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SOME OBSERVATIONS ON THE RESOLVING POWER OF THE MICHELSON ECHELON SPECTROSCOPE.[1]

By P. ZEEMAN.

1. ON A recent occasion[2] I gave a few observations on this subject. The acquisition of some new data induces me to return to it in this place.

In his "Investigations in Optics," Lord Rayleigh[3] expressed the wish that spectroscopists in possession of powerful instruments would compare the actual resolving power with that of which they are theoretically capable, and remarked that a carefully arranged succession of tests of gradually increasing difficulty would be of especial value.

I remembered these remarks as I tested the very original echelon invented by Michelson.

The echelon at my disposal, made by Hilger, London, consists of thirty plates each about 7.8 mm thick, made of light flint-glass, set with 1 mm steps. A clear aperture of 1 mm is left beyond the width of the largest glass plate. The number of apertures n, operative in the formation of the spectrum, is hereby one more than the number of plates. The mounting was somewhat improvised. Telescope and collimator belonging to a Kirchhoff spectroscope were employed. The telescope had object-glasses of 50 cm focus and 38 mm aperture. It is evident that when the mounting is made especially it is advisable to have glasses of shorter focus, so as to get greater intensity.

Denoting by $d\lambda_1$ the difference of wave-length of spectral lines when they are just distinguishable as separate in the spec-

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[1] Communicated by the author as advance proof of a paper to appear in the Proceedings of the *Amsterdam Academy of Sciences.*

[2] BOSSCHA, *Collection of Memoirs, Archiv. Néerl.*, Sér. II, **6**, 319, 1901.

[3] *Phil. Mag.*, 1879, 1880.

troscope, by t the thickness of the plates of glass, and by n the above mentioned number, then we have

$$q_t = \frac{d\lambda_1}{\lambda} = \frac{\lambda}{knt} , \tag{1}$$

if

$$k = (\mu - 1) - \lambda \frac{d\mu}{d\lambda} .$$

The resolving power is given by

$$r = \frac{\lambda}{d\lambda_1} = \frac{knt}{\lambda} . \tag{2}$$

For the green line $\lambda = 5460$ we obtain in the case of our echelon,

$$r = \frac{0.63 \times 31 \times 7.8}{5460 \times 10^{-7}} = 280000 \text{ and } q_t = \frac{d\lambda_1}{\lambda} = 3.6 \times 10^{-6} .$$

In the calculation of k I use the following values of the refractive indices given to me by Hilger:

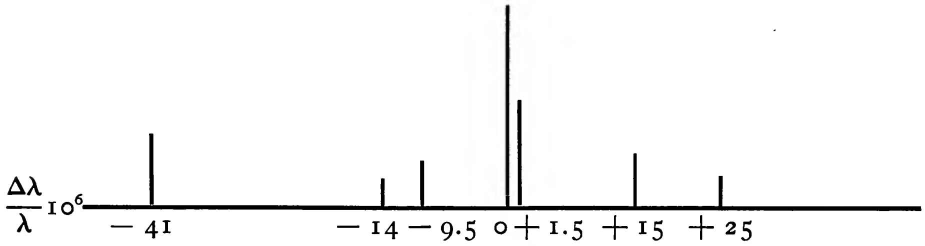
$$\mu_C = 1.5713$$
$$\mu_D = 1.5753$$
$$\mu_F = 1.5853$$
$$\mu_{G'} = 1.5936$$

Henceforth I will denote by q_t the theoretical value of the limit of resolution calculated according to (1), by q_e the experimental value. By means of a Hoffmann direct vision spectroscope the light of the vacuum tubes (driven by a Ruhmkorff) undergoes the necessary preliminary analysis. In some cases absorbing media were therefore sufficient. In some experiments the mercury arc-lamp of Fabry and Perot was used.

2. The very intense *green* line (λ 5460) of *mercury* was investigated first. Using the echelon in a position in which two strong lines of equal intensity corresponding to successive orders of the radiation were visible, I could distinguish also five faint, very narrow lines between the principal ones. The distance between two pairs of these lines was very small.

As I could not find a table of the wave-lengths of these feeble radiations, I addressed myself to Messrs. Fabry and Perot. I am very much obliged to Messrs. Perot and Fabry for their kindness in investigating for me anew the green radiation of the mercury arc *in vacuo*.

The following scheme represents the constitution of this very complex radiation according to their observations. The ordinates are *approximately* proportional to the intensities.



The numbers given are only approximate, especially (− 14) and (− 9.5).

The radiation (+1.5) was observed by Fabry and Perot only in the radiation of a Michelson tube; it is too close to the principal radiation to be seen separately in the arc light. In the photographic reproduction in the ASTROPHYSICAL JOURNAL[1] of the interference fringes of the green mercury line, the radiation (− 41) coincides with the radiation (+15) and is therefore invisible.

I could distinguish very clearly the radiations (− 9.5) and (− 14) as separate lines. For these radiations $q=\frac{d\lambda}{\lambda}=4.5\times 10^{-6}$ or $r=222{,}000$ and hence q_e rather smaller; calculation gave $q_t=3.6\times 10^{-6}$.

Using the *green* line of *thallium*[2] I very easily distinguished the faint radiation at a distance $\frac{d\lambda}{\lambda}=21\times 10^{-6}$ from the principal radiation, but I could not see as a separate line the the one determined by $\frac{d\lambda}{\lambda}=3\times 10^{-6}$.

Hence q_e exceeds 3×10^{-6} but is smaller than 21×10^{-6}.

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[1] FABRY and PEROT, ASTROPHYSICAL JOURNAL, **13**, 272, 1901.

[2] FABRY et PEROT, *Ann. de Chim. et de Phys.* (7) **16**, 134, 1899.

Indeed for the thallium radiation (λ 5440)

$$q_t = \frac{5440 \times 10^{-7}}{0.63 \times 31 \times 7.8} = 3.6 \times 10^{-6}.$$

For the *green* (λ 5086) line of *cadmium* it was just possible to see that this line is a double one. The distance of the components is according to Fabry and Perot[1] $\frac{d\lambda}{\lambda} = 5 \times 10^{-6}$. For $\lambda = 5086$ I calculate $q_t = 3.2 \times 10^{-6}$. Hence with the above mentioned echelon it is possible to approach rather nearly the limit of the theoretical resolving power.

3. Perhaps the best series of tests of gradually increasing difficulty can be obtained by observation of the change of spectral lines in magnetic fields of gradually increasing intensities, a Nicol between source and apparatus being used in order to reduce the complexity of the radiation. In this manner all values between, *e.g.*, 0.001 tenth-meter to about 1 tenth-meter can be obtained. Corresponding herewith are the values $q_t = 0.2 \times 10^{-6}$ and $r = 5{,}000{,}000$; resp. $q_t = 200 \times 10^{-6}$ and $r = 5000$. The performances of echelons and interferometers and of ordinary spectroscopes with a few glass prisms lie between the limits indicated. This test I have not yet applied systematically to the above mentioned echelon.

In order, however, to show its fitness I will use some observations of Lord Blythswood and Dr. Marchant.[2] In their § 6, "Results Obtained of the Zeeman Effect on the Chief Lines of the Mercury Spectrum," p. 397, these authors communicate observations with an echelon spectroscope concerning the difference in wave-length between the components of the outer components of the sextet of the blue line (λ 4358) of mercury. The following table is an extract:

H	$\delta\lambda_3$	
5.000	.....	tenth-meters
12.100	.....	
12.900	0.052	
20.000	0.098 ?	
21.300	0.09	
23.400	0.098	

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[1] *Loc. cit.* p. 137.

[2] *Phil. Mag.* 49, 384, 1900.

For a value of the field between 12.100 and 12.900 the splitting up of the lines becomes sufficient to make them appear as separate lines *on a photograph* (upon which the measurements were taken). Two lines can, of course, be *seen* separated at a rather smaller distance.

Thus now $q = \frac{0.052}{4358} = 11.9 \times 10^{-6}$ and q_e is rather smaller. For the echelons of these observers we have $t = 7.5$, $n = 15$.

With these data I calculate $q_t = 5.3 \times 10^{-6}$.

Thus it appears from the data given in this paper that it is possible to manufacture echelons performing nearly as well as they are theoretically expected to.