

likely to be adequately considered unless the sources of weakness in the respective methods are clearly understood.

Again, there has been an increasing tendency of late years, in most lines of physical research, to add figure to figure, and to aim at higher accuracy, or at least the appearance of higher accuracy. If people were content with giving magnetic force to four significant figures, the majority of the sources of uncertainty specified in this paper need awaken little apprehension. But now-a-days hardly any one is content with less than five significant figures, and one occasionally sees six. I am not prepared to say that the retention of six figures is indefensible in the case of open range magnetographs, when it is clearly understood that *differences* only are concerned, but I do think that with unifilar of the Kew pattern, as hitherto made, the least probable error we can reasonably expect in an absolute measurement is two or three units in the fifth significant figure.

§ 49. We have seen that there is every reason to expect that the values of the horizontal force given by a unifilar are in error to a different extent, according to the temperature and the magnitude of the force. This must introduce a source of uncertainty into the comparisons effected between unifilar at distant observatories through the intermediary of a travelling instrument. To adequately forewarn those engaged in such comparisons may be to put them in a position to obtain more satisfactory results.

§ 50. For the opinions expressed in this paper, and for the accuracy of its conclusions, I am alone responsible ; but it is only proper that I should acknowledge the valuable assistance given me by Mr. T. W. Baker, Chief Assistant at the Kew Observatory. For many years Mr. Baker has taken the great majority of magnetic force observations at Kew, and his experience in determining the "constants" of collimator magnets is probably quite unique. Mr. Baker has always been ready to place his great practical knowledge of the subject freely at my disposal, and I have also to thank him for carefully carrying out a variety of special experiments, made to elucidate doubtful points at various stages of the inquiry.

"The Absorption of Röntgen's Rays by Aqueous Solutions of Metallic Salts." By the Right Honourable LORD BLYTHS-WOOD, LL.D., and E. W. MARCHANT, D.Sc. Communicated by LORD KELVIN, F.R.S. Received March 11,—Read June 15, 1899.

The absorption of X rays by metallic salts is a subject that has not received very much attention up to the present time, although it appears to be of considerable importance. It seemed possible that if the

absorption were atomic, that is if the absorption of the rays were not produced so much by the nature of the molecule as by the constituents of the molecule, there ought to be some simple relation between the absorbing powers of salts having the same acid radicle. This investigation, however, was originally suggested with a view to finding out whether the very great difference in the transparency of individuals to Röntgen rays might not be caused by an excess of some salt in the composition of the blood or muscular tissue.\* Some results have been obtained by different experimenters, the most exhaustive treatment of the subject up to the present having been given by Dr. Gladstone and Mr. Hibbert (B.A. Reports, Section B, 1896, 1897, 1898).† They found that the physical condition of the absorbing substance (whether solid or liquid) produced no very marked differences, also that the absorption of a mixture of salts was the same as that of the double salt in the same state of division, and that the change in atomicity of the absorbing substance produced no appreciable effect, also that the total absorption produced by a solution was the sum of the absorptions of the salt and its solvent.

They also found that the absorptive power depended on the atomic weight and not on the density or combining proportions; using an aluminium stepped scale they found that the absorption appeared to increase logarithmically with the thickness of aluminium traversed. The same experimenters have also examined the absorptive power of various metals and metallic salts, and have compared that of different acid radicles. Before, however, their results were published the present investigation was taken up, and the results obtained appear to be of considerable interest. Similar results have been obtained by several others,‡ but all are included in the more exhaustive work of Dr. Gladstone and Mr. Hibbert.

The great difficulty found in the investigation was the obtaining of quantitative results, as, although it is a comparatively simple matter to obtain approximate qualitative results, it is much more difficult to obtain even approximately accurate quantitative values. The only method which appeared to offer much prospect of success was a photographic one, and all the values given below have been obtained photographically.

The first method adopted was to place two cells made of thin glass in front of two holes cut in a thick lead sheet, one cell being filled with water and the other with the solution to be tested; the photographic

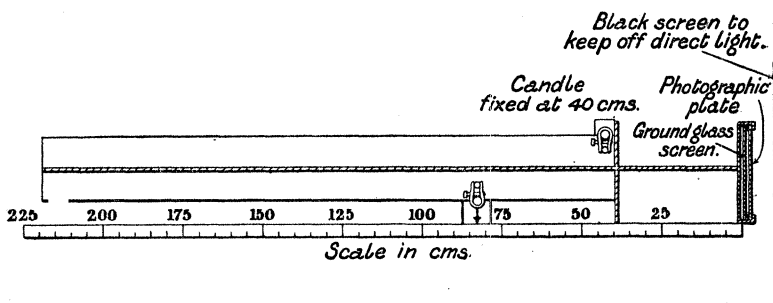
\* Cf. Bouchard, 'Comptes Rendus,' vol. 123, pp. 967 and 1042.

† 'Chemical News,' Nov. 13, 1896, and Oct. 21, 1898.

‡ Meslans, 'Comptes Rendus,' vol. 122, p. 307; Bleunard and Lablesse, *ibid.*, vol. 122, pp. 527 and 723; Van Aubel, 'Jour. de Physique,' vol 5, p. 511; Novak and Sule, 'Beiblätter,' vol. 20, part 5, p. 444; F. Ré, 'Elettricità' (Milan), pp. 261-264 (1898).

plate was placed behind the lead sheet, and exposed generally for ten minutes to the rays. The tube was placed in such a position that the anti-cathode was in the normal drawn to the photographic plate from the point midway between the two holes, and was 12 inches distant from it. The plates, after development, were placed in the photometer, and the relative intensities of the two spots compared, the arrangement adopted being that shown below, fig. 1, in which the two spots were illuminated by the light from two candles.

FIG. 1.



A ground glass screen was placed behind the plate to obtain uniform illumination of the spots. It was found with this arrangement that the relative intensities could be determined with considerable accuracy, but that the relative intensities depended to a certain extent on the time of development, as has also been noticed by Hurter and Driffield. Another disadvantage of this method was that the allowance that had to be made for the absorption of the glass was a comparatively large one with many solutions, and that the error incident on the determination of this correction was such as to materially alter the relative absorbing powers. Thus if  $a$  be the percentage of absorption due to the glass of the cells (which was within limits of experimental error equal for the two cells employed),  $b$  that due to the water in one cell, and  $b + c$  that due to the solution in the other cell,  $c$  being supposed to be that part of the absorption due to the presence of the dissolved salt, the ratio actually observed in this method by comparing the intensities of the two spots is—

$$\frac{a + b + c}{a + b} = \frac{\text{absorption due to the cell and dissolved salt}}{\text{absorption due to the cell and water}}$$

If therefore  $c$  is small compared with  $b$  or  $a$ , the accuracy attainable is very much reduced. For very absorbent substances, however, this method gave fairly good results.

A very important question in connection with this investigation was the standard with which all these aqueous solutions were to be com-

pared. It seemed most satisfactory, since all the solutions that were tested were aqueous, to choose water for the standard absorber, and all numbers given are relatively to water.

Now, to determine the relative absorbing power of the salt in solution, compared with the absorbing power of water, we may consider the absorption of the solution to be split up into two parts, one due to the absorption of the water of which the solution is made up, and the other part due to the salt dissolved.

Now, as above, let  $a$  = percentage absorption due to cell,  $b$  = percentage absorption due to the water,  $c$  = percentage absorption due to the salt. Then first comparing the intensities of two spots, as above, one obtained through an empty cell and one through a cell filled with water, we have

$$\frac{a+b}{a} = K_1 \text{ (say)}, \quad 1 + \frac{b}{a} = K_1, \quad \text{and} \quad a = \frac{b}{K_1 - 1}.$$

Then, comparing the intensities of two spots, one obtained through a cell filled with water, and the other through a cell filled with the solution, we have

$$\frac{a+b+c}{a+b} = K_2 \text{ (say)},$$

$$c = (a+b)(K_2 - 1),$$

and substituting for  $a$ , we have

$$c = b \frac{K_1(K_2 - 1)}{K_1 - 1},$$

$$\frac{c}{b} = \frac{K_1(K_2 - 1)}{(K_1 - 1)}.$$

The assumption here made is that the intensity of the black spot on the negative is proportional to the intensity of the light falling on it.

With the cells used  $K_1 = 1.7$ .

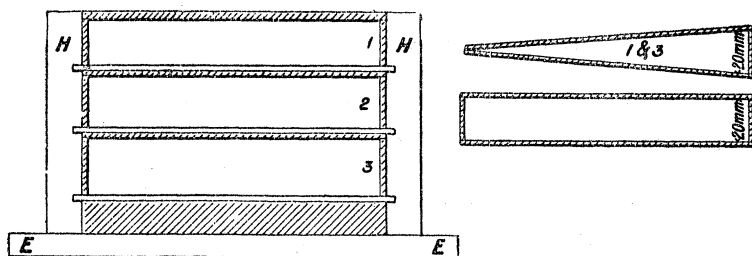
The second method used for the determination of the relative absorbing powers, was based on the fact that the amount of absorption of any substance varies with the thickness of the layer traversed by the ray.

The arrangement of the apparatus was as shown in fig. 2.

EE is a wooden base supporting the two uprights HH, to which is attached a thick lead sheet (shaded diagonally in the figure). In the uprights, HH, three grooves are cut, into which fit the bases of the three cells, 1, 2, 3, which are thus supported one above the other on their wooden stand. The cells 1 and 3 are wedge-shaped, being 137 mm. long, and 20 mm. wide at the broadest part, sloping away to nothing at the thin end of the wedge. The cells are about 25 mm.

deep. The middle cell 2 (above) is oblong in shape, being 137 mm. long by 20 mm. wide. All the cells are made of paraffined mahogany about 1.6 mm. thick. On the other side of the lead sheet the dark slide containing the plate is placed, stops being arranged so that the plate is always in the same position relatively to the wedges.

FIG. 2.



Opposite the cells three oblong holes 15 mm. long by 20 mm. wide are cut in the lead sheet, so as to allow the rays to fall on the photographic plate; the focus tube used was placed 300 mm. distant from the plate, and was arranged so that the centre of the reflector or anti-cathode was opposite the middle of the centre hole in the lead.

In an experiment the two wedge-shaped cells 1 and 3 were filled with the solutions that required testing, while the middle cell 2 was filled with water. It was found that the intensity of the radiation from the tube was very nearly constant over the whole plane of the plate, the variation in intensity of the strip obtained opposite the middle slit varying very little from one side to the other. Also, no difference could be perceived when the cells 1 and 3 were filled with the same liquid, thus showing that the variation in the vertical direction was negligible.

In all experiments the same focus tube was used, the intensity of the X rays being adjusted by heating. To give an idea of the penetrative power of the rays used, it may be stated that at a distance of 12 inches from the tube, the bones of the hand were clearly visible on a fluorescent screen, while the flesh still appeared dark. By this very rough test the tube was brought as nearly as possible to the same condition for each experiment. It was found, however, that the use of different penetrative powers had very little effect on the *relative* absorbing powers of the solutions, though the actual intensity of the rays was greatly altered. In all experiments the plates used were Edwards' "Cathodal Plates" (5 inches by 4 inches); they were developed by hydroquinone and potassium carbonate in from ten to twelve minutes during the warm weather, the time necessary being increased during the colder months.

Now to determine the absorbing powers by measurement of these plates, a special form of photometer was devised for the purpose, as shown below, fig. 3.

FIG. 3.—Plan.

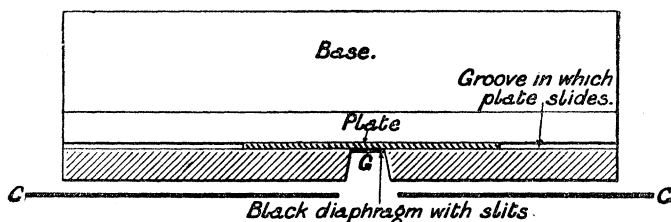
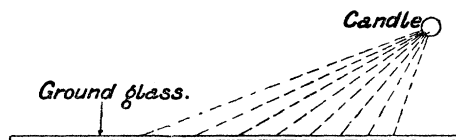
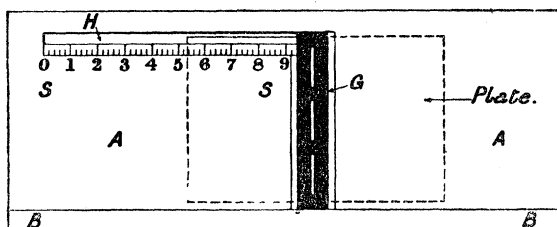


FIG. 4.—Elevation.



AA is a piece of wood about 10 inches by 6 inches, fixed to the base BB, and fitted at the back with grooves, so that a plate can slide from one end to the other along the grooves, figs. 3 and 4. G is a vertical slot cut in the wood, into which a diaphragm is fitted, pierced by three narrow slits, as shown in fig. 4, special precautions being taken that the three slits were all of the same width (0.5 mm.); H is a horizontal slot, cut as shown, to the bevel side of which a scale, SS, is attached. CC, fig. 3, is a blackened screen, placed so as to screen the eye from all light, except that which appears at the slits in G.

A piece of ground glass or white paper was placed behind the slit so as to form a uniformly illuminated background.

The plate was shifted along its slide until the intensity of the illumination of the slits 1 and 2 (say) was equal, the reading on the scale opposite the edge of the plate was then noted, a series of values was taken and the mean value calculated. The scale was so placed that the scale reading gave the distance from the end of the strip corre-

sponding to the thin edge of the wedge in the photographing apparatus, in terms of the whole length of the wedge.

*Results.*

	Weight (in grams) of anhydrous salt in 100 c.c. of normal solution.	Thickness (in mm.) of normal solution neces- sary to produce the same absorption as 20 mm. of water.
<b>Bromides:—</b>		
Magnesium.....	9·2	6·2
Calcium.....	10·0	5·5
Sodium.....	10·3	5·0
Iron (Ferrous).....	10·8	4·8
Cadmium.....	13·6	4·1
Potassium.....	11·9	4·1
Ammonium.....	9·8	4·1
Zinc.....	11·3	2·6

These results were obtained by method 2. The absorption both of these and of the iodides is rather too high to make great accuracy possible.

	Weight (in grams) of anhydrous salt in 100 c.c. of normal solution.	Thickness (in mm.) of normal solution neces- sary to produce the same absorption as 20 mm. of water.
<b>Chlorides:—</b>		
Lithium.....	4·3	18·1
Sodium.....	5·9	18·0
Potassium.....	7·5	17·8
Ammonium.....	5·3	15·1
Magnesium.....	4·8	13·4
Calcium.....	5·5	11·2
Cobalt.....	6·5	9·0
Iron (Ferric).....	5·4	8·3
Nickel.....	6·5	8·2
Zinc.....	6·8	8·2
Copper.....	6·7	7·2
Strontium.....	7·9	6·3
Barium.....	10·1	5·4
Cadmium.....	9·1	5·3
Lead.....	13·9	2·6
<b>Iodides:—</b>		
Magnesium.....	13·8	3·6
Calcium.....	14·6	3·4
Sodium.....	14·9	3·1
Zinc.....	15·9	2·9
Ammonium.....	14·4	2·9
Potassium.....	16·5	2·8
Cadmium.....	18·3	1·9

	Weight (in grams) of anhydrous salt in 100 c.c. of normal solution.	Thickness (in mm.) of normal solution neces- sary to produce the same absorption as 20 mm. of water.
<b>Acetates :—</b>		
Aluminium (powder)...	6·8	16·0
Iron (powder).....	8·7	10·9
Calcium.....	7·9	10·8
Potassium.....	9·8	9·4
Barium.....	12·7	8·2
Copper.....	9·0	7·0
Lead.....	16·2	2·0
<b>Nitrates :—</b>		
Aluminium.....	7·1	17·0
Magnesium.....	7·4	15·2
Calcium.....	8·2	12·4
Potassium.....	10·1	10·8
Cobalt.....	9·1	10·6
Nickel.....	9·1	8·3
Zinc.....	9·4	7·5
Copper.....	9·3	7·3
Barium.....	13·0	6·7
Strontium*.....	10·6	5·8
Cadmium.....	11·8	5·5
Lead.....	16·5	3·1
Uranium.....	14·2	1·9
<b>Sulphates :—</b>		
Aluminium.....	5·7	16·0
Magnesium.....	6·0	15·2
Sodium.....	7·1	13·5
Ammonium.....	6·6	13·0
Cobalt.....	7·7	8·9
Iron (Ferrous).....	7·6	8·0
Copper.....	7·9	7·1
Nickel.....	7·7	7·0
Zinc.....	8·0	6·8
Cadmium.....	10·4	4·6
<b>Carbonates :—</b>		
Ammonium.....	4·8	18·0
Sodium.....	5·3	18·2
<b>Bichromates :—</b>		
Ammonium.....	12·6	7·3
Potassium (saturated solution).....	..	8·3
Potassium chromate.....	9·7	7·8

Now proceeding to a consideration of the results obtained, it is at once clear that the absorption, in almost every case, in these normal solutions, increases with the atomic weight, *i.e.*, the higher the atomic

\* This salt contained a good deal of impurity, and the value given is therefore doubtful



weight of the elements of which a salt is composed the greater is the absorption. This effect is most noticeable in the case of bromides and iodides.\* In all cases these salts are absorbent, even when the bromine and iodine are combined with the transparent sodium and magnesium. The iodides also are more absorbent than the bromides.

Now proceeding to the consideration of the absorption produced by salts with other acid radicles, the differences are not so marked; but in all cases the least absorbent salt is the nitrate, the next the chloride, the most absorbent being the sulphate; this does not agree with the order of increase of the molecular densities, or of the atomic weights of the constituents. It would therefore appear that the absorptive power is not entirely dependent on the atomic weight of the components of the acid radicle, or on its molecular density; the order in the first case being (1) nitrates ( $N = 14$ ), (2) sulphates ( $S = 32$ ), and (3) chlorides ( $Cl = 35.5$ ); (2) and (3) being nearly equal. While in the second place the order should be: (1) Chlorides ( $Cl = 35.5$ ), (2) sulphates ( $SO_4 = 48$ ) (3) nitrates ( $NO_3 = 62$ ); while the order actually observed is (1) nitrates, (2) chlorides, (3) sulphates.

Acetates are slightly less absorbent than chlorides, though the number of salts tried is small; only four giving results to which weight can be attached, since aluminium and iron were simply powders in suspension and partially precipitated.

It now remains to be seen if there is any definite connection between the equivalent weight of the bases composing the different salts and their absorptive powers. Their order may be written down as follows:—

In ascending order of absorption.—

1. Lithium .....	(7)'	9. { Nickel .....	(58.6)"
2. { Magnesium .....	(24)"	10. { Copper .....	(63)"
3. { Aluminium .....	(27)'"	11. { Zinc .....	(65)"
4. { Sodium .....	(23)'	12. Strontium .....	(87)"
5. { Calcium .....	(40)"	13. Barium .....	(137)"
6. { Potassium .....	(39)'	14. Cadmium .....	(111.7)"
7. { Iron.....	(56)"	15. Lead .....	(206)"
8. { Cobalt.....	(58.6)"	16. Uranium .....	(240)"

The metals bracketed together have very nearly the same absorptive power. The order given above does not agree very nearly with the order of increase of equivalent weight; it agrees more closely, however, with the order of increase of atomic weight. It is to be noticed particularly, that the salts of the alkali metals are less absorbent than might have been expected from their equivalent weight, also

\* E. Sehrwald, 'Beiblätter' (1897), p. 64.

that in the calcium, strontium and barium group the amount of absorption does not increase rapidly with the increase in atomic weight. It may therefore be generally stated that the absorptive power of salts having different bases, but the same acid radicle, increases with the atomic weight of the metal forming the base, though not according to any definite law.

This agrees with the results obtained by Dr. Gladstone and Mr. Hibbert.

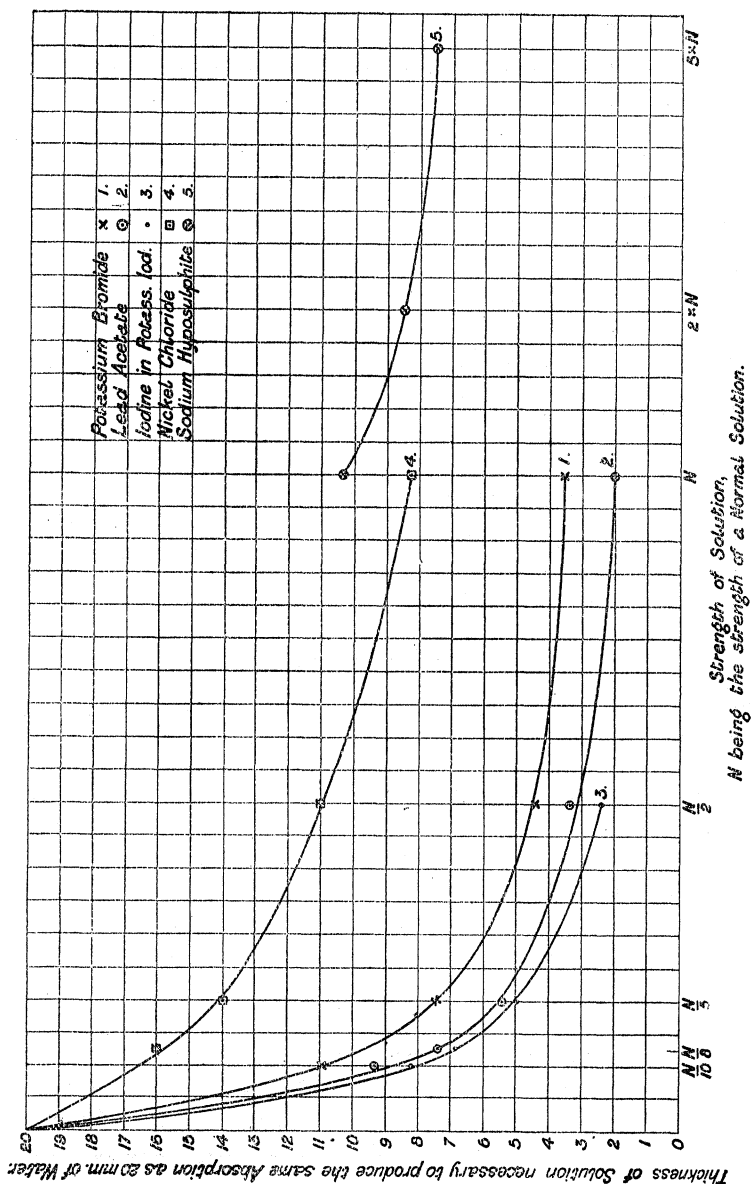
*Effect of Rays of different Penetrative Powers.*

As stated above, the penetrative power of the X rays used did not have much effect on the apparent relative absorptive powers of the different solutions, but as a still further check on the power of the rays used, the time taken for the developer to bring the strip on the plate photographed, through 20 mm. of water, to sufficient density (allowance being made for the temperature) was always observed, and if this differed much from that necessary on a normal plate, the experiment was repeated. Measurements made on these rejected plates, however, showed that within limits of experimental error, there was no difference between absorptions thus obtained and those calculated from measurements made on fully exposed negatives. Measurements were also made using rays of different penetrative power, and developing for the same time; but the plates obtained admitted of only such rough measurement that here again no differences were detected, the strips being either too dense, or the differences in intensity at the two ends corresponding to the thick and thin ends of the wedges being too slight, to admit of accurate photometry. It may be stated generally therefore that the rays of different penetrative powers do not appear to have any effect on the *relative* absorptive powers of the different solutions.

*Effect of Strength of Solution.*

In order to determine the effect produced by using solutions of different strengths, a number of measurements were made on various salts: (1) Lead acetate, (2) potassium bromide, (3) iodine in potassium iodide, (4) nickel chloride, (5) sodium thiosulphate (strong solution).

Curves are plotted below showing the relation between the amount of salt in solution and the thickness necessary to produce the same amount of absorption as 20 mm. of water. From these numbers it is clear that the amount of absorption is not proportional to the number of molecules of the salt traversed by the ray, and does not appear to follow any simple law. The connection appears to be logarithmic from the shape of the curves.



Thickness of Solution necessary to produce the same Absorption as  
20 mm. of Water.

Strength of solution.	Potassium bromide.	Lead acetate.	Iodide in potassium iodide.	Nickel chloride.
N.....	3·6	2·0	—	8·2
N/2.....	4·4	3·4	2·4	11·0
N/6.....	7·4	5·4	5·0	14·0
N/8.....	—	7·4	6·9	16·0
N/10.....	11·0	9·3	8·3	—
	Sodium thiosulphate.			
N.....	10·6			
2 × N.....	8·5			
5 × N.....	7·5			

*Effect of Thickness of Solution traversed.*

Various experiments have been made in order to verify the statement made by Messrs. Gladstone and Hibbert and others\* that the amount of absorption varies logarithmically with the thickness traversed by the ray—

$$r = \log (\lambda t + \mu),$$

where  $r$  = percentage of the rays absorbed by the solution under consideration. The results obtained appear to confirm their conclusion. As a preliminary experiment, the intensities at different distances along the strips on three of the plates above considered were carefully compared with the intensity of the strip photographed through 20 mm. of water. Now proceeding to consider these results—

Let  $A_0$  be the original intensity of the X rays.

$A_1$  the amount of the rays absorbed by the water.

$A_2$  the amount of the rays absorbed by a given thickness of the solution.

$\lambda_1$  be the coefficient of absorption for water.

$\lambda_2$  be the coefficient of absorption for the solution.

Then the intensity of the strip obtained by passing the rays through 20 mm. of water is proportional to  $A - A_1$ , and the intensity of the photographic image at the distance along the strip corresponding to the given thickness of the solution to  $A - A_2$ , and for the relative intensities of the photographic images ( $K_2$ ), we have

\* A. Bugnet, 'Comptes Rendus,' vol. 125, pp. 398—400; F. Ré, *loc. cit.*

$$K_2 = \frac{A - A_2}{A - A_1};$$

or, according to the above assumption,

$$K_2 = \frac{1 - \log(\lambda_2 t_2 + \mu_2)}{1 - \log(\lambda_1 t_1 + \mu_1)}.$$

If  $K_3, K_4$ , &c., are the values of  $K$  corresponding to the different thicknesses  $t_3, t_4$ , &c., of the solution, we have

$$K_2 \{1 - \log(\lambda_1 t_1 + \mu_1)\} = 1 - \log(\lambda_2 t_2 + \mu_2),$$

$$K_3 \{1 - \log(\lambda_1 t_1 + \mu_1)\} = 1 - \log(\lambda_2 t_3 + \mu_2).$$

$1 - \log(\lambda_1 t_1 + \mu_1)$  is a constant for any one plate =  $C$  (say); hence, subtracting,

$$C(K_2 - K_3) = \log \frac{(\lambda_2 t_3 + \mu_2)}{(\lambda_2 t_2 + \mu_2)}.$$

The value of  $\mu$  however (being that part of the absorption produced by the walls of the cell and the air traversed) is known to be very small compared with  $\lambda t$ , and may therefore in a first approximation be neglected. The above equation then reduces to

$$C(K_2 - K_3) = \log \frac{t_3}{t_2} = \log t_3 - \log t_2.$$

Below are given the results for the three plates used in the test experiments. The relative intensities were obtained by means of an arrangement similar to that described for the determination of the relative intensities of the spots on the photographic plate in method I; but arrangements were made to bring the illuminated images nearer to each other to enable more accurate comparison to be made.

The errors, when all precautions were taken, were not greater than 6 per cent. for the determination of the relative intensities, corresponding to 3 per cent. on the determination of the distances of the source of light necessary to produce equal illumination.

In the following table—

Column 1 gives the thickness of the solution traversed by the X rays in millimetres.

„ 2 gives the logarithms of these thicknesses, to base 10.

„ 3 gives the differences of the logarithms.

„ 4 gives the intensity of the image photographed through the thickness of the solution given in column 1, in terms of the intensity of the image photographed through 20 mm. of water.

„ 5 gives the differences of these intensities.

„ 6 gives the ratio of the differences of the logarithms in column 3 to the differences of the intensities in column 5.

It is clear therefore that if the logarithmic law holds, the numbers in column 6 should be equal for any given plate.

*Nickel Chloride N/8 Solution.*

$t$ in mm.	log.	Diff.	K.	Diff.	Ratio.
3·3	0·519		2·9		
5·0	0·699	0·18	2·4	0·5	0·36
8·4	0·924	0·225	1·8	0·6	0·37
16·0	1·204	0·28	1·0	0·8	0·35

The value of  $C$  therefore = 0·36.

And since  $C = 1 - \log(\lambda_1 t_1)$   $\log \lambda_1 t_1 = 0·64$

and since  $T = 20$  mm.  $\lambda_1 = 0·22$  (for water).

*Potassium Bromide N/10 Solution.*

$t$ in mm.	log.	Diff.	K.	Diff.	Ratio.
3·3	0·519		2·4		
5·0	0·699	0·18	1·92	0·48	0·37
8·4	0·924	0·225	1·36	0·56	0·40
11·0	1·042	0·128	1·0	0·36	0·36

The value of  $C = 0·38$ .

And since  $C = 1 - \log(\lambda_1 t_1)$   $\log(\lambda_1 t_1) = 0·62$ .

and since  $T = 20$  mm.  $\lambda_1 = 0·21$ .

*Sodium Thiosulphate, 2XN.*

$t$ in mm.	log.	Diff.	K.	Diff.	Ratio.
3·3	0·519		2·85		
5·0	0·699	0·18	2·0	0·85	0·47
6·7	0·826	0·127	1·44	0·56	0·44
8·5	0·929	0·103	1·0	0·44	0·43

The value of  $C = 0·45$ .

And since as above  $C = 1 - \log(\lambda_1 t_1)$   $\log(\lambda_1 t_1) = 0·55$ .

whence (as above)  $\lambda_1 = 0·18$ .

It will be seen, therefore, that the value of  $\lambda$  was not constant for water, and hence not for solutions, if they obey the same laws. This is confirmed by observations made on plates where the penetrative power was not sufficiently great to give a dense photograph. The variation

in the intensity of the photographic image, according to the thickness of the solution traversed, appearing to be much less than with rays of greater penetrative power, although, as stated above, the thickness of the solution necessary to produce the same amount of absorption as 20 mm. of water was constant within limits of experimental error.\* This agrees with the observation of M. Buguet (*loc. cit.*). The values of  $\lambda$  for the different solutions have not therefore been calculated.

The value of  $\mu$  for the apparatus used would (from the comparatively close agreement with theory of the above numbers) seem to be negligible.

The results given above show that the logarithmic law is at any rate approximately true.

### *Conclusions.*

1. The absorption produced by normal aqueous solutions of metallic salts having the same acid radicle, increases with increase of atomic weight of the base.
2. Metals belonging to the alkali group are not very absorbent, neither are those belonging to the calcium, strontium, and barium group, their atomic weight being taken into consideration.
3. Bromides and iodides of the metals are all highly absorbent.
4. With the three common acids, the order of increasing absorptive power is nitrate, chloride, sulphate.
5. The absorption produced by a salt is dependent mainly on the atomic weight of its constituents.

\* Considering this statement in the light of the known facts with regard to the photography of the bones of the hand, it will be seen that facts are not in contradiction to the conclusions drawn from these experiments. With rays of low penetrative power, the whole hand appears dark though the screen appears light (assuming  $\lambda$  large for the flesh and much larger for the bones), the reason being that both the flesh and bones absorb nearly all the rays. Assume, for example, that for this penetrative power the flesh allows only 1/100 of the light to pass and the bones 1/1000. Now, using rays of greater penetrative power we may assume that the flesh will allow 1/10th of the light to pass while the bones will only allow 1/100th to pass. The bones will now be faintly visible. Pushing the penetrative power still further, assume that the flesh now allows half of the light to pass, the bones will allow only 1/20th, and will be very sharply defined. With still further exhaustion of the tube the flesh may now be assumed to allow 9/10ths of the light to pass, while the bones still only allow 1/11th; and, as is known, at this stage the bones themselves begin to appear transparent.

At the same time it is not assumed that the ratio of the absorption for the different salts *does* remain constant throughout this very wide range, but that the fact that the ratio of the absorptions appears to remain constant through a limited range while the actual absorption may differ appreciably through this range, is not in contradiction to other observations.

6. The amount of absorption produced by a given thickness of a solution of a metallic salt is not proportional to the amount of salt in solution, but appears to follow approximately a logarithmic law.
7. The amount of absorption varies logarithmically with the thickness of the solution traversed by the rays. The percentage absorption may be represented by an equation of the form  $r = \log(\lambda t + \mu)$  where  $\lambda$  is a constant depending on the nature of the solution, and on the penetrative power of the X rays, and  $t$  is the thickness of the solution traversed.

It is to be noticed that all the above tables and conclusions are based on measurements made with solutions containing the equivalent weight of the salts, in grams per litre, so that the molecular absorption of the salts with divalent or trivalent bases is greater than that indicated in the tables.

The conclusions 1, 5, and 7, given above, are in exact agreement with those stated by Dr. Gladstone and Mr. Hibbert in their articles in the 'Chemical News' (*loc. cit.*).

Numerous references have been made throughout this paper to their articles and reports before the British Association, though it was not until the above investigations were nearly completed that attention was drawn to the work that had been done by them.

"On the Resistance to Torsion of certain Forms of Shafting, with special Reference to the Effect of Keyways." By L. N. G. FILON, M.A., Research Student of King's College, Cambridge, Fellow of University College, London, 1851 Exhibition Science Research Scholar. Communicated by Professor M. J. M. HILL. Received June 1,—Read June 15, 1899.

(Abstract.)

The object of the present paper is to obtain solutions of the problem of Torsion for certain cylinders, whose cross-sections are bounded by confocal conics. It is mainly an extension of de Saint-Venant's investigations, and is based upon his general equations of torsion.

The method employed depends upon the use of conjugate functions  $\xi$  and  $\eta$ , such that  $\xi = \text{const.}$  represents confocal ellipses and  $\eta = \text{const.}$  confocal hyperbolas.

The use of conjugate functions for the torsion problem has been suggested by Thomson and Tait,\* by Clebsch,† and by Boussinesq.‡

\* 'Natural Philosophy.'

† 'Theorie der Elasticität fester Körper,' §§ 33—35.

‡ 'Journal de Mathématiques,' pp. 177—186, série 3, vol. 6.



FIG. 3.—Plan.

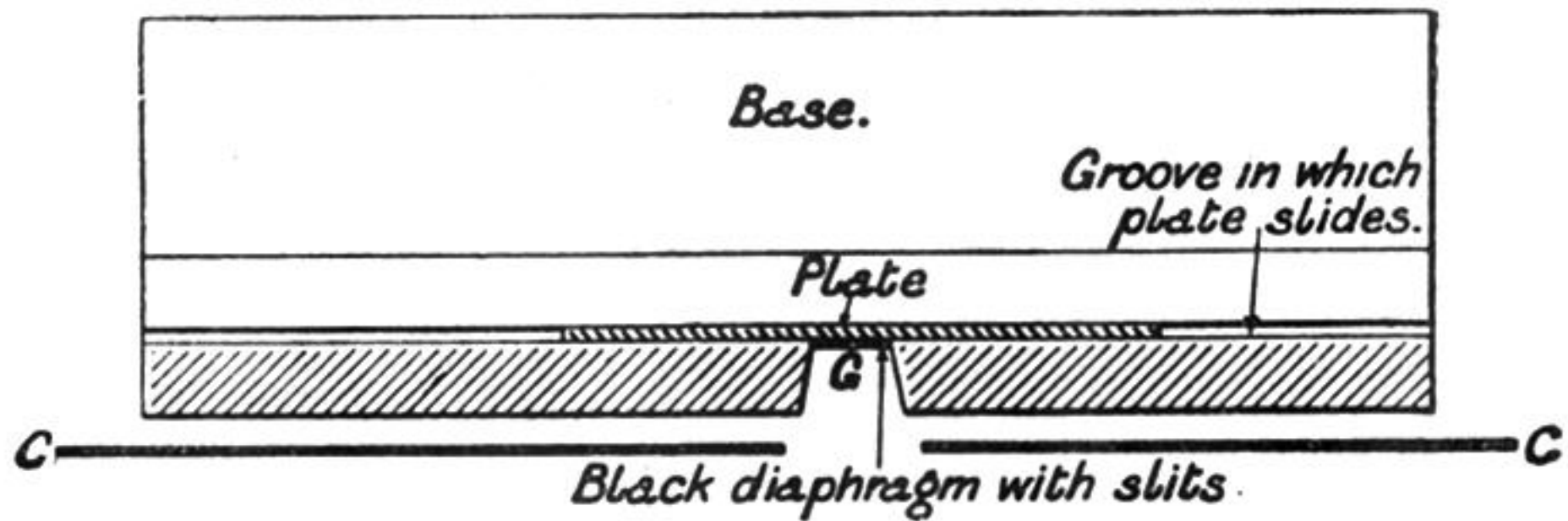
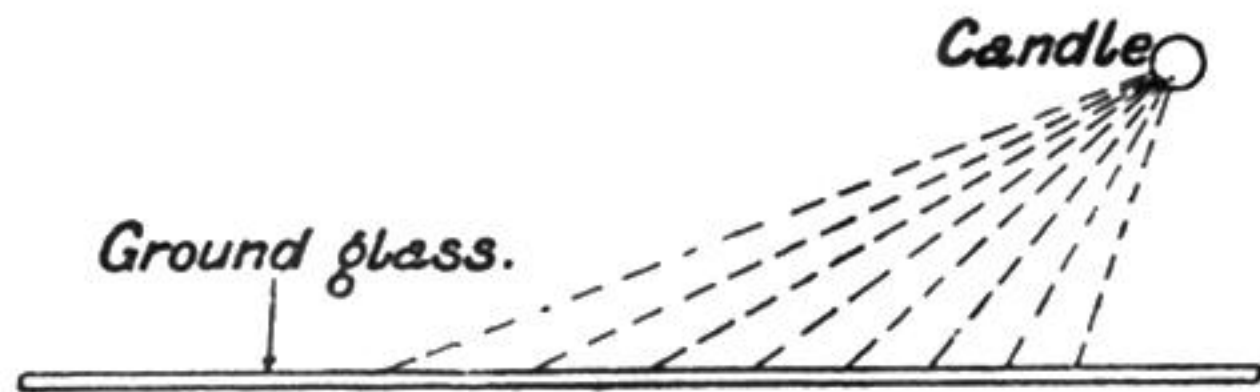


FIG. 4.—Elevation.

