / 0.46902
$r_4 =$ 1.66429
$i = 3°\,39'\,26'' =$ sin 8.80473
$n =$ 0.17898
$\lambda = 5\,31\,38 =$ sin 8.98371
$-1\,53\,12$ $r_4 =$ 1.66429
$\mu = 0\,33\,45.9$ 0.64800
$\delta = 2\,25\,57.9 =$ sin 8.62784 / 2.02016
104.752
$r_4 = \frac{46.163}{58.589}$

r_4 =	Color Ab =
47.163 =	.0160
44.877 =	.0000
Change 2.2860	.0160
.0142	.0001

Try

$d_4 = 253.645$
$r_4 = \frac{44.877}{298.522} =$ 2.47498 / 7.99218 / 0.46716
$r_4 =$ 1.65202
$i = 3°\,44'\,45.7 =$ sin 8.81514
$n =$ 0.17898
$\lambda = 5°\,39'\,42.8'' =$ sin 8.99412
$-1\,54\,56.6$ $r_4 =$ 1.65202
$\mu = 0\,33\,45.9$ 0.64614
$\delta = 2\,28\,42.4 =$ sin 8.63592 / 2.01021
102.381
$r_4 = \frac{44.877}{57.504}$
f_4

$A = \frac{1}{r_3} + \frac{1}{r_4}$ crown. $B = \frac{1}{r_2} - \frac{1}{r_1}$ flint.

$r_3 = 15.850 =$ l. 1.20003 / 8.79997 = 0.063091
$r_4 = 46.325 =$ 1.66582 / 8.33418 = 0.021586
$A =$ 0.084677

$r_2 = 15.735 =$ l. 1.19687 / 8.80313 = 0.063582
$r_1 = 48.684 =$ 1.68739 / 8.31261 = 0.020540
$B =$ 0.043042

X

$d_4 = 261.375$
$r_4 = \frac{46.163}{307.538} =$ 2.48790 / 7.97911 / 0.46701
$r_4 =$ 1.66429
$i = 3°\,38'\,25'' =$ sin 8.80272
$n =$ 0.18094
$\lambda = 5\,31\,35.2 =$ sin 8.98366
$-1\,53\,10.2$ $r_4 =$ 1.66429
$\mu = 0\,32\,45.8$ 0.64795
$\delta = 2\,25\,56.0 =$ sin 8.62775 / 2.02020
104.761
46.163
58.598
$.589$
$.009$ flint under corrected.

66 / 5364 / 1236 / 085

∴ change of -1 min in r_4 lessened ab. .007

$1 : 7 :: x : 9$ $\quad 7x = 9$ $\quad x = 1.286$

46.163
1.286
$r_4 = 44.877$ to correct –

$d_4 = 261.375$
$r_4 = \frac{44.877}{306.252} =$ 2.48608 / 7.97911 / 0.46519
$r_4 =$ 1.65202
$i = 3°\,43'\,44.7'' =$ sin 8.81317
$n =$ 0.18094
$\lambda = 5°\,39'\,42.8'' =$ sin 8.99411
$-1\,54\,56.6$ $r_4 =$ 1.65202
$\mu = 0\,32\,45.8$ 0.64613
$\delta = 2\,28\,42.4 =$ sin 8.63592 / 2.01021
102.381
$r_4 = \frac{44.877}{57.504}$
f_4

Color correction perfect. but $f_4 = 57.504$ inches

when $r_1 = 47.163$, $r_2 = 15.243$ } flint.
$r_3 = 15.358$, $r_4 = 44.877$ } crown

Measure the focal length $\frac{1}{31} = 59.359 = f_4$

then $r_1 = 48.684$, $r_2 = 15.735$ }
$r_3 = 15.850$, $r_4 = 46.325$ }

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$r_1 = r_4 = 47.000 \cdot$ = log. 1.67210

$\frac{1}{r_1} = \frac{1}{r_4} = .0212765^-$ = " 8.32790

$B = \frac{.04301 20}{.0642885} =$ " 8.80813

Flint $r_2 = 15.533^-$ = " 1.19187

$\frac{1}{r_4} = .0212765^-$

$A = \frac{.084677}{.0634005} =$ log. 8.80209

$r_3 = 15.773$ = " 1.19791

5614 Marginal

$y = 2.5 =$ log 0.39790

$r_1 =$ " 1.67210

$i = 3° 2' 55.7" =$ sin 8.72580

$n' =$ 0.20943

$\lambda = 1\ 52\ 54.5^-$ = sin 8.51637

$\gamma = 1\ 10\ 1.2$ $r_1 =$ 1.67210

0.18847

sin 8.30892

= 1.87985

75.779

$r_1 = 47.000$

$f_1 = 122.779$

.200

$d_2 = 122.579$

$r_2 = \frac{15.533^-}{107.024}$ = log 2.02948

$\gamma =$ sin 8.30892

0.33840

$i = 8° 3' 19.3"$ $r_2 =$ 1.19187

= sin 9.14653

$n' =$ 0.20943

= sin 9.35596

$\lambda = 13° 7' 6.6"$ $r_2 =$ 1.19187

$\gamma = 1\ 10\ 1.2$ 0.54783

$\delta = 3\ 53\ 46.1$ = sine 8.83218

= 1.71865

51.958

$d_2 = 15.533$

$f_2 = 36.403$

.001

$d_3 = 36.404$

$r_3 = \frac{15.773}{52.177}$ = 1.71748

β = sin 8.83218

0.54966

$r_3 =$ 1.19791

$i = 12° 59' 23"$ = sin 9.35175

= 0.17996

$\lambda = 8\ 32\ 28.6$ = sin 9.17179

$\beta = 4\ 26\ 54.4$ $r_3 =$ 1.19791

$\gamma = 3\ 53\ 46.1$ 0.36970

$\gamma = 0\ 33\ 8.3$ = sin 7.98405

2.38565

243.024

$d_3 = 15.773$

$f_3 = 258.797$

.400

$d_4 = 258.397$

$r_4 = \frac{47.000}{305.397}$ = 2.48486

γ = sin 7.98405

0.46891

$r_4 =$ 1.67210

$i = 3\ 35^-\ 27.5^-$ sin 8.79681

$n =$ 0.17996

$\lambda = 5^-\ 26\ 21.6$ sin 8.97677

$1\ 50\ 54.1$ $r_4 =$ 1.67210

$\gamma = 0\ 33\ 8.3$ 0.64887

$\delta = 2\ 24\ 2.4$ = sin 8.62208

2.02679

106.363

$r_4 = \frac{47.000}{59.363}$

f_4

.332

.031 Flint under corrected

5614 Central

$n' =$ 0.20943

$r_1 =$ 1.67210

1.88153

$n'-1 =$ 9.79216

$f_1 = 122.849$ = 2.08937

.200

$d_2 = 122.649$ = 2.08866

$r_2 =$ = 1.19187

3.28053

$d_2 = 2.08866$

$n-1 = \frac{9.79216}{1.88082} = 76.001$

$n' = 0.20943$

$r_2 = \frac{1.19182}{1.40130} = \frac{25.194}{50.809^-} = \frac{1.70592}{1.57461}$

$f_2 = 37.550$

.001

$d_3 = 37.551$ = 1.57462

r_3 = 1.19791

n = 0.17996

2.95249

$d_3 = 1.57462$

$n-1 = \frac{9.71048}{2.08805^-} = \frac{19.280}{122.476}$

1.285-10

$r_3 = \frac{15.773}{106.703} = \frac{0.54494}{3.507}$

= 2.40755

$f_3 = 255.594$

.400

$d_4 = 255.194$ = 2.40687

r_4 = 1.67210

4.07897

$d_4 = 2.40687$

$n-1 = \frac{9.71048}{2.11735^-} = 131.024$

$n = 0.17996$

$r_4 = \frac{1.67210}{1.85206} = \frac{71.131}{202.155^-} = 2.30568$

$f_4 = 59.332$ = 1.77329

Two years back a change of 2.202 = $r_1 = r_4$

Change at .135

2.202

31

2202

6606

135) 68.262 (.505

675

0762

675

870

$\therefore$ try $r_1 = r_4 = 47.506 = 1.67675$ 8.32325

$\frac{1}{r} = .021050$

$B = \frac{.043012}{.064062} = 8.80660$

$r_2 = 15.610$ = 1.19340

$\frac{1}{r_4} = .021050$

$A = \frac{.084677}{.063627} = 8.80384$

$r_3 = 15.717$ = 1.19636

31) .505 (.016

31

195

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$r_1 = r_4 = 47.506 = \log 1.67675$
$r_2 = 15.610 = \log 1.19340$
$r_3 = 15.717 = \log 1.19636$

$y = \log 0.39790$
$r_1 = \log 1.67675$
$i = 3°\ 0'\ 58.''7 = \sin 8.72115$
$n' = 0.20943$
$\lambda = 1\ 51\ 42.3 = \sin 8.57172$
$\gamma = 1°\ 9'\ 16.''4$ $r_1 = 1.67675$
$= 2i_n = 0.18847$
$= 8.30426$
$= 1.88421$

76.597
$r_1 = 47.506$
$f_1 = 124.103$
$,200$
$d_2 = 123.903$
$r_2 = 15.610 / 108.293 = 2.03460$
8.30426
0.33886
$r_2 = 1.19340$
$i = 8°\ 2'\ 7.''4 = \sin 9.14546$ 1100 93
$n' = 0.20943$
$\lambda = 13\ 5\ 8.3 = \sin 9.35489$ 1550 24
$5°\ 3'\ 0.''9$ $r_2 = 1.19840$
$\gamma = 1\ 9\ 16.4$ 0.54829
$\delta = 3\ 53\ 44.5 = \sin 8.83212$
$= 1.71617$
52.020
$r_2 = 15.610$
$f_2 = 36.410$
$,001$
$d_3 = 36.411$
$r_3 = 15.717 / 52.128 = 1.71707$
$\delta = i\ 8.83212$
0.54919
$r_3 = 1.19636$
$i = 13°\ 1'\ 21.''4 = \sin 9.35283$ 1801 41
$n = 0.17996$
$\lambda = 8\ 33\ 45.7 = \sin 9.17287$ 5000 km
$4\ 27\ 35.7$ $r_3 = 1.19636$
0.36923
$\beta = 3\ 53\ 44.5$
$\gamma = 0\ 33\ 51.2 = \sin 7.99332$ 22
$237.636 = 2.37591$
$r_3 = 15.717$
253.355
$f_3 = ,400$
$d_4 = 252.955$
$r_4 = 47.506 / 300.459 = 2.47778$
$\gamma = \sin 7.99332$
0.47110
$r_4 = 1.67675$
$i = 3°\ 34'\ 14.''6 = \sin 8.79435$
$n = 0.17996$
$\lambda = 5\ 24\ 30.6 = \sin 8.97431$ 140
$1\ 50\ 16.0$ $r_4 = 1.67675$
0.65106
$\gamma = 0\ 33\ 51.2$
$\delta = 2\ 24\ 7.2 = \sin 8.62232$
2.02874 60
106.841
$r_4 = 47.506$
$f_4 = 59.335$

$n' = 0.20943$
$r_1 = 1.67675$
1.88618
$n-1 = 9.79216$
$= 2.09402$
$f_1 = 124.171$
$,200$
$d_2 = 123.971 = 2.09332$
$r_2 = 1.19340$
3.28672

$d_2 = 2.09332$
$n-1 = 9.79216 / 1.88548 = 76.821$
$n' = 0.20943$
$r_2 = 1.19340 / 1.40283 = 25.283 / 51.538 = 1.71213$
$= 1.57459$
$f_2 = 37.548$
$,001$
$d_3 = 37.549 = 1.57460$
$= 1.19636$
r_3
$n = 0.17996$
2.95092

$d_3 = 1.57460$
$n-1 = 9.71048 / 1.28508 = 19.279$
$= 15.717 / 3.562 = 0.55169$
r_3
2.39923
$f_3 = 250.744$
$,400$
$d_4 = 250.344 = 2.39854$
$= 1.67675$
r_4
4.07529

$d_4 = 2.39854$
$n-1 = 9.71048 / 2.10902 = 128.535$
$n = 0.17996$
$r_4 = 1.67675 / 1.85671 = 71.897 / 200.432 = 2.30197$
$= 1.77332$
$f_4 = 59.336$
$,335$
$,001$ Mint was corrected

$(r_1 = r_4) = 47.506$ L
correction for $n-1$ $,016$
$r_1 = r_4 = 47.490 = 1.67660$
$\frac{1}{r_1} = ,021057 = 8.32340$
$B = ,043012 / ,064069 = 8.80665$
$r_2 = 15.608 = 1.19335$

$\frac{1}{r_4} = ,021057$
$A = ,084677 / ,063620 = 8.80359$
$r_3 = 15.719 = 1.19641$

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$r_1 = r_4 = 47.490$ } flint $r_2 = 15.608$ } flint $r_3 = 15.719$ crown $t_1 = .200$ $t_2 = .400$ $f_4 = 59.335$

corrects both for color + spherical aberration

In correcting the spherical aberration the focal length was increased .003 in but this does not alter perceptably the color correction for 3 pages back for it was only changed .016 in by a change in the focal length of 1.929 in

To make the focal length of this combination the same as it was when the crown lens was placed in front, viz 59.380 in increase each radius by $\frac{.045}{59.335}$ part of itself.

f_4 = 59.380 = log 1.77331
.045 = " 8.65321
x = 3.12010

47.490 = 1.67660
x = 3.12010
.036 = 8.55650
$r_1 = r_4$ = 47.526

r_2 = 15.620 = 1.19335 + 3.12010 = 8.07325
.012

r_3 = 15.731 = 1.19641 + 3.12016 = 8.07631
.012

Hence - Flint in front -

as completed
45.505
14.959
14.959
49.884
$\bar{r}$ = 59.370

se 26 leaves on

r_1 = 47.526
r_2 = 15.620
} flint ---- t_1 = .200
D = .001

r_3 = 15.731
r_4 = 47.526
} crown ---- t_2 = .400

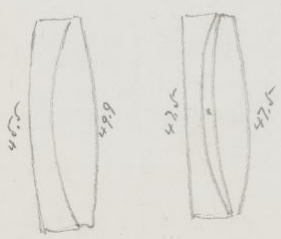
f = 59.380

2d Calculation Crown in Front. (Steps 5 leaves back)

r_1 = 49.3164
r_2 = 15.1394
} crown --- t_1 = .400
D = .000 touch at center .004 from edge

r_3 = 15.4609
r_4 = 49.3164
} flint ---- t_2 = .200

f = 59.380



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Lenses in front. To determine which form of lens is the best one.

C line. Marginal

$y_{2.5}$ = log 0.397900

$r_1 = 49.3164$ = 1.692992 ✓

$i = 2° 54' 19.''70$ ✓ = sin 8.704908 ✓

n = 0.178982

λ = 1 53 25.21 = sin 8.525926

γ = 0 58 54.49 r_1 = 1.692992

= sin 8.233881

96.6133 = 1.985037

r_1 = 49.3164

f_1 = 145.9297

.04000

d_2 = 145.5297

r_2 = 15.1894 / 160.6691 = 2.205932

γ = sin 8.233881 / 0.439813

r_2 = 1.180109 = sin 9.259704

$i = 10° 28' 38.''33$ n = 0.178982

= sin 9.438686

λ = 15 56 15.48 r_2 = 1.180109

5 27 37.15 0.618795

γ = 0 58 54.49

δ = 6 26 31.64 = sin 9.049991 / 1.568804

37.0818 =

r_2 = 15.1394

f_2 = 21.9119

D = 0.

d_3 = 21.9119

r_3 = 15.4609 / 37.3728 ✓ = 1.572536

δ = sin 9.049991 ✓ / 0.622547 ✓

r_3 = 1.189235 ✓

$i = 15° 44' 11.''5$ = sin 9.433312

n' = 0.207697

λ = 9 40 42.4 = sin 9.225615 ✓

β = 6 3 29.1 r_3 = 1.189235

γ = 6 26 31.64 0.414855 ✓

= sin 7.826249

387.794 = 2.588601 ✓

r_3 = 15.461

f_3 = 372.333 ✓

.200

d_4 = 372.133 ✓

r_4 = 49.3164 / 421.4494 = 2.624746

γ = sin 7.826249 ✓ / 0.450998 ✓

r_4 = 1.692992 = sin 8.758003 ✓

$i = 3° 17' 1.''32$ n' = 0.207697

= sin 8.965700 ✓

λ = 5 18 7.32 r_4 = 1.692992

2 1 6.00 0.658692 ✓

γ = 0 23 2.54

δ = 2 24 8.54 = sin 8.622390 / 2.036302 ✓

108.7181 =

r_4 = 49.3164

f_4 = 59.4017 ✓

.4012

Crown .0005 under corrected

C line. Central.

n = 0.178982

r_1 = 1.692992 / 1.871974

$n-1$ = 9.707586 = 2.164388

f_1 = 146.0118 / .4 / 145.6118 = 2.163197

d_2 = 2.163197

r_2 = 1.180109 / 3.343306

d_2 = 2.163197

$n-1$ = 9.707586 / 1.870783 = 74.2648

n = 0.178982

r_2 = 1.180109 / 1.359091 = 22.8608 / 97.1256 = 1.987334

= 1.355972

f_2 = 22.6972 / .0

d_3 = 22.6972 = 1.355972

n' = 0.207697

r_3 = 1.189235 / 2.752904

d_3 = 1.355972

$n-1$ = 9.787625 / 1.143597 = 13.91865 / 1.542225 = 0.188155 / 15.4609

= 2.564749

f_3 = 369.070 / .2

d_4 = 366.870 = 2.564512

r_4 = 1.692992 / 4.257504

d_4 = 2.564512

$n-1$ = 9.787625 / 2.352137 = 224.9764

n' = 0.207697

r_4 = 1.692992 / 1.900689 = 79.5390 / 304.5354 = 2.483638

f_4 = 59.4109 = 1.773866

A change of +0.79 in r_4 produced a change of −.013 in color correction

.790 / 13. = .0608 for .001

∴ .0304 to be added to r_4

to make color correction perfect.

Hence color correction is perfect when r_1 = 49.3164, r_2 = 15.1394, r_3 = 15.4609, r_4 = 49.3468 } to find A & B.

59.4109 central

.4017

.0092 central out

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Crown in front.

X. Marginal

$y = 0.397900$

$i = 2^\circ\ 54'\ 19.''70 = \sin 8.704908$

$n = 0.180944$

$\lambda = 1\ 54\ 53.98 = \sin 8.523964$

$y = 0\ 59\ 25.72$; $r_1 = 1.692992$

0.216956

$\sin 8.237700$

$95.3388 = 1.979256$

$\eta = 49.3164$

$f_1' = 144.6522$

$,4$

$d_2 = 144.2822$

$r_2 = 15.1394$

$159.3916 = 2.202465$

$\gamma = \sin 8.237700$

0.440165

$r_2 = 1.180109$

$i = 10^\circ\ 29'\ 9.''22 = \sin 9.260056$

$n = 0.180944$

$\lambda = 16\ 1\ 30.22 = \sin 9.441000$

$5\ 32\ 21.00$ $r_2 = 1.180109$

$y = 0\ 59\ 25.72$ 6.621109

$\delta = 6\ 31\ 46.72 = \sin 9.055826$

$36.7522 = 1.565283$

$r_2 = 15.1394$

$d_3 = f_2 = 21.6128$

$r_3 = 15.4609 / 37.0737 \checkmark = 1.569066$

$\beta = \sin 9.055826 \checkmark$

$0.624892 \checkmark$

$r_3 = 1.189235$

$i = 15^\circ\ 49'\ 26.''20 = \sin 9.435657 \checkmark$

$n' = 0.211227$

$\lambda = 9\ 39\ 6.83 = \sin 9.224430 \checkmark$

$6\ 10\ 19.87$ $r_3 = 1.189235$

$\beta = 6\ 31\ 46.72$ $0.413665 \checkmark$

$y = 0\ 21\ 26.85 = \sin 7.795100$

$= 2.618565 \checkmark$

415.494

$r_3 = 15.461$

$f_3 = 400.033 \checkmark$

$,2$

$d_3 = 399.833 \checkmark$

$r_4 = 49.3164 / 449.1494 \checkmark = 2.652398$

$\gamma = \sin 7.795100 \checkmark$

0.447491

$r_4 = 1.692992$

$i = 3^\circ\ 15'\ 26.''22 = \sin 8.754499 \checkmark$

$n' = 0.211227$

$\lambda = 5\ 18\ 8.47 = \sin 8.965726 \checkmark$

$2\ 2\ 42.25$ $r_4 = 1.692992$

$y = 0\ 21\ 26.85$ $0.658718 \checkmark$

$\delta = 2\ 24\ 9.10 = \sin 8.622418$

$2.036300 \checkmark$

108.7176

49.3164

$f_4' = 59.4012$

X. Central

$n = 0.180944$

$r_1 = 1.692992$

1.873936

$(9.713370) = n-1 = 9.713370$

$f_1 = 144.7325 = 2.160566$

$,4$

$d_2 = 144.3325 = 2.159364$

$r_2 = 1.180109$

3.339473

$d_2 = 2.159364$

$n-1 = 9.713370$

$1.872734 = 74.5992$

$n = 0.180944$

$r_2 = 1.180109$

$1.361053 = 22.9643$

$97.5635 = 1.989287$

$d_3 = f_2 = 22.3968 = 1.350186$

$n' = 0.211227$

$r_3 = 1.189235$

2.750648

$d_3 = 1.350186$

$n'-1 = 9.796852$

$1.147038 = 15.4609 / 14.02936 / 1.43454 = 0.156803$

$= 2.594845$

$f_3 = 393.410$

$,2$

$d_4 = 393.210 = 2.594624$

$r_4 = 1.692992$

4.287616

$d_4 = 2.594624$

$n'-1 = 9.796852$

$2.391476 = 246.307$

$n' = 0.211227$

$r_4 = 1.692992$

$1.904219 = 80.208$

$326.515 = 2.513903$

$= 1.773713$

$f_4 = 59.3900$

$r_1 = \log 1.692992$

$.0202772 = \frac{1}{r_1} = 8.307008$

$r_2 = " 1.180109$

$A = \frac{.0660528}{.0863300} = \frac{1}{r_2} = 8.819891$

$r_3 = 1.189235$

$= \frac{1}{r_3} = 8.810765$

$.0646793$

$r_4 = 1.693259$

$B = \frac{.0202647}{.0444146} = \frac{1}{r_4} = 8.306741$

59.4012 Marginal

$.3900$

$.0112$ Central in.

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Crown in front continued.

λ = 5614. Marginal

7.

$i = 2° 54' 19.''701$ = sin 8.704908
n = 0.179963
$\lambda = 1\ 55\ 9.58$ = sin 8.524945
$\gamma = 0\ 59\ 10.12$ r_1 = 1.692992
= sin 8.235797
= 1.982140

95.9710
r_1 = 49.3164
f_1 = 145.2874
.4
d_2 = 144.8874
r_2 = 15.1394 / 160.0268 = 2.204193
γ = sin 8.235797
0.439990
r_2 = 1.180109
$i = 10° 28' 53.''85$ = sin 9.259881
n = 0.179963
$\lambda = 15\ 58\ 52.''77$ = sin 9.439844
$5\ 29\ 58.92$ r_2 = 1.180109
$\gamma = 0\ 59\ 10.12$ = sin 9.052916
$\delta = 6\ 29\ 9.04$ = 1.567037
36.9209
r_2 = 15.1394
$d_3 = f_2$ = 21.7615
r_3 = 15.4609 / 37.2224 = 1.570804
β = sin 9.052916
0.623720
r_3 = 1.189235
$i = 15° 46' 48.''67$ = sin 9.434485
n' = 0.209428
$\lambda = 9\ 39\ 57.''22$ = sin 9.225057
$6\ 6\ 51.''45$ r_3 = 1.189235
$\beta = 6\ 29\ 9.04$ 0.414292
$\gamma = 0\ 22\ 17.''59$ = sin 7.811895
= 2.602397
400.311
r_3 = 15.461
ρ_3 = 384.850
.2
d_4 = 384.650
r_4 = 49.3164 / 433.9664 = 2.637456
γ = sin 7.811895
0.449351
r_4 = 1.692992
$i = 3° 16' 16.''61$ = sin 8.756389
n' = 0.209428
$\lambda = 5\ 18\ 11.''16$ = sin 8.965787
$2\ 1\ 54.''55$ r_4 = 1.692992
$\gamma = 0\ 22\ 17.''59$ 0.658779
$\delta = 2\ 24\ 12.''14$ = sin 8.622571
= 2.036208
108.6946
49.3164
f_4 = 59.3782

Best form of lens continued

λ = 5614 Central

n = 0.179963
r_1 = 1.692992 / 1.872955
$n-1$ = 9.710483 = 2.162472
f_1 = 145.3690 / .4
d_2 = 144.9690 = 2.161275
r_2 = 1.180109 / 3.341384

d_2 = 2.161275
$n-1$ = 9.710483 / 1.871758 = 74.4317
n = 0.179963
r_2 = 1.180109 / 1.360072 = 22.9125 / 97.3442 = 1.988310 / 1.353074
$d_3 = f_2$ = 22.8762
r_3 = 1.189235
n' = 0.209428 / 2.751737

d_3 = 1.353074
$n'-1$ = 9.792165 / 1.145289 = 13.97137 / 1.489573 = 0.173049 / 2.578688
f_3 = 379.043 / .200
d_4 = 378.843 = 2.578459
r_4 = 1.692992 / 4.271451

d_4 = 2.578459
n' = 9.792165 / 2.370624 = 234.760
n' = 0.209428
r_4 = 1.692992 / 1.902420 = 79.8767 / 314.637 = 2.497810 / 1.773641
f_4 = 59.3801
59.3782
Crown — .0019 under corrected

~~the crown of lens back~~
correction added instead of subtracted

When
r_1 = 49.3164
" = 49.3100
.0064
.000533
.0101

Δb = .0019 over corrected
= .0007 " "
.0012
.0001
.0019

$r_1 = r_4$ = 49.3164 / −.0177 / 49.2987 correct for .0019 Δb. over. as diagram 7 leaves back.

49.3100 / .0041 / 49.3059 correct for .0007

49.3164 / .0164 / 49.3000 diagram 7 leaves back

8.31

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$\lambda = 5614$ Marginal

$y = 2.5 = \log 0.397940$

$\gamma =$ 1.692838

$i = 2^\circ\ 54'\ 24''.38 = \sin 8.705102$

$n = 0.179963$

$\lambda = 1\ 55\ 12.66 = \sin 8.525139$

$\gamma = 0\ 59\ 11.72$ $\quad \tau_1 = 1.692838$

0.217977

$\sin 8.235992 = 1.981985$

95.9368

$\tau_1 = 49.2990$

$f_1 = 145.2358$

$.4$

$d_3 = 144.8358$

$\tau_2 = 15.1410$

$159.9768 = 2.204057$

$\gamma = \sin 8.235992$

0.440049

$\tau_2 = 1.180156$

$i = 10^\circ\ 28'\ 57''.90 = \sin 9.259893$

$n = 0.179963$

$\lambda = 15\ 58\ 57.39 = \sin 9.439856$

$5\ 29\ 59.49$ $\quad \tau_2 = 1.180156$

0.620012

$\gamma = 0\ 59\ 11.72$

$\delta = 6\ 29\ 11.21 = 9.052956$

$36.9025 = 1.567056$

$\tau_2 = 15.1410$

$d_3 = f_2 = 21.7615$

$\tau_3 = \dfrac{15.4562}{37.2177} = 1.570750$

$\beta = 9.052956$

0.623706

$\tau_3 = 1.189102$

$i = 15^\circ\ 47'\ 4''.64 = \sin 9.434604$

$n' = 0.209428$

$\lambda = 9\ 40\ 6.79 = \sin 9.225176$

$6\ 6\ 57.85$ $\quad \tau_3 = 1.189102$

0.414278

$\beta = 6\ 29\ 11.21$

$\gamma = 0\ 22\ 13.36 = \sin 7.810519$

$= 2.603759$

401.568

$\tau_3 = 15.4562$

$f_3 = 386.112$

$.2$

$d_4 = 385.912$

$\tau_4 = 49.299$

$435.211 = 2.638700$

$\gamma = \sin 7.810519$

0.449219

$\tau_4 = 1.692838$

$i = 3^\circ\ 16'\ 17''.20 = \sin 8.756381$

$n' = 0.209428$

$\lambda = 5\ 18\ 12.13 = \sin 8.965809$

$2\ 1\ 54.93$ $\quad \tau_4 = 1.692838$

0.655647

$\gamma = 0\ 22\ 13.36$

$\delta = 2\ 24\ 8.29 = \sin 8.622379$

$= 2.036269$

108.7099

$\tau_4 = 49.2990$

$f_4 = 59.4109$

$.4080$

$.0029$ over

$\lambda = 5614$ Central

$n = 0.179963$

$\tau_1 = 1.692838$

1.872801

$n-1 = 9.710483$

$f_1 = 14.53175 = 2.162318$

$.4$

$d_2 = 144.9175 = 2.161134$

$\tau_2 = 1.180156$

3.341290

$d_2 = 2.161134$

$n-1 = \dfrac{9.710483}{1.871617} = 74.4076$

$n = 0.179963$

$\tau_2 = \dfrac{1.180156}{1.360119} = \dfrac{22.9150}{97.3226} = \dfrac{1.988214}{1.353076}$

$d_3 = f_2 = 22.54634$

$\tau_3 = 1.189102$

$n' = 0.209428$

2.758606

$d_3 = 1.353076$

$n'-1 = 9.792165$ $\quad 15.456200$

$1.145241 = 13.971436 = 0.171668$

$1.484764 = 2.579938$

$f_3 = 380.135$

$.2$

$d_3 = 379.935 = 2.579709$

$\tau_4 = 1.692838$

4.272547

$d_3 = 2.579709$

$n'-1 = 9.792165$

$2.371874 = 235.437$

$n' = 0.209428$

$\tau_4 = \dfrac{1.692838}{1.902266} = \dfrac{79.848}{315.285} = 2.498703$

$= 1.773844$

$f_4 = 59.4080$

$\tau_1 = \tau_4 = 49.2990 = \log 1.692838$

$.0202844 = 8.307162$

$A = .0863300$

$.0660456 = 8.819844$

$\tau_2 = 15.14105 = 1.180156$

$\frac{1}{\tau_4} = .0202844$

$B = .0444146$

$.0646990 = 8.810898$

$\tau_3 = 15.4562 = 1.189102$

$\tau_1 = \tau_4 = 49.2990$

To correct ab. 4 of .0029 add $.0370$

49.3360

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Crown in front continued

New value of A. & B.

λ = 5614 Marginal

$i = 2°\,54'\,16.''52$

$\lambda = 1\ 55\ 7.47$

$\beta = 0\ 59\ 9.05$

$\gamma = \log 0.397940$

$r_1 = 1.693164$

$= \sin 8.704776$

$x = 0.179963$

$= \sin 8.524813$

$r_1 = 1.693164$

0.217977

$= \sin 8.235665$

$= 1.982312$

96.0090

$r_1 = 49.3360$

$f_1 = 145.3450$

$d_2 = 144.9450$

$r_2 = 15.1376 / 160.0826$

$\gamma = \sin 8.235665 = 2.204344$

$r_2 = 1.180056$

$= \sin 9.259953$

$i = 10°\,29'\,0.''18$

$\lambda = 15\ 59\ 2.57$

$5\ 30\ 2.36$

$\beta = 0\ 59\ 9.05$

$\delta = 6\ 29\ 11.41$

$x = 0.179963$

$= \sin 9.439916$

$r_2 = 1.180056$

0.619972

$= \sin 9.052960$

$= 1.567012$

36.8988

$r_2 = 15.1376$

$f_2 = 21.7612$

$d_3 =$

$r_3 = 15.4598 / 37.2210$

$= 1.570788$

$\beta = \sin 9.052960$

0.623748

$r_3 =$

$i = 15°\,46'\,56.''59 = \sin 1.189204$

$x' = 0.209428$

$\lambda = 9\ 40\ 1.95 = \sin 9.225116$

$6\ 6\ 54.64$

$r_3 = 1.189204$

$\beta = 6\ 29\ 11.41$

0.414320

$\gamma = 0\ 22\ 16.77 = \sin 7.811629$

$= 2.602691$

400.582

$r_3 = 15.460$

$f_3 = 385.122 / 0.2$

$d_4 = 384.922$

$r_4 = 49.336 / 434.258 = 2.637748$

$\gamma = \sin 7.811629$

0.449377

$r_4 = 1.693164$

$i = 3°\,16'\,12.''61 = \sin 8.756213$

$x' = 0.209428$

$\lambda = 5\ 18\ 4.73 = \sin 8.965641$

$2\ 1\ 52.12 + r_4 = 1.693163$

$\beta = 0\ 22\ 16.77$

$\delta = 2\ 24\ 8.89 = 0.658804$

8.622408

108.7417

2.036396

$r_4 = 49.3360$

$f_4 = 59.4057$

8.02

λ = 5614 Central

8.05

$x = 0.179963$

$r_1 = 1.693164$

1.873127

$x-1 = 9.710483 = 2.162644$

$f_1 = 145.4267 / .4 = 145.0267 = 2.161448$

$d_2 = = 1.180056$

$r_2 = 3941594$

$d_2 = 2.161448$

$x-1 = 9.710483 / 1.871931 = 74.4614$

$x = 0.179963$

$r_2 = 1.180056 / 1.360019 = 22.9097 / 97.3711 = 1.988430 = 1.353074$

$d_3 = f_2 = 22.5462 = r_3 = 1.189204$

$x' = 0.209428 / 2.751706$

$d_3 = 1.353074$

$x'-1 = 9.792165 / 1.145239 = 15.45980 / 13.97137 / 1.48843 = 0.172728 = 2.578978$

$f_3 = 379.296 / .2 = 379.096 = 2.578749$

$d_4 = = 1.693164$

$r_4 = 4.271913$

$d = 2.578749$

$x-1 = 9.792165 / 2.370914 = 234.917$

$x' = 0.209428$

$r = 1.693164 / 1.902592 = 79.908 / 314.825 = 2.498069$

$= 1.773844$

$f_4 = 59.4079 / .4057 / .0022$ under

8.32

$\log r_1 - r_4 = 49.3360 = \log 1.693164$

$.0202692 = 8.306836$

$A = .0863300 / .0660608 = 8.819944$

$r_2 = 15.1376 = 1.180056$

$.0202692$

$B = .0444146 / .0646838 = 8.810796$

$r_3 = 15.4598 = 1.189204$

49.3360 give 22 under

.2990 = 29 over

.0370 51

.0160 22

49.3360

49.3200

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λ = 56 1x Marginal

y = 0.397940
γ₁ = 0.693023
= sin 8.704917

i = 2° 54′ 19.″92
n = 0.179963
= sin 8.524954
γ₁ = 0.693023
0.217977
= sin 8.235806
= 1.982171

λ = 1 53 9.72
ȳ = 0 59 10.20

95.9479
γ₁ = 49.3200
f₁ = 145.2979
.4
d₂ = 144.8979
γ₂ = 15.1391
160.0370

= 2.204220
γ = sin 8.235806
0.440026
γ₂ = 1.180100
= sin 9.259926
n = 0.179963
= sin 9.439889
γ₂ = 1.180100
0.619989
= sin 9.052957
= 1.567032

i = 10° 28′ 57.″80
λ = 15 58 58.87
5 30 1.07
ȳ = 0 59 10.20
δ = 6 29 11.27

36.9005
γ₂ = 15.1391
d₃ = f₂ = 21.7614
γ₃ = 15.4582
37.2196

= 1.570772
β = sin 9.052957
0.623729
γ₃ = 1.189160
= sin 9.434569
n′ = 0.209428
= sin 9.225141
γ₃ = 1.189160
0.414301
= sin 7.811131
= 2.603170

i = 15° 47′ 0.″00
λ = 9 40 3.97
6 6 56.03
β = 6 29 11.27
ȳ = 0 22 15.24

401.0236
γ₃ = 15.4582
f₃ = 385.5654
.2
d₄ = 385.3654
γ₄ = 49.3200
434.6854

= 2.638176
γ = sin 7.811131
0.449307
γ₄ = 1.693023
= sin 8.756279
n′ = 0.209428
= sin 8.965707
γ₄ = 1.693023
0.658730
= sin 8.622385
= 2.036345

i = 3° 16′ 14.″43
λ = 5 18 7.63
2 1 53.20
ȳ = 0 22 15.24
δ = 2 24 8.44

108.7288
γ₄ = 49.3200
59.4088

.0008 over

λ = 56 1x Marginal Decimals

y = 0.397940
γ₁ = 1.693086
n = 0.179963
= sin 8.524891
γ₁ = 1.693086
0.217977
= sin 8.235743
= 1.982234

i = 2° 54′ 18.″40
λ = 1 53 8.72
ȳ = 0 59 9.68

95.9918
γ₁ = 49.3272
= 145.3190
.4
d₂ = 144.9190
γ₂ = 15.1384
160.0574

= 2.204276
γ = sin 8.235743
0.440019
γ₂ = 1.180080
= sin 9.259939
n = 0.179963
= sin 9.439902
γ₂ = 1.180080
0.619982
= sin 9.052959
= 1.567023

i = 10° 28′ 58.″94
λ = 15 59 0.64
5 30 1.70
ȳ = 0 59 9.68
δ = 6 29 11.38

36.8997
γ₂ = 15.1384
= 21.7613
γ₃ = 15.4590
37.2203

= 1.570780
γ = sin 9.052959
0.623739
γ₃ = 1.189180
= sin 9.434559
x′ = 0.209428
= sin 9.225131
γ₃ = 1.189180
0.414311
= sin 7.811359
= 2.602952

i = 15° 46′ 58.″60
λ = 9 40 3.16
6 6 55.44
δ = 6 29 11.38
ȳ = 0 22 15.94

400.8224
γ₃ = 15.4590
385.3634
.2
385.1624
γ₄ = 49.3272
434.4896

= 2.637979
γ = sin 7.811359
0.449338
γ₄ = 1.693086
= sin 8.756252
x′ = 0.209428
= sin 8.965680
γ₄ = 1.693086
0.658766
= sin 8.622397
= 2.036369

i = 3° 16′ 13.″70
λ = 5 18 6.44
2 1 52.74
ȳ = 0 22 15.94
δ = 2 24 8.68

108.7344
49.3272
59.4072

.0008 under

---

tng γ₁ = γ₄ = 49.3200 = log 1.693023
8.306977

A = .0202758 = 8.819900
.0863200
.0660542

γ₂ = 15.1391 = 1.180100

.0202758
B = .0444146
.0646904 = 8.810840
γ₃ = 15.4582 = 1.189160

---

tng γ₁ = γ₄ = 49.3272 = 1.693086
8.306914

.0202728
.0863300
.0660572 = 8.819920
= 1.180080

γ₂ = 15.1384

.0202728
.0444146
.0646874 = 8.810820
= 1.189180

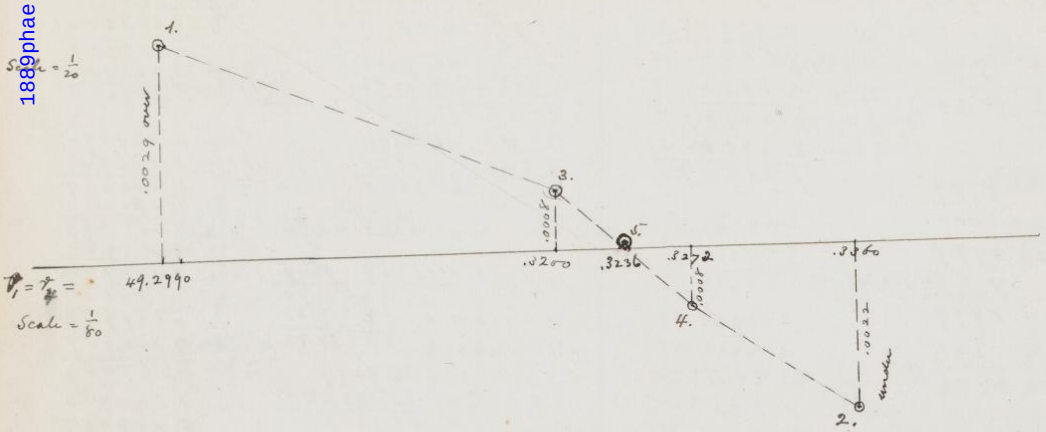
γ₃ = 15.4589 54

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Screen in front

Result of the last 4 calculations - for Spherical Aberration.



$\nu_1 = \nu_4 = 49.3236 = \log. 1.693055$

$.020\,2743 = \quad " \quad 8.306945$

$A = \dfrac{.0863300}{.0660557} = \quad . \quad 8.819910$

$\nu_2 = 15.13874 = \quad . \quad 1.180090$

$.020\,2743$

$B = \dfrac{.0444146}{.0646889} = \quad " \quad 8.810830$

$\nu_3 = 15.4586 = \quad " \quad 1.189170$

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Lenses in front continued

λ = 5614 Marginal

i = 2° 54' 19.15"
λ = 1 53 9.21
β = 0 59 9.94

95.9850
γ₁ = 49.3236
f₁ = 145.3086
,4
d₂ = 144.9086
γ₂ = 15.1387
160.0473

i = 10° 28' 58.32
λ = 15 58 59.69
5 30 1.37
β = 0 59 9.94
δ = 6 29 11.31
36.9905
γ₂ = 15.13874
f₂ = 21.76131
γ₃ = 15.4586
37.2199

i = 15° 46' 59.15"
λ = 9 40 3.48
6 6 55.67
β = 6 29 11.31
γ = 0 22 15.64
400.9073
15.4586
f₃ = 385.4487
,2
385.2487
γ₄ = 49.3236
434.5723

i = 3° 16' 14.14"
λ = 5 18 7.15
2 1 53.01
γ = 0 22 15.64
2 24 8.65
108.7314
γ₄ = 49.3236
f₄ = 59.4078
,4077
,0001 over.

y = 0.397940
γ₁ = 1.693053
= sin 8.704885
x = 0.179963
= sin 8.524922
γ₁ = 1.693053
0.217977
= sin 8.238774
= 1.982203

= 2.204248
β = sin 8.238774
0.440022
γ₂ = 1.180090
= sin 9.259932
x = 0.179963
= sin 9.439895
γ₂ = 1.180090
0.619985
= sin 9.052958
= 1.567027

= 1.570775
β = sin 9.052958
0.623733
γ₃ = 1.189170
= sin 9.434563
x' = 0.209428
= sin 9.225135
γ₃ = 1.189170
0.414305
= sin 7.811261
= 2.603044

= 2.638062
β = sin 7.811261
0.449323
γ₄ = 1.693053
= sin 8.756268
x' = 0.209428
= sin 8.965696
γ₄ = 1.693053
0.658751
= sin 8.622396
2.036355

λ = 5614 Central

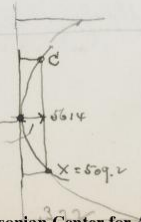
x = 0.179963
γ₁ = 1.693053
1.873018
x-1 = 9.710483
= 2.162535
f₁ = 145.3902
,4
d₂ = 144.9902
= 2.161339
γ₂ = 1.180090
3.341429

d = 2.161339
x-1 = 9.710483
1.871822 = 74.4427
x = 0.179963
γ₂ = 1.180090
1.360053 = 22.9115
97.3542 = 1.988353
= 1.353074
d₃ = f₂' = 22.5462
γ₃ = 1.189170
x' = 0.209428
2.751672

d = 1.353074
x'-1 = 9.792165
1.145239 = 13.97134
15.45860
1.487213 = 0.172378
f₃ = 379.572
,2
d₄ = 379.372
= 2.579065
γ₄ = 1.693053
4.272120

d = 2.579065
x'-1 = 9.792165
2.371230 = 235.088
x' = 0.209428
γ₄ = 1.693053
1.902483 = 79.888
314.976 = 2.498277
1.773843
59.4077 =

C + X, f₄ = 59.4290½
λ=5614 f₄ = 59.4078
,0212



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Corrs in front.

= C. Marginal

$i = 2^\circ\ 54'\ 19.''15$

$\lambda = 1\ 53\ 24.84$

$\beta = 0\ 58\ 54.31$

$y = 0.397940$
$\gamma_1 = 1.693053$
$= \sin\ 8.704885$
$n = 0.178982$
$= \sin\ 8.525903$
$\gamma_1 = 1.693053$
0.219855
$= \sin\ 8.233855$
$= 1.985100$

96.6273
$\gamma_1 = 49.3236$
$f_1 = 145.9509$
$.4$
$d_2 = 145.5309$
$\gamma_2 = 15.1387$
160.6896
$= 2.205988$
$\beta = \sin\ 8.233858$
0.439846
$\gamma_2 = 1.180090$
$= \sin\ 9.259756$
$a'' = 0.178982$
$= \sin\ 9.438738$
$\gamma_2 = 1.180090$
0.618828
$= \sin\ 9.059034$
$= 1.568794$

$i = 10^\circ\ 28'\ 42.''88$

$\lambda = 15\ 56\ 22.53$
$5\ 27\ 39.65$

$\beta = 0\ 58\ 54.31$
$\delta = 6\ 26\ 33.96$

37.0505
$\gamma_2 = 15.1387$
$f_2 = 21.9118$
$d_3 = \gamma_3 = 15.4586$
37.3704
$= 1.572528$
$\beta = \sin\ 9.059034$
0.622562
$\gamma_3 = 1.189170$
$= \sin\ 9.433392$
$n' = 0.207697$
$= \sin\ 9.225695$
$\gamma_3 = 1.189170$
0.414865
$= \sin\ 7.825658$
$= 2.589207$

$i = 15^\circ\ 44'\ 22.''16$

$\lambda = 9\ 40\ 48.86$
$6\ 3\ 33.30$

$\beta = 6\ 26\ 33.96$
$\delta = 0\ 23\ 0.66$

388.3355
$\gamma_3 = 15.4586$
$f_3 = 372.8769$
$,2$
$d_4 = 372.6769$
$\gamma_4 = 49.3236$
422.0005
$= 2.625313$
$\beta = \sin\ 7.825658$
0.450971
$\gamma_4 = 1.693053$
$= \sin\ 8.757916$
$n' = 0.207697$
$= \sin\ 8.965613$
$\gamma_4 = 1.693053$
0.658668
$= 8.622227$
$= 2.036441$

$i = 3^\circ\ 16'\ 58.''95$

$\lambda = 5^h\ 18\ 3.49$
$2\ 1\ 4.54$

$\beta = 0\ 23\ .66$
$\delta = 2\ 24\ 5.20$

108.7429
$\gamma_4 = 49.3236$
$f_4 = 59.4293$

$\frac{.4258}{.0005} = X$ under correction by flint lens.

Corrs for colr.

λ = C. Central

$n = 0.178982$
$\gamma_1 = 1.693053$
1.872035
$n-1 = 9.707586$
$= 2.164453$
$= 2.163260$
$\gamma_2 = 1.180090$
3.343350

$f_1 = 146.033$
$.4$
$d_2 = 145.633$

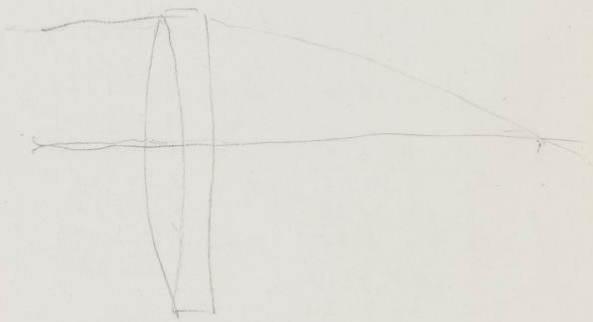
$d_2 = 2.163260$
$n-1 = 9.707586$
$2.870846 = 74.2756$
$n = 0.178982$
$\gamma_2 = 1.180090$
$1.359072 = \frac{22.8598}{97.1354} = \frac{1.987377}{1.358973}$
$d_3 = f_2 = 22.6972$
$\gamma_3 = 1.189170$
$n' = \frac{0.207697}{2.752840}$

$d_3 = 1.358973$
$n-1 = 9.787625$
$1.143598 = \frac{15.45860}{13.91868} = \frac{0.187498}{2.565342}$
$f_3 = 367.372$
$,2$
$d_4 = 367.372$
$= 2.565106$
$\gamma_4 = \frac{1.693053}{4.258161}$

$d_4 = 2.565106$
$n-1 = 9.787625$
$2.352731 = 225.2844$
$n' = 0.207697$
$\gamma_4 = 1.693053$
$1.900752 = \frac{79.5705}{304.8549} = \frac{2.484093}{1.774068}$

$f_4 = 59.4385$
$.4293$
$.0092$ under corrected by flint

Corrs also for Sph. Ab.



Marginal - C. $\gamma =$ 59.4293
" $\lambda = 5614$ $= \frac{.4078}{.0215}$

See 4 leaving book - Summer 1889

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Lesson in front.

$\lambda = X$ Marginal.

$i = 2^\circ\ 54'\ 19.15'' = \sin 8.704885$

$\lambda = 1\ 57\ 53.61 = \sin 8.523941$

$\beta = 0\ 59\ 25.54 = \sin 8.237679$

95.3492

$\gamma_1 = \dfrac{49.3236}{144.6728}$

$\dfrac{.4}{144.2728}$

$\gamma_2 = \dfrac{15.1387}{159.4115} = 2.202520$

$n = 0.180944$

$\gamma_1 = \dfrac{1.693053}{0.216996}$

$\gamma_2 = \dfrac{1.180090}{0.440199}$

$i = 10^\circ\ 29'\ 13.891 = \sin 9.260109$

$\lambda = 16\ 1\ 37.45 = \sin 9.441053$

$\beta = 6\ 31\ 49.10 = \sin 9.053870$

36.7518

$\gamma_2 = 15.1387$

$d_3 = f_2 = 21.6126$

$\gamma_3 = \dfrac{15.4586}{37.0712} = 1.569037$

$i = 15^\circ\ 49'\ 36.98 = \sin 9.435737$

$\lambda = 9\ 39\ 12.96 = \sin 9.224510$

$\beta = 6\ 31\ 49.10$

$\gamma_3 = \dfrac{1.189170}{0.413680}$

$\beta = 6\ 31\ 49.10$

$\beta = 0\ 21\ 25.08 = \sin 7.794502$

416.081

$\gamma_3 = 15.459$

$f_3 = 400.622$

$\dfrac{.2}{400.422}$

$d_4 = f_4$

$\gamma_4 = \dfrac{49.324}{449.746} = 2.652967$

$i = 3^\circ\ 15'\ 23.92 = \sin 8.754414$

$\lambda = 5\ 18\ 4.73 = \sin 8.965641$

$\beta = 0\ 21\ 25.08$

$\delta = 2\ 24\ 5.89 = \sin 8.622257$

108.7524

$\dfrac{49.3236}{59.4288}$

$f_4 = 59.4177$

$\dfrac{.4177}{.0111}$ Sph. At. of Cr. = Central over cor. by flint.

$\lambda = X$. Central.

$n = 0.180944$

$\gamma_1 = \dfrac{1.693053}{1.873999}$

$n-1 = 9.713370$

$144.7535 = 2.160629$

$\dfrac{.4}{144.3535} = 2.159427$

$\gamma_2 = \dfrac{1.180090}{3.339517}$

$d_2 = 2.159427$

$n-1 = 9.713370$

$1.872797 \neq 74.61010$

$n = 0.180944$

$\gamma_2 = \dfrac{1.180090}{1.361034} = 22.9633$

$97.5733 = 1.989331$

$d_3 = f_2 = 22.3968 = 1.350186$

$\gamma_3 = 1.189170$

$n' = \dfrac{0.211227}{2.750583}$

$d_3 = 1.350186$

$n-1 = \dfrac{9.796852}{1.147038} \quad \dfrac{15.45860}{14.02936} = \dfrac{0.153705}{2.595478}$

$f_3 = 393.983$

$\dfrac{.2}{393.783} = 2.595257$

$\gamma_4 = \dfrac{1.693053}{4.288312}$

$d_4 = 2.595257$

$n-1 = \dfrac{9.796852}{2.392109} = 246.666$

$n' = 0.211227$

$\gamma_4 = \dfrac{1.693053}{1.904282} = \dfrac{80.2199}{326.886} = 2.514396$

$f_4 = 59.4177 = 1.773916$

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Screen in front.

g line Marginal

$i = 2°\,54'\,19.''15$ ✓ = l. sin 8.70488 ✓

$n = 0.18324$ ✓

$\lambda = 1\ 54\ 17.2$ = sin 8.52164 ✓

$\gamma = 1\ 0\ 1.9$ ✓ $\quad r_1 = 1.69305$ ✓

0.21469 ✓

$i =$ sin 8.24209

$= 1.97260$ ✓

93.886

$r_1 = 49.324$ ✓

$f_1 = 143.210$ ✓

$.4$

$d_2 = 142.810$ ✓

$r_2 = \dfrac{18.139}{157.949}$ ✓ $= 2.19852$

sin $j = 8.24209$ ✓

0.44061 ✓

$r_2 = 1.18009$ ✓

$i = 10°\,29'\,50.''0 =$ sin 9.26052 ✓

$n = 0.18324$ ✓

$\lambda = 16\ 7\ 48.2 =$ sin 9.44376 ✓

$5\ 37\ 58.2$ ✓ $\quad r_2 = 1.18009$ ✓

0.62385 ✓

$\gamma = 1\ 0\ 1.9$ ✓

$\delta = 6\ 38\ 0.1 =$ sin 9.06268 ✓

$= 1.56121$ ✓

36.409

$r_2 = 18.139$ ✓

$d_3 = f_2 = 21.270$ ✓

$.2$

$r_3 = 18.459$ ✓

36.729 ✓ $= 1.56501$

sin $\delta = 9.06264$ ✓

0.62765 ✓

$r_3 = 1.18917$ ✓

$i = 15°\,53'\,47.''5 =$ sin 9.43848 ✓

$n' = 0.21570$ ✓

$\lambda = 9\ 36\ 53.''5 =$ sin 9.22278 ✓

$6\ 18\ 54.0$ ✓ $\quad r_3 = 1.18917$ ✓

0.41195 ✓

$\delta = 6\ 38\ 0.1$

$\gamma = 0\ 19\ 6.1$ ✓ $= 7.74480$

$= 2.66715$ ✓

464.68

$r_3 = 18.46$ ✓

$f_3 = 449.22$ ✓

$.2$

$d_4 = 449.02$ ✓

$r_4 = \dfrac{49.324}{498.344} = 2.69753$

sin $j = 7.74480$

0.44233 ✓

$r_4 = 1.69305$ ✓

$i = 3°\,13'\,6.''0$ sin 8.74928 ✓

$n' = 0.21570$ ✓

$\lambda = 5\ 17\ 35.''7$ sin 8.96498 ✓

$2\ 4\ 29.7$ ✓ $\quad r_4 = 1.69305$ ✓

0.66803 ✓

$\gamma = 0\ 19\ 6.1$ ✓

$\delta = 2\ 23\ 35.''8 =$ sin 8.62074 ✓

108.968 $= 2.03729$ ✓

$r_4 = 49.324$

$f_4 = 59.642$ ✓

$.6090$

$.0330$

Think 2÷ thick. $f_4 = 59.589$. calc. by mistake

g line Central

$n = 0.18324$ ✓

$r = 1.69305$ ✓

1.87629 ✓

$n-1 = 9.72007$ ✓

$= 2.15622$ ✓

$f_1 = 143.291$ $= 2.15500$

0.4

$d_2 = 142.891$ ✓ $\quad r_2 = 1.18009$ ✓

3.33509 ✓

$d_2 = 2.15500$ ✓

$n-1 = \dfrac{9.72007}{1.87507}$ ✓ $= 75.002$

$n = 0.18324$ ✓

$r_2 = 1.18009$ ✓

1.36333 ✓ $= \dfrac{23.085}{98.087} = \dfrac{1.99161}{1.34348}$ ✓

$f_2 = 22.054$ $\quad r_3 = 1.18917$ ✓

$n' = 0.21570$ ✓

2.74835 ✓

$d_3 = 1.34348$ ✓

$n'-1 = \dfrac{9.80838}{1.15186}$ ✓ $= \dfrac{15.4596}{14.186} = \dfrac{0.10469}{1.2726}$ ✓

$= 2.64366$ ✓

$f_3 = 440.21$

$.2$

$d_4 = 440.01$ ✓ $= 2.64346$

$r_4 = \dfrac{1.69305}{4.33651}$ ✓

$d = 2.64346$

$n'-1 = \dfrac{9.80838}{2.45184}$ ✓ $= 283.035$

$n' = 0.21570$ ✓

$r_4 = \dfrac{1.69305}{1.90875}$ ✓ $= \dfrac{81.049}{364.084} = \dfrac{2.56120}{1.77531}$ ✓

$f_4 = 59.609$

H line are 10 leaves from back

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~~Corona in front~~

Companion

Corona in front

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Flint in front. $r_1 = r_4 = 47.526$. $r_2 = 15.620$. $r_3 = 15.731$.

$\lambda = C$ Marginal

$y =$ log. 0.397940 ✓

$47.5260 = r_1 =$ 1.676931 ✓

$= 3° 0' 55.''12$ ✓ = sin 8.721009 ✓

$n' =$ 0.207697 ✓

$\lambda = 1\ 52\ 6.88$ (3.31) = sin 8.513312 ✓

$\gamma = 1\ 8\ 48.24$ ✓ $r_1 =$ 1.676931 ✓

$\delta = 1\ 8\ 51.81$ 0.190243 ✓

= sin 8.301311 ✓

= 1.888932 ✓

77.4341

$r_1 = 47.5260$

$f_1 = 124.9601$

,2000

$d_2 = 124.7601$

$r_2 = 15.6200$

109.1401

= 2.037987

$y =$ sin 8.301311

0.339298

$r_2 =$ 1.193681

sin 9.145617

$n' =$ 0.207697 ✓

sin 9.353314

$r_2 =$ 1.193681

0.546995

sin 8.827241

= 1.719754

$i = 8° 2' 17.''95$

$\lambda = 13\ 2\ 13.53$

$4\ 58\ 55.58$

$\gamma = 1\ 8\ 48.24$

$\delta = 3\ 51\ 7.34$

52.4510

$r_2 = 15.6200$

$f_2 = 36.8310$

0010

$d_3 = 36.8320$

$r_3 = 15.7310$

52.5630

= 1.720680

$\sin\delta =$ 8.827241

0.547921

$r_3 =$ 1.196756

sin 9.351165

$n =$ 0.178982 ✓

sin 9.172183

$r_3 =$ 1.196756

0.368939

sin 7.998369

2.370570

$i = 12° 58' 18.''99$

$\lambda = 8\ 32\ 56.61$

$4\ 25\ 22.29$

$\beta = 3\ 51\ 7.34$

$\gamma = 0\ 34\ 14.95$

234.731

$r_3 = 15.731$

$f_3 = 250.462$

.400

$d_4 = 250.062$

$r_4 = 47.526$

297.588

= ~~2.398048~~

2.473615

$\gamma =$ sin 7.998369

0.471984

$r_4 =$ 1.676931

sin 8.795053

$n =$ 0.178982 ✓

sin 8.974035

$r_4 =$ 1.676931

0.650966

sin 8.621852

2.029114

$i = 3° 34' 35.''39$

$\lambda = 5\ 24\ 18.26$

$1\ 49\ 42.87$

$\gamma = 0\ 34\ 14.95$

$\delta = 2\ 23\ 57.82$

106.9335

$r_4 = 47.5260$

$f_4 = 59.4075$

$\lambda = C$. ~~Contrad~~ Marginal

$i = 3\ 0\ 55.''12$

$\lambda = 1\ 52\ 3.31$

$\gamma = 1\ 8\ 51.81$ ✓ = 0.190243 ✓

sin 8.301686 ✓

= 1.888557 ✓

77.3672 ✓

$r_1 = 47.5260$ ✓

$f_1 = 124.8932$ ✓

.2

$d_2 = 124.6932$ ✓

$r_2 = 15.6200$ ✓

109.0732 ✓ = 2.037718 ✓

$y =$ Sin 8.301686 ✓

0.339404 ✓

$r_2 =$ 1.193681 ✓

= sin 9.145723 ✓

$i = 8° 2' 25.''06$ ✓

$n' =$ 0.207697 ✓

$\lambda = 13\ 2\ 26.27$ ✓ = sin 9.353420 ✓

$5\ 0\ 1.21$ ✓ $r_2 =$ 1.193681 ✓

$\gamma = 1\ 8\ 51.81$ ✓ 0.547101 ✓

$\delta = 3\ 51\ 9.40$ ✓ = sin 8.829305 ✓

52.4561 ✓ = 1.719796 ✓

$r_2 = 15.6200$ ✓

$f_2 = 36.8361$ ✓

+ ,001

$d_3 = 36.8371$ ✓

$r_3 = 15.7310$ ✓

52.5681 ✓ = 1.720722 ✓

$\beta = \delta =$ sin 8.827305 ✓

0.548027 ✓

$r_3 =$ 1.196756 ✓

$i = 12° 58' 30.''50$ ✓ = sin 9.351271 ✓

$n =$ 0.178982 ✓

$\lambda = 8\ 33\ 4.18$ ✓ = sin 9.172289 ✓

$4\ 25\ 26.32$ ✓ $r_3 =$ 1.196756 ✓

$\beta = 3\ 51\ 9.40$ ✓ 0.369045 ✓

$\gamma = 0\ 34\ 16.92$ ✓ = 9.998785 ✓

234.663 ✓ = 2.370260 ✓

$r_3 = 15.731$ ✓

$f_3 = 250.294$ ✓

.4

$d_4 = 249.894$ ✓

$r_4 = 47.526$ ✓

297.420 ✓ = 2.473370 ✓

$\gamma =$ sin 7.998785

0.472155 ✓

$r_4 =$ 1.676931 ✓

8.795224 ✓

$i = 3° 34' 40.''46$ ✓ = sin

$n =$ 0.178982 ✓

$\lambda = 5\ 24\ 25.95$ ✓ = sin 8.974206 ✓

$1\ 49\ 45.49$ ✓ $r_4 =$ 1.676931 ✓

$\gamma = 0\ 34\ 16.92$ ✓ 0.651137 ✓

$\delta = 2\ 24\ 2.41$ ✓ = sin 8.622083 ✓

= 2.029054 ✓

106.9188 ✓

$r_4 = 47.5260$ ✓

$f_4 = 59.3928$ ✓ – red

.3834 – blue

,0094

} Comm. two strong flint now corrected

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λ = X. Marginal

i = 3° 0′ 53.″12 = sin 8.721009 ✓
n' = 0.211227 ✓
λ = 1 57 12.41 ✓ = sin 8.509782 ✓
γ_1 = 1.676931 ✓
γ = 1 9 42.71 ✓ 0.186713 ✓
= sin ~~8.306188~~
= ~~1.873525~~ ✓

74.7353
γ_1 = 47.5260
f_1 = 122.2612
,2
d_2 = 120.0612
r_2 = 15.6200
104.4412
= 2.018872
γ = sin 8.313188
0.332060
r_2 = 1.193681
= sin 9.138379
n' = 0.211227 ✓
= sin 9.349606
r_2 = 1.193681
0.543287
= sin 8.826052
= 1.717235

i = 7° 57′ 16.″56
λ = 12 33 28.64
5 1 12.08
γ = 1 10 42.71
δ = 3 50 29.37 =

52.1477
r_2 = 15.6200
f_2 = 36.5277
.0010
d_3 = 36.5287
r_3 = 15.7310
52.2597
= 1.718167
$\beta = \delta$ = sin 8.826052
0.544219
r_3 = 1.196756
9.347463

i = 12° 51′ 35.″72 = sin
n = 0.180944 ✓
9.166519 ✓
λ = 8 26 14.90 = sin
4 25 20.82
r_3 = 1.196756
0.363275
β = 3 50 29.34
γ = 0 34 51.45 = sin 8.006015
= 2.357280

227.646
15.731
f_3 = 243.377
.4
d_4 = 242.977
r_4 = 47.526
290.503
= 2.463150
γ = 8.006015
0.469166
r_4 = 1.676931
i = 3° 33′ 12.″00 = sin 8.792235
n = 0.180944 ✓
λ = 5 23 39.85 = sin 8.973179
1 50 27.85 r_4 = 1.676931
γ = 0 34 51.45 0.650110
δ = 2 25 19.30 = sin 8.625927
= 2.024183

105.7263
r_4 = 47.5260
58.2003

λ = X Marginal

0.186713
γ = 1° 9′ 42.″71 = sin 8.307003 ✓
1.879710 ✓
= 75.8071 ✓
r_1 = 47.5260 ✓
f_1 = 123.3331 ✓
,2
d_2 = 123.1331 ✓
r_2 = 15.6200 ✓
107.5131 ✓ = 2.031461 ✓
γ = sin 8.307003 ✓
0.338464 ✓
r_2 = 1.193681 ✓
i = 8° 1′ 22.07 ✓ = sin 9.144783 ✓
n' = 0.211227 ✓
λ = 13 7 12.09 ✓ = sin 9.356010 ✓
5 5 50.02 ✓ r_2 = 1.193681 ✓
γ = 1 9 42.71 ✓ 0.549691 ✓
δ = 3 56 7.31 ✓ = sin 8.836521 ✓
1.713170 ✓

51.66185 ✓ =
15.6200 ✓
f_2 = 36.04185 ✓
.0001
d_3 = 36.04285 ✓
r_3 = 15.731 ✓
51.77385 ✓ = 1.714110 ✓
$\beta = \delta$ = sin 8.836521 ✓
0.556031 ✓
γ = 1.196756 ✓
i = 13° 3′ 16.″35 ✓ = sin 9.356387 ✓
n = 0.180944 ✓
λ = 8 33 50.06 ✓ = sin 9.172931 ✓
4 29 26.29 ✓ r_3 = 1.196756 ✓
β = 3 56 7.31 ✓ 0.369687 ✓
γ = 0 33 18.98 ✓ = sin 7.986377 ✓
2.383310 ✓

241.719 ✓ =
15.731 ✓
f_3 = 257.450 ✓
,4
d_4 = 257.050 ✓
r_4 = 47.526 ✓
304.576 ✓ = 2.483696 ✓
γ = sin 7.986377 ✓
0.470073 ✓
r_4 = 1.676931 ✓
3° 33′ 38.″78 ✓ = sin 8.793142 ✓
n = 0.180944 ✓
5 24 20.58 ✓ = sin 8.974086 ✓
1 50 41.80 ✓ r_4 = 1.676931 ✓
γ = 0 33 18.98 ✓ 0.651017 ✓
2 24 0.78 ✓ = 8.622001 ✓
= 2.029016 ✓

106.9094 ✓
r_4 = 47.5260
f_4 = 59.3834

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Flint in front.

λ = C.

A change of 1″ in r_4 produces a change of .009 in the color correction –

∴ 7) 9.4 / 1.343 plus to reduce crown.

r_4 = 47.5260 / 48.869

d_4 = 249.894 / 298.763 = 2.475 327

γ = sin 7.998 785 –

0.474112

r_4 = 1.689033

$i = 3° 29' 42''.69$ = sin 8.785 079

0.178982

λ = 5 16 55.22 = sin 8.964061

1 47 12.53 r_4 = 1.689033

γ = 0 34 16.92 0.653094

δ = 2 21 29.45 = sin 8.614382

2.038762

109.3354 =

48.8690

f_4 = 60.4667

0.8766 changes correction .0094

Eng r_4 = 47.5260 / 48.4026 ✓

d_4 = 249.8940 ✓ / 298.2966 ✓ = 2.474648 ✓

γ = sin 7.998785 – ✓

0.473433 ✓

r_4 = 1.684869 ✓

$i = 3° 31' 24''.19$ ✓ = sin 8.788564 ✓

n = 0.178982 ✓

λ = 5 19 28.87 ✓ = sin 8.967546 ✓

1 48 4.68 ✓ r_4 = 1.684869 ✓

γ = 0 34 16.92 ✓ 0.652415 – ✓

δ = 2 22 21.60 ✓ = sin 8.616990 ✓

2.035425 – ✓

108.4988 ✓

48.4026 ✓

f_4 = 60.0962

48.4026 / .0183 / 48.3843 = r_4

f_4 = 60.0816

59.4290

0.6526 shorten f_4

f = 60.0962

59.3975

f–f .6987 = 9.84429

r–r .8766 = 9.94280

9.90149

.0183 = 8.26245

.01459 = 8.16394

60.0962

60.0816

Color corr. perfect when. r_1 = 47.5260, r_2 = 15.6200, r_3 = 18.7310, r_4 = 48.3843 } f_4 = 60.0816

multiply all by 59.4290 / 60.0816 = (r₁) =

log 9.995256

" 1.676931

8.327813

47.0096 = r_1 =

9.995256

1.193681

15.4503 = r_2 = 1.188937

8.811063

λ = X

r_4 = 48.869

d_4 = 257.0500 / 305.919 = 2.485 607

γ = sin 7.986 377

0.471984

r_4 = 1.689033

$i = 3\ 28\ 41.11$ = sin 8.782951

n = 0.180944

λ = 5 16 47.94 = sin 8.963895

1 48 6.83 r_4 = 1.689033

γ = 0 33 18.98 0.652928

δ = 2 21 25.81 = sin 8.614146

2.038782

109.3407 =

48.8690

60.4717 blue

.4667 red

.0050 flint under corrected

Change of 1.343 in r_4 produced a change of .0144 in the color correction

∴ change of .009326 in r_4 produces a change of .0001 in the color correction

r_4 = 48.4026 ✓

d_4 = 257.0500 ✓ / 305.4526 ✓ = 2.484944

γ = sin 7.986377 ✓

0.471321 ✓

r_4 = 1.684869 ✓

$i = 3° 30' 22''.58$ ✓ = sin 8.786452 ✓

n = 0.180944 ✓

λ = 5 19 22.23 ✓ = sin 8.967396 ✓

1 48 59.65 ✓ r_4 = 1.684869 ✓

0 33 18.98 ✓ 0.682265 – ✓

2 22 18.63 ✓ = sin 8.616839 ✓

2.035426 ✓

108.4990 ✓

48.4026 ✓

60.0964

.0962

f_4 = .0002 flint under cor.

---

r_3 = 9.995256 / 1.196756 / 15.5601 = 1.192012 / 8.807988

r_4 = 9.995256 / 1.684704 / 47.8586 = 1.679960 / 8.320040

The color correction is perfect & f_4 = 59.4290 when –

$\frac{1}{r_1}$ = .0647237

$\frac{1}{r_2}$ = .0212722

B = .0434515 ✓

$\frac{1}{r_3}$ = .0642670

$\frac{1}{r_4}$ = .0208949

A = .0851619 ✓

r_1 = 47.5400 = 1.677059

8.322941

$\frac{1}{r_1}$ = .0210349

$\frac{1}{r_2}$ = .0434515

.0644864 = 8.809468

r_2 = 15.50715 = 1.190532

$\frac{1}{r_4}$ = .0851619

.0210349

.0641270 = 8.807041

r_3 = 15.59405 = 1.192959

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2 lens

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Flint in front. $r_1 = r_4 = 47.5400$ | $r_2 = 15.50715$ | $r_3 = 15.59405$ | Corlu o | Sph. Ab. ?

$\lambda = 5614$ Marginal

$y =$ log 0.397940 ✓
$\gamma =$ 1.677059 ✓
$i = 3° 0' 51.92''$ ✓ = sin 8.720881 ✓
$n' =$ 0.209428 ✓
$\lambda = 1\ 51\ 38.14$ ✓ = sin 8.511453 ✓
$\gamma = 1\ 9\ 13.78$ ✓ $r_1 =$ 1.677059 ✓
0.188512 ✓
$n =$ sin 8.303989 ✓
1.884523 ✓

76.68792 ✓ =
$r_1 =$ 47.54000 ✓
124.19192 ✓
$d_2 =$ 123.99192 ✓
$r_2 =$ 15.50715 ✓
~~139.49907~~ = ~~2.144591~~
108.48477 ✓ = 2.035369 ✓
$\gamma =$ sin 8.303989 ✓
0.339359 ✓
$r_2 =$ 1.190532 ✓
$i = 8° 5' 57.07$ ✓ = sin 9.148827 ✓
$n' =$ 0.209428 ✓
$\lambda = 13\ 11\ 28.29$ ✓ = sin 9.358255 ✓
$5\ 5\ 27.22$ ✓ $r_2 =$ 1.190532 ✓
$\gamma = 1\ 9\ 13.78$ ✓ 0.548787 ✓
$\delta = 3\ 56\ 13.44$ ✓ = sin 8.836708 ✓
57.53224 ✓ = 1.712079 ✓

$r_2 =$ 15.50715
$f_2 =$ 36.02509 ✓
+ .0001
$d_3 =$ 36.02609 ✓
$r_3 =$ 15.59405 ✓
51.62014 ✓ = 1.712819 ✓
$\delta =$ sin 8.836708 ✓
0.549527 ✓
$r_3 =$ 1.192959 ✓
$i = 13° 8' 12.89$ ✓ = sin 9.356568 ✓
$n =$ 0.179963 ✓
$\lambda =$ ~~8 38 13.96~~ ✓ = sin 9.176605 ✓
~~4 29 39.07~~ ✓ $r_3 =$ 1.192959 ✓
$\beta = 3\ 56\ 13.44$ ✓ 0.369564 ✓
$\gamma =$ 0 33 46.49 ✓ = sin 7.992312 ✓
238.370 ✓ = 2.377252 ✓

$r_3 =$ 15.594 ✓
$f_3 =$ 253.964 ✓
+ .14
$d_4 =$ 253.564 ✓
$r_4 =$ 47.540 ✓
301.104 ✓ = 2.478717 ✓
$\gamma =$ sin 7.992312 ✓
0.471029 ✓
$r_4 =$ 1.677059 ✓
$i = 3° 34' 3.27$ ✓ = sin 8.793970 ✓
$n =$ 0.179963 ✓
$\lambda = 5\ 24\ 13.69$ ✓ = sin 8.973933 ✓
$1\ 50\ 10.42$ ✓ $r_4 =$ 1.677059 ✓
$\gamma = 0\ 33\ 46.49$ ✓ 0.650992 ✓
$\delta = 2\ 23\ 56.91$ ✓ = sin 8.621806 ✓
106.95513 ✓ = 2.029186 ✓
$r_4 =$ 47.5400 ✓
$f_4 =$ 59.4113 ✓

$\lambda = 5614$ Central

$n' =$ 0.209428 ✓
$r =$ 1.677059 ✓
1.886487 ✓
$n - 1 =$ 9.792165 ✓
$f_1 =$ 124.2573 ✓ = 2.094322 ✓
,2
$d_2 =$ 124.0573 ✓ = 2.093622 ✓
$r_2 =$ 1.190032 ✓
3.284154 ✓

$d_2 = 2.093622$ ✓
$n-1 =$ 9.792165 ✓
1.885787 = 76.8753 ✓

$n' =$ 0.209428 ✓
$r_2 =$ 1.190532 ✓
1.399960 ✓ 25.11655 ✓
51.75887 ✓ = 1.713984
$f_2 =$ 37.1681 ✓ = 1.570170 ✓
,001
$d_3 =$ 37.16891 = 1.570182
$r_3 =$ 1.192959
$n =$ 0.179963
~~2.943099~~
2.943104

$d_3 = 1.570174$
$n-1 =$ 9.710483 15.59405
1.280660 = 19.07380
3.489778 = 0.542784
$f_3 =$ 251.368 = 2.400390
+ .14
$d_4 =$ 250.968 = 2.399618
$r_4 =$ 1.677059
4.076677

$d = 2.399618$
$n-1 =$ 9.710483
2.110101 = 128.8550
$n = 0.179963$
$r_4 =$ 1.677059
1.857622 = 71.9485
200.8035 = 2.302771
$f_4 =$ 59.4164 = 1.773906
.4113
.0051 flint over cor.

Sph. Ab. change of 2.202 in $r_1 = r_4$ = .1350 in Ab
,001631 = .0001
−.1256 = .0077
$r_1 = r_4 =$ 47.5400
47.4144

$r_1 = r_4 = 47.4144$ = log 1.675910
$\frac{1}{r_1} =$ .0210906 = 8.324090
B ---- = .0434515 ✓
.0645421 ✓ = 8.809843
$r_2 =$ 15.4938 = 1.190157

A --- = .0851619 ✓
$\frac{1}{r_4} =$ .0210906 ✓
.0640713 = 8.806663
$r_3 =$ 15.6076 = 1.193337

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Flint in front. $r_1 = r_4 = 47.4144$ $r_2 = 15.4938$ $r_3 = 15.6076$

$\lambda = 5614$ Marginal

$y = 0.397940$ ✓
$r_1 = 1.675910$ ✓
$i = 3°\ 1'\ 20''.69 = \sin 8.722030$ ✓
$n' = 0.209428$ ✓
$\lambda = 1\ 57\ 55''.90 = \sin 8.512602$ ✓
$\beta = 1\ 9\ 24''.79$ ✓ $r_2 = 1.675910$ ✓
0.188512 ✓
$= \sin 8.205138$
$= 1.883374$ ✓

76.4494
$r_1 = 47.4144$ ✓
$f_1 = 123.8638$ ✓
$,2$
$d_2 = 123.6638$ ✓
$r_2 = 15.4938$ ✓
108.1700 ✓ $= 2.034107$
$\gamma = \sin 8.305138$ ✓
0.339245 ✓
$r_2 = 1.190157$ ✓
$i = 8°\ 6'\ 11''.71 = \sin 9.149088$ ✓
$n' = 0.209428$ ✓
$\lambda = 13\ 11\ 50.34 = \sin 9.358516$ ✓
$5-\ 5-\ 38.63$ ✓ $r_2 = 1.190157$ ✓
$\beta = 1\ 9\ 24.79$ ✓ 0.548673 ✓
$\delta = 3\ 56\ 13.84$ ✓ $= \sin 8.836721$ ✓
$= 1.711952$
51.5172
$r_2 = 15.4938$ ✓
$f_2 = 36.0234$ ✓
$+,001$
$d_3 = 36.0244$ ✓
$r_3 = 15.6076$ ✓
51.6320 ✓ $= 1.712919$
$\sin \delta = 8.836721$ ✓
0.549640 ✓
$r_3 = 1.193337$ ✓
$i = 13°\ 7'\ 44''.53 = \sin 9.356303$ ✓
$x = 0.179963$ ✓
$\lambda = 8\ 37\ 57.86 = \sin 9.176340$ ✓
$4\ 29\ 49.67$ ✓ $r_3 = 1.193337$ ✓
$\delta = 3\ 56\ 13.84$ ✓ 0.369677 ✓
$\gamma = 0\ 33\ 35.83$ ✓ $= \sin 7.990022$ ✓
$239.693 = 2.379655$ ✓
$r_3 = 15.608$ ✓
$f_3 = 253.301$ ✓
$,4$
$d_4 = 254.901$ ✓
$r_4 = 47.414$ ✓
302.315 ✓ $= 2.480460$
$\gamma = \sin 7.990022$ ✓
0.470482 ✓
$r_4 = 1.675910$ ✓
$i = 3°\ 34'\ 21''.11 = \sin 8.794372$ ✓
$x = 0.179963$ ✓
$\lambda = 5\ 24\ 40.76 = \sin 8.974535$ ✓
$1\ 50\ 19.65$ ✓ $r_4 = 1.675910$ ✓
$\beta = 0\ 33\ 35.83$ ✓ 0.654445 ✓
$2\ 23\ 55.48$ ✓ $= \sin 8.621734$
2.028711 ✓
$106.8344 =$
$r_4 = 47.4144$ ✓
$f_4 = 59.4200$ ✓
59.4164
$,0036$ flint under cor.

$\lambda = 5614$ Central.

$n' = 0.209428$ ✓
$r_1 = 1.675910$ ✓
1.885338 ✓
9.792165 ✓
2.093173 ✓

$f_1 = 123.929$ ✓ $= 2.092472$ ✓
$,2$
$d_2 = 123.729$ ✓ $= 1.190157$ ✓
$r_2 = 3.282629$ ✓

$d_2 = 2.092472$ ✓
$n-1 = 9.792165$ ✓
1.884637 ✓ $= 76.6720$ ✓

$n' = 0.209428$ ✓
$r_2 = 1.190157$ ✓
1.399585 ✓ $= 25.0949$ ✓ $= 1.712457$ ✓
51.5771 $= 1.570172$ ✓

$f_2 = 37.1682$ ✓
$,001$
$d_3 = 37.1692 = 1.570183$
$r_3 = 1.193337$
$x = 0.179963$
2.943483

$d_3 = 1.570183$
$n-1 = 9.710483$
$1.280666 = 19.08384$ ✓
$r_3 = 15.6076$
$3.47624 = 0.541110$ ✓
$= 2.402373$ ✓

$f_3 = 252.565$
$,4$
$d_4 = 252.165$ $= 2.401685$ ✓
$r_4 = 1.675910$
4.077595 ✓

$d = 2.401685$
$n-1 = 9.710483$
$2.112168 = 129.4697$ ✓
$x = 0.179963$
$r_4 = 1.675910$
$1.855873 = 71.7585$ ✓
$201.2282 = 2.303689$
$59.4164 = 1.773906$

Change of 0.1256 in $r_1 = r_4$ changes Ab. $,0087$
$,0520$ ✓ $= ,0036$
47.4144
47.4664 to correct for Sph. Ab.

$r_1 = r_4 = 47.466x = 1.676386$
$\frac{1}{r_1} = ,021067\ 55 = 8.323614$
$B = ,043451\ 50$
$,064519\ 05 = 8.809688$
$r_2 = 15.4993\ldots = 1.190312$

$A = ,085161\ 90$
$\frac{1}{r_4} = ,021067\ 58$
$,064094\ 32 = 8.806820$
$r_3 = 15.6020\ldots = 1.193180$

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$r_1 = r_4 = 47.4664$ $r_2 = 15.4993$ $r_3 = 15.6020$

$\lambda = 5614$ Marginal

$i = 3^\circ\ 1'\ 8.''76$ ✓

$\lambda = 1\ 51\ 48.53\frac{1}{2}$

$\gamma = 1\ 9\ 20.22\frac{1}{2}$

$y = 0.397940$
$r_1 = 1.676386$ ✓
$= \sin 8.721554$ ✓
$n' = 0.209428$ ✓
$= \sin 8.512126$ ✓
$r_1 = 1.676386$ ✓
0.188512
$= \sin 8.304662$
$= 1.883850$

76.5332
$r_1 = 47.4664$
$f_1 = 123.9996$
$.2$
$d_2 = 123.7996$
$r_2 = 15.4993$
108.3003

$= 2.034630$
$\gamma = \sin 8.304662$
0.339292

$i = 8^\circ\ 6'\ 4.''41$

$\lambda = 13\ 11\ 38.33$
$5\ 5\ 33.92$
$\gamma = 1\ 9\ 20.22\frac{1}{2}$
$\delta = 3\ 56\ 13.69\frac{1}{2}$

$r_2 = 1.190312$
$= \sin 9.148980$
$n' = 0.209428$
$= \sin 9.358408$
$r_2 = 1.190312$
0.548720
$= \sin 8.836716$
$= 1.712004$

$5-1.5233$
$r_2 = 15.4993$
$f_2 = 36.0240$
$.1001$
$d_3 = 36.0250$
$r_3 = 15.6020$
$5-1.6270$

$= 1.712877$
$\gamma = \sin 8.836716$
0.549593
$r_3 = 1.193180$
$= \sin 9.356413$
$n = 0.179963$
$= \sin 9.176450$
$r_3 = 1.193180$
0.369630
$= \sin 7.990968$
$= 2.378662$

$i = 13^\circ\ 7'\ 56.''71$

$\lambda = 8\ 38\ 2.79$
$4\ 29\ 53.92$
$\delta = 3\ 56\ 13.69\frac{1}{2}$
$\gamma = 0\ 33\ 40.22\frac{1}{2}$

239.1454
$r_3 = 15.6020$
$f_3 = 254.7474$
$r_4 = 47.4664$
302.2138
$.4$
301.8138

$= 2.479739$
$\sin \gamma = 7.990968$
0.470707
$r_4 = 1.676386$
$= \sin 8.794321$
$n = 0.179963$
$= \sin 8.974284$
$r_4 = 1.676386$
0.650670
$= \sin 8.621763$
$= 2.028907$

$\varepsilon = 3^\circ\ 34'\ 13.''67$

$\lambda = 5\ 24\ 29.49$
$1\ 50\ 15.82$
$\gamma = 0\ 33\ 40.22\frac{1}{2}$
$2\ 23\ 56.04\frac{1}{2}$

106.88262
$r_4 = 47.4664$
$f_4 = 59.41622$

$\lambda = 5614$ Central

$n' = 0.209428$
$r_1 = 1.676386$
1.885814
$n-1 = 9.792165$
$= 2.093649$

$f_1 = 124.065$
$.2$
$d_2 = 123.865$
$= 2.092948$
$r_2 = 1.190312$
3.283260

$d_2 = 2.092948$
$n-1 = 9.792165$
$1.885113 = 76.75612$

$n' = 0.209428$
$r_2 = 1.190312$
$1.399740 = 25.10384$
~ 1.8199
$5-1.6823 = 1.713099$

$f_2 = 37.16815$
$.001$
$d_3 = 37.16915$
$= 1.570183$ ✓
$r_3 = 1.193180$ ✓
$n = 0.179963$ ✓
2.943326 ✓

$d_3 = 1.570183$ ✓
$n-1 = 9.710483$ ✓
$1.280666 = 19.08384$ ✓
$r_3 = 15.6020$ ✓
$3.481844 = 0.541809$ ✓
$= 2.401517$ ✓

$f_3 = 252.0676$ ✓
$.4$
$d_4 = 251.6676$ ✓
$= 2.400827$
$r_4 = 1.676386$
4.077213 ✓

$d_4 = 2.400827$
$n-1 = 9.710483$
$2.111310 = 129.2141$
$n = 0.179963$
$r_4 = 1.676386$
$1.856349 = 71.8371$
$201.0512 = 2.303307$
$= 1.773906$ ✓

$f_4 = 59.4163$
$.4162$
$.00008$ flint one ov.
$.0001$

Correction for .0007 =

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Flint in front. $r_1 = 47.4664$ &c.

λ = C. Marginal

y =

i = 3° 1′ 8.″76 ✓ = sin 8.721554 ✓
n′ = 0.207697 ✓
λ = 1 52 15.34 ✓ = sin 8.551385 ✓
y = 1 8 53.42 ✓ r_1 = 1.676386 ✓
0.190243 ✓
= sin 8.301853 ✓
= 1.888388 ✓

77.3371 ✓
r_1 = 47.4664 ✓
f_1 = 124.8035 ✓
,2
d_2 = 124.6035 ✓
r_2 = 15.4993 ✓
109.1042 ✓ = 2.037841 ✓
sin y = 8.301853 ✓
0.339696 ✓
r_2 = 1.190312 ✓
b = 8° 6′ 31.73 ✓ = sin 9.149384 ✓
n′ = 0.207697 ✓
λ = 13 9 10.80 ✓ = sin 9.357081 ✓
5 2 39.07 ✓ r_2 = 1.190312 ✓
y = 1 8 53.42 ✓ 0.547393 ✓
δ = 3 53 45.65 ✓ = sin 8.832163 ✓
= 1.715230 ✓

51.9075 ✓
r_2 = 15.4993 ✓
f_2 = 36.4082 ✓
,001
d_3 = 36.4092 ✓
r_3 = 15.6020 ✓
52.0112 ✓ = 1.716097 ✓
sin δ = 8.832163 ✓
0.548260 ✓
r_3 = 1.193180 ✓
i = 13° 5′ 29.″26 ✓ = sin 9.355080 ✓
n = 0.178982 ✓
λ = 8 37 37.41 ✓ = sin 9.176098 ✓
4 27 51.85 ✓ r_3 = 1.193180 ✓
δ = β = 3 53 45.65 ✓ 0.369278 ✓
y = 0 34 6.20 ✓ = sin 7.996516 ✓
= 2.372762 ✓

235.9184 ✓
r_3 = 15.6020 ✓
f_3 = 251.5204 ✓
,4
d_4 = 251.1204 ✓
r_4 = 47.4664 ✓
298.5868 ✓ = 2.475071 ✓
sin y = 7.996516 ✓
0.471587 ✓
r_4 = 1.676386 ✓
i = 3 34 39.78 ✓ = sin 8.795201 ✓
n = 0.178982 ✓
λ = 5 24 24.92 ✓ = sin 8.974183 ✓
1 49 45.15 ✓ r_4 = 1.676386 ✓
y = 0 34 6.20 ✓ 0.650569 ✓
2 23 51.35 ✓ = sin 8.621527 ✓
2.029042 ✓

106.9158 ✓ =
r_4 = 47.4664
f_4 = 59.4494 ✓ red.
,4241 blue
,0253 flint over-corrected.

λ = ~~C~~ color ~~central~~

see 3 preceding tracks Color cor.
$r_1 = \frac{1}{2} - r_4 = 47.526$ = .0094 over
r_4 changed to 48.4026 = .0002 under
.8766 = .0096

.0096 : 0253 :: .8766 : x

.8766 = log 9.942780
.0253 = " 8.403112
8.345892
.0096 = 7.982271
2.3102 = 0.363685

(r_4) = 47.4664
try r_4 = 49.7766 to correct for Color.

λ = C.

d_4 = 251.1204 ✓
r_4 = 49.7766 ✓
300.8970 ✓ = 2.478418 ✓
sin y = 7.996576 ✓
0.474934 ✓
r_4 = 1.697025 ✓
i = 3° 26′ 16.″41 ✓ = sin = 8.777909 ✓
n = 0.178982 ✓
λ = 5° 11′ 43.″00 ✓ sin = 8.956891 ✓
1 45 26.59 ✓ r_4 = 1.697025 ✓
y = 0 34 6.20 ✓ 0.653916 ✓
δ = 2 19 32.79 ✓ = sin 8.608326
2.045590 ✓
111.0683 =
r_4 = 49.7766
f_4 = 61.2917 red

λ = X

d_4 = 258.1551 ✓
r_4 = 49.777 ✓
307.932 ✓ = 2.488483 ✓
sin y = 7.984513 ✓
0.472968 ✓
r_4 = 1.697025 ✓
i = 3° 25′ 20.″45 ✓ = sin 8.775943 ✓
n = 0.180944 ✓
λ = 5° 11′ 42.83 ✓ = sin 8.956887 ✓
1 46 22.38 ✓ r_4 = 1.697025 ✓
y = 0 33 10.42 ✓ 0.653912 ✓
2 19 32.80 ✓ = sin 8.608326 ✓
= 2.045586 ✓

111.0672
49.7766
61.2906 blue

,0011 over - correct Correction strong

Change of ,0009277 in r_4 = change of ,0001 in Ab.
,1037 in r_4 = " " ,0004 in Ab.
49.7766
try r_4 = 49.8137

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Hint in front.

λ = X. Marginal

i = 3° 1′ 8.″76 ✓ = sin 8.721534 ✓
n′ = 0.211227 ✓
λ = 1 51 20.79 ✓ = sin 8.510327 ✓
j = 1 9 47.97 ✓ γ₁ = 1.676386 ✓
0.186713 ✓
sin 8.307549 ✓
= 1.879164 ✓

75.7119 ✓
γ₁ = 47.4664 ✓
f₁ = 123.1783 ✓
,2
d₂ = 122.9783 ✓
γ₂ = ,15.4993 ✓
107.4790 ✓ = 2.031324 ✓
sin j = 8.307549 ✓
0.338873 ✓
γ₂ = 1.190312 ✓
i = 8° 5′ 36.″10 ✓ = sin 9.148561 ✓
n′ = 0.211227 ✓
λ = 13 14 12,23 ✓ = sin 9.359788 ✓
5 8 36.13 ✓ γ₂ = 1.190312 ✓
0.550100 ✓
j = 1 9 47.97 ✓
δ = 3 58 48.16 ✓ = sin 8.841416 ✓
= 1.708684 ✓
51.1310 ✓
γ₂ = 15.4993 ✓
f₂ = 35.6317 ✓
,001
d₃ = 35.6327 ✓
γ₃ = 15.6020 ✓
51.2347 ✓ = 1.709564 ✓
sin δ = 8.841416 ✓
0.550980 ✓
γ₃ = 1.193180 ✓
i = 13° 10′ 30.″67 ✓ = sin 9.357800 ✓
n = 0.180944 ✓
λ = 8 38 32,09 ✓ = sin 9.176856 ✓
4 31 58.58 ✓ γ₃ = 1.193180 ✓
0.370036 ✓
δ = 3 38 48,16 ✓
j = 0 33 10.42 ✓ = sin 7.984573 ✓
= 2.385523 ✓
242.9553 ✓
γ₃ = 15.602 ✓
f₃ = 258.5555 ✓
,4
d₄ = 258.155 ✓
γ₄ = 47,4664 ✓
305.6214 ✓ = 2.485184 ✓
sin j = 7.984513 ✓
0.469697 ✓
γ₄ = 1.676386 ✓
i = 3° 33′ 43.″78 ✓ = sin 8.793311 ✓
n = 0.180944 ✓
λ = 5 24 28.19 ✓ = sin 8.974255 ✓
1 50 44.41 ✓ γ₄ = 1.676386 ✓
j = 0 33 10.42 ✓ 0.656641 ✓
2 23 54.83 ✓ = sin 8.621702 ✓
106,8905 ✓ = 2.028939 ✓
47.4664 ✓
f₄ = 59.4241 ✓

λ = X. Contrib. levlr

λ = C

d₄ = 251.1204 ✓
γ₄ = 49.8137 ✓
300.9341 ✓ = 2.478471 ✓
sin j = 7.996516 ✓
0.477487 ✓
γ₄ = 1.697349 ✓
i = 3° 26′ 8.″68 ✓ = sin 8.777638 ✓
n = 0.178982 ✓
λ = 5° 11 31,30 ✓ = sin 8.956620 ✓
1 45 22,62 ✓ γ₄ = 1.697349 ✓
0.653969 ✓
j = 0 34 6.20 ✓
2 19 28,82 ✓ = sin 8.608120 ✓
111.1345 ✓ = 2.045849 ✓
γ₄ = 49.8137 ✓
f₄ = 61.3208 ✓ red —
"

λ = X

d₄ = 258.153 ✓
γ₄ = 49.814 ✓
307.969 ✓ = 2.488507 ✓
sin j = 7.984513 ✓
0.473020 ✓
γ₄ = 1.697349 ✓
i = 3° 25′ 12.″72 ✓ = sin 8.775671 ✓
n = 0.180944 ✓
λ = 5 11 31.09 ✓ = sin 8.956615 ✓
1 46 18.37 ✓ γ₄ = 1.697349 ✓
0.653964 ✓
j = 0 33 10.42 ✓
2 19 28.79 ✓ = sin 8.608118 ✓
2,045846 ✓
111.1338 ✓
49.8137 ✓
61,3201 ✓ blue —
,0007 over

---

11 leaves back —
Change of γ₄
.01420 = Change of ,0001 in errlr,
of prop ,00913 = " " " "
" ,00928 = " " " "
above ,00954 = " " " "

,0668 to correct for ,0007
49.8137
for γ₄ = 49.8805

7),0668
,00954 to correct γ₄

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Flint in front.

Color correction

λ = C

d_4 = 251.1204 ✓

r_4 = 49.8805 ✓ / 301.0009 ✓ = 2.4785768 ✓

sin j = 7.9965576 ✓ / 0.4750084 ✓

r_4 = 1.6979931 ✓ / 8.7771573 ✓

i = 3° 25′ 54″.86 ✓ = sin n = 0.1789822 ✓ / 8.9861355 ✓

λ = 5 11 10.39 ✓ / 1 45 15.53 ✓ / 6 34 6.20 ✓ / 2 19 21.73 ✓ = sin r_4 = 1.6979931 ✓ / 0.6540666 ✓ / 8.6077752 ✓ / 2.0463314 ✓

111.2536 ✓

49.8805 ✓

f_4 = 61.3731 ✓ red

λ = X

d_4 = 258.1558 ✓

r_4 = 49.8805 ✓ / 308.0355 ✓ = 2.4886601 ✓

sin j = 7.9845713 ✓ / 0.4731114 ✓

r_4 = 1.6979931 ✓ / 8.7751837 ✓

i = 3° 24′ 58″.88 ✓ = sin n = 0.1809944 ✓ / 8.9561277 ✓

λ = 5 11 10.04 ✓ / 1 46 11.16 ✓ / 0 33 10.42 ✓ / 2 19 21.58 ✓ = sin r_4 = 1.6979931 ✓ / 0.6540588 ✓ / 8.6077744 ✓ / 2.0463314 ✓

111.2536 ✓

49.8805 ✓

f_4 = 61.3731 ✓ blue

.00000

59.4290 = log 1.7739987 ✓

61.3731 = log 1.7879787 ✓

9.9860200 ✓

1.6763812

(r_1) = 1.6624067 ✓ / 8.3375933

r_1 = 45.9628 / .0217567

9.9860200

1.1903120

(r_2) = 1.1763332 ✓ / 8.8236668

r_2 = .0666297

B = .04487295 ✓

9.9860200

1.1931800

(r_3) = 1.1792000 ✓ / 8.8208000

r_3 = .0661912

9.9860200

1.6979931

(r_4) = 1.6839951 ✓ / 8.3160049

r_4 = 48.3004 / .0207075

A = .08689495 ✓

$r_1 = r_4$ = 47.0000 = log 1.6720987 ✓ = log 8.3279013 ✓

$\frac{1}{r_1} = \frac{1}{r_4}$ = .02127660 ✓

B = .04487295 ✓ / .06614955 ✓ = 8.8205270 ✓ = 1.1794730 ✓

r_2 = 15.1173 ✓

$\frac{1}{r_4}$ A = .08689495 ✓ / .02127660 ✓ / .06561835 ✓ = 8.8170255 ✓ = 1.1829745 ✓

r_3 = 15.2396 ✓

Color correction perfect when

r_1 = 47.4664 } Flint

r_2 = 15.4993 }

r_3 = 15.6020 } Crown

r_4 = 49.8805 }

f_4 = 61.3731

To make the focal length = 59.4290

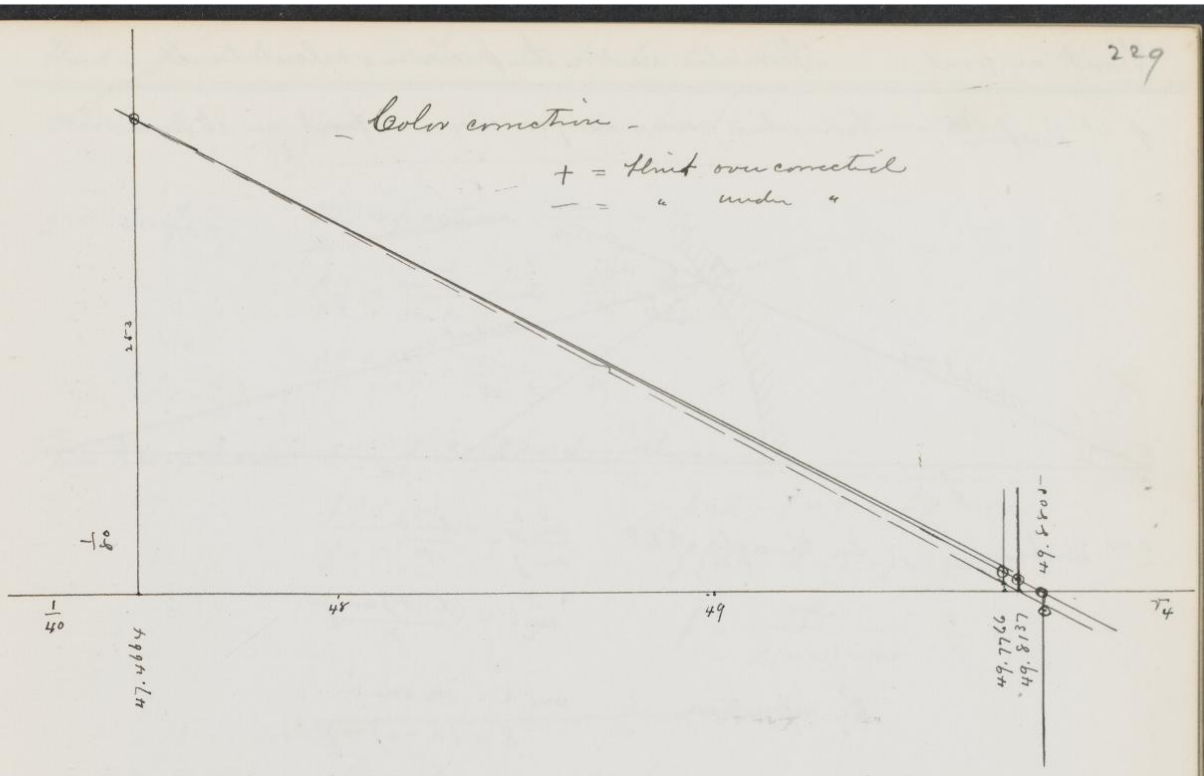
multiply each by $\frac{59.4290}{61.3731}$

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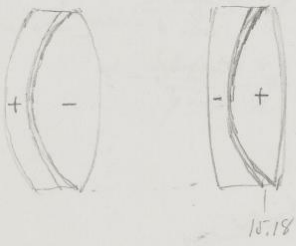
Color correction

+ = flint over corrected
− = " under "



$\gamma_1 = \gamma_4 = 47.000$
47.435

Flint too strong Sph. Ab = +0,0302
" " weak " " −0.0065

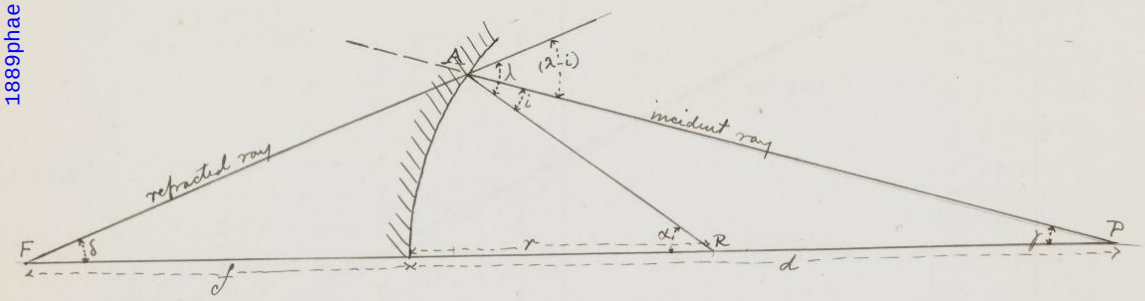


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Flint in front, Formulae used in the preceding calculations

1st Surface - Formulae same as for crown in front see 16 leaves back



2nd Surface - In triangle ARP $\frac{\sin i}{\sin \gamma} = \frac{d-r}{r}$

$$\sin i = \frac{(d-r)\sin\gamma}{r}$$

By refraction, $\sin\lambda = n \sin i$

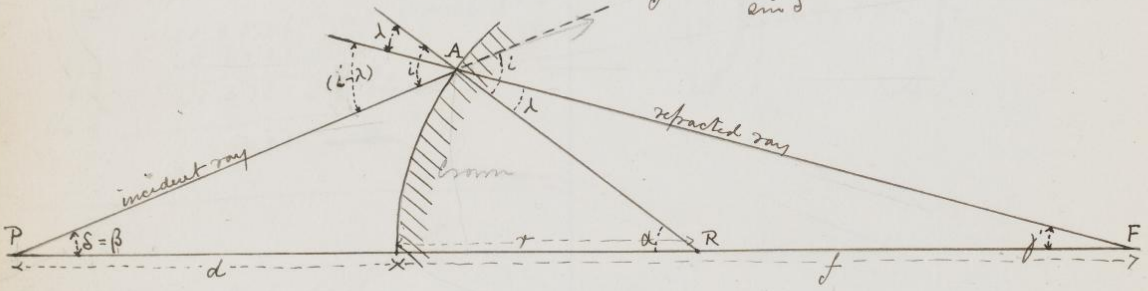
$$\delta = (\lambda - i) - \gamma$$

When $(\lambda - i) = \gamma$ the refracted ray is parallel to the axis, when less than γ the focus falls behind the surface, and when $(\lambda - i)$ is greater than γ the focus falls in front of the surface as in the present case.

In triangle ARF $\frac{\sin\lambda}{\sin\delta} = \frac{f+r}{r}$

$$f + r = \frac{r\sin\lambda}{\sin\delta}$$

$$f = \frac{r\sin\lambda}{\sin\delta} - r$$



3rd Surface - In triangle ARP $\frac{\sin i}{\sin\beta} = \frac{d+r}{r}$

$$\sin i = \frac{(d+r)\sin\beta}{r}$$

By refraction $\sin\lambda = \frac{\sin i}{n}$

$$\gamma' = (i - \lambda) - \beta$$

When $(i-\lambda) = \beta$ the refracted ray is parallel to the axis; when less than β the focus falls in front of the surface; and when greater than β the focus falls behind this surface, as in the present case.

In triangle $\frac{\sin\lambda}{\sin\gamma'} = \frac{f-r}{r}$ $\therefore f - r = \frac{r\sin\lambda}{\sin\gamma'}$

$$\therefore \quad f = \frac{r\sin\lambda}{\sin\gamma'} + r$$

4th Surface - Formulae same as for second surface, crown in front see 16 leaves back

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1st Surface - Same as for crown in front - see 16 leaves back.

2nd Surface - By refraction $\frac{\sin i}{\sin \lambda} = \frac{1}{n}$

$$\frac{AF}{FR} = \frac{\sin \alpha}{\sin \lambda} \text{ and } \frac{AP}{PR} = \frac{\sin \alpha}{\sin i}$$

$$\frac{AF \times PR}{FR \times AP} = \frac{\sin i}{\sin \lambda} = \frac{1}{n}$$

When A is on the axis - $AF = f$ and $AP = d$. Hence -

$$\frac{f(d-r)}{(f+r)d} = \frac{1}{n} \quad \therefore \quad fnd - fnr = fd + rd$$

$$\therefore \quad f(dn - d - nr) = rd$$

$$\therefore \quad f = \frac{rd}{d(n-1) - nr}$$

3rd Surface. By refraction $\frac{\sin i}{\sin \lambda} = n$

$$\frac{AF}{FR} = \frac{\sin \alpha}{\sin \lambda} \text{ and } \frac{AP}{PR} = \frac{\sin \alpha}{\sin i}$$

$$\frac{AF \times PR}{FR \times AP} = \frac{\sin i}{\sin \lambda} = n$$

When A is on the axis - $AF = f$ and $AP = d$ Hence

$$\frac{f(d+r)}{(f-r)d} = n \quad \therefore \quad fd + fr = fnd - drn$$

$$\therefore \quad f(dn - d - r) = drn$$

$$\therefore \quad f = \frac{drn}{d(n-1) - r} \checkmark$$

4th Surface - Same as for second surface, crown in front, see 16 leaves back.

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Hint in front $r_1 = 47.0000$ $r_2 = 15.1173$ $r_3 = 15.2396$ $r_4 = r_1$

λ = C red (color correction) λ = X blue

$y = \log$ 0.397940

$\eta =$ 1.672098

$i = 3° 2' 56.''71$ = sin 8.725842

$n' =$ 0.207697

$\lambda = 1° 53' 22.''19$ = sin 8.518145

$r_1 =$ 1.672098

$\gamma = 1\ 9\ 34.52$ = sin 8.306152

= 1.884091

76.6757

$r_1 = 47.0000$

$f_1 = 123.6757$

,2000

$d_2 = 123.3757$

$r_2 = \frac{15.1173}{108.2584}$ = 2.034462

$\gamma =$ sin 8.306152

0.340614

$r_2 =$ 1.179473

$i = 8° 19' 58.''40$ = sin 9.161141

$n' =$ 0.207697

$\lambda = 13° 31' 14.''49$ = sin 9.368838

$r_2 =$ 1.179473

$\gamma = 1\ 9\ 34.52$ = sin 0.548311

$\delta = 4\ 1\ 41.57$ sin 8.846632

= 1.701679

50.3129

$r_2 = 15.1173$

$f_2 = 35.1956$

,0010

$d_3 = 35.1966$

$r_3 = \frac{15.2396}{50.4362}$ = 1.702742

$\sin\beta =$ 8.846632

0.549374

$r_3 =$ 1.182975

$i = 13° 26' 36.''78$ = sin 9.366399

$n =$ 0.178982

$\lambda = 8\ 51\ 24.02$ = sin 9.187417

$4\ 35\ 12.76$ $r_3 =$ 1.182975

$\beta = 4\ 1\ 41.57$ 0.370392

$\gamma = 0\ 33\ 31.19$ = sin 7.989021

= 2.381371

240.642

$r_3 = 15.240$

$f_3 = 25.882$

,4

$d_4 = 25.482$

$r_4 = \frac{47.0000}{302.482}$ = 2.480700

$\gamma =$ sin 7.989021

0.469721

$r_4 =$ 1.672098

$i = 3° 35' 51.''90$ = sin 8.797623

0.178982

$\lambda = 5\ 26\ 14.12$ = sin 8.976605

$1\ 50\ 22.22$ $r_4 =$ 1.672098

$\gamma = 0\ 33\ 31.19$ 0.648703

$\delta = 2\ 23\ 53.41$ = sin 8.621830

= 2.027073

106.4322

47.0000

$f_4 = 59.4322$

$i = 3° 2' 56.''71$ ✓ = sin 8.725842 ✓

$n' =$ 0.211227 ✓

$\lambda = 1\ 52\ 27.11$ ✓ = sin 8.514615 ✓

$\gamma = 1\ 10\ 29.60$ ✓ $r_1 =$ 1.672098 ✓

0.186713 ✓

= sin 8.311844 ✓

74.9668 ✓ = 1.874869 ✓

$r_1 = 47.0000$

$f_1 = 121.9668$ ✓

,2000

$d_2 = 121.7668$

$r_2 = \frac{15.1173}{106.6841}$ = 2.027959

$\gamma =$ sin 8.311844

0.339803

$r_2 =$ 1.179473

$i = 8° 19' 2.''05$ = sin 9.160330

$n' =$ 0.211227

$\lambda = 13\ 36\ 26.05$ = sin 9.371557

$5\ 17\ 24.00$ $r_2 =$ 1.179473

$\gamma = 1\ 10\ 29.60$ 0.551030

$\delta = 4\ 6\ 54.40$ = sin 8.853886

= 1.695144

49.5614

$r_2 = 15.1173$

$f_2 = 34.4441$

,0010

$d_3 = 34.4451$

$r_3 = \frac{15.2396}{49.6847}$ = 1.696223

$\sin\beta =$ 8.853886

0.552109

$r_3 =$ 1.182975

$i = 13° 31' 48.''31$ = sin 9.369134

$n =$ 0.180944

$\lambda = 8\ 52\ 21.27$ = sin 9.188190

$4\ 39\ 27.04$ $r_3 =$ 1.182975

$\beta = 4\ 6\ 54.40$ 0.371165

$\gamma = 0\ 32\ 32.64$ = sin 7.976190

= 2.394975

248.2990

$r_3 = 15.2396$

$f_3 = 263.539$

,4

$d_4 = 263.139$

$r_4 = \frac{47.}{310.139}$ = 2.491556

$\gamma =$ sin 7.976190

0.467746

$r_4 =$ 1.672098

$i = 3° 34' 53.''06$ = sin 8.795648

$n =$ 0.180944

$\lambda = 5\ 26\ 13.53$ = sin 8.976592

$1\ 51\ 20.47$ $r_4 =$ 1.672098

$\gamma = 0\ 32\ 32.64$ 0.648690

$\delta = 2\ 23\ 53.11$ = sin 8.621615

2.027075

106.4324

47.0000

$f_4 = 59.4324$ blue

59.4322 red

.0002

(Hint the stronger)

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$\lambda = 5.614$ Marginal

(19)

$i = 3^\circ\ 2'\ 56.''71 = \sin 8.725842$

$\lambda = \begin{array}{r} 1\ 52\ 55.65 \\ 1\ 10\ 1.06 \\ \hline \end{array}$

$\beta = \begin{array}{r} 1\ 10\ 1.06 \\ \hline \end{array}$

$n' = 0.209428 = \sin 8.516414$

$r_1 = \begin{array}{r} 1.672098 \\ 0.188512 \\ \hline \end{array} = \sin 8.308904 = 1.879608$

$r_1 = \begin{array}{r} 75.7893 \\ 47. \\ \hline \end{array}$

$f_1 = \begin{array}{r} 122.7893 \\ ,200 \\ \hline \end{array}$

$d_2 = 122.5893$

$r_2 = \begin{array}{r} 15.1173 \\ 107.4720 \\ \hline \end{array} = 2.031295$

$\beta = 8.308904$

$\gamma = 0.340199$

$r_2 = 1.179473$

$i = 8^\circ\ 19'\ 29.''55 = \sin 9.160726$

$n' = 0.209428$

$\lambda = \begin{array}{r} 13\ 33\ 45.03 \\ 5\ 14\ 15.48 \\ \hline \end{array} = \sin 9.370154$

$r_2 = 1.179473$

$\beta = \begin{array}{r} 1\ 10\ 1.06 \\ 4\ 4\ 14.42 \\ \hline \end{array} = \sin 0.549627$

$= \sin 8.851178$

$= 1.698449$

$r_2 = \begin{array}{r} 49.9401 \\ 15.1173 \\ \hline \end{array}$

$f_2 = \begin{array}{r} 34.8228 \\ ,0010 \\ \hline \end{array}$

$d_3 = 34.8238$

$r_3 = \begin{array}{r} 15.2396 \\ 50.0634 \\ \hline \end{array} = 1.699520$

$\beta = \delta = \sin \begin{array}{r} 8.851178 \\ 0.550698 \\ \hline \end{array}$

$r_3 = 1.182975$

$i = 13^\circ 29'\ 7.''31 = \sin 9.367723$

$n = 0.179963$

$\lambda = \begin{array}{r} 8\ 51\ 49.41 \\ 4\ 37\ 17.90 \\ \hline \end{array} = \sin 9.187760$

$r_3 = 1.182975$

$\beta = \begin{array}{r} 4\ 4\ 14.42 \\ 0\ 33\ 3.48 \\ \hline \end{array} = \sin 0.370735$

$\gamma = \sin 7.982996$

$= 2.387739$

$r_3 = \begin{array}{r} 244.1963 = \\ 15.2396 \\ \hline \end{array}$

$f_3 = \begin{array}{r} 229.4359 \\ ,4 \\ \hline \end{array}$

$d_4 = 229.0359$

$r_4 = \begin{array}{r} 47. \\ 306.0359 \\ \hline \end{array} = 2.485772$

$\gamma = \sin \begin{array}{r} 7.982996 \\ 0.468768 \\ \hline \end{array}$

$r_4 = 1.672098$

$i = 3\ 35\ 23.48 = \sin 8.796670$

$n = 0.179963$

$\lambda = \begin{array}{r} 5\ 26\ 15.39 \\ 1\ 50\ 51.91 \\ \hline \end{array} = \sin 8.976633$

$r_4 = 1.672098$

$\gamma = \begin{array}{r} 0\ 33\ 3.48 \\ 2\ 23\ 55.39 \\ \hline \end{array} = \sin \begin{array}{r} 0.648731 \\ 8.621720 \\ \hline \end{array}$

$= 2.027001$

$r_4 = \begin{array}{r} 106.4146 = \\ 47. \\ \hline \end{array}$

$f_4 = 59.4146$

Central $\begin{array}{r} 59.3844 \\ .0302 \\ \hline \end{array}$ flint too strong

$\lambda = 5.614$ Central

$n' = 0.209428$

$r_1 = \begin{array}{r} 1.672098 \\ 1.881526 \\ \hline \end{array}$

$n'-1 = \begin{array}{r} 9.792168 \\ 2.089361 \\ \hline \end{array}$

$f_1 = \begin{array}{r} 122.846 \\ ,200 \\ \hline \end{array} = 2.088653$

$d_2 = 122.646$

$r_2 = \begin{array}{r} 1.179473 \\ 3.268126 \\ \hline \end{array}$

$d_2 = 2.088653$

$n'-1 = \begin{array}{r} 9.792168 \\ 1.880818 \\ \hline \end{array} = 76.0008$

$n' = 0.209428$

$r_2 = \begin{array}{r} 1.179473 \\ 1.388901 \\ \hline \end{array} = \begin{array}{r} 24.485555 \\ 51.555555 \\ \hline \end{array} = \begin{array}{r} 1.711940 \\ 1.556186 \\ \hline \end{array}$

$f_2 = \begin{array}{r} 35.99035 \\ ,001 \\ \hline \end{array}$

$d_3 = 35.99135 = 1.556198$

$r_3 = 1.182975$

$n = \begin{array}{r} 0.179963 \\ 2.919136 \\ \hline \end{array}$

$d_3 = 1.556198$

$n-1 = \begin{array}{r} 9.710483 \\ 1.266681 \\ \hline \end{array} = 18.4791$

$r_3 = \begin{array}{r} 18.2396 \\ 3.2395 \\ \hline \end{array} = \begin{array}{r} 0.510478 \\ 2.408658 \\ \hline \end{array}$

$f_3 = \begin{array}{r} 256.247 \\ ,4 \\ \hline \end{array}$

$d_4 = 255.847 = 2.407980$

$r_4 = 1.672098$

$d_4 = 2.407980$

$n-1 = \begin{array}{r} 9.710483 \\ 2.118463 \\ \hline \end{array} = 131.3600$

$n = 0.179963$

$r_4 = \begin{array}{r} 1.672098 \\ 1.852061 \\ \hline \end{array} = \begin{array}{r} 71.1314 \\ 202.4984 \\ \hline \end{array} = \begin{array}{r} 2.306406 \\ 1.773672 \\ \hline \end{array}$

$f_4 = 59.3844$

4 leaves back –

increasing $r_1 = r_4$ – $\begin{cases} 0.1256 & \text{Chang Sph. Ab. } .0087 \\ .0520 & .0023 \\ .0736 & .0060 \end{cases}$

hence

increasing $r_1 = r_4$ $\begin{array}{r} .4350 \\ \hline \end{array}$ will Chang Sph Ab. .0302

try $r_1 = r_4 = \begin{array}{r} 47.0000 \\ 47.4350 \\ \hline \end{array}$

$r_1 = r_4 = 47.4350 = \log 1.676099$

$\frac{1}{r_1} = \frac{1}{r_4} = .0210818 = 8.323901$

$B = .0448729$

$\frac{1}{r_2} = .0658544 = 8.818244$

$r_2 = 15.1620 = 1.180756$

$A = .0868949$

$\frac{1}{r_4} = .0210815$

$.0658134 = 8.818315$

$= 1.181685$

$r_3 = 15.1944$

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Flint in Front. $r_1 = r_4 = 47.4350$ $r_2 = 15.1620$ $r_3 = 15.1944$

$\lambda = 5614$ Marginal

(20)

$i = 3^\circ\ 1'\ 15.''95$
$\lambda = 1\ 51\ 52.97$
$\beta = 1\ 9\ 22.98$

$y = l$ 0.397940
r_1 = 1.676099
sin 8.721841
n' = 0.209428
sin 8.512413
r_1 = 1.676099
0.188512
sin 8.304980
= 1.883562

76.4825
r_1 = 47.4350
f_1 = 123.9175
,2000
d_2 = 123.7175
r_2 = 15.1620
108.5555 = 2.035652

y = 8.304980
0.340602
r_2 = 1.180756
sin 9.159846
n' 0.209428
sin 9.369274
r_2 = 1.180756
0.550030
sin 8.851132
= 1.698898

$i = 8^\circ\ 18'\ 28.''47$
$\lambda = 5\ 13\ 35.84$
$\beta = 4\ 4\ 12.86$

49.9917
r_2 = 15.1620
f_2 = 34.8297
,1001
d_3 = 34.8307
r_3 = 15.1944
50.0251 = 1.699188

$\beta = \delta$ sin 8.851132
0.550320
r_3 = 1.181685
sin 9.368635
n = 0.179963
sin 9.188672
r_3 = 1.181685
0.370357
sin 7.991229
= 2.379128

$i = 13^\circ\ 30'\ 51.''32$
$\lambda = 8\ 52\ 57.02$
$\beta = 0\ 33\ 41.44$

239.4022
r_3 = 15.1944
f_3 = 254.5966
,4
d_4 = 254.1966
r_4 = 47.4350
301.6316 = 2.479477

y = 7.991229
0.470706
r_4 = 1.676099
sin 8.794607
n = 0.179963
sin 8.974570
r_4 = 1.676099
0.650669
sin 8.622044
= 2.028625

$i = 3^\circ\ 34'\ 22.''15$
$\lambda = 5\ 24\ 42.34$
$\beta = 0\ 33\ 41.44$
$\delta = 2\ 24\ 1.65$

106.8132
47.4350
f_4 = 59.3782

$\lambda = 5614$ Central

n' = 0.209428
r_1 = 1.676099
1.885527
$n'-1$ = 9.792165
= 2.093362

f_1 = 123.9830
,2
d_2 = 123.7820
= 2.092661
r_2 = 1.180756
3.273417

d_2 = 2.092661
$n'-1$ = 9.792165
1.884826 = 76.7057

n' = 0.209428
r_2 = 1.180756
1.390184 = 24.5575
52.1479 = 1.717237
= 1.556180

f_2 = 35.9899
,1001
d_3 = 35.9909
= 1.556192
r_3 = 1.181685
n = 0.179963
2.917840

d_3 = 1.556192
$n-1$ = 9.710483
1.266675 = 18.47884
r_3 = 15.1944
3.28444 = 0.516461
= 2.401379

f_3 = 251.9875
,4
d_4 = 251.5875
= 2.400697
r_4 = 1.676099
4.076796

d_4 = 2.400697
$n-1$ = 9.710483
2.111180 = 129.1755

n = 0.179963
r_4 = 1.676099
1.856062 = 71.7897
200.9652 = 2.303121
= 1.773675

f_4 59.3847
Marginal = ,3782
,0065 flint too weak

Change of .0367 in Δs produced by change of .4350 in $r_1 = r_4$

$\therefore$ Change of .0065 would be produced by .0770 change in $r_1 - r_2$

Try $r_1 = r_4$ = 47.4350 / 47.3580

$r_1 = r_4$ = 47.3580 = l 1.675393
.021115 77 = 8.324607
.044872 95 = 8.819470
.065988 72 = 1.180530
r_2 = 15.1541

.086894 95
.021115 77
.065779 18 = 8.818088
= 1.181912
r_3 = 15.2024

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$r_1 = r_4 = 47.3580$ $r_2 = 15.1541$ $r_3 = 15.2024$ 235

r_2 is so nearly equal to r_3 that there would be a bad reflection at the focus — hence make $r_2 = r_3$ and get rid of this reflection entirely see 6 leaves ova-

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(4½)

Index of Refraction – $n = \frac{\sin \frac{1}{2}(\alpha + \delta)}{\sin \frac{1}{2}\alpha}$

Crown $\alpha = 60° 0' 20''$ Flint $\alpha = 60° 0' 34''$

Crown

B line

$2\delta = 75° 58' 18''$ pow
$75° 58' 20$ good
$75° 58' 30$ good

$2\delta = 75° 58' 20$ (Ave)
$\frac{1}{2}\delta = 18\ 59\ 37$ ✓
$\frac{1}{2}\alpha = 30\ 0\ 18$ ✓
$48\ 59\ 55$ ✓ = sin 9.877765 ✓
$\frac{1}{2}\alpha$ = " 9.699025 ✓
log 0.178740 ✓

$n = 1.509177$ ✓ = log 9.706869 ✓
$n-1 = .509177$ ✓ = " 9.706869 ✓

75 58 25 remeasured
18 59 36
30 0 15
48 59 51 = 9.877763
9.699025
0.178738
1.509169
0.509169 = 9.706869

Seine ⅓ from F towards G.

$2\delta = 77° 55' 45''$
$77\ 55\ 87½$
$77\ 55\ 15$
call ave $77\ 55\ 32$
$\frac{1}{2}\delta = 19\ 28\ 53$ ✓
$\frac{1}{2}\alpha = 30\ 0\ 18$
$49\ 29\ 8$ = sin 9.880952 ✓
$\frac{1}{2}\alpha$ = " 9.699025 ✓
log = 0.181927

$n = 1.520296$ log
$n-1 = .520296$ " = 9.71625

H, line

$2\delta = 79° 23' 0''$ (Repeated)
$\frac{1}{2}\delta = 19\ 50\ 45$ ✓
$\frac{1}{2}\alpha = 30\ 0\ 18$ ✓
$49\ 51\ 0$ ✓ = sin 9.883297 ✓
$\frac{1}{2}\alpha$ = " 9.699025 ✓
= log 0.184272 ✓

$n = 1.528527$
$n-1 = .528527$ = " 9.723067

G. line

center of band. (2 lines lie towards red
both lie a bright line with dark line on edge

$2\delta = 78° 34' 52''$ Feb. 22 '91
$\frac{1}{2}\delta = 19\ 38\ 43$ ✓
$\frac{1}{2}\alpha = 30\ 0\ 15$
$49\ 38\ 58$ = sin 9.882010
$\frac{1}{2}\alpha$ = " 9.699025
log 0.182985

$n = 1.52400$
$n-1 = .52400$ = " 9.71933

$n' = 0.215164$
$n = 0.182985$
$N = 0.032179 = 1.07691$
$N-1 = \log 8.88598$ .07691

Flint

B line

$2\delta = 94° 45' 52''$
$94\ 45\ 30$
$94\ 45\ 38$
$2\delta = 94\ 45\ 40$
$\frac{1}{2}\delta = 23\ 41\ 22$ Ave ✓
$\frac{1}{2}\alpha = 30\ 0\ 17$ ✓
$53\ 41\ 39$ ✓ = sin 9.906264 ✓
$\frac{1}{2}\alpha$ = sin 9.699032 ✓
= log 0.207232 ✓

$n' = 1.611506$
$n'-1 = .611506$ = " 9.786401

abt 2 weeks after
$94° 45' 23''$
$94\ 45\ 15$
Ave = $94\ 45\ 19$
$23\ 41\ 20$

N = 0.107849

Seine ⅓ from F towards G.

$2\delta = 99° 2' 52''$
$99\ 3\ 15$
$99\ 3\ 15$
call ave $99\ 3\ 7$ /2
$\frac{1}{2}\delta = 24\ 45\ 48$ ✓
$\frac{1}{2}\alpha = 30\ 0\ 17$
$54\ 46\ 05$ = sin 9.912128
$\frac{1}{2}\alpha$ = " 9.699032
= 0.213096

$n' = 1.633413$ log
$n'-1 = .633413$ " = 9.80169

abt 2 weeks later
$99\ 3\ 22$
$99\ 3\ 0$
$99\ 3\ 30$
$99\ 3\ 17$

H, line

$2\delta = 102° 35' 45''$
$102\ 35\ 45$
Ave = $102\ 35\ 45$
$\frac{1}{2}\delta = 25\ 38\ 56$ ✓
$\frac{1}{2}\alpha = 30\ 0\ 17$ ✓
$55\ 39\ 13''$ = log sin 9.916792 ✓
$\frac{1}{2}\alpha$ = " 9.699032 ✓
log = 0.217760 ✓

$n' = 1.651049$
$n'-1 = .651049$

H. line. (g, see back 26 Pagan)

center line of group
$2\delta = 100° 35' 45''$
$100\ 35\ 23$
$100\ 35\ 30$
Ave $100\ 35\ 33$
$\frac{1}{2}\delta = 25\ 8\ 53$
$\frac{1}{2}\alpha = 30\ 0\ 17$
$55\ 9\ 10$

$2\delta = 100° 36' 37''$ same line as Crown. Feb. 22 '91

= sin 9.914173
$\frac{1}{2}\alpha$ = " 9.699032
= log 0.215141

$n' = 1.641123$

$2\delta = 100° 36' 37''$ same line as Crown
$\frac{1}{2}\delta = 25\ 9\ 9$
$\frac{1}{2}\alpha = 30\ 0\ 17$
$55\ 9\ 26$ = sin 9.914196
$\frac{1}{2}\alpha$ = 9.699032
$n' = 1.641221$ = log 0.215164
$n'-1 = .641221$ = " 9.80700

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Index of Refraction - continued

Crown

A. line

Vernier

	Waxed			Plain		
	120	1	0	300	0	30
Mirror Lens moved between readings	44	22	0	224	21	45
Prism	75	39	0	75	38	45
Flint	82	10	45	262	10	37
	120	9	15	300	9	0
	44	31	15	224	30	30
Yard	75	38	0	75	38	30
	105	38	45	285	38	30
	30	0	45	210	0	0
Yard	75	38	0	75	38	30

$2\delta = 75^\circ\ 38'\ 15''$

$\frac{1}{2}\delta = 18\ 54\ 34$

$\frac{1}{2}\alpha = \frac{30\ 0\ 15}{48\ 54\ 49}$ = sin 9.877210

$\frac{1}{2}\alpha =$ " 9.699025

$n = 1.50725 = 0.178185$

$n-1 = .50725 = 9.70522$

Flint

A line

Vernier

Feb. 15th 91.

	Waxed			Plain		
	300	0	0	120	0	15
	205	53	30	25	53	52
$2\delta =$	94	6	30	94	6	23
	300	0	15	120	0	45
	205	53	30	25	53	45
$2\delta =$	94	6	45	94	7	0

Ave = 94° 6′ 40″

$2\delta = 94^\circ\ 6'\ 40''$

$\frac{1}{2}\delta = 23\ 31\ 40$

$\frac{1}{2}\alpha = \frac{30\ 0\ 17}{53\ 31\ 57}$ = sin 9.905361

$\frac{1}{2}\alpha =$ " 9.699032

$n' = 1.60815 = \log 0.206329$

$n'-1 = .60815 = \log 9.784016$

$N = \frac{n'}{n}$ $\quad n' = 1.60815 = 0.206329$

$n = \quad = 0.178185$

$= 0.028144$

$N = 1.0669 =$

$N-1 = .0669 = 8.82575$

56 1/4 line

Vernier

	Waxed			Plain		
	40	1	15	220	0	15
	136	21	30	316	21	0
Readings on 2δ instrument probably out in opposite direction	96	20	15	96	20	45
	120	0	52	300	0	15
	23	39	7	203	38	52
2δ	96	21	45	96	21	23
Ave	96	21	34			
	116	22	15	296	21	52
	20	1	7	200	0	0
2δ	96	21	7	96	21	52
Ave	96	21	30			

Ave 96° 21′ 32″ 319 59 20

21 34	140	0	0	319	59	30
21 30	43	39	0	223	38	30
21 0	96	21	0	96	21	0
21 18						
21 8						
5) 90						
21 18						
	136	22	52	316	23	0
	40	2	0	220	1	15
	96	20	52	96	21	45

Ave (96° 21′ 18″)

96 21 9

Ave of all = 96° 21′ 19″

141 22 0						
21 52						
	141	21	52	321	21	30
	45	0	52	225	0	15
96 21 0	96	21	0	96	21	15

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$$\delta\varphi = -\frac{1}{2} A \frac{dn_0}{dn_0'} \cdot \frac{d^2n'}{dn^2} \cdot \delta n^2$$

$n_F = 1.5\overline{7}865$
$n_C = 1.5\overline{1}002$
$\delta n = .00863 = \log 7.86301$
$\delta n^2 = \overline{5}.72602$
$\frac{1}{2}\frac{d^2n'}{dn^2} = \gamma = 1.13277$
$\frac{dn_0}{dn_0'} = 0.96316$

$\frac{dn_0}{dn_0'} = \beta + 2\gamma n$

$\frac{1}{2}\frac{d^2n'}{dn^2} = \gamma = 13.576$

$n = 0.17898$
$\gamma = 1.13277$
$2 = 0.30103$
$1.61278 = 41.000 - 39.167$
$\beta = -39.167$
1.833

$A = 0.71734$
(5.2161)
$0.\overline{5}0018$
7.83929

$\delta\varphi = -3.1633 = -.0069070$

$60 \overline{)\ .0215}$
$.00036$

$\frac{dn_0}{dn_0'} = \beta + 2\gamma n.$

$n = 0.17996$
$\gamma = 1.13277$
$2 = 0.30103$
$41.092 = 1.61376$

$\delta n = n_F - n_0$
39.167
1.925

Try 80.259 below

For H, ray

$n_F = 1.5\overline{2}853$
$n_0 = 1.5\overline{1}343$
$\delta n = .01510 = \log 8.17898$
$\delta n^2 = \overline{7}.35796$
$\gamma = 1.13277$
$1.926 = \frac{dn_0}{dn_0'} = 0.28443$
$A = 0.71734$
$= 9.49250$

$\delta\varphi = .31081$

$\overline{7}.35796$
1.13277
0.71734
$80.259 = 1.90449$
$12.959 = 1.11256$

$4\frac{1}{2}$ O.G.

Index of Refraction remeasured Feb. 15th 1891. to check previous measurement

Lenses

B line — Vernier

	Waxed	Plain
	126° 58′ 45″	305° 58′ 20″
	50 0 45	230 0 0
2δ =	75 58 0	75 58 20
	120 0 0	299 59 45
	44 1 52	224 1 7
2δ =	75 58 8	75 58 38

Ave = 75° 58′ 19″

C line — Vernier

	Waxed	Plain
	116° 9′ 0″	296° 8′ 50″
	40 1 45	220 1 0
2δ =	76 7 15	76 7 50

Flint

B line — Vernier

	Waxed	Plain
	300° 0′ 30″	120° 0′ 0″
	205 15 15	25 15 15
2δ =	94 45 15	94 44 45
	240 1 0	60 0 15
	145 15 45	325 15 0
2δ =	94 45 15	94 45 15

Ave 94° 45′ 22″
94 46 5

{ See next page

C line — Vernier

	Waxed	Plain
	260° 0′ 30″	80° 0′ 0″
	164 53 15	344 53 0
2δ =	95 5 15	95 5 0
	250 0 45	70 0 0
	154 53 0	334 57 37
2δ =	95 5 45	95 5 23

Ave = 95° 5′ 21″

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Index of Refraction
Crown — Continued — Flint

5614 line — Vernier

Worked			Plain		
100	0	45	280° 0′ 0″		
23	16	45	203	16	15
76	44	0	76	43	45
100	1	0	280	0	30
23	17	15	203	16	30
76	43	45	76	44	0

Ave 76° 43′ 52″

7. line.

	100	1	7	280	0	30
	22	21	15	202	20	45
Fair	77	39	52	77	39	45
	117	38	30	297	38	30
	40	1	0	220	0	0
Good	77	37	30	77	38	30

5614 = See preceding leaf over

28 = 96° 21′ 18″

F line — Vernier

	Worked			Plain		
	148	24	0	328	24	0
	50	0	15	230	0	0
28 =	98	23	45	98	24	0
	145	0	52	325	0	37
	46	36	52	226	36	30
28 =	98	24	0	98	24	7

Good — Ave = 98° 23′ 58″

G line

	140	0	0	320	0	0
	38	59	0	218	58	52
good!	101	1	0	101	1	8

Ave = 101° 1′ 4″

B line

	136	46	45	316	46	45
	42	1	7	222	0	30
good!	94	45	38	94	46	15
	144	46	45	324	46	15
	50	0	15	230	0	0
good!	94	46	30	94	46	15

Ave = 94° 46′ 22″

	150	0	0	330	0	0
	55	14	7	235	14	0
	94	45	53	94	46	0

good! 94° 45′ 57″

Ave of all = 94° 46′ 5″

$\frac{1}{2}\delta$ = 23 41 31

$\frac{1}{2}\alpha$ = 30 0 17

9.906278 = a_i = 53 41 48

9.699032 = $\frac{1}{2}\epsilon$

0.207246 = 1.611535-8

0.611535-8

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In the calculation for best color correction. it was found that for a focal length of 1

$A = +5.216082 = \log 0.7173448$

$B = -2.708038 = \text{"} \; 0.4326548$

In calculated O.G. 7 leaves over - with flint in front.

for focal length of 59.67 about, color corrected for marginal rays (59.37 + .30)

$A = .0.868950$

$B = .0.448729$

$59.67 = \frac{0.71734}{1.77576}{}^{7=60.028} = \frac{0.71734}{1.77835} = \frac{0.71734}{8.93899}$

$A = .087414 \quad A = .086895$

$59.67 = \frac{0.43265}{1.77576}{}^{7=60.028} = \frac{0.43265}{1.77835} = \frac{0.43265}{8.65430}$

$B = .045383 \quad B = .045113$

$.044873$

$.000240$

16 leaves back, lenses in front. $7 = 59.40 + .30 = 59.70$

$A = .0863300$

$B = .0444146$

Index of Refraction Apr. 4th 91

C line	Flint Vernier Plain	Vernier reversed
	325° 7′ 0″	145° 7′ 0″
	230 0 30	50 1 15
	95 6 30	95 5 45
	Ave 95° 6′ 7″	
	309 59 45	130 0 30
	214 53 30	34 53 45
	95 6 15	95 6 45
	305 5 37	125 5 45
	209 59 0	29 59 15
	95 6 37	95 6 30
	299 59 30	119 59 30
	204 52 45	24 53 0
	95 6 45	95 6 30
	275 6 15	115 6 0
	299 59 30	20 0 0
	95 6 45	95 6 0

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$R = 45.5 = \log 1.6580114$

$R^2 = 2070.25 \quad 3.3160228 =$

$rd_o = l.\ 7.9033971$

$R = 1.6580114$

6.2452957

2.4905914

$x = .000175\overline{91}$

$x^2 =$

$y = .004 - \sqrt{.000016 - .000000030945\overline{06}}$

$.000015969\overline{05494} = 5.2032791$

7.6016395

$.00\overline{4}3996130$

$y = .00000\overline{3870}$

Convex

$d_o = 2.001$

$x = .000175\overline{91}$

$d = 2.000\overline{82409} = 0.2012089$

$d^2 = 0.6024178$

$h = 45.5 - \sqrt{2070.25 - 4.003296}$

$2066.2467 = 3.315\overline{1822}$

1.6575911

45.5

$45.45\overline{5990}$

$h = .044\overline{0}10$

$y = .000\overline{0}004$

$.044014$

$S = 4.4014$

$d^2 = 0.6024178$

$S = 0.6435908$

1.2460086

$2h = .08802 = 8.9445814$

$\log k = 2.3014272$

Concave

$d_o = 2.001$

$x = 0.000175\overline{91}$

$d = 2.0011\overline{7591} = 0.3012853$

$d^2 = 0.6025706$

$h = 45.5 - \sqrt{2070.25 - 4.004470}$

$2066.2453 = 3.315\overline{1820}$

1.6575910

45.5

$45.45\overline{5980}$

$h = .044\overline{0}20$

$y = .000\overline{0}004$

$.044016$

$S = 4.4016$

$d^2 = 0.6025706$

0.6436106

1.2461812

$2h = .08804 = 8.9447\overline{6800}$

$\log k = 2.3015012$

Index of Refraction

Flint

F line

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Spherometer

continued from following page

When $R = 45.5$

~~$h = R - \sqrt{R^2 - d_0^2} = .044052$~~

$$x = \frac{rd}{R} = \frac{.004 \times 2.001}{45.5} = .000175\text{-}9121$$

$$y = r - \sqrt{r^2 - x^2} = .004 - \sqrt{.000016 - x^2} = .000,003869$$

Convex

$d_0 = 2.0010000$

$x = .0001759$

$d = 2.0008241 = \log 0.$

$h_0 = .044052$

$y = .0000038$

$h = .044046$

$h = R - \sqrt{R^2 - d^2}$

$h = .044005$

$y = .000004$

$.044009$

$S = 4.4009$

$k = 50\, d^2$

$d = 2.000824 = \log 0.30120859$

$4.003296 = d^2 = 0.60241778$

$50 = 1.6989700$

$\log k = 2.3801387\text{8}$

$d^2 = 0.60241778$

$S = 0.643547\text{15}$

$1.246\text{5}9593$

$2h = 8.94\text{x}5320$

2.3014273

Concave

$d_0 = 2.001000$

$x = .0001759$

$d = 2.0011759 = \log 0.30128593$

$2070\,4.25\,4.004706$ ✓

2066.2453

$= \log 3.3151819$ ✓

$d^2 = 0.60257066$

$50 = 1.6989700$

$\log k = 2.3015408$

$1.6989709^5 = 45.5\,45.4559774$ ✓

8.17

9.7x

$2h = .044026$ ✓

$y = .0000004$

$.044022$ ✓

$S = 4.4022$ ✓

$d^2 = 0.60257066$ ✓

$S = 0.64366988$ ✓

1.24624044 ✓

$2h = .088052 = 8.94\text{x}7392$ ✓

$\log k = 2.3015012$ ✓

When $R = 15$ $\quad h = R - \sqrt{R^2 - d^2} = .13406$

$$x = \frac{rd}{R} = \frac{.004 \times 2.001}{15} = .0005336$$ ✓

$$y = r - \sqrt{r^2 - x^2} = .0000035750$$ ✓

Convex

$h = R - \sqrt{R^2 - d^2}$

$d_0 = 2.0010000$

$x = .0005336$

$d = 2.0004664$

$h_0 = .13406$

$y = .0000004$

$h = .13402$

~~$S = 13.402$~~

$d = \log 0.30011313$

$d^2 = 0.60022626 = 4.001866$

$2h = .26804 = 1.4281996 = 2.3443886$

$S = 1.1740630 = 1.1721943$

$R^2 = 225$

$15,14.866007$

$k = .133993$ ✓

$y = .000036$

$.134029$

$S = 13.4029$

$d^2 = 0.6022626$

$= 1.1271987$

1.7294613

$2h = .267986 = 9.4281121$

$\log k = 2.3013492$ ✓

Concave

$d_0 = 2.0010000$

$x = .0005336$

$d = 2.0015336$

$h_0 = .13406$

$y = .0000\text{x}$

$h = .134\text{x}0$

~~$S = 13.410$~~

$d = 2.0015336 = 0.30013629$

$d^2 = 4.0061367 = 0.60272\text{5}8$

$220.9938633 = 2.3443802$

$15,14.865865 = 1.1721901$

$k = .134175$

$y = .000036$

$.134099$

$S = 13.4099$

$d^2 = 0.60272\text{5}8$

$= 1.1274\text{x}\text{x}$

$1.7802\text{x}\text{x}$

$2h = .26834 = 9.4285\text{x}\text{x}$

$\log k = 2.3015\text{x}\text{x}$ ✓

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$d_o = 2.001$
$r = .1004$

$R : r :: d_o : x$ nearly

$x = \frac{r d_o}{R}$

$y = r - \sqrt{r^2 - x^2}$

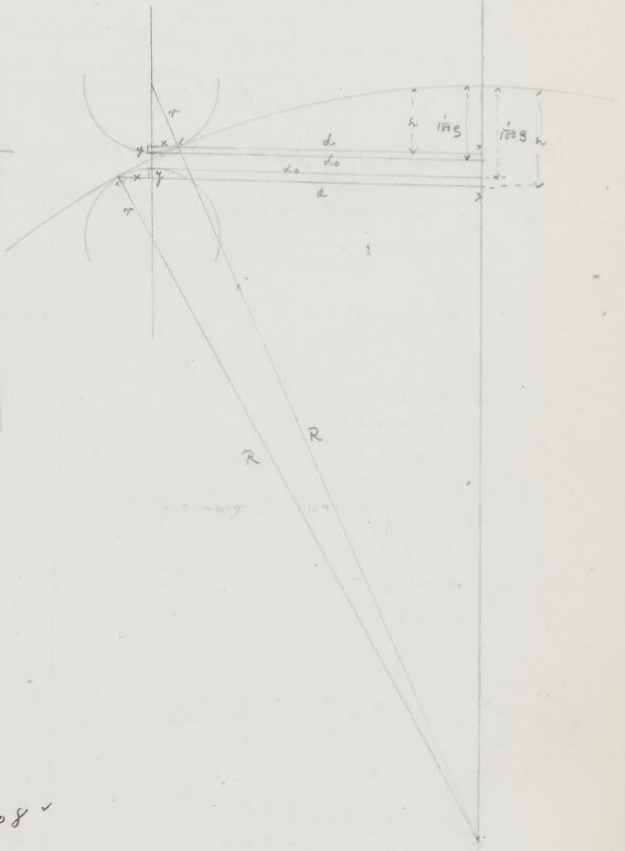
$R = K + \frac{h}{2}$
$\log R = \log K - \log s$

$K = \frac{d^2}{2h} = \frac{k}{s}$ 243

to thread pitch.

$h = \frac{s}{t}$ $k = \frac{t d^2}{2}$

convex	concave
$d = d_o - x$	$d = d_o + x$
$h = R - \sqrt{R^2 - d^2}$	$h = R - \sqrt{R^2 - d^2}$
$100 s = h + y$	$s = \frac{h - y}{100}$
$k = \frac{d^2 s}{2h}$	$k = \frac{d^2 s}{2h}$



$R = 50$.

$x = \frac{r d_o}{R} = \frac{.1004 \times 2.001}{50} = .00016008$ ✓

$y = r - \sqrt{r^2 - x^2} = .000003204\overline{6}$ ✓

convex

$d_o = 2.001\,00000$
$x = .00016008$
$d = 2.000\,83992$ ✓ $= 0.3012124$ ✓
$d^2 = 4.003361\overline{8}$ ✓ $= 0.6024248$ ✓
2495.9964 ✓ $= 3.3972439$ ✓
49.99954 $= 1.6986219$ ✓
$h = .040046$
$y = \frac{.000003}{.040049}$
$s = 4.0049$

$d^2 = 0.6024248$ ✓
$s = 0.6025917$ ✓
1.2049165 ✓
$2h = .08009\overline{2}$ ✓ 8.9035891 ✓
$k = 2.3014294$ ✓

concave

$d_o = 2.001\,00000\,00$
$x = .00016008$
$d = 2.001\,0,160\,8$ ✓ $= 0.3012506$ ✓
$d^2 = 4.004065$ ✓ $= 0.6025012$ ✓
2495.9969 $= 3.3972439$
49.99954 $= 1.6986219$
$h = .040046$
$y = \frac{.000003}{.040043}$
$s = 4.0043$

$d^2 = 0.6025012$ ✓
$s = 0.6025266$ ✓
1.2050278 ✓
$2h = .08009\overline{2} = 8.9035891$ ✓
$k = 2.3074387$ ✓

R	Log k convex		Log k concave	
15	2.301	35 ✓	2.301	58 ✓
45½		43 ✓		50 ✓
50		43		44 ✓

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$R = 15$ $\quad h_0 = R - \sqrt{R^2 - d^2} = .13393$

$\left\{ \begin{array}{l} d = 2.001 \\ r = .004 \end{array} \right.$

See preceding page

$x = \frac{.005 \times 2}{15} = \frac{.01}{15} = .0006666666$

$y = .005 - \sqrt{.005^2 - .000\frac{2}{3}^2}$

$= .005 - \sqrt{.000025 - .000000444444}$

$= .005 - .004995355$

$= .00044645$

Convex

$d_0 = 2.00000$
$x = .0006666$
$d = 1.9993333$

$h_0 = .13393$
$y = .0004$
$.13389$

$K = \frac{d^2}{2h}, \quad K = \frac{k}{S} \therefore k = Ks$

$d = \log \frac{0.3008851}{0.6017702}$

$2h = .26778 = \frac{9.4277781}{1.1739921}$

$K = \frac{1.1267481}{2.3007402}$

$S = \log. k =$

Concave

$d_0 = 2.00000$
$x = .0006666$
$d = 2.0006666$

$h_0 = .13393$
$y = .0004$
$h = .13397$

$d = \log \frac{0.3011788}{0.6023576}$

$2h = .26794 = \frac{9.4280376}{1.1743200}$

$K = \frac{1.1270076}{2.3013276}$

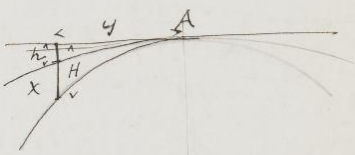
$S = \log k =$

Concave $\log k = 2.3013276$

Convex " $\frac{2.3007402}{.0005874}$

A. Clarke's method of enlarging curved surfaces with Spherometer

$H : h :: R : r$



If parabolas $y^2 = 4ax$

at vertex $R = 2a \therefore y^2 = 2Rx$

" " $R_1 = \frac{y^2}{2x_1}$

$R_2 = \frac{y^2}{2x_2}$

$\frac{R_1}{R_2} = \frac{x_2}{x_1}$

or

or

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Spherometer

When steel legs end in perfect points

S = number of turns of screw

$$R = \frac{h}{2} + \frac{d^2}{2h}$$

$$R = \frac{d^2}{2h} + \frac{h}{2}$$

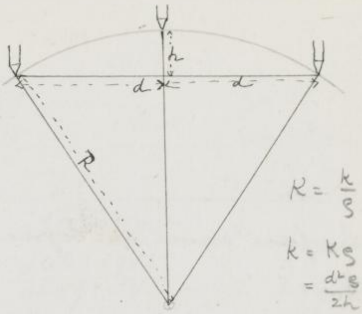
$$R = K + \frac{h}{2}$$

$$\log K = \log k - \log S$$

$$K = \frac{d^2}{2h} = \frac{d^2}{2S\frac{1}{100}''} = \frac{50d^2}{S}$$

$$k = \frac{d^2}{2} \cdot \frac{1}{100} = .005\,d^2$$

$d = 2 \quad \therefore k = .200.$



$$R = \frac{k}{S}$$

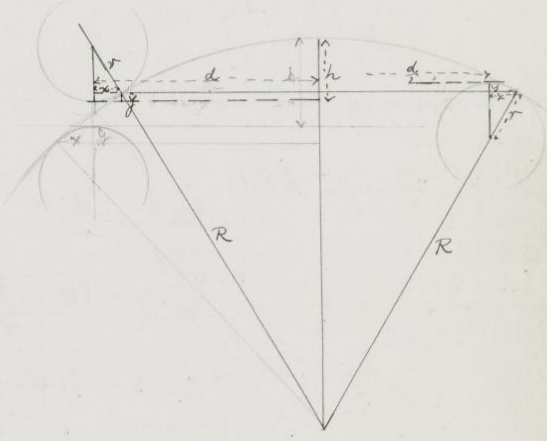
$$k = KS = \frac{d^2 S}{2h}$$

When steel points end in small spheres –

r = radius of small sphere on feet

x = correction to d { subtracted for convex / added " concave

y = " " h { subtracted for convex / added " concave



$R : r :: d : x$ nearly

$$x = \frac{rd}{R}$$

$$y = r - \sqrt{r^2 - x^2}$$

When $R = 48''$. $\quad h = R - \sqrt{R^2 - d^2} = .04169''$ uncorrected $\pm .000004$

convex

$$-x = \frac{.005 \times 2}{48} = \frac{.01}{48} = .0002083334$$

$$-y = .005 - \sqrt{.000025 - .000000043402 8}$$

$$= .005 - .004998672$$

$$= .000004328$$

$d_0 = 2.000000$
$x = -.0002083334$
$d = 1.999791666$

$h_0 = .04169$
$y = -.000004$
$h = .04164$

$k = 50d^2$

$d = 0.3009848$
$d^2 = 0.6019696$
$50 = 1.6989700$
$\log k = 2.3009396$

concave

$+x = .$

$d_0 = 2.000$
$x = +.0002083334$
$d = 2.0002083334$

$k = 50d^2$

$d = 0.3010051$
$d^2 = 0.6021802$
$50 = 1.6989700$
$\log k = 2.3011202$

Concave $k = \log 2.3011202$
Convex " $= 2.3009396$
$.0001806$

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Flint in front. Formulae when $r_2 = r_3$

$$N = \frac{n'}{n}$$

1st Surface same as before

2nd Surface – (2nd and 3rd as before).



In triangle ARP. $\frac{\sin i}{\sin \gamma} = \frac{d-r}{r}$

$$\sin i = \frac{(d-r)\sin\gamma}{r}$$

$$\sin\lambda = N \sin i$$

$$\delta = \gamma - (\lambda - i)$$

In triangle ARF. $\frac{\sin\lambda}{\sin\delta} = \frac{f-r}{r} \quad \therefore f - r = \frac{r\sin\lambda}{\sin\delta}$

$$f = \frac{r\sin\lambda}{\sin\delta} + r$$

Secondary

$\frac{\sin i}{\sin\lambda} = \frac{1}{N}$

$\frac{AF}{FR} = \frac{\sin\alpha}{\sin\lambda} \quad \frac{AP}{PR} = \frac{\sin\alpha}{\sin i}$

$\frac{AF \times PR}{FR \times AP} = \frac{\sin i}{\sin\lambda} = \frac{1}{N}$

when A is on axis

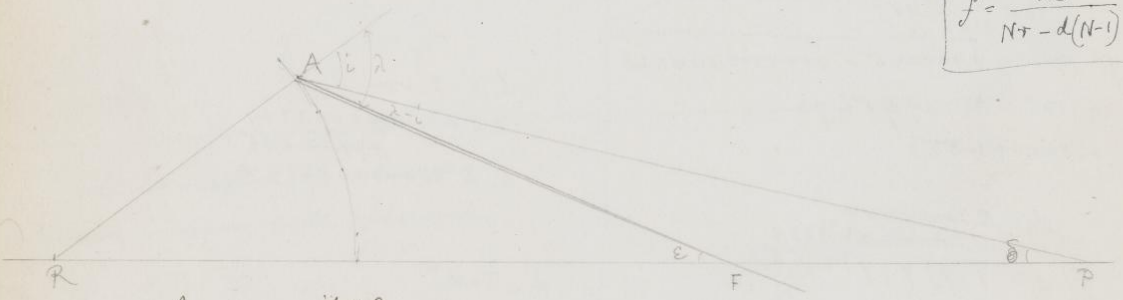
$\frac{f(d-r)}{(f-r)d} = \frac{1}{N}$

$fdN - frN = fd - rd$

$f[(dN-d) - rN] = -rd$

$f = \frac{-rd}{d(N-1) - Nr}$

$f = \frac{rd}{Nr - d(N-1)}$



In triangle ARP. $\frac{\sin i}{\sin\delta} = \frac{d+r}{r}$

$$\sin i = \frac{(d+r)\sin\delta}{r}$$

$$\sin\lambda = n \sin i$$

$$\varepsilon = \delta + (\lambda - i)$$

In triangle ARF. $\frac{\sin\lambda}{\sin\varepsilon} = \frac{f+r}{r} \quad \therefore f + r = \frac{r\sin\lambda}{\sin\varepsilon}$

$$f = \frac{r\sin\lambda}{\sin\varepsilon} - r$$

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Six leaves back r_2 nearly equals r_3 which would cause a bad reflection at the focus. for that reason try making $r_2 = r_3$

(20)

$r_1 = 47.4350$
$r_2 = 15.1620$ } Flint

$r_3 = r_2 = 15.1620$
$r_4 = 47.7542$

For crown, $\frac{1}{r_4} = A - \frac{1}{r_3}$

$A = .08689495$
$\frac{1}{r_3} = .06595544$
$\frac{1}{r_4} = .02094055$ = 8.320988
$r_4 = 47.7542$ = 1.679012

$f_2 = 34.8297$
$d_3 = 34.8297$
$r_3 = \frac{15.1620}{49.9917}$ = 1.698898

β = sin 8.851132
0.850030
r_3 = 1.180756
9.369274
$i = 13° 32' 4.''31$ = sin 0.179963
n = 9.189311
$\lambda = \frac{8\ 53\ 44.48}{4\ 38\ 19.83}$ = sin r_3 = 1.180756
0.370067
$\beta = \frac{4\ 4\ 12.86}{0\ 34\ 6.97}$ = sin 7.996679
γ = 2.373388

236.259
$r_3 = \frac{15.162}{251.421}$
$f_3 = \frac{-.4}{}$
$d_4 = 251.021$
$r_4 = \frac{47.7542}{298.775}$ = 2.475344

γ = sin 7.996679
0.472023
r_4 = 1.679012
= sin 8.793011
$i = 3° 33' 34.''91$ n = 0.179963
= sin 8.972974
$\lambda = \frac{5°\ 23\ 30.61}{1\ 49\ 55.70}$ r_4 = 1.679012
0.651986
$\gamma = \frac{0\ 34\ 6.97}{\delta = 2\ 24\ 2.67}$ = sin 8.622096
2.029890
107.1248
$r_4 = \frac{47.7542}{59.3706}$

Marginal
.3844
Central thickness
.0140

In this case the crown should have been weakened
$\therefore r_2 = r_3$ made of shorter curvature instead of greater

(19)

$r_1 = 47.0000$
$r_2 = 15.1173$ } Flint

$r_3 = 15.1173$
$r_4 = 48.2034$

$A = .08689495$
$\frac{1}{r_3} = .06614953$
$\frac{1}{r_4} = .02074540$ = 8.316922
$r_4 = 48.2034$ = 1.683078

$f_2 = 34.8228$
$d_3 = 34.8228$
$r_3 = \frac{15.1173}{49.9401}$ = 1.698449

β = sin 8.851178
0.849627
r_3 = 1.179473
9.370154
$i = 13° 33' 45.''00$ = sin n = 0.179963
9.190191
$\lambda = \frac{8\ 57\ 50.00}{4\ 38\ 55.00}$ = sin r_3 = 1.179473
0.369664
$\beta = \frac{4\ 4\ 14.42}{0\ 34\ 40.58}$ = sin 8.003752
γ = 2.365912

232.227
$r_3 = \frac{15.1173}{247.344}$
$f_3 = \frac{-.4}{}$
$d_4 = 246.944$
$r_4 = \frac{48.2034}{295.147}$ = 2.470039

γ = sin 8.003752
0.473791
r_4 = 1.683078
$i = 3° 32' 27.''19$ = sin 8.790713
n = 0.179963
$\lambda = \frac{5°\ 21\ 47.93}{1\ 49\ 20.74}$ = sin 8.970676
r_4 = 1.683078
$\gamma = \frac{0\ 34\ 40.58}{\delta = 2\ 24\ 1.32}$ 0.653754
= sin 8.622028
2.031726
107.5761
$r_4 = \frac{48.2034}{59.3727}$

.3845
.0115

$r_2 = r_3 = 15.1620$
15.1173
.0447

.0140
.0118
.0022

22 : 118 :: 447 : x
118
3576
447
447
22 | 52746 | 2397
44
87
66
216
198
180

15.1173
.2397
148776
$= r_2 = r_3$

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Hint in front $r_2 = r_3 = 14.8776$

$r_2 = 14.8776 = l\ 1.172534$
$\frac{1}{r_2} = .0672150\ 3$ ✓ $\quad 8.827466$ ✓
$B = .0448729\ 8$ ✓
$.0223420\ 8$ ✓ $= 8.349123$ ✓
$r_1 = 44.7587$ ✓ $= 1.650877$ ✓

$r_3 =$ l. 1.
$\frac{1}{r_3} = .0672150\ 3$ ✓
$A = .0868944\ 8$ ✓
$\frac{1}{r_4} = .0196799\ 2$ ✓ $= 8.294023$ ✓
$r_4 = 50.8133$ ✓ $= 1.705977$ ✓

$\lambda = 56$ ✓ Marginal

$y = l\ 0.397940$
$r_1 = 1.650877$
$i = 3°12'6.''94 = \sin 8.747063$
$n' = 0.209428$
$\lambda = 1\ 58\ 34.53 = \sin 8.537635$
$y = 1\ 13\ 32.41$ $r_1 = 1.650877$
0.188512
$= \sin 8.330218$
$= 1.858294$

72.1596
44.7587
$f_1 = 116.9183$
$.2$
$d_2 = 116.7183$
$r_2 = \frac{14.8776}{101.8407} = 2.007921$ ✓
$y = \sin 8.330218$
0.338139

$r_2 = 1.172534$
$i = 8°25'10.''58 = \sin 9.165805$
$N = 0.029465$
$\lambda = 9\ 0\ 55.52 = \sin 9.195070$
$0\ 35\ 44.94$ $r_2 = 1.172534$
$y = 1\ 13\ 32.41$ 0.367604
$\delta = 0\ 37\ 47.47 = \sin 8.041108$
$= 2.326496$

212.078
$r_2 = 14.8776$
$f_3 = 226.9556$
$.4$
$d_4 = 226.5556$
$r_4 = \frac{50.8133}{277.3689} = 2.443058$ ✓
$\delta = \sin 8.041108$
0.484166

$r_4 = 1.705977$
$i = 3°26'24.''40 = \sin 8.778189$
$n = 0.179963$
$\lambda = 5\ 12\ 37.54 = \sin 8.958152$
$1\ 46\ 13.14$ $r_4 = 1.705977$
$\delta = 0\ 37\ 47.47$ 0.664129
$\varepsilon = 2\ 24\ 0.61 = \sin 8.621992$
2.042137

110.1887
$r_4 = 50.8133$
$f_4 = 59.3754$ Marginal
59.3693 Central
$.0061$

Central

$n' = 0.209428$ ✓
$r_1 = 1.650877$ ✓
1.860305 ✓
$n'-1 = 9.792168$ ✓
$= 2.068140$ ✓

$f_1 = 116.9876$ ✓
$.2000$ ✓
$d_3 = 116.7876$ ✓
$= 2.067397$ ✓
$r_3 = 1.172534$ ✓
3.239931 ✓

$N = 0.029465$ ✓
$r_3 = 1.172534$ ✓
1.201999 ✓ $= 15.92205$ ✓

$d_3 = 2.067397$ ✓
$N-1 = \frac{8.846337}{0.913734} = \frac{8.19850}{7.72355}$ ✓ $= \frac{0.887817}{2.352114}$ ✓
$f_3 = 224.9645$ ✓
$,4$
$d_4 = 224.5645$ $= 2.351341$ ✓
$r_4 = 1.705977$ ✓
4.057318 ✓

$d_4 = 2.351341$ ✓
$n-1 = \frac{9.710483}{2.061824}$ ✓ $= 115.2986$ ✓
$n = 0.179963$ ✓
$r_4 = \frac{1.705977}{1.888940}$ ✓ $= \frac{76.9024}{192.2010}$ ✓ $= 2.283756$ ✓
$= 1.773562$ ✓
$f_4 = 59.3693$ ✓

$r_2 = r_3$	Sph. Ab. Central = 0
15.1620	−.0140
14.8776	+.0061
Change = .2844	.0201
.00142	.0001
.0866	.0061
14.8776	
14.9642	

$r_2 = r_3$	Sph. Ab.	
14.8776	+ .0061	
14.9642	− .0016	
.0866	.0045	.0077
.0308	.0016	
∴ 14.9950	= .0000	

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Hint in front $r_2 = r_3 = 14.9642$

$r_2 = 14.9642 = l\ 1.175053$

$\frac{1}{r_2} = .0668262 = 8.824947$

$B = \frac{.0448729}{.0219533} = 8.341500$

$r_1 = 45.58512 = 1.658800$

$\frac{1}{r_3} = .0668262$

$A = \frac{.0868949}{.0200687} = 8.302519$

$r_4 = 49.8289 = 1.697481$

$\lambda = 5614$ Marginal

$y = l\ 0.397940$

$r_1 = 1.658800$

$i = 3°\ 8'\ 46.''18 = \sin 8.739440$

$x' = 0.209428$

$\lambda = 1\ 56\ 30.69 = \sin 8.530012$

$\gamma = 1\ 12\ 15.49$ $r_1 = 1.658800$

$0.188512 = \sin 8.322581 = 1.865931$

$\gamma = \frac{73.4397}{45.58512}$

$f_1 = \frac{118.9909}{.2}$

$d_3 = 118.7909$

$r_3 = \frac{14.9642}{103.8267} = 2.016309$ ✓

$y = \sin 8.322581$

0.338890

$r_3 = 1.175053$

$i = 8°\ 23'\ 6.''55 = \sin 9.163837$

$N = 0.029465$

$= \sin 9.193302$

$\lambda = 8\ 58\ 42.59$ $r_3 = 1.175053$

$0\ 35\ 36.04$ 0.368355

$\gamma = 1\ 12\ 15.49$

$\delta = 0\ 36\ 39.45 = \sin 8.027813$

$= 2.340542$

$r_3 = 219.0494$

$f_3 = \frac{14.9642}{234.0136}$

$d_4 = \frac{.4}{233.6136}$

$r_4 = \frac{49.8289}{283.4425} = 2.452465$ ✓

$\delta = \sin 8.027813$

0.480278

$r_4 = 1.697481$

$i = 3°\ 28'\ 36.''67 = \sin 8.782797$

$n = 0.179963$

$\lambda = 5\ 15\ 58.20 = \sin 8.962760$

$1\ 47\ 21.53$ $r_4 = 1.697481$

$\delta = 0\ 36\ 39.45$ 0.660241

$\varepsilon = 2\ 24\ 0.98 = \sin 8.622011$

$= 2.038230$

$r_4 = 109.2019$

$f_4 = \frac{49.8289}{59.3730}$

Central

$n' = 0.209428$

$r_1 = 1.658800$

1.867928

$n'-1 = 9.792165$

$= 2.075763$

$f_1 = 119.0592$

$.2$

$d_3 = 118.8592 = 2.075033$

$r_3 = 1.175053$

3.250086

$N = 0.029465$

$r_3 = \frac{1.175053}{1.204518} = 16.01467$

$d_3 = 2.075033$

$N-1 = \frac{8.846387}{0.921370} = \frac{8.34392}{7.67075} = \frac{0.884838}{2.365248}$

$f_3 = 231.8718$

$.4$

$d_4 = 231.4718 = 2.364498$

$r_4 = 1.697481$

4.061979

$d_4 = 2.364498$

$n-1 = \frac{9.710483}{2.074981} = 118.8450$

$n = 0.179963$

$r_4 = \frac{1.697481}{1.877444} = \frac{75.4126}{194.2576} = \frac{2.288378}{1.773601}$

$f_4 = 59.3746$

$.3730$ Marginal

$- .0016$ (Crown the stronger)

When color correction was perfect. $f_4 = 59.4300$ and as the crown is the stronger for Spherical Ab. it is also for color.

My $r_4 = 49.8959$

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Flint in front. $r_2 = r_3$ continued.

$r_4 = 49.8959$ Marginal

$d_4 = 233.6136$
$r_4 = 49.8959$
283.5095

$\sin \delta = 2.4525568$
$8.0278\overline{13}$
$0.4803\overline{81}$
$r_4 = 1.6980\overline{65}$
$= \sin 8.7823\overline{16}$

$i = 3^\circ\ 28'\ 22''.79$
$n = 0.179963$
$= \sin 8.962279$

$\lambda = 5^\circ\ 15'\ 37''.13$
$1\ 47\ 14.34$
$r_4 = 1.6980\overline{65}$
$= \sin 0.660344$

$\delta = 0\ 36\ 39.45$
$\Sigma = 2\ 23\ 53.79$
$= \sin 8.621649$
2.038695

109.3189
$r_4 = 49.8959$
$f_4 = 59.4230$

Central

$d_4 = 2.364498$
$r_4 = 1.6980\overline{65}$
$4.062\overline{563}$

$d = 2.364498$
$n = 9.710483$
$2.074981 = 118.8450$

$n = 0.179963$
$r_4 = 1.6980\overline{65}$
$1.878928 = 75.5140 = 2.2886\overline{05}$
$194.3590 = 1.773958$

59.4235
Marginal $.4230$
$.0005$ Sph. Ab.

When $r_4 = 49.8959$ Sph. Ab $= .0005$
" $= 49.8289$ " $= .0016$
Change $= .0670$ $.0011$

$11 : 5 :: .0670 : x$
$11)\overline{3350}$
$.0304\overline{5}$ to be added
49.8959
49.9263

Sph. Ab $= 0$ when $r_4 =$

but this would make f_4 too great.

$r_4 = 49.8289$ $f_4 = 59.3746$
$= 49.8959$ " $= 59.4235$
$.0670$ $.0489$

Find A. + B. when $r_4 = 49.8959$ as above.
which causes the Sph. Ab. $.0005$

$r_1 = 45.5512$
$\lambda = C.$ $r_2 = r_3 = 14.9642$ $r_4 = 49.8959$

$i = 3^\circ\ 8'\ 46''.18 = \sin 8.739440$
$n' = 0.207697$
$\lambda = 1\ 56\ 58.62 = \sin 8.531743$
$\gamma = 1\ 11\ 47.56$ $r_1 = 1.6585\overline{00}$
0.190243
$= \sin 8.319775$
$= 1.870468$

74.2110
$r_1 = 45.5512$
$f_1 = 119.7622$
2
$d_2 = 119.5622$
$r_2 = 14.9642$
104.5980
$= 2.019524$
8.319775
0.339299
$r_2 = 1.175\overline{03}$
$i = 8^\circ\ 23'\ 30''.2 = \sin 9.164246$
$N = 0.028715$
$= \sin 9.192961$

$\lambda = 8\ 58\ 17.0$
$0\ 34\ 41.8$
$\gamma = 1\ 11\ 47.56$
$\delta = 0\ 37\ 5.76$
$r_2 = 1.175\overline{03}$
0.368014
$= 8.033045$
2.334969

$2,16.2565$
$r_2 = 14.9642$
$f_2 = 231.2207$
$.4$
$d_4 = 230.8207$
$r_4 = 49.8959$
280.7166
$= 2.488268$
$\delta = \sin 8.033045$
0.521313
$r_4 = 1.6980\overline{65}$
$= \sin 8.823248$

$i = 3^\circ\ 49'\ 0,24$
$n = 0.178982$
$= \sin 9.002230$

$\lambda = 5^\circ\ 46\ 7.75$
$1\ 57\ 7.51$
$r_4 = 1.6980\overline{65}$
0.700295

$\delta = 0\ 37\ 5.76$
$2\ 34\ 13.27$
$= \sin 8.651724$
2.048571

111.8333
$r_4 = 49.8959$
$f_4 = 61.9374$

This makes the focal length for the red long ray from the flint is two strong.

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Flint in front. $\nu_2 = \nu_8 = 14.9950$

$\nu_2 = 14.9950 = 1.175946$

$\frac{1}{\nu_2} = .0666890 = 8.824054$

$B = \frac{.0448729}{.0218161} = 8.338777$

$= 1.661223$

$\nu_1 = 45.8377$

$A = .0868949$

$\frac{1}{\nu_3} = .0666890$

$.0202059 = 8.305478$

$\nu_4 = 49.4905 = 1.694522$

λ = C. Marginal

$y = 0.397940$

$\nu_1 = 1.661223$

$i = 3° 7' 35".32 = \sin 8.736717$

$n' = 0.207697$

$\lambda = 1\ 56\ 14.73 = \sin 8.529020$

$\nu_1 = 1.661223$

$\beta = 1\ 11\ 20.59$

0.190243

$\sin = 8.317047$

$= 1.873196$

74.6786

$\nu_1 = 45.8377$

$f_1 = 120.5163$

$.2$

$d_2 = 120.3163$

$\nu_2 = 14.9950$

105.3213

$= 2.022516$

$\gamma = 8.317047$

0.339563

$\nu_2 = 1.175946$

$i = 8° 22' 57".19 = \sin 9.163617$

$N = 0.028715$

$\lambda = 8\ 57\ 29.84 = \sin 9.192332$

$\nu_2 = 1.175946$

0.368278

$\beta = 1\ 11\ 20.59$

$\delta = 0\ 36\ 41.94 = \sin 8.028376$

$= 2.339902$

218.727

$\nu_2 = 14.9950$

$f_2 = 233.722$

$.4$

$d_4 = 233.322$

$\nu_4 = 49.4905$

282.8125

$= 2.451499$

$\delta = \sin 8.028376$

0.479875

$\nu_4 = 1.694522$

$i = 3° 29' 50".64 = \sin 8.785353$

$n = 0.178982$

$\lambda = 5\ 17\ 7.25 = \sin 8.964335$

$\nu_4 = 1.694522$

$1\ 47\ 16.61$

0.658857

$\delta = 0\ 36\ 41.94$

$\varepsilon = 2\ 23\ 58.55 = \sin 8.621889$

$= 2.036968$

108.8850

$\nu_4 = 49.4905$

$f_4 = 59.3945$

λ = × Marginal

$i = 3° 7' 35".32 = \sin 8.736717$

$n' = 0.211227$

$\lambda = 1° 55' 18".25 = \sin 8.525490$

$\beta = 1\ 12\ 17.07$ $\nu_1 = 1.661223$

0.186713

$= \sin 8.322739$

$= 1.863974$

73.1095

$\nu_1 = 45.8377$

$f_1 = 118.9472$

$.2$

$d_2 = 118.7472$

$\nu_2 = 14.9950$

103.7522

$= 2.015997$

$\gamma = \sin 8.322789$

0.338736

$\nu_2 = 1.175946$

$i = 8° 21' 53".35 = \sin 9.162790$

$N = 0.030283$

$\lambda = 8\ 58\ 25.41 = \sin 9.193073$

$\beta = 0\ 36\ 32.06$ $\nu_2 = 1.175946$

$\gamma = 1\ 12\ 17.07$

0.369019

$\delta = 0\ 35\ 45.01 = \sin 8.016996$

$= 2.385023$

224.9173

$\nu_2 = 14.9950$

$f_2 = 239.9123$

$.4$

$d_4 = 239.5123$

$\nu_4 = 49.4905$

289.0028

$= 2.460902$

$\delta = \sin 8.016996$

0.477898

$\nu_4 = 1.694522$

$i = 3° 28' 53".39 = \sin 8.783376$

$n = 0.180944$

$\lambda = 5\ 17\ 6.59 = \sin 8.964320$

$\nu_4 = 1.694522$

$1\ 48\ 13.20$

0.658842

$\beta = 0\ 35\ 45.01$

$\varepsilon = 2\ 23\ 58.71 = \sin 8.621872$

2.036970

108.8855

49.4905

$f_4 = 59.3950$ blue

$.0945$ red

(C) $.0005$ flint strongest

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Flint in front $r_2 = r_3 = 14.9950$. as before.

$\lambda = 5614$ Marginal

$i = 3° 7' 38".32 = \sin 8.736717$

$n' = 0.209428$

$\lambda = 1° 55' 46.98 = \sin 8.527289$

$\gamma = 1\ 11\ 48.34$ $\quad \gamma_1 = 1.661223$

0.188512

$= \sin 8.319853$

$= 1.868659$

$73.902.5$

$r_1 = 45.8377$

$f_1 = 119.7462$

$.2$

$d_2 = 119.5402$

$r_2 = 14.9950$

104.5452

$= 2.019304$

$\gamma = 8.319853$

0.339157

$r_2 = 1.175946$

$i = 8° 22' 22".76 = \sin 9.163211$

$N = 0.029465$

9.192676

$\lambda = 8\ 57\ 55.62 = \sin$

$0\ 35\ 32.86$ $\quad r_2 = 1.175946$

0.368622

$\gamma = 1\ 11\ 48.34$

$\delta = 0\ 36\ 15.48 = \sin 8.023122$

2.345500

221.564

$r_2 = 14.9950$

$f_2 = 236.559$

$.4$

$d_4 = 236.159$

$r_4 = 49.4905$

$285.6495 = 2.452833$

$\delta = \sin 8.023122$

0.478955

$r_4 = 1.694522$

$i = 3° 29' 23".96 = \sin 8.784433$

$n = 0.179963$

$\lambda = 5\ 17\ 9.93 = \sin 8.964396$

$1\ 47\ 45.97$ $\quad r_4 = 1.694522$

$\delta = 0\ 36\ 15.48$ $\quad 0.658918$

$\varepsilon = 2\ 24\ 1.45 = \sin 8.622034$

$= 2.036884$

108.8639

$r_4 = 49.4905$

59.3734

$f_4 =$

C + X $\quad f_4 = 59.3947\frac{1}{2}$

$\lambda = 5614$ $\quad f_4 = 59.3734$

0.0213

$\lambda = 5614$ Central

$n' = 0.209428$

$\gamma_1 = 1.661223$

1.870651

$n-1 = 9.792165$

$= 2.078486$

$f_1 = 119.8081$

$d_2 = 119.6081$

$= 2.077760$

$r_2 = 1.175946$

3.253706

$N = 0.029465$

$r_2 = 1.175946$

$1.205411 = 16.04763$

$d_2 = 2.077760$

$N-1 = 8.846337$

$0.924097 = 8.39648$

$7.65115 = 0.883727$

$= 2.369979$

$f_2 = 234.4115$

$.4$

$d_4 = 234.0115$

$= 2.369237$

$r_4 = 1.694522$

4.063759

$d_4 = 2.369237$

$n-1 = 9.710483$

$2.079720 = 120.1490$

$n = 0.179963$

$r_4 = 1.694522$

$1.874485 = 74.9006$

$195.0496 = 2.290145$

$= 1.773614$

$f_4 = 59.3765$

Marginal - .3734

Central - .3765

.0031 Error under cor.

Error made 2 leaves back -

$r_2 = r_3$	Sph. Ab.	
14.8776	+ .0061	
.9642	− .0016	.0308 = .0015
.9950	− .0031	.0620 = .0031
Diff. .1174	= Diff. 0092	
" .0866	= " .0077	
.0012.8	.0001	
.0011.2	.0001	

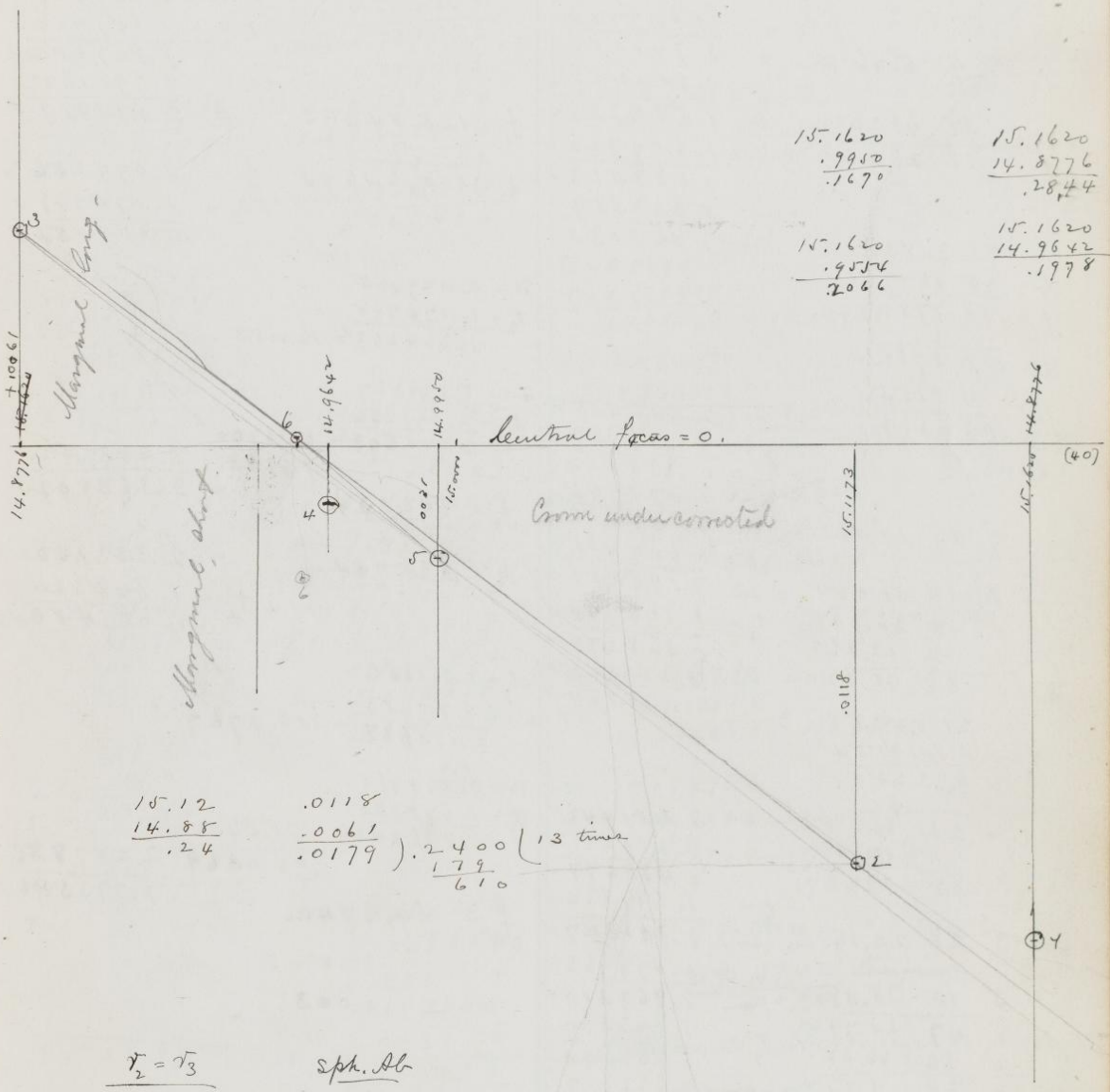
$r_2 = r_3$	Sph. Ab
14.9462	.0000

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Diagram of Spherical Aberration

$r_2 = r_3$



15.1620 .9950 .1670

15.1620 14.8776 .2844

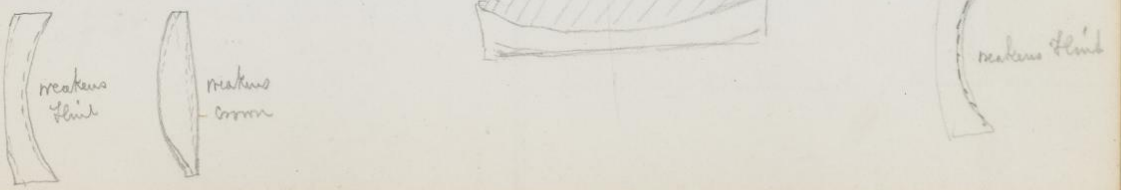
15.1620 .9554 .2066

15.1620 14.9642 .1978

15.12 14.88 .24

.0118 .0061 .0179). 2400 (13 times 179 610

$r_2 = r_3$	Sph. Ab
14.9950	−.0031
14.8776	+.0061
.1174	.0092
.0396	.0031
14.9554	.0000



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Hint in front $\rho_2 = \rho_3 = 14.9554$

$\rho_2 = 14.9554 = 1.174798$ ✓

$\frac{1}{\rho_2} = .066865^{-5}$ ✓ $= 8.825202$ ✓

$B = \frac{.0448729}{.0219926}$ ✓ $= 8.342276$ ✓

$\rho_1 = 45.4699$ ✓ $= 1.657724$ ✓

$A = .0868950$ ✓

$\frac{1}{\rho_3} = \frac{.0668653^{-1}}{.0200295}$ ✓ $= 8.301670$ ✓

$\rho_4 = 49.9264$ ✓ $= 1.698330$ ✓

$\lambda = 5614$ Marginal

$v = 0.397940$ ✓

$\rho_1 = 1.657724$ ✓

$i = 3° 9' 6.''46$ ✓ sin $= 8.740216$ ✓

$n' = 0.209428$ ✓

$\lambda = 1\ 56\ 43.20$ ✓ sin $= 8.530788$ ✓

$\gamma = 1\ 12\ 23.26$ ✓ $\rho_1 = 1.657724$ ✓

0.188512 ✓

$1 - \sin = 8.323359$ ✓

$= 1.865153$ ✓

73.3083 ✓

$\rho_1 = 45.4699$ ✓

$f_1 = 118.7782$ ✓

$\frac{.2}{d_2 = 118.5782}$ ✓

$\rho_2 = \frac{14.9554}{103.6228}$ ✓ $= 2.015455$ ✓

$\gamma = 8.323359$ ✓

0.338814 ✓

$i = 8° 23' 19.''08$ ✓ $\rho_2 = 1.174798$ ✓

sin $= 9.164016$ ✓

$N = 0.029461$ ✓

$\lambda = 8\ 58\ 56.02$ ✓ sin $= 9.193481$ ✓

$0\ 35\ 36.94$ ✓ $\rho_2 = 1.174798$ ✓

$\gamma = 1\ 12\ 23.26$ ✓ 0.368279 ✓

$\delta = 0\ 36\ 46.32$ ✓ sin $= 8.029235$ ✓

2.339044 ✓

21.8295 ✓ $=$

$\rho_2 = 14.9554$ ✓

$f_2 = 233.2550$ ✓

$\frac{.4}{d_4 = 232.8550}$ ✓ $= 2.451442$ ✓

$\rho_4 = \frac{49.9264}{282.776}$ ✓ $\delta = 8.029235$ ✓

0.480677 ✓

$\rho_4 = 1.698330$ ✓

$i = 3° 28' 23.''69$ ✓ $= \sin 8.782347$ ✓

$n = 0.179963$ ✓

$\lambda = 5\ 15\ 38.48$ ✓ $= \sin 8.962310$ ✓

$1\ 43\ 14.79$ ✓ $\rho_4 = 1.698330$ ✓

$\delta = 0\ 36\ 46.32$ ✓ 0.660640 ✓

$\varepsilon = 2\ 24\ 1.11$ ✓ $= \sin 8.622017$ ✓

2.038623 ✓

109.3007 ✓

49.9264 ✓

$f_4 = 59.3743$ ✓

$\lambda = 5614$ Central

$n' = 0.209428$ ✓

$\rho_1 = 1.657724$ ✓

1.867152 ✓

9.792168^{-} ✓

$= 2.074987$ ✓

$f_1 = 118.8467$ ✓

$\frac{.2}{d_2 = 118.6467}$ ✓ $= 2.074256$

$\rho_2 = 1.174798$ ✓

3.249054 ✓

$N = 0.029465^{-}$

$\rho_2 = \frac{1.174798}{1.204263} = 16.005^{-3}$

$N-1 = 8.846337$

$d_2 = \frac{2.074256}{0.920593^{-}} \leq \frac{8.32900}{7.6783}$ ✓ $= 0.885^{-}152$

$= 2.363902$ ✓

$f_2 = 231.154$

$\frac{.4}{d_4 = 230.754}$ ✓ $= 2.363150$

$\rho_4 = \frac{1.698330}{4.061480}$ ✓

$d_4 = 2.363150$ ✓

$n-1 = \frac{9.710483}{2.073638}$ ✓ $= 118.4767$

$n = 0.179963$ ✓

$\rho_4 = \frac{1.698330}{1.878293}$ ✓ $= \frac{75.5602}{194.0369} = 2.287884$ ✓

$= 1.773596$ ✓

$f_4 = 59.3740$

$.3743$

$+ .0003$

$\rho_2 - \rho_3 = 14.9554$

38 to correct for .0003

14.9592

Curvatures measured by Spherometer Nov. 12 92 - annual years after completion

$\rho_1 = 45.468$

$\rho_2 = 14.959$

$\rho_3 = 14.959$

$\rho_4 = 49.865$

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Think in front $r_2 = r_3 = 14.9592$

$r_2 = 14.9592 = 1.174908$

$.0668486 = 8.825092$

$B = .0448729 = 8.341942$

$.0219757 = 1.658058$

$r_1 = 45.5049$

$A = .0868950$

$\frac{1}{r_3} = .0668486 = 8.302036$

$.0200464 = 1.697964$

$r_4 = 49.8843$

$\lambda = 5614$ Marginal

$y = 0.397940$

$r_1 = 1.658058$

$i = 3° 8' 57".73 = \sin 8.739882$

$n' = 0.209428$

$\lambda = 1\ 56\ 37.80 = \sin 8.530454$

$r_1 = 1.658058$

$\beta = 1\ 12\ 19.93$

0.188512

$L = \sin 8.322026$

$= 1.865486$

73.3645

$r_1 = 45.5049$

$f_1 = 118.8694$

$.2$

118.6694

$r_2 = 14.9592$

103.7102

$= 2.015821$

$y = \sin 8.322026$

0.338847

$r_2 = 1.174908$

$i = 8° 23' 13".69 = \sin 9.163939$

$N = 0.029465$

$\lambda = 8\ 58\ 50.23 = \sin 9.193404$

$0\ 35\ 36.54$

$r_2 = 1.174908$

$\beta = 1\ 12\ 19.93$

0.368312

$\delta = 0\ 36\ 43.39 = \sin 8.028658$

2.339654

$=$

218.602

$r_2 = 14.9592$

$f_2 = 233.561$

$.4$

$d_4 = 233.161$

$r_4 = 49.8843$

283.045

$= 2.451856$

$\delta = \sin 8.028658$

0.480514

$r_4 = 1.697964$

$i = 3° 28' 29".54 = \sin 8.782550$

$n = 0.179963$

$\lambda = 5\ 15\ 47.36 = \sin 8.962513$

$1\ 47\ 17.82$

$r_4 = 1.697964$

$\delta = 0\ 36\ 43.39$

0.660477

$2\ 24\ 1.21 = \sin 8.622022$

2.038455

$109.2585 =$

$r_4 = 49.8843$

$f_4 =$ 59.3742

$\lambda = 5614$ Central

$n' = 0.209428$

$r_1 = 1.658058$

1.867486

$n-1 = 9.792165$

2.075321

$f_1 = 118.9381$

$.2$

$d_2 = 118.7381 = 2.074590$

$r_2 = 1.174908$

3.249498

$N = 0.029465$

$r_2 = 1.174908$

$1.204373 = 16.00933$

$d_2 = 2.074590$

$N-1 = 8.846337 = 8.33541 = 0.885017$

$0.920927 \quad 7.67392 \quad = 2.364481$

$f_2 = 231.4628$

$.4$

$d_4 = 231.0628 = 2.363730$

$r_4 = 1.697964$

4.061694

$d_4 = 2.363730$

$n-1 = 9.710483 = 118.6357$

2.074213

$n = 0.179963$

$r_4 = 1.697964$

$1.877927 = 75.4966 = 2.288096$

$194.1317 \quad = 1.773598$

$f_4 = 59.3742$

59.3742 Marginal

$.0000$

Sphinical Aberration is perfectly corrected

$B = \frac{1}{r_2} - \frac{1}{r_1} = .0448729$ | $.0448729$

$A = \frac{1}{r_3} + \frac{1}{r_4} = .0868950$ | $.0868950$

When rays continued 9 leaves over

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To find the effect on Spherical Aberration of a change in r_4

Sph. Ab. = 0 when r_4 = 49.884

.100

Try r_4 = 49.784

Marginal | Central

Marginal

d_4 = 233.161

r_4 = 49.784

282.945 = 2.45170

δ = sin 8.02866

0.48036 ✓

r_4 = 1.69709

ξ = 3 28 21.5 = sin 8.78327 ✓

0.17996 ✓

λ = 5 16 19.0 = sin 8.96323 ✓

1 47 57.5 ✓ r_4 = 1.69709

δ = 0 36 43.4 ✓ 0.66032 ✓

ε = 2 24 40.9 ✓ = sin 8.62401

= 2.03631 ✓

108.72

r_4 = 49.784

f'_4 = 58.936 ✓

Central

d_4 = 2.36373

r_4 = 1.69709

4.06082 ✓

$d_4(n-1)$ = 118.635

n = 0.17996

r_4 = 1.69709

1.87705 ✓ = 75.344

193.979 = 2.28775

f'_4 = 59.302 = 1.77307 ✓

Central f = 59.302

Marginal f = 58.936

0.366 crown under cor.

Hence Change of 0.100 in r_4 changes the Sph. Ab. 0.366 in.

Decreasing r_4 strengthens Crown }
Increasing r_4 weakens Crown }

Lenses measured Feb. 10th 1889. $R = K + \frac{h}{2}$ $\log K = \log k - \log s$

	s	log k	log s	log K	K	$\frac{h}{2}$	R	Nov. 12 - 92. s	R
R_1	4.402	2.30143	0.64365	1.65778	45.476	.022	45.498	4.409	45.468
R_2	13.434	2.30158	1.12830	1.17328	14.903	.067	14.970	13.455½	14.959
R_3	13.430	2.30135	1.12808	1.17327	14.903	.067	14.970	13.432½	14.959
R_4	4.021	2.30143	0.60433	1.69710	49.785	.020	49.805	4.413	49.865

R_2 = log 1.17522

$\frac{1}{R_2}$ = 8.82478 = .066801

R_3 =

$\frac{1}{R_3}$ = = .066801

R_1 = log 1.65799

$\frac{1}{R_1}$ = 8.34201 = .021979

.044822

B = 51

Error

.044873

R_4 = log 1.69727

$\frac{1}{R_4}$ = 8.30273 = .020078

.086879

A = 16

Error

.086895

As made Error is too strong for color.

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Lerrow in front, $A = .086330$ Lerrow — $B = .044415$ —
$.086879$ $.044822$
$.000549$ $.000407$

Flint in front $A = .086895$ — $B = .044893$ — Calculated

To find the effect on Spherical Aberration of a change in $r_2 = r_3$

$r_1 + r_4$ remaining as before — $14.9592 - .1000 = 14.8592$ try

Marginal

$d_2 = 118,6694$

$r_2 = \frac{14.8592}{103.810} = \log$ 2,01624

$\gamma = \sin$ 8,32303
0.33927

$r_2 =$ 1.17199
9.167.28

$i = 8^\circ 27' 8'' = \sin$ 0.02946
9.19674

$N =$ 1.17199
0.36873

$\lambda = 9^\circ\ 3'\ 1\frac{1}{2} = \sin$ 8,025-32
2.343.41

$\gamma = 1\ 12\ 20$
$\delta = 0\ 36\ 26\frac{1}{2}$
$0\ 35\ 53\frac{1}{2}$
220.50

$r_2 = \frac{14.86}{235.36}$
$f_2 = \frac{.40}{234.96}$
$d_4 =$

$r_4 = \frac{49.884}{284.84} = 2.45460$

$\delta = \sin$ 8.02532
0.47992

$r_4 =$ 1.69796
8.78196

$i = 3^\circ 28' 12.\frac{1}{2} = \sin$ 0.17996
8.9861.92

$n =$
$\lambda = 5^\circ\ 15'\ 21\frac{1}{2}$
$1\ 47\ 9$
$\delta = 0\ 36\ 26\frac{1}{2}$
$\varepsilon = 2\ 23\ 35\frac{1}{2} = \sin$ 8.62072
2.03916

$r_4 =$ 1.69796
0.65988

109.435^-

$r_4 = \frac{49.884}{59.5^-81}$
$f_4 =$

59.544
$.007$ Marginal beyond central

Central

$d_2 = 118,738 =$ 2.07459
$r_2 =$ 1.17199
3.24658

$N = 0.02946$
$r_2 = \frac{1.17199}{1.20145^-} = 15^-,902$

$d_2 = 2.07459$
$N-1 = \frac{8.84634}{0.92093} = \frac{8.3354}{7.5666} = 0.87890$

$f_2 = \frac{233,175^-}{1.000} = 2.36768$
$d_4 = 232,775^- = 2.36694$
$r_4 = 1.69796$
4.06490

$d_4 = 2.36694$
$n-1 = \frac{9.71048}{2.07742} = 119.5^-15^-$
$nr_4 = \frac{75.497}{195^-.012} = 2.29006$
$f_4 = 59.544 = 1.77484$

Hence Change of .100 in r_2 $(= r_3)$ changes Sph Ab. only .007

Decreasing r_2 strengthens the flint

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(Flint in front. $r_2 = r_3$.)

To find if this O.G. can be converted into a photographic lens by placing the Crown in front and separating the lenses - 2½ in.

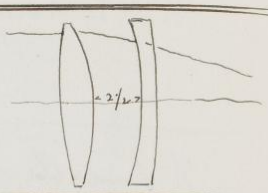
Crown $\begin{cases} R_1 = 49.884 = \log 1.69796 \\ R_2 = 14.959 = \text{"} 1.17491 \end{cases}$

Flint $\begin{cases} R_3 = R_2 \\ R_4 = 45.505 = \text{"} 1.65806 \end{cases}$

$t_1 = 0.4$

$D = 2.5$

$t_2 = 0.2$



Marginal $\lambda = 5°6.4$

$y = \log 0.39794$

$\gamma_1 = \text{"} 1.69796$

$i = 2°\,52'\,21\tfrac{1}{2}'' = \sin 8.69998$

$n = 0.17996$

$\lambda = 1\ 53\ 51\tfrac{3}{4} = \sin 8.52002$

$\gamma = 0\ 58\ 29\tfrac{3}{4}$ $\quad \gamma_1 = 1.69796$

$\sin 8.23083$

$97.085 = 0.21798$

$= 1.98715$

$r_1 = 49.884$

$f = 146.969$

$.4$

$d_2 = 146.569$

$r_2 = 14.959 / 161.528 = 2.20825$

$\sin \gamma = 8.23083 / 0.44908$

$\gamma_2 = 1.17491 = \sin 9.27417$

$i = 10°\,50'\,11''$ $\quad n = 0.17996 = \sin 9.45413$

$\lambda = 16\ 31\ 37 / 5\ 41\ 40$ $\quad \gamma_2 = 1.17491 / 0.62904$

$\gamma = 0\ 58\ 29\tfrac{3}{4} = \sin 9.06498$

$\delta = 6\ 40\ 10 = 1.56406$

36.649

$r_2 = 14.959$

21.690

$f_2 = 2.500$

$d_3 = 19.190$

$r_3 = 14.959 / 34.149 = 1.53338$

$\sin \beta = \sin \delta = 9.06498 / 0.59836$

$\gamma_3 = 1.17491 = \sin 9.42345$

$i = 15°\,22'\,28''$ $\quad n' = 0.20943 = \sin 9.32140$

$\lambda = 9\ 25\ 16$ $\quad \gamma_3 = 1.17491 / 0.38893$

$(i-\lambda) = 5°\,57\,12$ $\quad = \sin 8.09685 / 2.29208$

$\beta = 6\ 40\ 10$

$\gamma = 0\ 42\ 58$

195.92

$r_3 = 14.96$

$f_3 = 180.96$

$.20$

$d_4 = 180.76$

$r_4 = 45.505 / 226.265 = 2.35462$

$\gamma = \sin 8.09685 / 0.48147$

$\gamma_4 = 1.65806 / 8.79341$

$i = 3°\,33'\,47''$ $\quad \sin n' = 0.20943 / 9.00284$

$\lambda = 5\ 46\ 37$ $\quad \sin = 1.65806 / 0.66090$

$2\ 12\ 50$

$\gamma = 0\ 42\ 58$

$\delta = 2\ 55\ 48 = \sin 8.70856 / 1.95234$

89.607

$r_4 = 45.505 / 44.102$

Central

$n = 0.17996$

$\gamma_1 = 1.69796 / 9.87792$

$n-1 = 9.71048 / 2.16744$

$f_1 = 147.04 = 2.16625$

$.4$

$d_2 = 146.64$

$r_2 = 1.17491 / 3.34116$

$d_2 = 2.16625$

$n-1 = 9.71048 / 1.87673 = 75.289$

$n = 0.17996$

$r_2 = 1.17491 / 1.35487 = 22.639 / 97.928 = 1.99091 / 1.35025$

$f_2 = 22.400$

$n' = 0.20943$

$d_3 = 2.500 / 19.900 = 1.29885$

$r_3 = 1.17491 / 2.68319$

$d_3 = 1.29885$ $\quad y = 14.959$

$n'-1 = 9.79216 / 1.09101 = 12.331 / 2.628 = 0.41962 / 2.26357$

$f_3 = 183.47$

$.20$

$d_4 = 183.27 = 2.26309$

$r_4 = 1.65806 / 3.92115$

$d_4 = 2.26309$

$n'-1 = 9.79216 / 2.05525 = 113.567$

$n' = 0.20943$

$r_4 = 1.65806 / 1.86749 = 93.704 / 187.271 = 2.27247 / 1.64868$

$f_4 = 44.533$

Central $f_4 = 44.533$

Marginal $f_4 = 44.102$ / .431 Crown stronger

When in contact. — .132 about

.563 change in f/∞ th.

caused by separating lenses 2½ in.

$.132 + .068 = \frac{.2 \times 2\frac{1}{2}}{.563} = 0.9$ ≐ about will correct

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Photographic O.G. – (O.G. reversed)

To find the Sph. Ab. of (Y) ray when the lenses are separated 0.9 =

g Ray

$i = 2° 52' 21\frac{1}{2}''$ ✓ = sin 8.69998 ✓

$n = 0.18324$ ✓

$\lambda = 1° 53' 0''$ ✓ = sin 8.51674 ✓

$\gamma = 0\ 59\ 21\frac{1}{2}$ ✓ $\gamma_1 = 1.69796$ ✓

0.21470 ✓

sin 8.23718 ✓

= 1.97752 ✓

94.953 ✓

$\gamma_1 = 49.884$ ✓

$f_1 = 144.839$ ✓

.4

$d_2 = 144.439$ ✓

$\gamma_2 = 14.989$ ✓

159.398 ✓

= 2.20248 ✓

sin j = 8.23718 ✓

0.43966 ✓

$\gamma_2 = 1.17491$ ✓

$i = 10° 36' 4''$ ✓ = sin 9.26475 ✓

$n = 0.18324$ ✓

$\lambda = 16\ 17\ 33$ ✓ = sin 9.47799 ✓

5 41 29 ✓ $\gamma_2 = 1.17491$ ✓

$\gamma = 0\ 59\ 21\frac{1}{2}$ ✓

$\delta = 6\ 40\ 50\frac{1}{2}$ ✓ = sin 9.06571 ✓

= 1.55719 ✓

36.074 ✓

14.989 ✓

$f_2 = 21.115$ ✓

.900

$d_3 = 20.215$

$\gamma_3 = 14.989$

35.174

= 1.54622

δ = sin 9.06571

0.61193

$\gamma_3 =$ 1.17491

$i = 15° 53' 30''$ = sin 9.43702

$n' = 0.21570$ ✓

$\lambda = 9\ 34\ 56$ = sin 9.22132

$\beta = 6\ 40\ 50\frac{1}{2}$ $\gamma_3 = 1.17491$

$\gamma = 0\ 28\ 16$ 0.39623

= sin 7.83046

= 2.56577

367.93

$\gamma_3 = 14.96$

$f_3 = 352.97$

.20

$d_3 = 352.77$

$\gamma_4 = 45.50$

398.27

= 2.60018

sin j = 7.83046

0.43064

$\gamma_4 = 1.65806$

$\varepsilon = 3° 23' 45''$ = sin 8.77258

$n' = 0.21570$ ✓

$\lambda = 5\ 35\ 9$ = sin 8.98828

2 11 24 $\gamma_4 = 1.65806$

$\gamma = 0\ 23\ 16$ 0.64634

$\delta = 2\ 34\ 40$ = sin 8.65298

= 1.99336

98.483

$\gamma_4 = 45.505$

$f_4 = 52.978$

$n = 0.18324$ ✓

$\gamma_1 = 1.69796$ ✓

1.88120 ✓

$n-1 = 9.72007$ ✓

$f_1 = 144.92$ ✓ = 2.16113 ✓

.4

$d_2 = 144.52$ ✓ = 2.15993 ✓

$\gamma_2 = 1.17491$ ✓

3.33484 ✓

$d_2 = 2.15993$ ✓

$n-1 = 9.72007$ ✓

1.88000 ✓ = 75.858 ✓

$n = 0.18324$ ✓

$\gamma_2 = 1.17491$ ✓

1.35815 = 22.811 ✓

98.669 = 1.99418 ✓

$f_2 = 21.911$ ✓ = 1.34066 ✓

.9

$d_3 = 21.011$ = 1.32245

$n' = 0.21570$

$\gamma_3 = 1.17491$

2.71306

$d_3 = 1.32245$

$n'-1 = 9.80838$ ✓ 14.989

1.13083 = 13.51154

1.4436 = 0.15945

= 2.55361

$f_3 = 357.795$

.2

$d_4 = 357.575$ = 2.55337

$\gamma_4 = 1.65806$

4.21143

$d_4 = 2.55337$

$n'-1 = 9.80838$ ✓

2.36175 = 230.01

$n' = 0.21570$

$\gamma_4 = 1.65806$

1.87376 = 74.776

304.79 = 2.48400

= 1.72743

$f_4 = 53.386$

52.978 Marginal in

.408 = Sph. Ab.

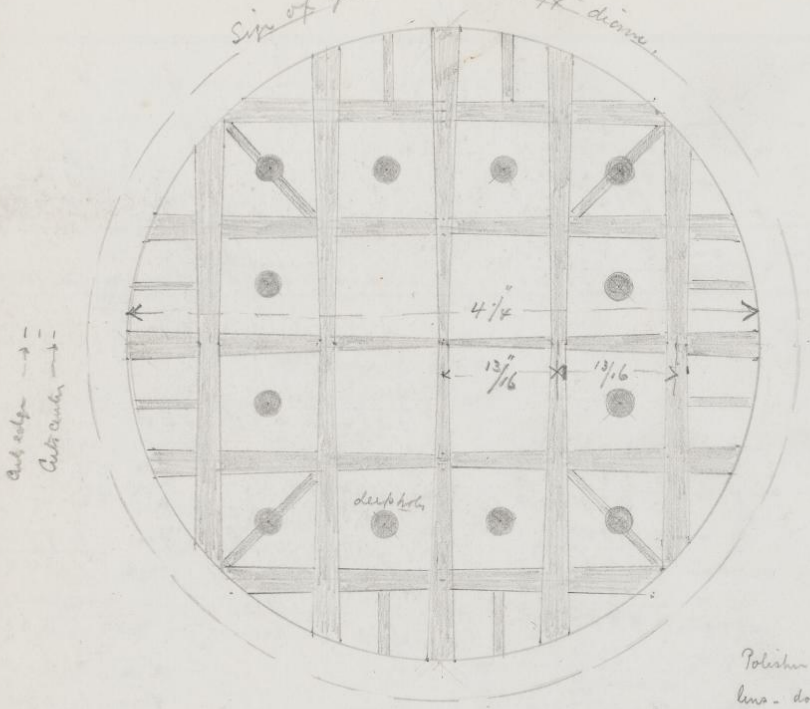
Crown too strong

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5-5/8" d. - even squares
cuts edge faster slowly
1 hr. 5 polishing showing distinctly

Size of glass lens - 4 3/4 ± diam.



5 1/4 cuts center
little faster than edge
5 1/2" does not change
Sph. Ab.
5 37/16 - th pd. cut center perceptibly

5 1/2 / 4 3/4 = 1.158

Polisher 1.158 times diam of
lens - does not change Sph aberration

Apr. 12th 1889.

Polisher made as above, dug center of concave flint rapidly and evenly -

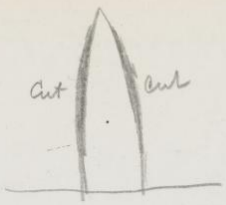
Grooves cut shallow near center and deep near edge.

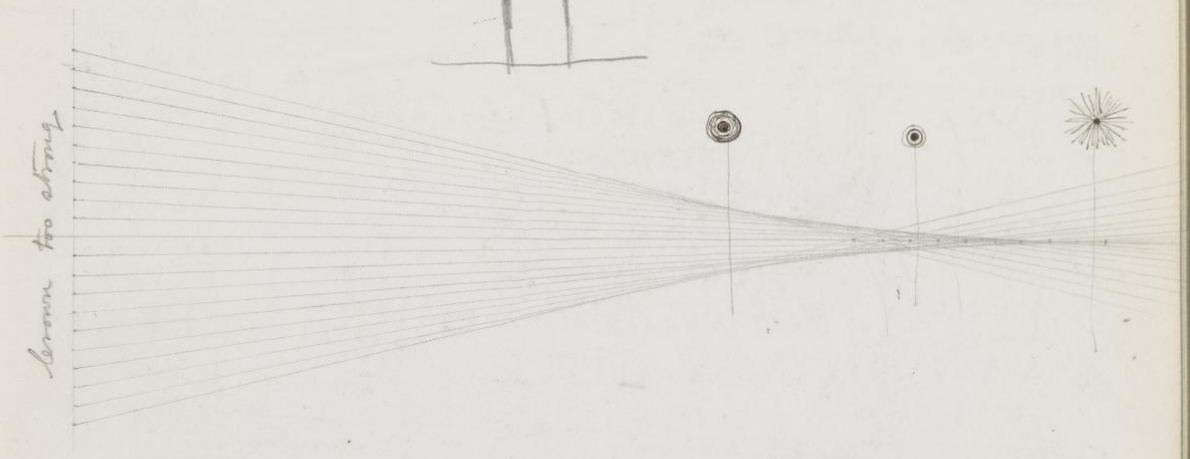
Separation		Sph. Ab.
.9	makes	.405
.4	"	.125
Change .5	Changes	.280
" of .232	"	.128
.168	makes	-.081

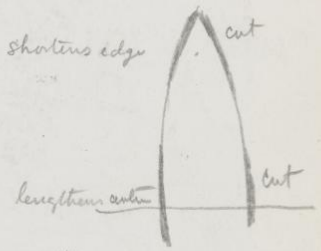


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Photographic - continued

try separation of .4 =

g ray



$f_2 = 21.115$

$d_3 = 20.715$

$r_3 = 14.959$

$35.674 = 1.552385$

$\sin\beta = 9.065\,71$

$0.618\,06$

$i = 16^\circ\ 6'\ 24''$ $= \sin$ $9.443\,15$

$\lambda = 9\ 43\ 12$ $= \sin$ $9.227\,45$

$\beta = 6\ 40\ 50\tfrac{1}{2}$

$\gamma = 0\ 17\ 38\tfrac{1}{2}$ $= \sin$ $7.710\,25$

$2.692.11$

$r_3 = 1.17491$

$9.443\,15$

$x' = 0.215\,70$

$9.227\,45$

$r_3 = 1.17491$

$0.402\,36$

492.16

$\frac{r_3}{d_3} = \frac{14.96}{477.20}$ $\quad .20$

$d_4 = 477.00$

$r_4 = \frac{45.50}{522.50} = 2.71809$

$\sin = 7.710\,25$

$0.428\,34$

$r_4 = 1.65806$

$8.770\,28$

$i = 3^\circ\ 22'\ 40.''\tfrac{3}{4} = \sin$ $x' = 0.215\,70$

$\lambda = 5\ 33\ 23\tfrac{3}{4} = \sin$ $8.785\,98$

$\gamma = 0\ 17\ 38\tfrac{1}{2}$ $r_4 = 1.65806$

$\delta = 2\ 28\ 21\tfrac{1}{2} = \sin$ $0.644\,04$

$8.630\,90$

$2.009\,14$

102.127

$r_4 = 45.505$

$f_4 = 56.622$

$f_2 = 21.911$

$d_3 = \frac{.4}{21.511} = 1.332\,66$

$x' = 0.215\,70$

$r_3 = 1.174\,91$

$2.723\,27$

$d_3 = 1.332\,66$

$x-1 = \frac{9.808\,38}{1.141\,04} = \frac{14.959}{13.837} = \frac{0.049\,99}{2.673\,28}$

$f_3 = 471.28$ $\quad .20$

$d_4 = 471.08 = 2.673\,09$

$r_4 = 1.658\,06$

$4.331\,15$

$d_4 = 2.673\,09$

$x-1 = \frac{9.808\,38}{2.481\,47} = 303.02$

$x' = 0.215\,70$

$r_4 = \frac{1.658\,06}{1.873\,76} = \frac{74.776}{377.796} = \frac{2.577\,26}{1.775\,389}$

$f_4 = 56.740$

56.622 Marginal $\doteq$

$.128$ = Sph. Ab.

brown too strong

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Crown in front. to find approximate forms of lenses when $r_2 = r_3$

Crown $A = .086330 = \frac{1}{f} + \frac{1}{r_2}$

Flint $B = .044415 = \frac{1}{r_3} - \frac{1}{r_4}$

Try $r_1 = \infty$

$\frac{1}{r_2} = .086330 = \log 8.93616$ / 1.06384

$r_2 = 11.5835$

$\frac{1}{r_4} = \frac{1}{r_3} - B$

$.086330$

$\frac{1}{r_4} = \frac{.044415}{.041915} = \log 8.62237$ / 1.37763

$r_4 = 23.85-8$

Marginal

$N = \frac{n'}{n}$ $\quad \sin i = \frac{y}{r_3}$ $\quad \gamma = i - \lambda$

$\sin \lambda = \frac{\sin i}{N}$ $\quad f_3 = \frac{r_3 \sin \lambda}{\sin \gamma}$

$d_4 = f_3 + t_2$

$\sin i = \frac{(d_4 - r_4)\sin \gamma}{r}$

$\sin \lambda = n' \sin i$

$\delta = (\lambda - i) - \gamma$

$f_4 = \frac{r_4 \sin \lambda}{\sin \delta} - r$

Central

$f_3 = \frac{N r_3}{N-1}$

$d_4 = f_3 + t_2$

$f_4 = \frac{r_4 d_4}{d_4(n'-1) - n' r_4}$

g ray

$f_2 = 21.115$ / $.168$ Separation

$d_3 = 20.947$

$t_3 = \frac{14.959}{35.906} =$

$\sin \beta = \frac{1.535517}{9.065771}$ / 0.620088

$r_3 = 1.17491$

$i = 16^\circ 12' 53''$ $= \sin 9.445977$

$n' = 0.21570$

$\lambda = 9\ 47\ 2$ $= \sin 9.23027$

$r_3 = 1.17491$

$\beta = 6\ 40\ 80\frac{1}{2}$ / 0.40518

$\gamma = 0\ 14\ 59\frac{1}{2} = \sin 7.63957$

$= 2.76561$

$d_3 = 582.92$ / 14.96

$f_3 = 567.96$ / $.20$

$d_4 = 567.76$

$t_4 = 45.50$ / 613.26

$= 2.78764$

$\sin \gamma = \frac{7.63957}{0.42721}$

$r_4 = 1.65806$

$i = 3^\circ 22' 9''$ $= \sin 8.76915-$

$n' = 0.21570$

$\lambda = 5\ 32\ 30\frac{1}{2} = \sin 8.98485-$

$r_4 = 1.65806$

$\gamma = 0\ 14\ 59\frac{1}{2}$ / 0.64291

$\delta = 2\ 25\ 21 = \sin 8.62601$

$= 2.01690$

103.968

$r_4 = 45.50\ 1-$

$f_4 = 58.463$

Photographic continued

$f_2 = 21.911$ / $.168$

$d_3 = 21.743 = 1.33732$

$n' = 0.21570$

$r_3 = 1.17491$ / 2.72793

$d_3 = 1.33732$

$n'-1 = \frac{9.80838}{1.14570} = \frac{14.959}{13.986} / 0.973 = \frac{9.98811}{2.73982}$

$= 2.73966$

$f_3 = 549.31$ / $.20$

$d_4 = 549.11$ $\quad r_4 = 1.65806$ / 4.39772

$d_4 = 2.73966$

$n'-1 = \frac{9.80838}{2.54804} = 353.22$

$= \frac{74.776}{428.00} = 2.63144$

$n' r_4$ $= 1.76658$

$f_4 = 58.382$

Marginal 58.463

central 58.382

.081 Crown too weak

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Photographic continued

g ray

$f_2 = 21.115$
$.250$ Separation
$d_3 = 20.865$
$\tau_3 = 14.959$
$35.824 = 1.553417$
$\beta = \sin 9.065-71$
0.619188

$i = 16°10'34'' = \sin 9.444497$
$\lambda = 9\ 45\ 40 = \sin 9.229227$
$\beta = 6\ 40\ 50\tfrac{1}{2}$
$\gamma = 0\ 15\ 56\tfrac{1}{2} = 7.666225$
$= 2.73793$

$\tau_3 = 546.93$
14.96
$f_3 = 531.97$
$.20$
$d_4 = 531.77$
$\tau_4 = 45.50$
$577.27 = 2.76138$
$\gamma = \sin 7.666225$
0.427763

$i = 3°22'21'' \sin 8.769857$
$\lambda = 5\ 82\ 50 \sin 8.985-27$
$\gamma = 0\ 15\ 56\tfrac{1}{2}$
$\delta = 2\ 26\ 25\tfrac{1}{2} = \sin 8.629221$
$= 2.01412$

103.305
$\tau_4 = 45.505$
$f_4 = 57.800$

$\tau_3 = 1.174991$
$\sin 9.444497$
$x' = 0.215770$
$\sin 9.229227$
$\tau_3 = 1.174991$
0.404184
7.666225
$\tau_4 = 1.655806$
$\sin 8.769857$
$x' = 0.215770$
$\sin 8.985-27$
$\tau_4 = 1.655806$
0.643333

$f_2 = 21.911$
$.250$
$d_3 = 21.661 = 1.335568$
$x' = 0.215770$
$\tau_3 = 1.174998$
2.726229

$d_3 = 1.335568$
$x-1 = 9.80838$
$1.14406 = 13.9335$
14.959
$1.02555 = 0.010094$
$= 2.715535$
$= 2.715518$
$\tau_4 = 1.655806$
4.373324

$d_4 = 2.715518$
$x-1 = 9.80838$
$2.523556 = 333.86$
$x\tau_4 = 74.78$
$408.64 = 2.61134$
$= 1.76190$

$f_3 = 57.922$
$.120$
$d_4 = 57.802$

$f_4 = 57.796$

Marginal 57.800
Central 57.796
.004

Crown too weak

0 .168 .240 .4 .9

Change of .082 in separation - changed Sph. Ab. .077

Hence Sph. Ab. is corrected for (g) line - when separation of lenses = 0.254 in and $f_4 = 57.767$

58.382
57.796
0.586 in

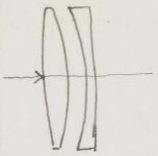
Change of .082 in separation changed Focal length .004 " " changes " " .029

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– Photographic – continued – Crown placed in front.

Lenses separated 0.254 ± to find the Sph. Ab. of the F ray.



$i = 2^\circ\ 52'\ 21''$ = sin 8.69998
$n = 0.18146$
$\lambda = 1\ 53\ 28$ = sin 8.51852
$\gamma_1 = 1.69796$
$\gamma = 0\ 58\ 53\frac{1}{2}$ 0.21648
sin 8.23376
= 1.98272

96.099
$\gamma_1 = 49.884$
$f_1 = 145.983$
.4
$d_2 = 145.583$
$\gamma_2 = 14.959$
160.542

= 2.20559
γ = sin 8.23376
0.43935
γ_2 = 1.17491
= sin 9.26444
$n = 0.18146$
= sin 9.44590
$d_2 = 1.17491$
0.62081
$i = 10^\circ\ 35'\ 37''$ = sin 9.06045
= 1.56036

$\lambda = 16\ 12\ 43$
5 37 6
$\gamma = 0\ 58\ 53\frac{1}{2}$
$\delta = 6\ 35\ 59\frac{1}{2}$
36.338
$\gamma_2 = 14.959$
$f_2 = 21.379$
.254
$d_3 = 21.125$
$\gamma_3 = 14.959$
36.084

Separations

= 1.55731
δ = sin 9.06045
0.61776
γ_3 = 1.17491
sin 9.44285
$i = 16^\circ\ 5'\ 43''$ = n' = 0.21221
sin 9.23064
$\lambda = 9\ 47\ 32$ = γ_3 = 1.17491
6 18 11
$\beta = 6\ 35\ 59\frac{1}{2}$ 0.40555
$\gamma = 0\ 17\ 48\frac{1}{2}$ = sin 7.71435
= 2.69120

491.13
$\gamma_3 = 14.96$
$f_3 = 476.17$
.20
$d_4 = 475.97$
$\gamma_4 = 45.505$
521.47

= 2.71723
sin γ = 7.71435
0.43158
γ_4 = 1.65806
sin = 8.77352
$i = 3^\circ\ 24'\ 12''$ sin n' = 0.21221
= 8.98573
$\lambda = 5\ 33\ 11$ sin γ_4 = 1.65806
2 8 59
$\gamma = 0\ 17\ 48\frac{1}{2}$ 0.64379
$\delta = 2\ 26\ 47\frac{1}{2}$ = sin 8.62020
= 2.01349

103.155
$\gamma_4 = 45.505$
$\rho = 57.650$
γ_4

$n = 0.18146$
$\gamma_1 = 1.69796$
1.87942
$n-1 = 9.71488$
= 2.16454

$f_1 = 146.064$
,4
$d_2 = 145.664$
= 2.16335
$\gamma_2 = 1.17491$
3.33826

$d_2 = 2.16335$
$n-1 = 9.71488$
1.87823 = 75.549

$n = 0.18146$
$\gamma_2 = 1.17491$
1.35637 = 22.718
98.267 = 1.99241
= 1.34585

$f_2 = 22.174$
,254
$d_3 = 21.920$
= 1.34084
$n' = 0.21221$
$\gamma_3 = 1.17491$
2.72796

$d_3 = 1.34084$
$n-1 = 9.79941$ 14.959
1.14025 = 13.812
1.147 = 0.059856
= 2.66840

$f_3 = 466.02$
.20
$d_4 = 465.82$
= 2.66822
$\gamma_4 = 1.65806$
4.32628

$d_4 = 2.66822$
$n'-1 = 9.79941$
2.46763 = 293.52

$n' = 0.21221$
$\gamma_4 = 1.65806$
1.87027 = 74.177
367.70 = 2.565 49
1.76079

$f_4 = 57.649$

Marginal $f = 57.650$
Central $f = 57.649$
.001

The F ray is also corrected for Sph. Ab.

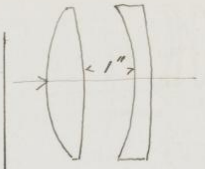
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Photographic Lenses continued

Crown lens reversed and placed 1" in front.
To find the Spherical Aberration of the y ray

$r_1 = 14.959$
$r_2 = 49.884$
$r_3 = 14.959$
$r_4 = 45.505$



14.959
$i = 9°\ 37'\ 13''$

$\lambda = 6\ 17\ 31$
$3\ 19\ 42$ ✓
$j = 3\ 19\ 42$ ✓

$y = 0.39794$
$r_1 = 1.17491$ ✓
$\sin i = 9.22303$ ✓
$n = 0.18324$ ✓
$\sin = 9.03979$ ✓
$r_1 = 1.17491$ ✓
0.21470 ✓
$\sin = 8.76321$
$= 1.45149$ ✓

$n = 0.18324$ ✓
$r_1 = 1.17491$ ✓
1.35815 ✓
$n-1 = 9.72007$ ✓
$= 1.63808$ ✓
$= 1.63406$
$r_2 = 1.69796$
3.33202 ✓

28.281
14.959
$f_1 = 43.240$ ✓
0.4
$d_2 = 42.840$ ✓
$r_2 = \frac{49.884}{92.724}$ ✓

$= 1.96719$
$\sin j = 8.76321$
0.73020 ✓
$r_2 = 1.69796$
$\sin = 9.03244$ ✓
$n = 0.18324$
$\sin = 9.21568$ ✓
$r_2 = 1.69796$
8.91384 ✓
$= \sin 9.06046$
$= 1.85318$ ✓

$i = 6°\ 18'\ 09''$

$\lambda = 9\ 27\ 27$
$3\ 18\ 18$ ✓
$j = 3\ 19\ 42$ ✓
$\delta = 6\ 38\ 00$ ✓

71.345
$r_2 = 49.884$
$f_2 = 21.431$ ✓
1.
$d_3 = 20.431$
$r_3 = \frac{14.959}{35.390}$ ✓

$d_2 = 1.63406$
$n-1 = 9.72007$ ✓
1.35413 ✓ $= 22.601$

$n = 0.18324$ ✓
$r_2 = 1.69796$
1.88120 $= \frac{76.068}{98.669}$ ✓ $= 1.99418$
$= 1.33784$ ✓
$f_2 = 21.769$
1.
$d_3 = 20.769$ ✓
$= 1.31742$
$n' = 0.21570$ ✓
$r_3 = 1.17491$ ✓
2.70803 ✓

$= 1.54888$
$\delta = \sin 9.06046$
0.60934 ✓
$r_3 = 1.17491$
9.43443 ✓
$= \sin 0.21570$
$n' = 9.21873$ ✓
$= \sin 1.17491$
$r_2 = 0.39364$ ✓
$= \sin 7.78179$
$= 2.61185$ ✓

$d_3 = 1.31742$
$n'-1 = 9.80838$ ✓ $= \frac{14.959}{13.36598}$
1.12580 ✓ $= 1.58992$ ✓ $= 0.20390$
2.50413 ✓
$f_3 = 319.25$
2
$d_4 = 319.05$ ✓
$= 2.50386$
$r_4 = 1.65806$ ✓
4.16192 ✓

$i = 15°\ 46'\ 41''$

$\lambda = 9\ 31\ 29$
$6\ 15\ 12$
$\delta = 6\ 36\ 00$
$0\ 20\ 48$ ✓
$j = 409.12$
$r_3 = 14.96$
$f_3 = 394.16$ ✓
2
$d_4 = 393.96$ ✓
$r_4 = \frac{45.50}{439.46}$ ✓

$d_4 = 2.50386$
$n'-1 = 9.80838$ ✓
2.31224 ✓ $= 205.23$

$n' = 0.21570$ ✓
$r_4 = 1.65806$
1.87376 $= \frac{74.776}{280.01}$ ✓ $= 2.44717$
1.71475 ✓
$f_4 = 51.851$

$= 2.64292$
$\sin j = 7.78179$
0.42471 ✓
$r_4 = 1.65806$
$\sin = 8.76665$ ✓
$n' = 0.21570$
$\sin = 8.98235$ ✓
$r_4 = 1.65806$
0.64041 ✓
$\sin = 8.64084$
$= 1.99957$ ✓

$i = 3°\ 20'\ 59\frac{1}{2}''$

$\lambda = 5\ 30\ 35\frac{1}{2}$
$2\ 9\ 36$ ✓
$j = 0\ 20\ 48$
$\delta = 2\ 30\ 24$ ✓

99.901
$r_4 = 45.505$
$f_4 = 54.396$ ✓

Marginal - 54.396
Central - $\frac{51.851}{2.545}$ lenses too weak

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Photographic O. G. continued

Try. Brown lens reversed as last – also Flint lens reversed 1" apart.



g ray

$r_3 = 45.805$
$d_3 = 20.431$
$25.074 = 1.39922$ ✓

$\sin\beta = 9.06046$ ✓
0.45968 ✓
$r_3 = 1.65806$ ✓
8.80162 ✓
$n' = 0.21570$ ✓
$\sin = 8.58592$
$r_3 = 1.65806$
0.24398
$\sin = 8.95543$
1.28855

$i = 3^\circ\ 37'\ 52''$ ✓ $= \sin$
$\lambda = 2\ 42\ 32 = \sin$
$1\ 25\ 20$
$\beta = 6\ 36\ 0$
$\gamma = 5\ 10\ 40 = \sin$

$r = 45.805$
19.4384
26.0726
$.2$
$f_3 = 25.8726$
$d_4 = 14.959$
$r_4 = 10.9136 = 1.03797$

d_3 is less than r_3

hence – $\sin i = \frac{(r-d)\sin\beta}{r}$ $(= \delta)$ ✓
$\sin\lambda = \frac{\sin i}{n'}$ ✓
$\gamma = \beta - (i - \lambda)$ ✓
$f_3 = r - \frac{r\sin\lambda}{\sin\gamma}$ ✓

$d_4 = f_3 - t_2$

$\sin i = \frac{(d-r)\sin\gamma}{r}$ ✓
$\sin\lambda = n'\sin i$ ✓
$\delta = \gamma - (\lambda - i)$ ✓
$f_4 = \frac{r\sin\lambda}{\sin\delta} + r$ ✓

1.03797
8.99543
9.99340
1.17491

$\sin = 9.00082$
9.92035
$r_4 = 1.17491$
$\sin = 8.74544$
$n' = 0.21570$
$\sin = 8.96114$
$r_4 = 1.17491$
0.13605
$\sin = 8.89901$
$= 1.32704$

$i = 3^\circ\ 11'\ 24''$
$\lambda = 5\ 14\ 47\frac{1}{2}$
$2\ 3\ 23\frac{1}{2}$
$\gamma = 5\ 45\ 0$
$\delta = 3\ 41\ 36\frac{1}{2} = \sin$
21.2344
$r_4 = 14.959$
36.193
$\frac{r}{f_4}$ Marginal $f_4 = 48.794$

$3^\circ\ 46'\ 36'' = 8.81849$
0.21570
$6\ 12\ 40 = 9.03419$
$2\ 26\ 10$ 1.17491
$5\ 10\ 40$ 0.20910
$2\ 44\ 30 = 8.67973$
$33.835 = 1.52937$
14.959
48.794

central

$f_3 = \frac{n'dr}{r + d(n-1)}$

$f_4 = \frac{dr}{-d(n'-1) + nr}$

central

$n' = 0.21570$ ✓
$d = 1.31742$ ✓
$r = 1.65806$ ✓
3.19118 ✓

$d = 1.$

$d = 1.31742$
$n'-1 = \frac{9.80835}{1.12580}$ ✓ $= \frac{45.805}{13.360}$
58.865 ✓ $= \frac{1.76986}{1.42132}$ ✓

$\frac{f}{f_3} = \frac{26.383}{26.183}$ $= 1.41802$
$d_4 = 26.183$ $r_4 = \frac{1.17491}{2.59293}$ ✓

$d = 1.41802$
$n-1 = \frac{9.80838}{1.22640}$ ✓ $= 16.842$

$n = 0.21570$
$r = \frac{1.17491}{1.39061} = \frac{24.582}{7.740} = \frac{0.88874}{1.70419}$

$\frac{f}{f_4} = 50.605 =$

$\frac{48.794}{1.811}$ = Marginal
lessens much too strong –

central 50.605
Marginal $\frac{48.794}{1.811}$ Sph Ab.
lessens too strong

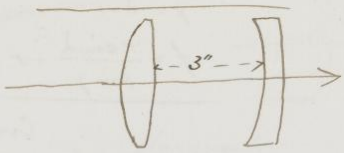
~~This manner of placing the lenses is the most of all~~

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Photographic O. G. continued –

Lerown Lens reversed and placed 3″ in front of Flint. ocmes as 2 pass forward. To find Spr. Ab. of g. ray.



$f_2 = 21.431$
$3.$
$d_3 = 18.431$
14.959
$33.390 = \log\ 1.52362$
$\delta = \sin\ 9.06046$
0.58408
$\tau_3 = 1.17491$
$i = 14° 51' 55'' = \sin\ 9.40917$
$n' = 0.21570$
9.19347
$\lambda = 8° 58' 55'' = \sin\ 1.17491$
$5° 53' 0'' \quad \tau_3 = 0.36838$
$\delta = 6\ 36\ 0$
$\gamma = 0° 43' 0'' = \sin\ 8.09718$
2.27120
$186.725 =$
$\tau_3 = 14.959$
$f_3 = 171.766$
$.2$
$d_4 = 171.566$
$\tau_4 = 45.505 = 2.33660$
$217.071 \quad \gamma = \sin\ 8.09718$
0.43378
$\tau_4 = 1.65806$
$i = 3° 25' 14'' = \sin\ 8.77572$
$n' = 0.21570$
$\lambda = 5\ 37\ 36 = \sin\ 8.99142$
$2\ 12\ 22 \quad \tau_4 = 1.65806$
0.64948
$\gamma = 0\ 43\ 0$
$\delta = 2\ 55\ 22 = \sin\ 8.70748$
1.94200
$87.499 =$
$\tau_4 = 45.505$
$f_4 = 41.994$ Marginal
40.937 Central
1.057 Lerown too weak

Central

$f_2 = 21.769$
$3.$
$d_3 = 18.769 = \log\ 1.27344$
$n' = 0.21570$
$\tau_3 = 1.17491$
2.66405

$d_3 = 1.27344$
$n-1 = 9.80838 \quad 14.959$
$1.08182 = 12.073$
$2.886 = 0.46030$
$= 2.20375$
$f_3 = 15.986$
$.2$
$d_4 = 15.966 = 2.20320$
$\tau_4 = 1.65806$
3.86126

$d_4 = 2.20320$
$n-1 = 9.80838$
$2.01158 = 102.702$
$n' = 0.21570$
$\tau_4 = 1.65806$
$1.87376 = 74776$
$177.478 = 2.24914$
1.61212
$f_4 = 40.937 =$

$2 : 1.488 :: x : 1.057$

$x = \frac{2.314}{1.488}$

$2.314 = 0.3644$
$1.488 = 0.1726$
$1.555 = 0.1918$
3.000
4.555

$1^{m} = 2.545$
$\frac{3^{m}}{2} = 1.057$
$= 1.488$

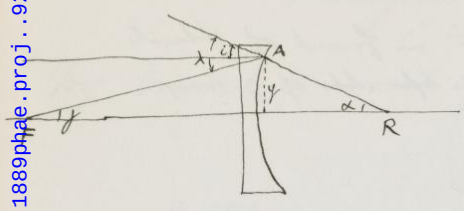
When lenses are separated 4″.555 Spherical Aberration should be corrected for the g ray

(continued 2 leaves over.

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Plano-concave Flint in front



Marginal Central

$\sin i = \frac{y}{r}$ $\sin j = n \sin i$

$y = \lambda - i$

$f = \frac{r \sin \lambda}{\sin y} - r$ $f = \frac{r}{n-1}$

$\lambda = 56.4$

$B = .044873 = \log 8.65198$
$= 1.34802$

$r_2 = 22.2854$

$y = 0.39794$
$r_2 = 1.34802$
$= 9.04992$
$n' = 0.20943$
$= 9.25-935$
$r_2 = 1.34802$
0.60737
$= 8.84685-$
$= 1.76082$

$i = 6° 26' 28''$
$\lambda = 10\ 28\ 7$
$y = 4\ 1\ 39$

57.653
$22.285-$
35.368
$+.02$
35.388

$r_3 = 24.000$
59.388

$= 1.77370$
$\sin y = 8.84685-$
$0.62025-$
$r_3 = 1.38021$
9.24004
$n' = 0.17996$
$= 9.06008$
$r_3 = 1.38021$
0.44039
$= 8.02937$
2.41102

$i = 10° 20' 31''$
$\lambda = 6\ 35\ 39$
$(i-\lambda) = 3\ 24\ 52$
$y = 4\ 1\ 39$
$0\ 36\ 47 = \delta$

$y - (i-\lambda) = 257.64$
f_3 falls in front of surface $- 24.000$
233.64
$f = \frac{r \sin \lambda}{\sin \delta} - r.$
$+.4$
$d_4 = 234.04$
$r_4 = 40.135-$
$198.905- = 2.29789$
$\sin \delta = 8.02937$
0.31696
$r_4 = 1.60352$
8.71344
$n = 0.17996$
8.89340
$r_4 = 1.60352$
0.49692
$= \sin 8.20120$
2.29562

$i = 2° 57' 47\frac{1}{2}''$
$\lambda = 4\ 29\ 13\frac{1}{2}$
$1\ 31\ 26$
$\delta = 0\ 36\ 47$
$\varepsilon = 0\ 54\ 39$

197.524
$40.135-$
$f_4 = 157.389$

The Flint is a great deal too strong

f_4 for central ray would be about

59.40.

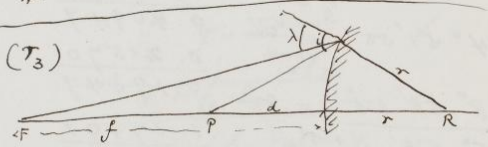
Crown

$r_3 = 24.000 = \log 1.38021$

$A = .086895-$

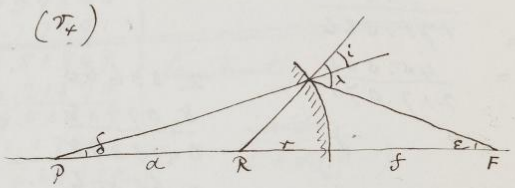
$\frac{1}{r_4} = .061979 = 8.61979$
$.024916 = 8.39648$
$= 1.60352$

$r_4 = 40.135-$



$\frac{\sin \lambda}{\sin \delta} = \frac{f+r}{r}$

$f_3 = \frac{r \sin \lambda}{\sin \delta} - r$



$\sin i = \frac{(d-r)\sin \delta}{r}$ $\sin \lambda = n \sin i$

$\varepsilon = (\lambda - i) - \delta$

$f_4 = \frac{r \sin \lambda}{\sin \varepsilon} - r$

$\log r_3 = r_4 = \frac{2}{A}$

$2 = \log 0.30103$
$A = \frac{8.93899}{1.36204}$
$=$

$r_3 = r_4 = 23.017$

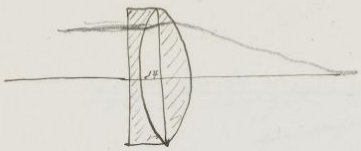
$r_3 = \text{Inf.} - = \frac{1}{A} = 1.06101$

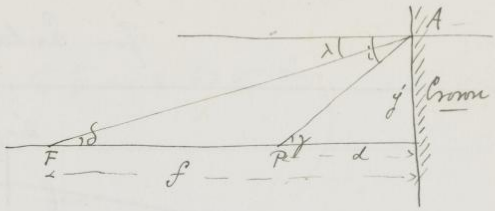
$r_4 = 11.5883$

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Plano concave flint
Plano convex crown





Marginal

$i = \gamma$

$\sin\lambda = \frac{\sin i}{n}$

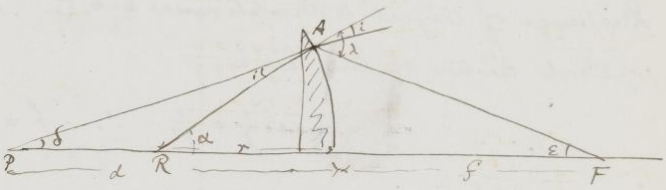
$f = \frac{d \tan\gamma}{\tan\lambda}$

Central

$n = \frac{\sin i}{\sin\lambda} = \frac{\sin\gamma}{\sin\delta} = \frac{AF}{AP}$

Accurate

$n = \frac{f}{d} \quad \therefore \quad f = nd$



$\frac{\sin i}{\sin\delta} = \frac{d-r}{r}$

$\sin i = \frac{(d-r)\sin\delta}{\sin\lambda} = n\sin r$

$\varepsilon = (\lambda - i) - \delta$

$\frac{\sin\varepsilon}{\sin\lambda} = \frac{r}{r+f}$

$f = \frac{r\sin\lambda}{\sin\varepsilon} - r$

$n = \frac{\sin\lambda}{\sin i} = \frac{\frac{\sin\lambda}{\sin\alpha}}{\frac{\sin i}{\sin\alpha}} = \frac{\frac{f+r}{AF}}{\frac{d-r}{AP}} = \frac{\frac{f+r}{f}}{\frac{d-r}{d}}$

Accurate

$n = \frac{df + dr}{df - fr}$

$f = \frac{dr}{d(n-1) - nr}$

$f_2 = 35.368$
$+ .140$
$d_2 = 35.508$

$4° 1' 39''$ $i = \gamma$ = sin 8.84653
n = 0.17996
$2° 39\ 36$ λ = sin 8.66659

d = 1.55033
tan γ = ~~8.84763~~ ~~2.702970~~ 0.39796
tan λ = 8.66707 ~~17.03863~~
$f_3 = 53.813$ = 1.73089
$+ 1.4$
$d_4 = 54.213$
$r_4 = 11.585$
42.628 = 1.62966
$\lambda = \delta$ = sin 8.66659
0.29625
r_4 = 1.06101
$i = 9\ 53\ 57$ = sin 9.23524
n = 0.17996
$\lambda = 15\ 4\ 41$ = 9.41520
$5\ 10\ 50$ r = 1.06101
$\delta = 2\ 39\ 36$ 0.47621
$\varepsilon = 2\ 31\ 14$ = sin 8.64323
68.074 = 1.83298
$r_4 = 11.585$
$f_4 = 56.489$

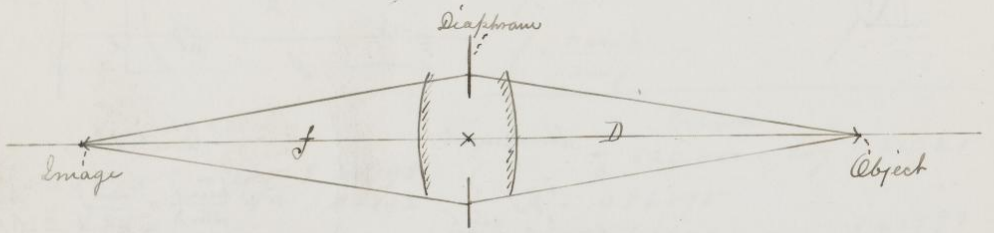
Crown a little too strong

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Small Dallmeyer Photographic Lens, to be used for Enlargements.

Lens should be reversed.



Focal length of lens = $F = \frac{12\frac{13}{16}}{4} = 3\frac{13}{64}^{in} = 3.203^{in}$

Distance of Object to Diaphragm = $6\frac{13}{32}^{in}$ Hence the Diaphragm is at the optical centre of the Lens.

$$\frac{1}{D} + \frac{1}{f} = \frac{1}{F} \quad \therefore \quad f = \frac{FD}{D-F}$$

$$\text{Magnifying Power} = \frac{\text{Diam of Image}}{\text{Diam of Object}} = \frac{f}{D} = m \quad \therefore \begin{cases} f = (m+1)F \\ D = \left(\frac{m+1}{m}\right)F = \frac{f}{m} \end{cases}$$

$$D = F + \frac{F}{m}$$

Table giving distance of Object and Image from Diaphragm for diff. Magnifing Powers

$\frac{m}{\text{Mag. Power}}$	D	f	$D+f$	D	f
	in	in	in		
1	$6\frac{13}{32}$	$6\frac{13}{32}$	$12\frac{13}{16}$	6.406	6.406
1¼	$5\frac{49}{64}$	$7\frac{13}{64}$	$12\frac{63}{64}$		
1½	$5\frac{11}{32}$	8	$13\frac{11}{32}$		
1¾	$5\frac{1}{32}$	$8\frac{13}{16}$	$13\frac{27}{32}$		
2	$4\frac{13}{16}$	$9\frac{39}{64}$	$14\frac{13}{32}$	4.804	9.609
2½	$4\frac{31}{64}$	$11\frac{7}{32}$	$15\frac{11}{16}$	4.484	11.210
3	$4\frac{17}{64}$	$12\frac{13}{16}$	$17\frac{5}{64}$	4.271	12.812
4	4	$16\frac{1}{64}$	$20\frac{1}{64}$	4.004	16.015
5	$3\frac{27}{32}$	$19\frac{7}{32}$	$23\frac{1}{16}$	3.844	19.218
6	$3\frac{47}{64}$	$22\frac{27}{64}$	$26\frac{5}{32}$	3.737	22.421
8	$3\frac{39}{64}$	$28\frac{53}{64}$	$32\frac{27}{64}$	3.603	28.824
10	$3\frac{33}{64}$	$35\frac{7}{16}$	$38\frac{3}{4}$	3.522	35.222

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$6\frac{5}{8}$ = Euryscope

Focal length = $F = \frac{26\frac{1}{2}}{4} = 6\frac{5}{8} = 6.625$ in

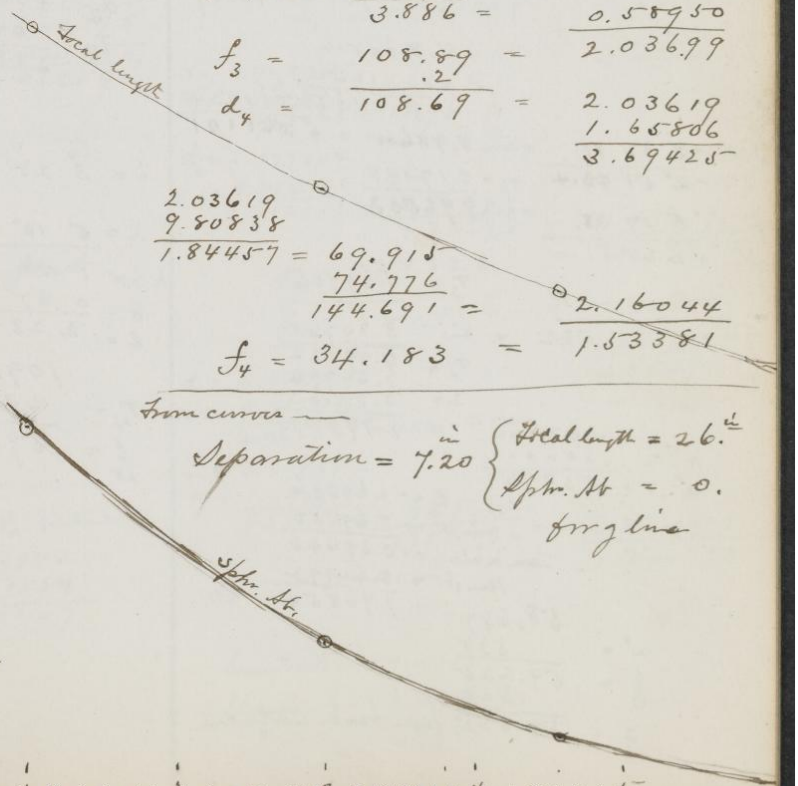
m Mag. Power.	D	D + f
1	$13\frac{1}{4}$	$26\frac{1}{2}$
$1\frac{1}{8}$	$12\frac{1}{2}$	$26\frac{37}{64}$
$1\frac{1}{4}$	$11\frac{59}{64}$	$26\frac{53}{64}$
$1\frac{3}{8}$		
$1\frac{1}{2}$	$11\frac{3}{64}$	$27\frac{19}{32}$
$1\frac{5}{8}$		
$1\frac{3}{4}$	$10\frac{13}{32}$	$28\frac{5}{8}$
$1\frac{7}{8}$		
2	$9\frac{15}{16}$	$29\frac{13}{16}$

Photographic C. G. continued from 2 leaves ~~backward~~.

$f_2 = 21.431$
4.565
$d_3 = 16.876$
14.959
31.835 = $1.502\,90$
$9.060\,46$
0.56336
1.17491
$14^\circ\ 9'\ 29''$ = 9.38845
0.21570
$8\ 33\ 37$ = 9.17275
$5\ 35\ 52$ 1.17491
$6\ 36\ 0$ 0.34766
$1\ 0\ 8$ = 8.24282
127.303 2.10484
14.959
$f_3 = 112.344$
12
$d_4 = 112.144$
45.505
157.649 = 2.19769
8.24282
0.44051
1.65806
$3^\circ\ 28'\ 27''$ = 8.78245
$n' =$ 0.21570
$5\ 42\ 53$ = 8.99815
$2\ 14\ 26$ 1.65806
$1\ 0\ 8$ 0.65621
$3\ 14\ 34$ = 8.75256
80.103 = 1.90365
45.505
$f_4 = 34.598$
34.183
$.415$ Error too much

$f_2 = 21.769$
4.565
$d_3 = 17.214$ = $1.235\,88$
$n' =$ $0.215\,70$
$r_3 =$ $1.174\,91$
$2.626\,49$

$d_3 = 1.235\,88$
$n'-1 = 9.808\,38$ 14.959
$1.044\,26$ = 11.073
3.886 = $0.589\,50$
$f_3 =$ 108.89 = $2.036\,99$
$d_4 =$ $.2$ $2.036\,19$
108.69 = $1.658\,06$
$3.694\,25$



$2.036\,19$
$9.808\,38$
$1.844\,57$ = 69.915
74.776
144.691 = $2.160\,44$
$1.853\,81$
$f_4 = 34.183$

from curves —
Separation = 7.20 in { Focal length = 26.½
Spher. Ab = 0.
for g line

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Flint in front - continued from 9 leaves back. $r_2 = r_3 = 14.9892$

$r_1 = 45.5049 = \log 1.6558058$
$r_2 = 14.9892 = \quad 1.1749908$
$r_3 = 14.9892 = \quad 1.1749908$
$-r_4 = 49.8843 = \quad 1.6979964$

$A = \frac{r_1}{r_2} = \log 0.4831515$
$A' = \frac{r_2}{r_3} = \quad 0.0000000$
$A'' = \frac{r_3}{r_4} = \quad (-)9.4769515$

Leitrim formulae
3 refractors

C line - Marginal

$\phi' = r_2 + t_1 = 15.159$
$\phi = r_1 = 45.5049$
$\phi' - \phi = -30.346 = \log 1.4821010$
$r_2 = 1.1749100$
$B = -0.3071910$

$\phi'' = r_3 - (t_1 + t_2) = -49.284$
$+15.159$
$\phi'' - \phi' = -64.443 = -\log 1.8091810$
$-r_3 = -1.6979600$
$B_1 = +0.1112210$

$k = \log. 0.3979400$
$r_1 = 1.6558060$
$\alpha = 8.7398800 = 3° 8' 57.''7$
$\nu - \alpha = -3° 8' 57.''7$
$= \sin - 8.7398800$
$n' = 0.2077000$
$= \sin - 8.5321800$

$\nu' - \alpha = -1° 57' 5.''3$
$\alpha = 3 8 57.7$
$\nu' = +1° 11' 52.''4$
$= \sin + 8.3202600$

$A = +0.4831515$
$-9.0153303 = .1035920$

$B = +0.3071910$
$-8.6274500 = .0424080$
$= \sin \bar{9}.1643500 = -.1460000$

$\nu'' - \alpha' = -8° 23' 42.''$
$\alpha' = +9° 35' 34.''4$
$\nu'' - \alpha' = -8° 57' 49.''8$
$\nu'' = +0 38 24.6$
$= \sin 8.0481600$

$n' = 0.0287100$
$n'' = \sin \bar{9}.1920600$
$A' = \bar{9}.4769515$
$+8.6690100 = .0466670$

$B' = +0.1112200$
$8.1859380 = .0144340$
$+ .0611010$

$\nu''' - \alpha'' = +8° 30' 11.''$
$\alpha'' = -2° 51' 46.''4$
$\nu''' - \alpha'' = 5° 17' 38.''$
$\nu''' = +2 25 51.6$
$= \sin \bar{8}.7860500 = +.0611010$

$n = 0.1789800$
$= \sin 8.9650300$

$r_3 = 1.6979600$
$\frac{1}{2}\alpha'' = -1° 25' 53.''2 = \sin \bar{8}.3976100$
$+8.7952200$
$r_3 = -1.6979600$
$2 = 0.3010300$
$= -8.7942100$

$-.0622600$
$q'' = +.6000000$
$a'' = +.5377400$

$r_3 = -1.6979600$
$\sin \alpha'' = -8.6985000$
$K'' \log = +0.3964600$
$\tan \nu''' = 8.6279200$
$= 1.7685400$

58.687
$a'' = .538$
$\xi = 59.225$
$.600$
$z = 58.625$ from back surface

C line - Central Marginal

$i = 3° 8' 57.''73 = \sin 8.7398820$
$n' = 0.2076970$
$\lambda = 1° 57' 5.''77 = \sin 8.5321850$
$\gamma = 1 11 51.96$
$r_1 = 1.6558058$
0.1902430
$= \sin 8.3202180$
$= 1.8700280$

$r_1 = 74.1353$
45.5049
$f_1 = 119.6402$
$,2$
$d_2 = 119.4402$
$r_2 = 14.9892$
$104.4810 = 2.0190370$
$\gamma = \sin 8.3202180$
0.3992850
$r_2 = 1.1749080$
$i = 8° 23' 42.''27 = \sin 9.1643470$
$N_c = 0.0287150$
$\lambda - 8° 58' 24.''89 = \sin 9.1930620$
$\lambda - i = 0 34 42.32$
$\gamma = 1 11 51.96$
$\delta = 0 37 9.64 = \sin 8.0338010$
$= 2.3341690$

215.8558
$r_2 = 14.989$
$f_2 = 230.817$
$,4$
$d_4 = 230.417$
$r_4 = 49.884$
$280.301 = 2.4476250$
$\sin \delta = 8.0338010$
0.4814260
$r_4 = 1.6979640$
$i = 3° 28' 55.''87 = \sin 8.7834620$
$n = 0.1789820$
$\lambda = 5° 15' 44.36 = \sin 8.9624440$
$\lambda - i = 1 46 48.49$
$\delta = 0 37 9.64$
$\varepsilon = 2 23 58.13 = \sin 8.6218680$
$= 2.0385400$

$r_4 = 1.6979600$
0.6604080

109.2799
$r_4 = 49.8843$
$f_4 = 59.3956$
$,3$

59.4
,3
4.5 | 59.7 | 13.26
45
147
135
120
90
30

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Slit in front continued $r_2 = r_3 = 14.9892$ as before.

X line. Marginal

$i = 3° 8' 57.73 = \sin 8.739882$

$n' = 0.211227$

$\lambda = 1° 56' 8.88 = \sin 8.528655$

$r_1 = 1.658058$

$\beta = 1\ 12\ 48.85$

0.186713

$= \sin 8.325909$

$= 1.860804$

$r = 72.5778$

46.5049

$f_1 = 118.0827$

$.2$

$d_2 = 117.8827$

$r_2 = 14.9892$

102.9235

$= 2.012515$

$\sin \beta = 8.325909$

0.338424

$r_2 = 1.174908$

$i = 8° 22' 44.09 = \sin 9.163516$

$N = 0.030283$

$\lambda = 8\ 59\ 19.91 = \sin 9.193799$

$0\ 36\ 35.82$

$r_2 = 1.174908$

$\beta = 1\ 12\ 48.85$

0.368707

$\delta = 0\ 36\ 13.03 = \sin 8.022633$

$= 2.346074$

221.857

$r_2 = 14.9892$

$f_2 = 236.816$

$.4$

$d_4 = 236.416$

$r_4 = 49.884$

286.300

$= 2.456821$

$\sin \delta = 8.022633$

0.479454

$r_4 = 1.697964$

$\varepsilon = 3° 27' 59.00 = \sin 8.781490$

$n = 0.180944$

$\lambda = 5^h\ 15^m\ 43.91 = \sin 8.962434$

$1\ 47\ 44.91$

$r_4 = 1.697964$

$\delta = 0\ 36\ 13.03$

0.660398

$\varepsilon = 2\ 23\ 57.94 = \sin 8.621854$

2.038540

109.2799

$r_4 = 49.8843$

$f_4 = 59.3956$

$\log \frac{59.3956}{0}$ looks perfect.

Marginals 59.3956

Central 59.3889

Sp. Ab. = .0067

X line Central

$n' = 0.211227$ ✓

$r_1 = 1.658058$ ✓

1.869285 ✓

$n'-1 = 9.796852$

$= 2.072433$ ✓

$f_1 = 118.1498$ ✓

$.2$

$d_2 = 117.9498$ ✓ $= 2.071697$ ✓

$r_2 = 1.174908$ ✓

3.246605

$N = 0.030283$

$r_2 = 1.174908$ ✓

1.205191 ✓ $= 16.0395$ ✓

$d_2 = 2.071697$ ✓

$n-1 = 8.858645$

$0.930342 = 8.518088$ ✓ $= 0.876300$ ✓

7.527142 ✓ $= 2.370305$ ✓

$f_2 = 234.588$ ✓

$.4$

$d_4 = 234.188$ ✓ $= 2.369565$

$r_4 = 1.697964$

4.067529 ✓

$d = 2.369565$ ✓

$n-1 = 9.713370$

2.082933 ✓ $= 121.0417$ ✓

$n = 0.180944$

$r_4 = 1.697964$ ✓

1.878908 ✓ $= 75.6673$ ✓

196.7090 ✓ $= 2.293824$ ✓

$= 1.773705$ ✓

$f_4 = 59.3889$ ✓

C line Central

$n' = 0.207697$

$r_1 = 1.658058$

1.865755

$n'-1 = 9.787628$

$= 2.078130$

$f_1 = 119.7100$

$d_2 = 119.5100$ $= 2.077404$

$r_2 = 1.174908$

3.252312

$N = 0.028715$

$r_2 = 1.174908$

$1.203623 = 15.9817$

$d_2 = 2.077404$

$n-1 = 8.834761$

$0.912165 = 8.16892$ $= 0.892806$

7.81278 $= 2.358506$

$f_2 = 228.826$

$.4$

$d_4 = 228.426$ $= 2.358745$

$r_4 = 1.697964$

4.056709

$d = 2.358745$

$n-1 = 9.707586$

$2.066331 = 116.5014$

$n = 0.178982$

$r_4 = 1.697964$

$1.876946 = 75.3262$ $= 2.282911$

191.8276 $= 1.773798$

$f_4 = 59.4016$

Central – 59.4016

Marginals – 59.3956

.0060

f_4 central

$56.14 = 59.3742$

$x = 59.3889$

$.0147$

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Flint in front continued — $r_2 = r_3$ as before

g line Marginal

$i = 3° 8' 57.73$ = sin 8.73988
$n' = 0.21570$
$\lambda = 1\ 54\ 57.8$ = sin 8.52418
$\gamma = 1\ 13\ 59.9$ $g_1 = 1.65806$
0.18224
i = sin 8.33291
= 1.84933

$r_1 = 70.685$
48.808
$f_1 = 116.190$
$.2$
$d_2 = 115.990$
$r_2 = 14.959$
101.031 = 2.00445

γ = sin 8.33291
0.33736
$r_2 = 1.17491$
$i = 8° 21' 29.''6$ = sin 9.16245
$N = 0.03246$
$\lambda = 9\ 0\ 43.5$ = sin 9.19491
$0\ 39\ 13.9$ $r_2 = 1.17491$
$\gamma = 1\ 73\ 59.9$ 0.36982
$\delta = 0\ 34\ 46.0$ = sin 8.00488
= 2.36494
231.708
$r_2 = 14.959$
$f_2 = 246.667$
$.4$
$d_4 = 246.267$ = ~~2.39141~~
$r_4 = 49.884$
296.151 = 2.47151

sin δ = 8.00488
0.47639
$r_4 = 1.69796$
$i = 3° 26' 31.''3$ = sin 8.77843
$n = 0.18324$
$\lambda = 5\ 15\ 10.4$ = sin 8.96167
$1\ 48\ 39.1$ $r_4 = 1.69796$
$\delta = 6\ 34\ 46.0$ 0.65963
$\varepsilon = 2\ 23\ 25.1$ = sin 8.62020
2.03943
109.504 =
$r_4 = 49.884$
$f_4 = 59.620$

Marginal 59.620
central 59.599
.0210

g line central

$n' = 1.64324$ = log 0.21570
$\gamma_1 = 1.65806$
1.87376
$n'-1 = 9.80838$
$= 2.06538$
$f_1 = 116.247$
$.2$
$d_2 = 116.047$ = 2.06463
$r_2 = 1.17491$
3.23954

$N = 0.03246$
$r_2 = 1.17491$
$1.20737 = 16.1202$

$d_2 = 2.06463$
$N-1 = \frac{8.89006}{0.95469} = \frac{9.0093}{7.1109} = \frac{0.85192}{2.38762}$
$f_2 = 244.13$
$.4$
$d_4 = 243.73$ = 2.38691
$r_4 = 1.69796$
4.08487

$d = 2.38691$
$n-1 = \frac{9.77807}{2.10698} = 127.932$

$n = 0.18324$
$r = \frac{1.69796}{1.88120} = \frac{76.068}{204.000} = \frac{2.30963}{1.77524}$
$f_4 = 59.599$ = 1.77524

Ray	γ = Crown in front		Flint in front	
	Marginal	central	Marginal	central
A			59.436	59.448
B			59.378	59.394
C = 6562	59.4293	59.4385	59.3959	59.4016
. 5614	59.4078	59.4077	59.3742	59.3742
X = 5092	59.4288	59.4177	59.3956	59.3835
F				59.443
$\frac{1}{2}$F-G				
G				59.542
g = 4226	59.642	59.609	59.620	59.599
H_1 =			59.754	59.716

		$\frac{dE}{F}$
	104	.00124
	36	.00046
	36	.00016
		.00116
		.00282
	413	.00378
	638	.00578

	Differences			
A		0.075	0.062	0.074
B			0.016	0.028
C = 6562	0.0215	0.0308	0.0214	0.0274
. 5614	0.	0.	0.	0.
X = 5092	0.0210	0.0100	0.0214	0.0093
F				0.069
$\frac{1}{2}$F-G				0.168
G =				
g = 4226	0.234	0.201	0.246	0.2250
(G)				
H_1	0.372	0.311	0.380	0.342

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λ

Flint in front

275

C 6562 .0274

5614

0.1

0.2

1/4

X 5092 .0293

F 4860

Combine C + F centrical rays for perfect color correction

Secondary

g 4226 .2250

Index of Refraction - Crown.

Scale 20

Scale 40

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Hint in front - continued $r_2 = r_3$ as before

H, line Marginal

$i' = 3° 8' 57.''73$ — sin 8.73988

$n' = 0.21776$ ✓

$\lambda = 1\ 54\ 24.8$ sin = 8.52212

$\gamma = 1\ 14\ 32.9$ r_1 = 1.65806

0.18018

sin = 8.33613

= 1.84405

69.831

r_1 = 45.505

f_1 = 115.336

.2

d_2 = 115.136

r_2 = 14.959

100.177

= 1.90387

γ = sin 8.48298

0.38685

r_2 = 1.17491

= sin 9.21194

n' = 0.21776

9.42970

n = 0.18427

= sin 9.24543

r_2 = 1.17491

0.42034

sin 8.12236

= 2.29798

$i = 9° 22' 32''$

$\lambda = 10° 8' 6''$

$\delta = 0\ 45\ 34$

198.60

r_2 = 14.96

f_2 = 213.56

.4

d_4 = 213.16

r_4 = 49.88

263.04

= 2.42002

sin δ = 8.12236

0.54238

r_4 = 1.69796

= sin 8.84442

n = 0.18427

= sin 9.02869

r_4 = 1.69796

0.72665

= sin 8.70172

= 2.02493

$i = 4° 0' 27.''8$

$\delta = 0\ 7\ 57.1$

$2\ 7\ 29.3$

$\delta = 0\ 45\ 34.$

$\varepsilon = 2\ 53\ 3.3$

105.908

r_4 = 49.884

f_4 = 56.024

log

$n' = 0.21776$

$n = \frac{0.18427}{0.03349} = 1.08016$

$N = 1.08016$

$N-1 = 9.90396 = .08016$

H, line ~~Central~~ Marginal

100.177 = log 2.00077

γ = sin 8.33613

0.33690

r_2 = 1.17491

= sin 9.16199

n' = 0.21776

9.37975

n = 0.18427

= sin 9.19548

r_2 = 1.17491

0.37039

sin 8.07099

= 2.29940

$8° 20' 5''8$

$9\ 1\ 27$

$\delta = 0\ 40\ 29$

199.25

r_2 = 14.96

f_2 = 214.21

.4

d_4 = 213.81

r_4 = 49.88

263.69

$3° 34' 7.''7$

$5\ 27\ 35.0$

$1\ 53\ 27.3$

$\delta = 0\ 40\ 29.0$

$\varepsilon = 2\ 33\ 56.3$

106.028

r_4 = 49.884

f_4 = 56.144

sin δ = 2.42109

8.07099

0.49208

r_4 = 1.69796

= 8.79412

n = 0.18427

= λ = 8.97839

r_4 = 1.69796

0.67635

sin = 8.65093

2.02542

~~Central~~

n' = log 0.21776

r_1 = 1.65806

1.87582

$n'-1$ = 0.65105 = 9.81361

f_1 = 115.401 = 2.06221

.2

d_3 = 115.201 = 2.06146

r_3 = 1.17491

3.23637

$n' = 0.21776$

$r_3 = \frac{1.17491}{1.39267}$

$n = \frac{0.18427}{1.20840} = 16.1585$

$d_3 = 2.06146$

$N-1 = \frac{8.90396}{0.96542} = \frac{9.2347}{6.9238} = \frac{0.84034}{2.39603}$

f_3 = 248.903 = 2.39533

.4

d_4 = 248.503 = 1.69796

r_4 = 4.09329

$d_4 = 2.39533$

$n-1 = \frac{9.72307}{2.11840} = 131.34$

$n = 0.18427$

$r_4 = \frac{1.69796}{1.88223} = \frac{76.258}{207.588} = \frac{2.31720}{1.77609}$

f_4 = 59.716 ~~Central~~

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1009phae.proj.920H

Same Continued

B linear Marginal

$i = 3^\circ\ 8'\ 57.7$ = sin 8.73988

$\lambda = 1\ 54\ 24.8$ — $n' = 0.21776$

$\gamma = 1\ 14\ 32.9$ — $\gamma_1 = 1.65806$

1.87805 = sin 8.33613 = 0.18018

69.831 − 45.505 = 115.336 + .2 = 115.136 − 14.959 = 100.177

= 2.00077

γ = sin 8.33613 = 0.33690

γ_3 = 1.17491

$i = 8^\circ\ 20'\ 57''.5$ = sin 9.16199

N = 0.03349

$\lambda = 9\ 1\ 26.4$ = sin 9.19548

$\chi = 0\ 40\ 28.9$ — γ_3 = 1.17491

$\gamma = 1\ 14\ 32.9$ = 0.37039

$\delta = 0\ 34\ 4.0$ — sin 8.07097

199.26 = 2.29942

Error

γ_3 = 14.959

f_3 = 214.219 + .4

d_4 = 213.82

γ_4 = 49.884 − 263.70

= 2.42111

sin δ = 8.07097

γ_4 = 1.69796

$3^\circ\ 34'\ 7''.7$ — sin = 8.79412

n = 0.18427

$5\ 27\ 35.0$ = 8.97839

$1\ 53\ 27.3$ — γ_4 = 1.69796

$0\ 40\ 28.9$ = 0.67635

$\varepsilon = 2\ 38\ 56.2$ = sin 8.65092

= 2.02543

106.030 − 49.884 = 56.136

γ_4 = 49.884

f_4 = 56.136

This checks preceding page —

$\delta = 0^\circ\ 34'\ 4.0$ = sin 7.99605 = 2.37434

0.37039

236.78 − 14.96 = 251.74 + .4 = 251.34 − 49.88 = 301.22

= 2.47888

sin δ = 7.99605

0.47493

γ_4 = 1.69796

$3^\circ\ 25'\ 49''.7$ = sin = 8.77697

n = 0.18427

$5\ 14\ 51.7$ = sin = 8.96124

$1\ 49\ 2.0$ — γ_4 = 1.69796

$\delta = 0\ 34\ 4.0$ = 0.65920

$\varepsilon = 2\ 23\ 6.0$ = sin 8.61924

2.03996

109.638 − 49.884 = 59.754 + .374 + .380 = .6-40

γ_4 = 49.884

f_4 = 59.754 Marginal

$i = 3^\circ\ 8'\ 57.7$ = sin 8.73988

$\lambda = 1\ 57\ 13.3$ — n' = 0.20723

$\gamma = 1\ 11\ 44.4$ = sin 8.53265

γ_1 = 1.65806

= 0.19071

= sin 8.31946

= 1.87125

74.345 − 45.505 = 119.850 + .2 = 119.650 − 14.959 = 104.691

= 2.01991

γ = 8.31946

0.33937

γ_3 = 1.17491

$i = 8^\circ\ 23'\ 50.0$ — sin = 9.16446

N = 0.02849

$\lambda = 8\ 58\ 16.0$ = sin = 9.19295

$\chi = 0\ 34\ 26.0$ — γ_3 = 1.17491

$\gamma = 1\ 11\ 44.4$ 0.36786

$\delta = 0\ 37\ 18.4$ = sin = 8.03551

= 2.33235

214.955 − 14.959 = 229.914 + .4 = 229.514 − 49.884 = 279.398

= 2.44623

sin δ = 8.03551

0.48772

γ_4 = 1.69796

$3^\circ\ 29'\ 47''.8$ — sin = 8.78377

n = 0.17874

$5\ 15\ 47.9$ = 8.96251

$1\ 46\ 42.2$ — γ_4 = 1.69796

$\delta = 0\ 37\ 18.4$ = 0.66047

$\varepsilon = 2\ 24\ 0.6$ = sin 8.62199

= 2.08848

109.265 − 49.884 = 59.381 too small, see next page.

$n' = 0.20723$

$\gamma_1 = 1.65806$

= 1.86529

= 9.78640

= 2.07889

Central

~~Δ = 354.136~~

0.61150 $n-1$

f_1 = 119.920 + .2

d_3 = 119.72

= 2.07817

γ_3 = 1.17491

3.25308

$N = 0.02849$

$\gamma_3 = 1.17491$ / 1.20340 = 15.9735

$d_3 = 2.07817$

$N-1 = 8.83123 / 0.90940 = 8.1171 / 7.8564$ = 0.89522

= 2.35786

f_3 = 227.96 + .4

d_4 = 227.56

= 2.35710

γ_4 = 1.69796

4.05506

$d_4 = 2.35710$

$n-1 = 9.70687 / 2.06397 = 115.87$

$n = 0.17874$

$\gamma_4 = 1.69796 / 1.87670 = 75.284 / 191.154$ = 2.28138

f_4 = 59.385 = 1.77368

See next page

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Flint in front continued

B line – continued

Marginal

$i = 3° 8' 57".73$ $= \sin 8.73988$

$\lambda = 1\ 57\ 13.3$ $n' = 0.20723$

$\eta = 1\ 11\ 44.4$ $= \sin 8.53265$

$\tau_1 = 1.65806$

0.19071

$= \sin 8.31946$

$= 1.87125$

74.345

$\tau_1 = 45.505$

$f_1 = 119.850$

$d_3 = 119.650$

$\tau_3 = 14.959$

104.691

$= 2.01991$

$\sin \eta = 8.31946$

0.33937

$\tau_2 = 1.17491$

$i = 8° 23' 50".0$ $= \sin 9.16446$

$N = 0.02849$

$\lambda = 8\ 58\ 16.1$ $= \sin 9.19295$

$0\ 34\ 26.1$ $\tau_2 = 1.17491$

$\eta = 1\ 11\ 44.4$ 0.36786

$\delta = 0\ 37\ 18.3$ $= \sin 8.03549$

$= 2.33237$

214.965

$\tau_3 = 14.959$

$f_3 = 229.924$

$d_4 = 229.524$

$\tau_4 = 49.884$

279.408

$= 2.44624$

$\sin \delta = 8.03549$

0.48173

$\tau_4 = 1.69796$

$3° 29' 4".8$ $= \sin 8.78377$

$x = 0.17874$

$5\ 15\ 47.2$ $= \sin 8.96251$

$1\ 46\ 42.4$ $\tau_4 = 1.69796$

$\delta = 0\ 37\ 18.3$ 0.66047

$\varepsilon = 2\ 24\ 0.7$ $= \sin 8.62200$

$= 2.03847$

109.262

$\tau_4 = 49.884$

$f_4 = 59.378$

This checks as correct the calculation on the preceding page.

59.342

.036

Shows to 59.4084 b.f.r. curve

.378

.030 Error

Central

$n' = 0.20723$

$\tau_1 = 1.65806$

1.86529

$n-1 = 9.78640$

$f_1 = 119.92$ $= 2.07889$

$d_3 = 119.72$ $= 2.07817$

$\tau_3 = 1.17491$

3.25308

$N = 0.02849$

$\tau_3 = \frac{1.17491}{1.20340} = 15.9734$

$d_3 = 2.07817$

$N-1 = \frac{8.83126}{0.90943} = \frac{8.1776}{78558} = 0.89519$

$= 2.35789$

$f_3 = 227.977$

$d_4 = 227.577$ $= 2.35713$

$\tau_4 = 1.69796$

4.05509

$d_4 = 2.35713$

$n-1 = 9.70687$

$2.06400 = 115.878$

$n = 0.17874$

$\tau_4 = 1.69796$

$1.87670 = \frac{75.284}{191.162} = \frac{2.28140}{1.77369}$

f_4 59.387

This checks as correct the calculation on the preceding page.

59.387

59.378

Sph ab = .009

59.3742

.0420

Shows to 59.4162 b.f.r. curve

.387

.029 Error.

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Flint in front continued

A line

Marginal –

$(\frac{q}{\tau_1})$ = $i = 3° 8' 57.73$ = sin 8.73988

$\lambda = 1\ 57\ 27.9$ — $n' =$ 0.20633

$\gamma = 1\ 11\ 29.8$ — $\tau_1 =$ 1.65806

= sin 8.31798 — 0.19161

= 1.87363

$\tau_1 = 74.753$

$\delta = 120.288$ (.2)

$d_3 = 120.058$

$\tau_3 = 14.959$

105.099 = 2.02160

γ = sin 8.31798

0.33958

$\tau_3 =$ 1.17491

$i = 8° 24' 5.0$ = sin 9.16467

$N =$ 0.02814

$\lambda = 8\ 58\ 5.7$ = sin 9.19281

$\gamma = 1\ 11\ 29.8$ $\tau_3 =$ 1.17491

0.36772

$\delta = 0\ 37\ 29.1$ = sin 8.03758

= 2.33014

213.865

$\tau_3 = 14.959$

228.824 (.4)

$d_4 = 228.424$

$\tau_4 = 49.884$

278.308 = 2.44453

δ = sin 8.03758

0.48210

$\tau_4 =$ 1.69796

$i = 3° 29' 15.6$ = sin 8.78414

$n =$ 0.17818

$\lambda = 5\ 15\ 38.9$ = sin 8.96232

$1\ 46\ 23.3$ $\tau_4 =$ 1.69796

$\delta = 0\ 37\ 29.1$ 0.66028

$\varepsilon = 2\ 23\ 52.4$ = sin 8.62158

= 2.03870

109.320

$\tau_4 = 49.884$

$f_4 = 59.436$

.374

.058

59.448

59.436

Sept 4th = .012

Central

$n' =$ 0.20633

$\tau_1 =$ 1.65806

1.86439

$n'-1 =$ 9.78402

= 2.08037

$f_1 = 120.33$ (.2)

$d_3 = 120.13$

= 2.07965

$\tau_3 =$ 1.17491

3.25456

$N =$ 0.02814

$\tau_3 =$ 1.17491

$1.20305 = 15.9606$

$d_3 =$ 2.07965

$N-1 =$ 8.82575 = 8.0427

0.90540 7.9179 = 0.89861

= 2.35595

$f_3 = 226.96$ (.4)

$d_4 = 226.56$

= 2.35318

$\tau_4 =$ 1.69796

4.05314

$d_4 =$ 2.35378

$n-1 =$ 9.70522

$2.06040 = 114.921$

$n =$ 0.17818

$\tau_4 =$ 1.69796

$1.87614 = 75.186$

$190.107 =$ 2.27900

= 1.77414

$f_4 = 59.448$ (.374 (1814))

.074

00123

$n' =$ 0.20725 ✓

$\tau_1 =$ 1.65806 ✓

1.86531 ✓

$n'-1 =$ 9.78644 ✓

$f_1 = 119.914$ ✓ = 2.07887 ✓

(.2)

$d_3 = 119.714$ ✓ = 2.07814 ✓

$\tau_3 =$ 1.17491 ✓

3.25305 ✓

$N =$ 0.02851 ✓

$\tau_3 =$ 1.17491 ✓

$1.20342 = 15.9742$ ✓

$d_3 =$ 2.07814 ✓

$(N-1) =$ 8.83153 ✓

0.90969 ✓ 8.1225

7.8517 ✓ = 0.89496 ✓

$f_3 = 228.089$ ✓ = 2.35809 ✓

(.4)

$d_4 = 227.689$ ✓ = 2.35732½ ✓

$\tau_4 =$ 1.69796 ✓

4.05528½ ✓

B line

with indices of refraction remeasured

$n' =$ 0.20725

$n =$ 0.17874 ✓

$N =$ 0.02851 ✓ = 1.06785 ✓

$(N-1) =$ 8.83153 ✓ = 0.06785 ✓

59.7).02500(00042

2388

1120

$d_4 =$ 2.35732½

$n-1 =$ 9.70686

$2.06418\frac{1}{2} = 115.927$ ✓

$n =$ 0.17874

$\tau_4 =$ 1.69796

$1.87670 = 75.284$ ✓

$191.211 =$ 2.28154 ✓

= 1.77377½ ✓

$f_4 = 59.399$ ✓

$f_{5614} =$ .374 ✓

.025

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Flint

~~Canon~~ in front. continued ~~$\delta_1 = 49.324$~~ ~~$\delta_2 = 15.139$~~ ~~$\delta_3 = 15.459$~~ ~~$\delta_4 = 49.324$~~

4. line – Marginal – Central

$n' = 0.21516$

$\delta_1 = \frac{1.65806}{1.87322}$

$n'-1 = \frac{9.80700}{2.06622} = 2.06547$

$\delta_1^0 = 116.472$

$d_3 = 116.272$

$\delta_3 = \frac{1.17491}{3.24038}$

$N = 0.03218$

$\delta_3 = \frac{1.17491}{1.20709} = 161100$

$d_3 = 2.06547$

$N-1 = \frac{8.88598}{0.95145} = \frac{8.9423}{7.1677} = \frac{0.85338}{2.38500}$

$\delta_3 = 242.66$

$d_4 = 242.26$

$= 2.38428$

$\delta_4 = \frac{1.69796}{4.08224}$

$d_4 = 2.38428$

$n-1 = \frac{9.71933}{2.10361} = 126.944$

$n = 0.18298$

$\delta_4 = \frac{1.69796}{1.88094} = \frac{76.022}{202.966} = \frac{2.30742}{1.77482}$

$\delta_4^0 = 59.542$

59.5) 118.0 (2
119
49 00
47 60
1400

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Flint in Front continued

Lens $\frac{1}{3}$ from 7 towards 9.

$n' = 0.213096$
$n = 0.181927$
$1.07441 = N = 0.031169$
$.07441 = N-1 = 8.87163$

$n' = 0.21308$
$\gamma_1 = 1.65806$
1.87114
$n'-1 = 9.80169$
$= 2.06945$
$= 2.06871$
$\gamma_3 = 1.17491$
3.24362

$f_1 = 117.341$
$d_3 = 117.141$

$N = 0.03117$
$\gamma_3 = 1.17491$
$1.20608 = 16.0724$

$d_3 = 2.06871$
$N-1 = 8.87163$
$0.94034 = 8.7165$
$7.3559 = 0.86664$
$= 2.37698$
$= 2.37625$
$\gamma_4 = 1.69796$
4.07421

$f_3 = 238.22$
$d_4 = 237.82$

$d_4 = 2.37625$
$n-1 = 9.71625$
$2.09250 = 123.737$

$n = 0.18193$
$\gamma_4 = 1.69796$
$1.87989 = 75.839$
$199.576 = 2.30011$
$= 1.77410$

$f_4 = 59.443$

59.443
.374
579.5 | .0690 (116
579
910
579
331 0

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Comparison of Glass used in $3\frac{1}{2}^{\doteq}$ O.G. and in $4\frac{1}{2}^{\doteq}$ O.G.

	Index of Refraction			
	$3\frac{1}{2}^{\doteq}$ O.G.		$4\frac{1}{2}^{\doteq}$ O.G.	
	Crown	Flint	Crown	Flint
C	1.517328	1.578079	1.510018	1.613232
$\lambda = 5614$	1.516885	1.578611	1.513432	1.619676
F	1.522246	1.589476	1.518654	1.630097
C	.918	1397	8636	16865
$\lambda = 5614$	861	865	8222	10421
F	0	0	0	0
C	10000	10000	10000	10000
$\lambda = 5614$	6112	6192	6047	6179
F	0	0	0	0
	Diff = 80		Diff = 132	

0.61. 1.00

$B = 5.0$ $\gamma = 5.4$ $\delta n^2 = .0000436q$ $\delta\varphi = .00118$

$B = 2.7$ $\gamma = 13.0$ $\delta n^2 = .0000376q$ $\delta\varphi = .00132$

F - D .00614

F - D .00661

C $\lambda = 5614$ F

Crown $3\frac{1}{2}^{\doteq}$.

" $4\frac{1}{2}^{\doteq}$

Flint $3\frac{1}{2}^{\doteq}$

" $4\frac{1}{2}^{\doteq}$

The above magnified 100 times

$\lambda = 5614$

Crown $3\frac{1}{2}^{\doteq}$

" $4\frac{1}{2}^{\doteq}$

Flint $3\frac{1}{2}^{\doteq}$ Secondary spectrum

" $4\frac{1}{2}^{\doteq}$ Secondary spectrum

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Comparison of values of A & B. obtained in different ways - for $4\frac{1}{2}$ Dg.

		Focal length = 1	
		$A = \frac{1}{r_1} + \frac{1}{r_2}$	$-B = \frac{1}{r_3} + \frac{1}{r_4}$
1	C and .5092 = X Marginal Rays united between in front	.5.1286	2.6386
2	" " " " " " Flint " "	.5.1593	2.6643
	Ave. of the above	.5.1439	2.6514
3	By Hastings formulae for finding X ray (48 hours work)	.5.2161	2.7080
	By ordinary formulae - * $\begin{cases} (n_c-1)A + (n'_c-1)B = (n'_x-1)A + (n'_x-1)B \\ 1 = (n_o-1)A + (n'_o-1)B \end{cases}$		
4	C and X = .5092 rays united	.5.2193	2.7107
5 †	C and F " "	.5.0909	2.6043
	Uniting central C and F, unite marginal C and X nearly		

27. = 1.431 − .5.640 = 7.071−

.00118 = .00132 = 7.121

.0.431 + .1.114 − .5.576

	$\frac{A}{B}$
1	1.9437
2	1.9365−
3	1.9262
4	1.9254
5−	1.9548

* $B = \frac{n_c - n_x}{n'_c - n'_x} A$

$1 = (n_o - 1)A - (n'_o - 1)B$

† $B = \frac{n_c - n_7}{n'_c - n'_7} A$

$1 = (n_o - 1)A - (n'_o - 1)B$

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Crown in Front.

H. line

Marginal

$i = 2° 54' 19.1 = \sin 8.70488$

$n = 0.18427$

$\lambda = 1° 54\ 1.0 = \sin 8.52061$

$\gamma = 1\ 0\ 18.1$

$\tau_1 = 1.69305$ / 0.21366

$= \sin 8.24403$

$= 1.96963$

93.246

$\tau_1 = 49.324$

$f_1 = 142.560$

$\frac{.4}{}$

$d_2 = 142.160$

$\tau_2 = 15.139$ / $157.299 = 2.19673$

$\sin \gamma = 8.24403$ / 0.44076

$\tau_2 = 1.18009$

$i = 10° 30' 3''$ $= \sin 9.26067$

$n = 0.18427$

$\lambda = 16\ 10\ 30.$ $= \sin 9.44494$

$\tau_2 = 1.18009$ / 0.62503

$\gamma = 1\ 0\ 18$

$\delta = 6\ 40\ 45 = \sin 9.06562$ / $= 1.55941$

36.2585

15.139

$f_2 = 21.1195 = d_3$

$\tau_3 = 15.459$ / $36.5785 = 1.56323$

$\sin \delta = 9.06562$ / 0.62885

$\tau_3 = 1.18917$

$i = 15° 5' 8''$ $= \sin 9.43968$

$n' = 0.21776$

$\lambda = 9\ 35\ 44$ $= \sin 9.22192$

$\tau_3 = 1.18917$ / 0.41109

$\delta = 6\ 40\ 45$

$\gamma = 0\ 17\ 59 = \sin 7.71859$ / $= 2.69250$

492.61

$\tau_3 = 15.46$

$f_3 = 477.15$

$\frac{.2}{}$

$d_4 = 476.95$

$\tau_4 = 49.32$ / $526.27 = 2.72121$

$\sin \gamma = 7.71859$ / 0.43980

$\tau_4 = 1.69305$

$i = 3° 11' 58''.5 = \sin 8.74675$

$n' = 0.21776$ / $= \sin 8.96451$

$\lambda = 5\ 17\ 14.9$

$\gamma = 0\ 17\ 59.$ $\tau_4 = 1.69305$ / 0.65756

$\delta = 2\ 23\ 15.4 = \sin 8.61972$ / $= 2.03784$

109.104

$\tau_4 = 49.324$

59.780

Central

$n = 0.18427$

$\tau_1 = 1.69305$ / 1.87732

$n-1 = 9.72307$

$f_1 = 142.643 = 2.15425$

$\frac{.4}{}$

$d_2 = 142.243 = 2.15303$

$\tau_2 = 1.18009$ / 3.33312

$d_2 = 2.15303$

$n-1 = 9.72307$ / $1.87610 = 75.180$

$n = 0.18427$

$\tau_2 = 1.18009$ / $1.26436 = 23.140$ / $98.320 = 1.99264$

$f_2 = 21.902 = d_3 = 1.34048$

$n' = 0.21776$

$\tau_3 = 1.18917$ / 2.74741

$d_3 = 1.34048$

$n'-1 = 9.81361$ / $1.15409 = 14.259$ 15.459 / $1.200 = 0.07918$ / 2.66823

$f_3 = 465.83$

$\frac{.2}{}$

$d_4 = 465.63 = 2.66804$

$\tau_4 = 1.69305$ / 4.36109

$d_4 = 2.66804$

$n'-1 = 9.81361$ / $2.48165 = 303.14$

$n' = 0.21776$

$\tau_4 = 1.69305$ / $1.91081 = 81.436$ / $384.576 = 2.58498$ / $= 1.77611$

$f = 59.719$

59.780

$.719$

$60 \overline{)\ .061}$

$.0\,0102$

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Crown in Front.

A. Iris –

Marginal

Central

$n = 0.17818$

$r_1 = 1.69305-$

1.87123

$n-1 = 9.70522$

$f_1 = 146.558 = 2.16601$

$d_2 = 146.158 = 2.16482$

$r_2 = 1.18009$

3.34491

$d_2 = 2.16482$

$n-1 = 9.70522$

$1.87004 = 74.138$

$n = 0.17818$

$r_2 = 1.18009$

$1.35827 = 22.818$

$96.956 = 1.98657$

$f_2 = 22.8213 = 1.35834$

$n' = 0.20633$

$r_3 = 1.18917$

2.75384

$d_3 = 1.35834$

$n'-1 = 9.78402$ 15.459

$1.14236 = 13.8790$

$1.580 = 0.19866$

$= 2.55518$

$f_3 = 359.07$

$d_4 = 358.87 = 2.55493$

$r_4 = 1.69305-$

4.24798

$d_4 = 2.55493$

$n'-1 = 9.78402$

$2.33895 = 218.26$

$n' = 0.20633$

$r_4 = 1.69305-$

$1.89938 = 79.320$

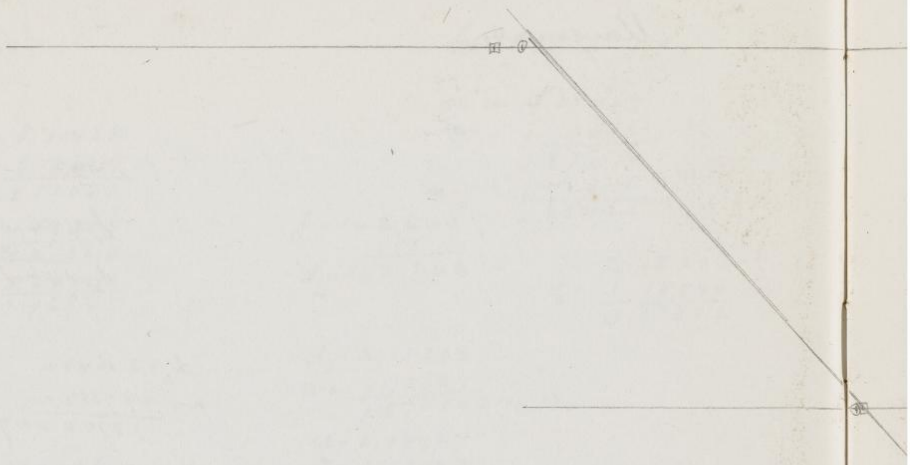
$297.57 = 2.47359$

1.77439

$f_4 = 59.483 =$

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$4\frac{1}{2}$ m

July 11'21

Scale 20 for Iceland ⊙

Scale 40 for Flint ⊡

$n - n_B$

$\frac{1}{\lambda^2}$ on 65 cm brake

$\frac{1}{\lambda^2}$

Scale 20

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Color correction taking into account the distance between the lenses.

K = distance between lenses, expressed as some fractional part of f' $\underline{a}$ that is $K = af'$

Then $\frac{1}{f} = \frac{1}{1-a} \cdot \frac{1}{f'} + \frac{1}{f''}$ when crown is in front.

$$Q = \frac{1}{1-a}\left(\frac{n'-1}{5893}\right)A + \left(\frac{n''-1}{5893}\right)B = 1$$

$$A = -B\left(B + 2\gamma n'_{5893}\right)(1-a)$$

} condition of best color correction

lenses in front -

$r_1 = 49.316$
$r_2 = 15.139$
} lenses $f' = 22.53$ cm total

$r_3 = 15.461$
$r_4 = 49.316$
} flint

$K = 0.30\ a$
$a = \frac{1}{75}$

$$1 = \frac{75}{74}(0.5\text{-}1343)A + 0.61968\,B$$

$$A = -B(-39.167 + 2 \times 13.576 \times 1.51343)$$

$$1 = 0.52037\,A + 0.61968\,B$$

$$A = -1.926\,B \times \tfrac{74}{75}$$

$$1 = -.98882\,B + 0.61968\,B$$

$$1 = -.36914\,B$$

$$B = -2.709$$

$$A = +5.148$$

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When flint is in front.

$$\frac{1}{f} = \frac{1}{1+a}\cdot\frac{1}{f'} + \frac{1}{f''}$$

$$\varphi = \frac{1}{1+a}(n'_{5614}-1)A + (n''_{5614}-1)B = 1$$

$$A = -B\left(\beta + 2\gamma n'_{5614}\right)(1+a)$$

$$\varphi = \frac{1}{1+a}(n'-1)B + (n-1)A = 1$$

$$A = -B(\beta+2\gamma n)\frac{1}{1+a}$$

$K = .20 \quad \therefore \quad a = \frac{1}{75}$

$$a = \frac{K}{f_r} = \frac{K}{(n'-1)B}$$

$$1 = \frac{75}{76}(.51343)A + 0.61968B$$

$$A = -1.926B \times \frac{76}{75}$$

$$1 = -.50669A + 0.61968B$$

$$1 = -.98888B + .61968B$$

$$1 = -.36920B$$

$$B = -2.7086$$

$$A = +5.2862$$

For photographic O.G. formed by advancing the crown lens having given A. B. &c to find a

$$\varphi = \frac{1}{1-a}(n'_G-1)A + (n''_G-1)B = 1$$

$$1 = \frac{1}{1-a}(.52400)\overset{5.4073}{5.1593} + (.64121)\overset{-2.8075}{(-2.6643)}$$

$$1 = \frac{1}{1-a}(2.7035) - 1.7083$$

$$2.7083 = \frac{2.7035}{1-a}$$

$$2.7083 - 2.7083a = 2.7035$$

$$-2.7083a = -.0058$$

$$a = +.00214$$

$$K = .045$$

This cannot be correct. The same values of A + B as above derived

see next page

$$1 = \frac{1}{1-a}(2.8334) - 1.8002$$

$$2.8002 = \frac{2.8334}{1-a}$$

$$2.8002 - 2.8002a = 2.8334$$

$$-2.8002a = .0334$$

$$a = .012$$

$$K = .27$$

This would make the G line have same focal length as the $\lambda = 5614$.

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line f = line $\frac{1}{3}$ F – G – Photographic lens – continued

* $\frac{1}{1-a}(n_f - 1)A + (n'_f - 1)B = \frac{1}{1-a}(n_H - 1)A + (n'_H - 1)B.$

$\frac{1}{1-a}(.52030)\,5.4073 - (.63341)\,2.8075 = \frac{1}{1-a}(.52853)\,5.4073 - (.65105)\,2.8075$

$\frac{.52030 \times 5.4073}{1-a} - \frac{.52853 \times 5.4073}{1-a} = .63341 \times 2.8075 - .65105 \times 2.8075$

$a = 1 - \frac{.52030 \times 5.4073 - .52853 \times 5.4073}{.63341 \times 2.8075 - .65105 \times 2.8075}$

$a = 1 - \frac{(.52030 - .52853)\,5.4073}{(.63341 - .65105)\,2.8075}$

$a = 1 - \frac{-.044502}{-.049625}$

$a = 1 - .89659$

$a = 0.10141$

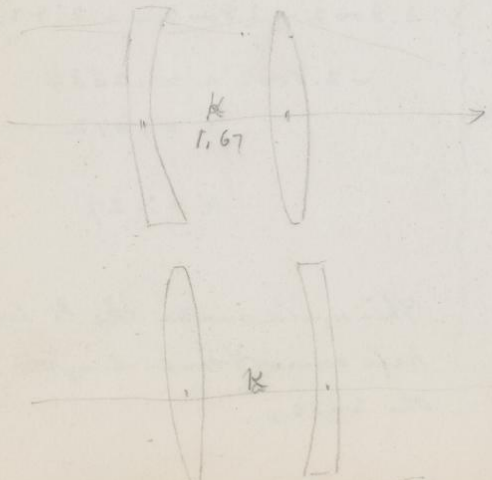
$K = a f_2 = 2.23$ inches

What is ~~to~~ convert the 4½ A-G. (flint in front) into a photographic A.G. it should be reversed, bringing the crown in front & optical center ~~being~~ should then be brought out a distance of 2.23 in from thick of the flint. between surfaces 1.93 .30

---

* This formulae reduces to $a = 1 - \frac{A(n_f - n_H)}{B(n'_H - n'_f)}$ ✓

~~In this case where B is negative~~ ~~$a = 1 - \frac{A(n_f - n_H)}{B(n_f - n'_H)}$~~



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To find separation so that with flint in front, = telescope O.G. 291
but with crown in front, it will be a photographic O.G.

see 2 pages over

Conditions: Flint in front. $\frac{1}{1+a}(n_0-1)A + (n'_0-1)B = 1$ *

$\frac{A}{B} = -(B + 2f n'_0)(1+a)$

Crown in front, n_f united with n_H

$a = 1 - \frac{A}{B}\cdot\frac{n_f - n_H}{n'_H - n'_f}$

reduces to * $-B = (n_0-1)(B + 2f n'_0) = 1$

Indices as in 4½" O. G.

$\frac{1}{1+a}(.51343)A + .61968B = 1$

$\frac{A}{B} = -1.926 \times (1+a)$

$a = 1 - \frac{-1.926(.00823)(1+a)}{.01764}$

~~$a = 1 - .8986(1-a)$~~

$a = 1 - .8986 + .8986a$

$.1014a = .1014$

$a = 1$

$a = .053405$

~~$a = 0.1014$~~

~~$\frac{1}{1.1014}(.51343 \times (-1.926)B) + .61968B = 1$~~

$-.89781B + .61968B = 1$

$-.27813B = 1$

$-B = 3.5956$

$A = 6.9249$

$K = af_2$

$\frac{A}{B} = -1.926 \times 1.0534 = 2.0284$

$\frac{1}{1.0534}(.51343)\frac{-1.926}{2.0284}B + .61968B = 1$

$-.98888B + .61968B = 1$

$-.36920B = 1$

$B = -2.7086$

$\frac{1}{f_1} = (n_0-1)A$

$f_1 = 0.28125$

$k = af_1 = .02852$ = dist between lenses when $Z_0 = 1$

When $Z_0 = 58.5$ $k = 1.668$

$A = B(B+2fn'_0)(1+a)$

$= 2.7086 \times 1.926 \times 1.0534$

$= 5.4953$

$\frac{1}{1+a}(.51343)A + .61968B = 1$

$\frac{A}{B} = -1.926 - 1.926a$

$a = 1 - \left((-1.926 - 1.926a)\frac{-.00823}{.01764}\right)$

$a = 1 - [(-1.926 - 1.926a)(-.46655)]$

$a = 1 - [.8986 + .8986a]$

$a = 1 - .8986 - .8986a$

$a + .8986a = .1014$

$1.8986a = .1014$

$a = .053405$

A

823	7.915740
1764	8.246510
.46655 =	9.668250
1.926	0.28466
.8986	9.953590

.1014 =	9.00604
1.8986 −	0.27846
a =	8.72758

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To find an expression for the Secondary Spectrum
based on article by Prof. E. S. Hastings in the American Journal
of Science Vol. 37. Apr. 1889.

$$\frac{1}{f_0} = \varphi_0 = (n_0 - 1)A + (n_0' - 1)B = 1 \quad \text{---------} \quad (1)$$

$$A = -B\frac{dn'}{dn} \quad \text{also} \quad A = -B(\beta + 2\gamma n_0) \text{----} \quad (2)$$

Instead of expressing value for φ_0 in terms of A, as in the above article, express it in terms of B.

$$\varphi_0 = -(n_0 - 1)\frac{dn'}{dn}B + (n_0' - 1)B$$

$$\varphi_n = -(n_0 + \delta n - 1)\frac{dn'}{dn}B + (n_0' + \delta n' - 1)B \quad \text{---} \quad (b)$$

$$\varphi_0 - \varphi_n = \delta\varphi = -\frac{dn'}{dn}.\delta n.B + \delta n' B$$

$$\delta\varphi = \left(\delta n' - \frac{dn'}{dn}.\delta n\right)B$$

As shown in Hastings article $\delta n' = (\beta + 2\gamma n)\delta n + \gamma(\delta n)^2 \quad (a)$

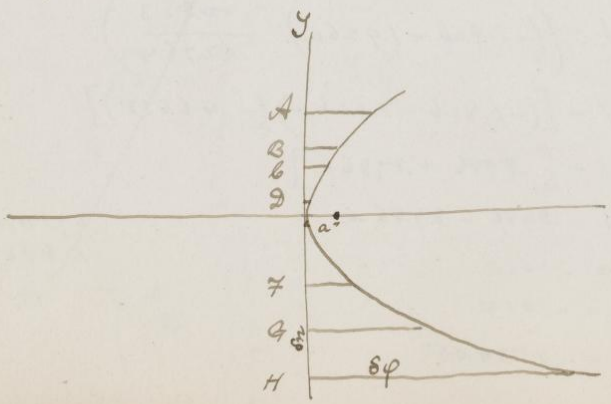
$$= \frac{dn'}{dn}.\delta n + \gamma(\delta n)^2$$

$$\delta\varphi = \left\{\frac{dn'}{dn}.\delta n + \gamma(\delta n)^2 - \frac{dn'}{dn}.\delta n\right\}B$$

$$\delta\varphi = B\gamma(\delta n)^2 \quad (3).$$

which is the expression required for the secondary spectrum.
δn is the difference between n_0 and index considered (b).

Hence if we plot the values of n (crown glass) to scale at right angles to the axis of O.G. (~~abscissa~~ ordinates) and draw abscissæ equal to δn for corresponding values of n, the curve so traced will be a parabola



Eq. of parabola
$y^2 = 4ax$
$\delta n^2 = \frac{1}{B\gamma}.\delta\varphi$
$a = \frac{1}{4B\gamma}$ = abs. of focus
$x = \delta\varphi$
$y = \delta n$

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To find a for 4½" O.G.

$$a = \frac{1}{4By} \qquad \frac{d^2\varphi}{dn^2} = 2By$$

$B = -.2,7080 = \log 0.43265-$
$y = 13.576 = \quad 1.13278$
$4 = \quad\quad 0.60206$
$\quad\quad 2.16749$

$a = -.006800 = 7.832551$
$\quad\quad 1.775251-$
$\quad\quad 9.60776$

$= 1.565543$

$By = 36.76$

In 3½" O.G. $By = 18.12$

Eq. Focal Lenght = 59.6
$a = -0.4053$

As that O.G. is the best in which a is greatest

If for the combinations of several kinds of glass in pairs the values of By are tabulated

Those combinations where By is small are the best and when $By = 0$ the color correction is perfect. $\frac{d^2\varphi}{dn^2} = 2By = 0$

For a near approximation - B can be found from eq. (1) + (2). and y from eq. (a). as in Hastings article

---

4½" O.G.

δn_H $n_0 - n_H = .01510 = l. 8.1790$
$\quad\quad 6.3580$
$By = 36.76 = 1.56534$
$\delta\varphi = .008383 = 7.9234$

$7_H = 59.719 = 1.77611$
$7_0 = 59.374 = 1.77360$
$\quad\quad 0.00251$

when $7_0 = 1.$
$7_H = 1.0058$

$\delta 7_H = .348 \quad \frac{\delta 7_H}{7_H} = .347$ (c)

To express (3) in terms of 7.

$$\delta\varphi = \frac{1}{7_H} - \frac{1}{7_0} = \frac{7_0 - 7_H}{7_0\, 7_H} = \frac{\delta 7}{7_H}$$ because $7_0 = 1$ see (1)

to 3 significant figures $7_H = 7_0$ see (c)

Hence $\delta\varphi = \delta 7 = By(\delta n)^2$

The above proves that the two rays that must be united at the same focus to give the best color correction must be such that their index of refraction for the crown glass must differ by the same amount from $n_{1.5614}$ one greater and the other less, which is the conclusion arrived at in finding No. 2

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With flint in front O.G. telescopic but with crown in front. Photographic —

To find the separation K.

Telescope

$$\frac{1}{1+a}(n'-1)B + (n-1)A = 1 \qquad (1)$$

$$A = -B \cdot \frac{\beta + 2\gamma n}{1+a}$$

Photographic

$$a = 1 - \frac{A}{B} \cdot \frac{n_f - n_H}{n'_H - n'_f} \qquad (2)$$

$$\left[(n-1) - \frac{(n'-1)}{\beta + 2\gamma n}\right] A = 1$$

$$B = -A \cdot \frac{1+a}{\beta + 2\gamma n}$$

$$a^2 = 1 - (\beta + 2\gamma n)\frac{n_f - n_H}{n'_H - n'_f}$$

$K =$

This will not work because $\underline{a}$ in eq. (1) $= \frac{K}{f}$ of flint

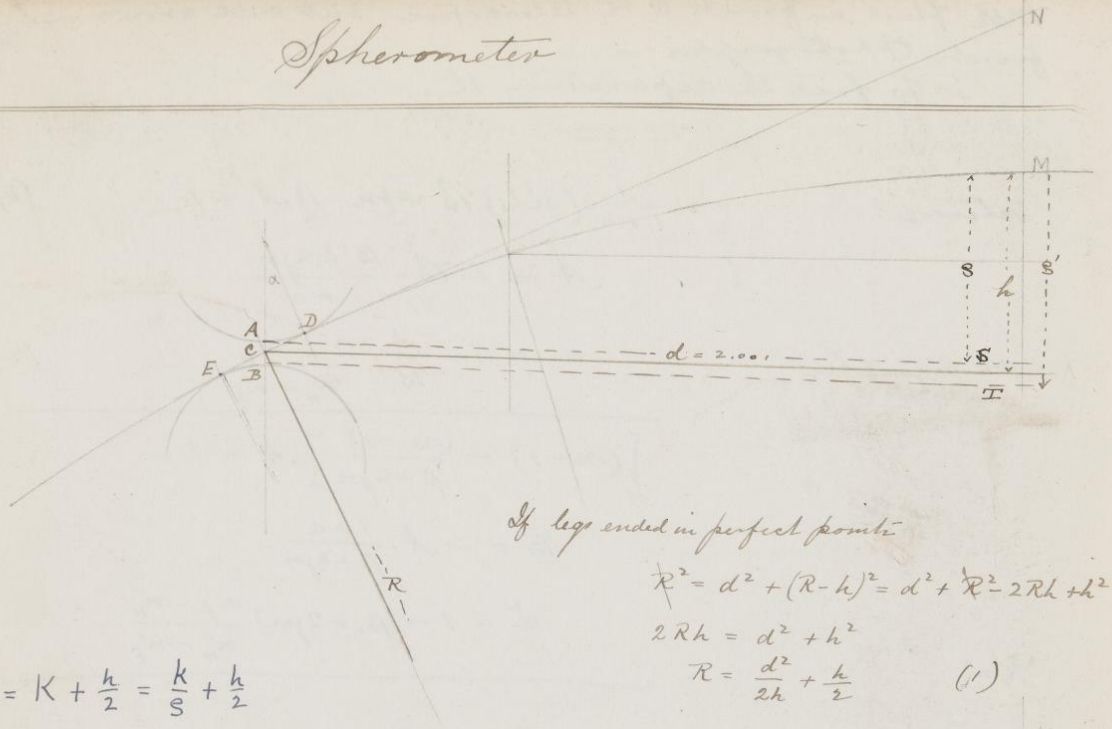
$\underline{a}$ in eq 2 $= \frac{K}{f}$ of crown

and as K is the same in both cases $\underline{a}$ is therefore different

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Spherometer



If legs ended in perfect points

$$R^2 = d^2 + (R-h)^2 = d^2 + R^2 - 2Rh + h^2$$

$$2Rh = d^2 + h^2$$

$$R = \frac{d^2}{2h} + \frac{h}{2} \qquad (1)$$

$$R = K + \frac{h}{2} = \frac{k}{s} + \frac{h}{2}$$

But this condition being impossible, make the legs end in spherical surfaces of radius r about $\frac{1}{100}$", which will seldom exceed $\frac{R}{1000}$ and CD will be less than $\frac{R}{15000}$

DE is therefore sensibly straight, and AC = BC = $\frac{1}{2}$ AB

G. P. H.'s Spherometer has 100 threads per inch, and d = 2.001

Let s be the number of turns of screw to measure MS (convex surface)

" s' " " " " " MT' (concave ")

$$\frac{h}{100} = s + AC = s' - AC \qquad \text{or} \quad s = \frac{h}{100} - AC \qquad s' = \frac{h}{100} + AC$$

G. P. H.'s Spherometer repaired by Mr. Lundin

after the fire - legs end in arc of circle d = 2.000 ±

Measurement of inside surface of 4½ in O.G. r = 14.959

convex $100\frac{h}{s} = \frac{s}{13.403} + .014 = 13.417$

concave $100\frac{h}{s} = 13.432 - .014 = 13.418$

$$K = \frac{d^2}{2h} = \frac{4}{\frac{2}{100}(s+.014)} = \frac{2}{\frac{1}{100}(s+.014)} = \frac{200.}{s + \frac{s}{957.35}} = \frac{200}{\frac{958.35}{957.35}s} = \frac{200 \times \frac{957.35}{958.35} = k}{s} = \frac{k}{s}$$

(14.959)

k = log 2.30056 ✓ for convex = 2.30056 } d = 2.000 make $r_2 = r_3 = 14.973$

= " 2.30150 ✓ " concave = 2.30150 }

2.30099 } d = 2.001 " = 14.988

2.30193 }

$$\frac{k}{s} = \frac{d^2}{2h} = \frac{4}{2 \cdot \frac{s}{100}} = \frac{2}{\frac{s}{100}} = \frac{200}{s}$$

$\therefore k = 200.$ ---------- { 2.30103 } Inside edge = 2.000

2.30197 }

k = 200.43 for concave

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Spherometer

To find the value of k for C. P. Howard's Spherometer - in which

number of threads per inch = 100

d = 2.001 inch.

The inner surfaces of 4½" Object Glass have same radius - one being convex and the other concave.

Three readings of the Spherometer on these surfaces on different days gave the following -

Date, 1892.	Surface	S	AC - BC in fraction of thread of screw.	k	log k
Nov 8th	Convex	13.436	.009	.13445	2.30117
"	Concave	13.454	.009	.13445	2.30175
Nov. 12th	Convex	13.4325	.011½	.13444	2.30109
"	Concave	13.4533	.011½	.13444	2.30184
Nov. 18th	Convex	13.431	.010	.13441	2.30114
"	Concave	13.451	.010	.13441	2.30179

The readings on the first two dates, were taken with lenses in the photographic cell, - those on the last date were taken with lenses out of the cell and surfaces cleaned with alcohol.

While all were as good as could be got at the time, the last is considered the most reliable - therefore (May 19, 94 13.433 / 13.454)

This spherometer lost in fire remade by the Pendulum 1901

$$\log k = \begin{cases} 2.30114 & \text{for convex surface} \\ 2.30179 & \text{" concave "} \end{cases}$$

in the formula $R = \frac{k}{S} + \frac{S}{200}$

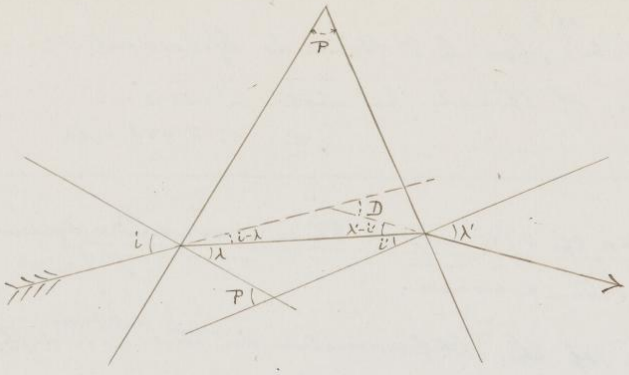
See 1st front page

{ see 7th O. P. Book p. 240 }

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Deviation and Dispersion through Prism -



$\sin\lambda = \frac{\sin i}{n}$

$i' = P - \lambda$

$\sin\lambda' = n \sin i'$

$D = i - \lambda + \lambda' - i'$

$= i - \chi + \lambda' - P + \chi$

$= i + \lambda' - P$

For small angles $\lambda' = ni'$ hence $D = i + ni' - P$

$= i + n(P - \lambda) - P$

$= i + nP - n\lambda - P$

$= i + P(n-1) - n\lambda$

$= i + P(n-1) - \lambda \cdot \frac{i}{\lambda}$

$= P(n-1)$

The deviation is proportional to the angle of the prism and to $(n-1)$

To find the angles of two prisms to give the same dispersion

Crown

$D = P(n-1)$

$dD = P\,dn$

Flint

$D' = P'(n'-1)$

$dD' = P'\,dn'$

$dD = dD'$

$P\,dn = P'\,dn'$

$P' = P \cdot \frac{dn}{dn'} = P\left(\frac{}{\beta + 2\gamma n}\right)$

$D = P(n-1)$

$D + \delta D = P(n+\delta n) - P$

$\delta D = P\,\delta n$

$P\,\delta n = P'\delta n'$

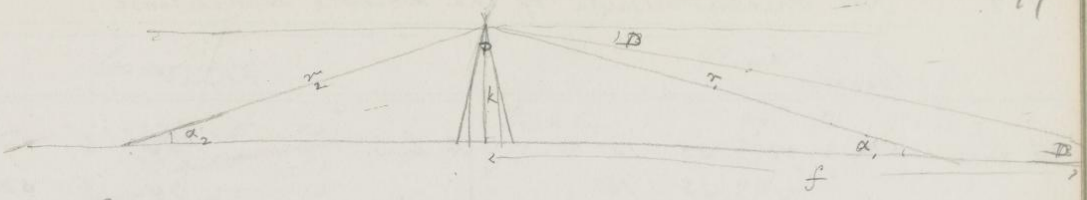
$P' = P\,\frac{\delta n}{\delta n'} =$

Example, What angle of flint prism will give same dispersion as 60° prism of crown - glass $4\frac{1}{2}$"

$P = 60°$ $\quad \delta n = .00863$ $\quad \delta n' = .01684$ (c-f) $\quad P' = 30°\,45'$

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Refracting angle of lens = $\alpha_1 + \alpha_2$

$$P = \alpha_1 + \alpha_2$$

$$P = \frac{k}{r_1} + \frac{k}{r_2}$$

$$D = \left(\frac{k}{r_1} + \frac{k}{r_2}\right)(n-1)$$

This gives the deviation of a ray by the lens. and measures the strength of the lens.

For parallel rays.

$$\sin D = \frac{k}{f}$$

For small angles. $D = \frac{k}{f}$

For small lenses. $\frac{k}{f} = \left(\frac{k}{r_1} + \frac{k}{r_2}\right)(n-1)$

$$\frac{1}{f} = \left(\frac{1}{r_1} + \frac{1}{r_2}\right)(n-1)$$

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4½ in. All measurements of the Double Deviation.

Crown

A line
75° 38′ 15″
75 38 15

B line
75° 5′ 8″ 30″
75 5 8 30
75 5 8 15
75 5 8 23

C line
76° 7′ 0″ } Original
76 7 11 } Original
76 7 23 } Original
76 7 32

λ = 5614 line
76° 42′ 49″ } Original
76 43 29 } Original
76 43 52
76 43 52

7 line
77° 38′ 4″ } Original
77 38 18 } Original
77 38 0

Flint

A. line
94° 6′ 27″
94 6 52

B line
94° 45′ 52″ +15
94 45 30 +7
94 45 38 +1
94 45 23 −14
94 45 15 −22
94 45 0 −37
94 45 15 Feb 15 91 −22
94 45 56 +19
94 46 22 +45
94 45 57 +20
Ave. = 94 45 37

C line
95° 5′ 33″ } Original
95 5 30 } Original
95 5 8
95 5 34
95 6 7
95 6 30 Nov. 4 '91
95 6 33 Nov. 4 '91
95 6 37 Nov. 4 '91
95 6 23 Nov. 4 '91

λ = 5614 line
96° 20′ 45″ −22
96 20 42 Original −25
96 20 56 −11
+16 96 21 34 +27
+12 96 21 20 +23
18 −18 96 21 0 −7
0 96 21 18 +11
−11 96 21 7 0
96 21 7

7 line
98° 23′ 34″ } Original
98 23 52 } Original
98 23 52
98 24 3
98 23 22
98 23 58

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Lesoume

Dark line	77°	53′	45″
$\frac{1}{3}$ 7 – 9.	77	53	37
λ = 467	77	53	15

G line 78° 34′ 52″ Feb 22 91

Centre line of group, 2 lines lie towards the red. Looks like a bright line with dark line on edge.

g line 78° 44′ 22″

H line 79° 23′ 0″ "repeated"

(Inner H.)

Hunt

Dark line	99°	2′	52″
$\frac{1}{3}$ 7 – 9	99	3	15
	99	3	15
	99	3	22
	99	3	0
	99	3	30

G line 100° 36′ 37″

g line 101° 1′ 6″
101 1 4

H line 102° 35′ 45″
102 35 45

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Charles S. Hastings measured the Lerroux and Klein Prisms for 4½" C. G. Dec. 28 1891. Prob. error not greater than ±3" as follows

Double Deviation

	Lerroux			CRH error	Klein			CRH error
A.	75°	38′	15.″2	0	94°	5′	48.″8	+ 1′ 9″
B.	75	57	53.2	+32″	94	44	39.8	+ 0 57
b.	76	7	24.0	−4″	95	4	55.8	+ 1 0
λ = 5614	76	48	17.8	−4′ 48″	96	30	{39.5 / 37.4}	− 9 31
7.	77	38	17.8	−11″	98	23	26.8	+ 1 23
9.	78	33	20.8	+39″	100	34	57.5	+ 1 43
H.	79	21	8.5	+1′ 52″	102	34	16.9	+ 1 28

b 2δ = 76° 7′ 24″
½δ = 19 1 51
½α = 30 0 15 / 49 2 6 = sin 9.878010
½α = 9.699025 = 0.178985

CRH = 1.51003 / 2 / .00001

b 2δ = 95° 4 56
½δ = 23 46 14
30 0 17
53 46 31 = 9.906715
9.699032
1.61318 = 0.207683
23 / .00005

λ = 5614 2δ = 76 48 19
½δ = 19 12 4½
30 0 15
49 12 19½ = 9.879128
9.699025
1.51392 = 0.180103
43 / 97
CRH .00049

λ = 5614 96 30 38
24 7 39½
30 0 17
54 7 56½ = 9.908684
9.699032
0.209652 / 9

1.62051 / 180 / 1.62871 — 1.62051 / 1968 / .00083

7 2δ = 77 38 18
½δ = 19 24 34½
30 0 15
49 24 49½ = 9.880486
9.699025
1.51866 = 0.181461 / 43

1.51866 / 1.51003 / .00863 — 1.51866 / 65 / .00001

1.51866 / 1.51392 / 474 / 1.50918

1.51292 / .00574 / D = 1.51307

0.5131 = 9.7104
.00583 = 7.9360
V = 59.48 = 1.7744

7 2δ = 98 22 27
24 35 37 =
30 0 17
54 35 54 = 9.911217
9.699032
1.62999 / .63040 CRH / .00021 — 0.212185 / .212213 / .000028

B 2δ = 75 57 53
½δ = 18 59 28
½α = 30 0 15
48 59 43 = sin 9.877749
½α = 9.699025
0.178724 / 20

1.50912

7 = 1.62999
C = 1.61318
.01681

n = 1 − 0.6287 = 9.7984
.00681 = 8.2256
= 1.5728

V = 37.40

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4½ in. O.G. 4 and B central

Nov. 1905

Corona

B line
$2\delta = 75^\circ\ 57'\ 53''$
$\frac{1}{2}\delta = 18\ 59\ 28$ ✓
$\frac{1}{2}\alpha = 30\ 0\ 15$ ✓
$\frac{1}{2}(\delta+\alpha) = 48\ 59\ 43$ ✓

sin 9.8777488 ✓
sin ½α = 9.6990247 ✓

$n = 1.509121$ ✓ = 0.1787241 ✓
$n-1 = 0.509121$ ✓ = 9.706821 ✓

Flint

B line
$2\delta = 94^\circ\ 45'\ 40''$
$\frac{1}{2}\delta = 23\ 41\ 25$ ✓
$\frac{1}{2}\alpha = 30\ 0\ 17$ ✓
$\frac{1}{2}(\delta+\alpha) = 53\ 41\ 42$ =

sin 9.9062686 ✓
9.6990320 ✓
$n' = 1.611523$ ✓ = 0.2072366 ✓
$n'-1 = 0.611523$ ✓ = 9.786413 ✓

F line
$2\delta = 77^\circ\ 38'\ 18''$ ✓
$\frac{1}{2}\delta = 19\ 24\ 34\frac{1}{2}$ ✓
$\frac{1}{2}\alpha = 30\ 0\ 15$ ✓
$49\ 24\ 49\frac{1}{2}$ =

sin 9.8804863 ✓
9.6990247 ✓
$n = 1.518664$ ✓ = 0.1814616 ✓
$n-1 = 0.518664$ ✓ = 9.714886 ✓

F line
$2\delta = 98^\circ\ 23'\ 27''$ ✓
$\frac{1}{2}\delta = 24\ 35\ 52$ ✓
$\frac{1}{2}\alpha = 30\ 0\ 17$ ✓
$54\ 36\ 9$ =

sin 9.9112392 ✓
9.6990320 ✓
$n' = 1.630074$ ✓ = 0.2122072 ✓
$n-1 = 0.630074$ ✓ 9.799392 ✓

B
$n' = 0.2072366$ ✓ N =
$n = 0.1787241$ ✓
0.0285125 ✓
$N = 1.067856$ ✓
$N-1 = 0.067856$ ✓ = 8.83159 ✓

$\frac{n'}{n}$ F
$n' = 0.2122072$ ✓
$n = 0.1814616$ ✓
$N = 1.073360$ ✓ = 0.0307456 ✓
$N-1 = 0.073360$ ✓ = 8.865546 ✓

$t_1 = .2$
$t_2 = .4$
$t_3 = 14.957$
$t_4 = 49.865$
as measured on the O.G.

B central

$n' = 0.2072372$ ✓
$\tau = 1.657702$ ✓
8.864494 ✓
$n'-1 = 9.786412$ ✓
$f_1 = 119.819$ ✓ = 2.078524 ✓
,200
$d_2 = 119.619$ ✓ = 2.07780 ✓
$\tau_2 = 1.17490$ ✓
3.252270 ✓

$N = 0.0285121$ ✓
$\tau = 1.17490$ ✓
1.203412 ✓ = 15.974 ✓

$d = 2.07780$ ✓
$N-1 = 8.83159$ ✓
0.90939 ✓ 8.1169 ✓
7.8571 ✓ 0.89526 ✓
$f_2 = 227.740$ ✓ = 2.35744 ✓
,400
$d_4 = 227.340$ ✓ = 2.356672 ✓
$\tau_4 = 1.697792$ ✓
4.05447 ✓

$n = 0.178722$ ✓
$\tau = 1.697792$ ✓
1.876514 ✓ = 75.252 ✓
$d = 2.356672$ ✓
$n-1 = 9.70682$ ✓
2.063492 ✓ = 115.743 ✓
190.995 ✓ = 2.28102 ✓
$f_4 = 59.354$ ✓ = 1.77345 ✓

F

$n' = 0.212207$ ✓
$\tau_1 = 1.657702$ ✓
1.869909 ✓
$n'-1 = 9.799392$ ✓
117.630 ✓ = 2.070524 ✓
,200
117.430 ✓ = 2.06978 ✓
$\tau_2 = 1.17490$ ✓
3.244678 ✓

$N = 0.0307456$ ✓
1.17490
1.205642 ✓ = 16.0563 ✓

$d = 2.06978$ ✓
$N-1 = 8.865546$ ✓
0.935524 ✓ 8.6147 ✓
7.4416 ✓ 0.871662 ✓
$f_2 = 236.056$ ✓ = 2.373012 ✓
,400
$d_4 = 235.656$ ✓ = 2.372284 ✓
$\tau_4 = 1.697792$ ✓
4.070076 ✓

$n = 0.181461$ ✓
$\tau = 1.697792$ ✓
1.879253 ✓ 75.728 ✓

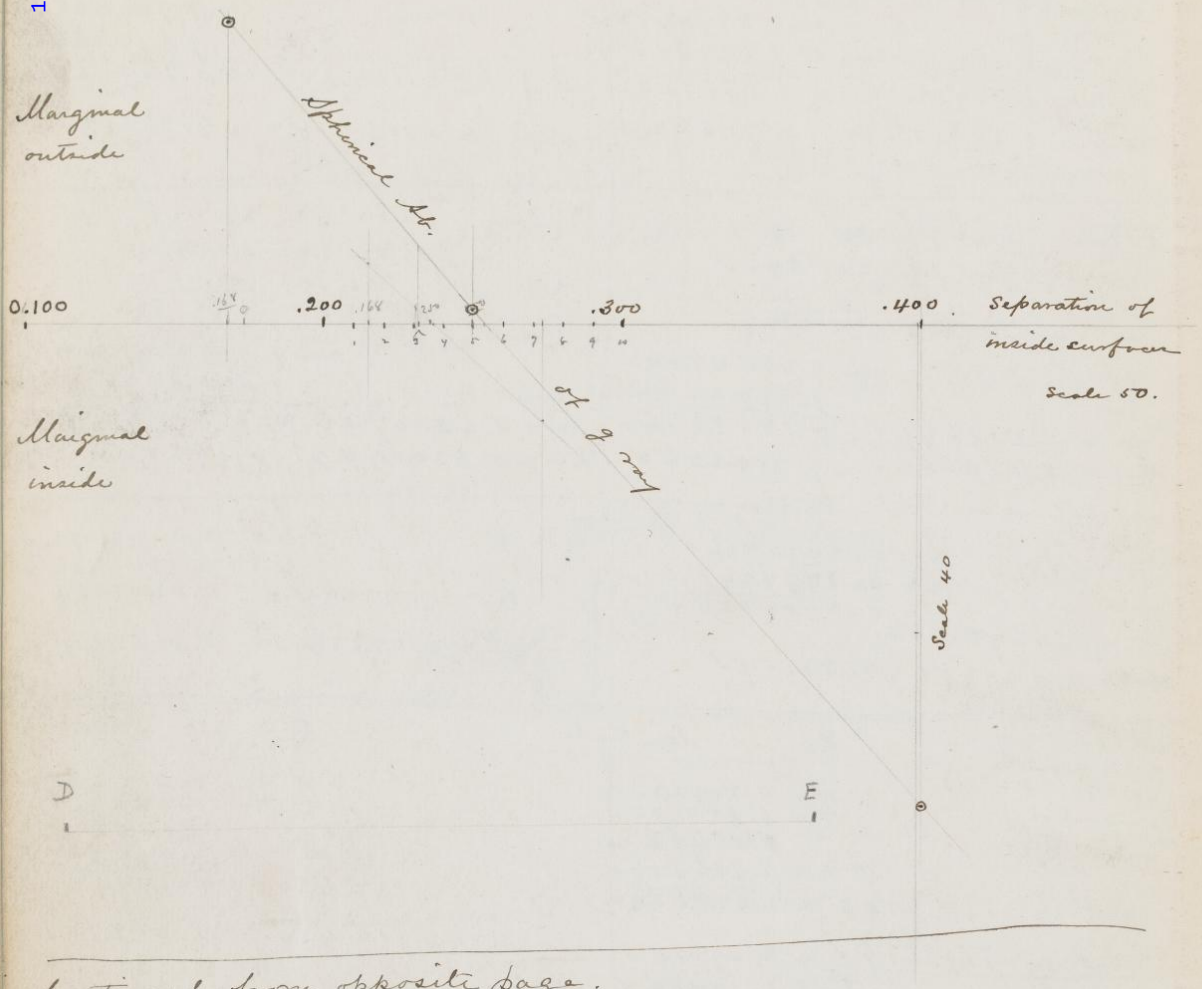
$d = 2.372284$ ✓
$n-1 = 9.714882$ ✓
2.087166 ✓ = 122.226 ✓
197.954 ✓ = 2.296562 ✓
$f_4 = 59.362$ ✓ = 1.77351 ✓
.3574 ✓ B short
.008 ✓
60/ .00013

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4½ O. G. reversed for photographic O. G.

Spherical Aberration of the g ray corresponding to distance apart of inside surfaces.



continued from opposite page.

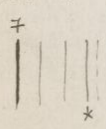
B n = 1.52149
56.4 n = 1.51590
.00559

56.4 = 1.51590
B = 1.51135
.00455

1.52045 = Index of Refr. of ray to combine with the B line.

°	′	″		″
78	16	45	-	35
78	18	15	+	55
78	16	0	-	80
78	18	15	+	55
78	18	15	+	55
78	17	0	-	20
78	18	0	+	40
78	17	20		

Third line from 7 towards red.



7 = 78 26 15
78 15 16
2 10 59
Deviation less than 4 line } 5.30"

3rd dispersion line commence here.

4) 78 15 16
19 33 49
30 4 38
49 38 27

= 9.881954
½ρ = 9.699982
1.52045 = 0.181972

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1889phae.proj..920H

7 in Jena - 18 -

418 Glass - Angle of Prism Dec. 9th 1893.

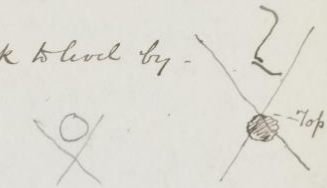
	119°	51′	15″	P	
	0	0	30		
β =	119	50	45	= 60°	9′ 15″

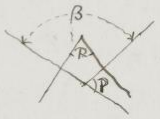
	129	53	0		
	10	2	15		
β =	119	50	45	= 60°	9′ 15″

	419	51	45		
	300	1	0		
β =	119	50	45	= 60°	9′ 15″

Angle of prism = 60° 9′ 15″

Mark to level by -





P = 180 − β

60° 7′ 10″ Instrument worked hard - when measurement built. May 24 94 Objectives 92.

Index of Refraction $n = \frac{\sin \frac{1}{2}(P+\delta)}{\sin \frac{1}{2} P}$

δ = min. dev. of ray.

(B) line ~~C~~

196	40	15
120	1	15
76	39	0

206	40	15
130	1	30
76	38	45

186	40	7
110	1	15
76	38	52

	4)	76	38	50
½δ =		19	9	42
½P =		30	4	38
		49	14	20 = sin 9.879347
			½P = "	9.699982
				0.179365

n = 1.51135

64

+ 22

76 38 50
37 30
1′ 20″

57
35
22

F line

208	27	15
130	1	0
78	26	15

180	28	15
102	2	0
78	26	15

198	27	30
120	1	15
78	26	15

	4)	78	26	15
		19	36	34
		30	4	38
		49	41	12 = sin 9.882250
			½P = "	9.699982
				= 0.182268

n = 1.52149

76

+ 20

78° 54′ 32″
26 28

1.52149 7
1.51590 56.4
.00559
1.51590 56.4
1.51031

1.51590 B
1.51135 56.4
.00455
.00455.

5614 line

202	28	15
125	1	15
77	27	0

177	28	45
100	2	0
77	26	45

	4)	77	26	52
		19	21	43
		30	4	38
		49	26	21
	= sin.			9.880652
	"			9.699982
				0.180670

n = 1.51590

679

D | | | 5614 E |

D line

197	19	30
120	2	15
77	17	15

187	19	15
110	1	45
77	17	30

	4)	77	17	38
		19	19	24
		30	4	38
		49	24	2 = sin 9.880402
				9.699982
1.51590				= 0.180420

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7½ in Jena Flint #23

$n = \frac{\sin \frac{1}{2}(P+\delta)}{\sin \frac{1}{2}P}$ Augusch 4 94

B line

$\delta = 80^\circ\ 3'\ 0''$
$\quad\ 80\ 2\ 30$
$\delta = 80^\circ\ 2'\ 45''$

$P = 180 - \beta = 59^\circ\ 57'\ 30''$
$\frac{1}{2}P = \quad 29\ 58\ 45$

$\frac{1}{2}\delta = 20\ 0\ 41$
$\frac{1}{2}P = 29\ 58\ 45$
$49\ 59\ 26 = \sin\ 9.884194$
$\frac{1}{2}P = \ \ "\ \ 9.698696$
0.185498

$n' = 1.5\text{-}3285\text{-}$

D. line

$2\delta = 80\ 47\ 15\text{-}$
$\quad\ 80\ 47\ 30$
Ave $80\ 47\ 22\frac{1}{2}$
$\quad\ 80\ 47\ 15\text{-}$
$\frac{1}{2}\delta = 20\ 11\ 49 = \sin$
$\quad\ 29\ 58\ 45$
$50\ 10\ 34 = \sin\ 9.885371$
$\quad\ 9.698696$
0.186675

$n' = 1.5\text{-}3700$

$80\ 47\ 0$
$80\ 47\ 15\text{-}$
$80\ 47\ 8$

$.000053$
80
135
67

F line

$2\delta = 82^\circ\ 8'\ 0''$
$\quad\ 82\ 7\ 30$
Ave $82\ 7\ 45\text{-}$
$\frac{1}{2}\delta = 20\ 31\ 59$
$\quad\ 29\ 58\ 45\text{-}$
$50\ 30\ 44 = \sin\ 9.887482$
$\quad\ 9.698696$
0.188786

$n' = 1.5\text{-}4449$
$1.5\text{-}4443$, on small book

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Earth quake shock. Sunday. Aug. 10th 1884. 2h 07m p. m. whilst at the dinner table.

Yellow color in Parlor-
White
Raw Sienna
Raw Umber
Pale Yellow Ochre

Color of Dome ~~Dec~~ 1901 (Warm Gray)
White
Scotch Black } most of raw umber
Raw Umber
Raw Sienna
Venetian Red
In order of quantity used

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astro-ph/9603044 26 Mar 1996

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