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LXXIII. *An Investigation of the Optical Properties of Films of Magnetic Metals.* By CLARENCE A. SKINNER, *Ph.D.*, Professor of Physics, and A. Q. TOOL, *M.A.*, Assistant in Physics in the University of Nebraska*.

[Plate XXIV.]

THE object of this investigation was to study the magnetic rotation and ellipticity produced in plane-polarized light by films of magnetic metals, along with other properties intimately associated in theory with these—namely, the refractive indices and extinction coefficients.

That a thorough investigation of this kind would prove fruitful seemed evident from the results obtained in this laboratory by W. D. Harris†, who found that iron films, obtained by cathode deposit in a glow current, exhibited magnetic effects differing with the gas in which they were produced. His results also show that the variation in the magnetic rotation of these films with the wave-length of light is strikingly different from that obtained by Lobach‡ for electrolytic iron.

After improving the optical system used by Harris, we have been able to extend observations on these films into the region of relatively greater absorption, which this type is found to possess. We find there that both magnetic rotation

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† W. D. Harris, *Phys. Rev.* xxiv. p. 337 (1907).

‡ W. Lobach, *Wied. Ann.* xxxix. p. 347.

and ellipticity reverse their direction with respect to the magnetizing current.

By varying the method of producing the films of iron we have obtained three distinct types, one of which, as stated, exhibits a marked absorption region in the visible spectrum, while the other two seem to have the centre of such a region shifted well out in the ultra-violet. Similar characteristic differences are found in films of cobalt. Cathodic films of nickel were found to be almost imperceptibly *active*, though electrolytic nickel gives measurable values.

We have also found that a measurable ellipticity is imparted to the originally plane-polarized light by all films producing a measurable magnetic rotation.

EXPERIMENTAL METHODS.

1. *Production of Films.*

As stated above, three distinct types of both iron and cobalt were obtained—two by the glow current in gases, the other by electrolytic deposition.

Iron.—Using a glow current, the films were deposited from a circular disk cathode of Swedish iron (diam. 10 mm.). The form of discharge chamber is represented in fig. 1. To confine the current to the face of the cathode K, this was backed by a porcelain disk and its stem sheathed in porcelain tubing, the temperature in some cases running too high for glass. The films were deposited on very thin (0.1 to 0.2 mm.) microscope cover-glasses, selected plane, free from double refraction, and of measured magnetic rotation—the latter being generally a small fraction of that imparted by the metal film. To make a film, one of these glasses was mounted parallel to the face of the cathode at an adjustable distance below it. The discharge chamber was then evacuated and usually dried by leaving it in connexion with a chamber containing phosphorus pentoxide. Dry gas (hydrogen, unless otherwise stated) was finally admitted to a pressure of one to three millimetres of mercury. The electric current—furnished by a 1000-volt storage-battery—was then passed from the iron disk as cathode.

Fig. 1.

In those cases where the current was adjusted to a magnitude such that a film of the desired opacity was produced in two to four hours, the appearance of the film, as also its optical characteristics, was very different from those produced in a few seconds on raising the cathode to a white heat by cutting resistance out of the circuit. These latter films appear by reflected light as perfect metallic mirrors, while the former are much like polished dark glass. The latter are very hard, and seem to be fused on to the glass; while the former are soft and brittle, lacking the coherence of fused iron. For the same opacity the *metallic* films are strikingly thinner than the *dark* ones, being too thin to show the least trace of interference-fringes, while with the *dark* these may be very distinct. The *metallic* films impart no tint to transmitted light; the *dark* appear a yellow-brown arising from a marked relative absorption of the shorter waves. When deposited in hydrogen the *metallic* type absorb the gas at a remarkable rate even for some time after the current is broken*; but the *dark*, which exhibit like properties whether deposited in hydrogen or helium, take up no observable quantity of the gas either during or after the process of deposition. For this reason the exceptional properties of the *dark* films must be ascribed to the form in which the metal is deposited, and not to a chemical combination of the metal with the gas.

In a few cases films were obtained which exhibited optical properties intermediate between those of the two types described; but since these appeared to be made up of layers of different hardness, and the conditions of deposit were such as made it likely, we conclude that they were simply a mixture of the two already described †.

Films were also deposited electrolytically from a solution of ferrous ammonium sulphate on glass platinized according to the method of Kundt. The appearance of these is like that of the *metallic* type of cathode film.

Cobalt.—Three types of cobalt films were readily produced in the same way as the corresponding ones of iron. They are similar in appearance to the iron. They differ greatly in their

* See W. Heald, *Phys. Rev.* xxiv. p. 269.

† To this mixed type belong, to all appearances, those obtained by Harris (*l. c.*) in hydrogen; while those he deposited in nitrogen belong to that designated here as *dark* (arising probably from less heating of the cathode in nitrogen). Hence the variation which Harris ascribes to a change in the kind of gas was caused in fact by the consequent change in the temperature of the cathode. This, however, does not explain the characteristics exhibited by the films which he deposited in oxygen. These were probably largely oxidized in the process of deposition.

magnetic effects and also in their extinction. Compared with the corresponding ones of iron, cathodic films of cobalt are considerably more transparent; though such is not the case with electrolytic films.

Nickel.—With the glow current, only films giving metallic reflexion could be produced with nickel, though these varied considerably in hardness. The densest revealed only a very faint activity in the magnetic field. As stated above, films of nickel of relatively pronounced activity were, however, obtained by electrolytic deposition, the same as with iron and cobalt.

2. Thickness of Films.

This was measured by a slight but very convenient modification of the customary interference method. The film was cleared from the glass to an abrupt edge at the point to be measured. Over this was laid a cover-glass, which produced under perpendicular reflexion of monochromatic light two adjacent sets of interference-bands—one arising from the interference of light reflected from the upper and lower boundaries of the air-space between the two plates of glass; the other from that contained between the upper plate and the film. Obviously the thickness of the film is one-half the relative retardation of the two sets of bands, provided no phase difference arises at the surfaces. That no measurable surface effect of this kind was present was shown by the fact that films known from their magnetic rotation to be too thin to produce, by their thickness alone, a measurable displacement of the bands, gave coincidence of the two sets.

A micrometer microscope was used for measuring the fractional part of a band displacement.

The modification referred to consisted in the use of sunlight passed through a Fuess spectral instrument as a source of monochromatic light, variable in colour and intensity. By varying the width of the collimator-slit of the instrument, that intensity producing the clearest bands—a very important factor—was easily obtained. By changing the colour, the direction of motion of the bands revealed immediately the direction of the relative shift; and by noting the successive wave-lengths that gave coincidence, the whole number of wave-lengths of each colour was obtained readily by inspection, each setting at the same time contributing a measured value to the desired retardation. Finally, in those cases where the film was too thin to give a coincidence of the bands with any colour, the greatest accuracy was attained by using the shortest waves consistent with clear vision. It

was found that a wave-length of about $430\ \mu\mu$ fulfilled this condition very satisfactorily, inasmuch as this colour gave generally the most distinct bands of all.

3. *Optical Thickness of Films.*

The refractive index of the films was obtained as the ratio between the *optical thickness* and the *air thickness*—that is, the ratio of the number of wave-lengths in the film to that in the same thickness of air. The *optical thickness* was measured by means of an interferometer of the Zehnder type, following the method used at different times in this laboratory*. Fig. 2

Fig. 2.

presents a diagram of the system. Light from a Nernst glower S (or slit illuminated with sunlight) passes through a lens L_1 , a polarizing nicol N, and is divided into two components at the half-silvered surface of the interferometer-plate A. These rays pass respectively over the two paths ABC and AB'C, and recombine beyond the interferometer-plate C under conditions producing interference. The object of the nicol is to eliminate reflexion from the glass-air surface of the interferometer-plates, and the consequent blurring of the bands arising from the superposition of the two sets thus produced. This is possible because the angle of incidence on the plates is very nearly the polarizing angle. The film F whose retardation is to be measured is placed to intercept the lower half of one of the component rays. Just beyond this is placed a compensator K, consisting of two thin mica strips of equal thickness, one placed parallel to the film with its upper edge in line with the upper edge of the film, the other placed to intercept the part of the ray which passes above the film and the companion strip of mica. Both have their optic

* Cartmel, Phil. Mag. [6] vi. p. 214; Clark, Phys. Rev. xxiii. p. 422.

axis in the plane of polarization. This upper strip of mica is so mounted that its inclination to the ray can be varied by rotating about a vertical axis, and thus a retardation produced in the upper half of the ray equal to that which the film introduces in the lower half. P is a compensating plate used to right the irregularity of form in the bands arising from the plate on which the film is deposited. Beyond C is placed a lens L_2 , which focusses (through the plane mirror M) the film F on the collimator-slit of a spectroscope. Viewed through the spectroscope, the field exhibits two parallel channelled spectra with the interference-bands in the one displaced relative to those in the other. If the movable compensator strip be parallel to its companion strip, the observed displacement arises from the optical path in the film being greater than that in the same thickness of air. The angular displacement of the collimator, which gives coincidence of bands in any part of the spectrum, is used for determining this difference. As a convenient formula for calculating the relative retardation we have used the following, for which we are indebted to Professor Tuckerman of this laboratory :—

$$\delta = k\alpha^2(1 + 5.3 \cdot 10^{-5} \cdot \alpha^2),$$

where δ is the retardation in wave-lengths, α the displacement of the compensator in degrees, and k a constant depending on the thickness of the mica and its refractive index. The value of k is experimentally determined for the various colours by observing the value of α required to produce one or more wave-lengths' retardation with the film removed. The accuracy (one-half per cent.) of this formula is well within the experimental errors.

The *optical thickness* of the film is obtained for each colour by adding the corresponding δ to the *air thickness* given in terms of the wave-length considered.

4. *Transmission and Reflexion.*

For measuring the ratio of the intensity of the transmitted to the incident light, a Brace spectrophotometer was used in the customary way: a rotating sector and an adjustable slit serving to reduce the intensity of the unabsorbed component to *match* it with that which has passed through (or been reflected from) the film. To eliminate the effect of reflexion in the transmission measurements, the usual method of measuring the transmission of two different thicknesses was followed. For reflexion measurements, an attachment described by Clark (*l. c.*) was used.

5. Magnetic Rotation and Ellipticity.

The rotation of plane-polarized light by the films, when subjected to a magnetizing force in the direction of the ray, was measured for both transmission and reflexion. The corresponding ellipticity produced in the originally plane vibration was also measured. Finally, plane-polarized light sent through the films in a direction normal to the field, and with its azimuth of vibration at 45° to it, was tested in the most promising films for ellipticity, but none detected.

Rotation.—Figure 3 presents a diagram of the system used for measuring rotation. A very clear sun as source was necessary for all observations where transmitted light was studied. This was concentrated by a long-focus lens L_1 on

Fig. 3.

the collimator slit S_1 of a Fuess spectral instrument so adjusted as to furnish at the emergent slit S_2 a practically monochromatic bundle of rays of any desired colour. The extremes of the bundle differed in wave-length usually by about $10 \mu\mu$. These rays passed successively through an achromatic lens L_2 , a polarizing prism P , the film F (placed between the magnet-poles), and the Lippich half-shade analysing pair A_1 and A_2 , which were mounted in the axis of a graduated circle. A viewing telescope focussed on the edge of the half nicol A_1 completed the optical system. Settings were made by rotating the analysing pair (fixed relative to each other) until the customary *match* was obtained.

For investigating the reflected light the rays from the spectral system were brought in from the side and turned by means of a total-reflecting prism through a polarizer of much smaller aperture than that used in testing the transmitted light. The rays were reflected from F' back over the polarizer, entering the analysing system so placed as to receive them. The angle of incidence on the film with this arrangement was not greater than two degrees.

Ellipticity.—For measuring this a Brace half-shade elliptic polarizer and compensator was used. To convert the above rotation system into one for measuring ellipticity, the half nicol A_1 was removed and A fixed at extinction. The mica half-shade elliptic polarizer was placed in the position originally occupied by A_1 , covering half the field and fixed at maximum illumination. The compensator, a thicker sheet of mica, was then mounted (covering the whole field) in the graduated circle. Settings were made by rotating this compensator until a *match* was established. To eliminate the effect arising from mere rotation of the plane by the film, the polarizer P was arranged to be conveniently rotated a sufficient amount to compensate for this. This was determined with suitable accuracy by rotating to minimum intensity of field. The half-shade was of the order $\cdot 009 \lambda_D = 3\cdot 2$ degrees. The compensator, carefully measured according to Stokes' method *, was found to be of the order $60\cdot 5$ for a wave-length of $560 \mu\mu$. The order of a similar piece of mica, a quarter-wave plate for the same colour, was carefully measured for the various spectral colours, and these values used in determining the order of the compensator for the various wave-lengths studied. The ellipticity of the light was calculated from the formula

$$E = \tan \nu_1 [\sin 2(\phi - \phi_0) + \sin 2\phi_0],$$

in which E = ratio of minor to major axis of the elliptic vibration; $2\nu_1$ = order of the compensator; ϕ_0 = angle through which the compensator is rotated to change from a *match* on plane-polarized light to the nearest position of no effect on this light; and ϕ = the angular displacement of the compensator from its position of *match* on plane-polarized light to a *match* on the light having an ellipticity E . If the compensator and half-shade are of the same material, ϕ_0 does not change with the colour. This formula is accurate for thin compensators. All measurements of both rotation and

* Phil. Mag. [4] ii. p. 420.

ellipticity were obtained by reversing the magnetizing current in the electromagnet, which doubled the magnitude of the quantity sought.

The direction of vibration in the ellipse was determined by comparing the compensator with a quarter-wave plate, the *slow* and *fast* azimuths of which had been determined by means of the interferometer.

EXPERIMENTAL RESULTS.

6. *Dark Iron.*

In Table I. (p. 842) are incorporated the values of the magnetic rotation and ellipticity imparted by three different films of dark iron to light transmitted through them along the lines of force, and with field-strengths giving maximum effects. Two of these films (Nos. 3 and 4) were deposited in an atmosphere of hydrogen, the third (No. 2) in helium. The rotation and compensator values are half the observed, which were, as already stated, obtained by reversing the magnetizing current. The ellipticity (ratio of minor to major axis) was obtained from the compensator values by use of the formula given on page 840. Positive values represent rotation (or vibration) in the direction of the magnetizing current; negative, the opposite direction. By all three films the rotation is reversed in direction at a wave-length of about $540\ \mu\mu$, and the ellipticity at about $460\ \mu\mu$. This similarity in the results from films deposited in hydrogen and in helium indicates that their peculiar properties are to be ascribed to the form in which the iron is deposited rather than to the existence of any chemical combination with the gas. This conclusion is strengthened by the fact that iron deposited by Harris in nitrogen (*l. c.*) gives also zero rotation and ellipticity at the same positions in the spectrum.

Fig. 4 (Pl. XXIV.) represents graphically the results from film 3. The abscissas represent wave-lengths; the ordinates in the rotation curve give the rotation in degrees multiplied by ten, and in the ellipticity curve the ratio of minor to major axis multiplied by one thousand. In the same figure is plotted the transmission curve of the film, the ordinates representing the per cent. transmission divided by five. The values for this latter curve are taken from Table II. The relatively large transmission of the longer waves causes the film to impart a rich golden tint to white light.

In Table II. (p. 843) are given for the same films the values of rotation and ellipticity divided by the thickness of the

TABLE I.—*Dark Iron.*Thickness : No. 2, 540×10^{-7} cm.; No. 3, 490×10^{-7} cm.; No. 4, 200×10^{-7} cm.

Wave-length. ($\mu\mu$).	No. 2.—Field, 7,600.			No. 3.—Field, 7,500.			No. 4.—Field, 13,200.		
	Rotation. (deg.)	Compens. (deg.)	Ellipticity $\times 10^3$.	Rotation. (deg.)	Compens. (deg.)	Ellipticity $\times 10^3$.	Rotation. (deg.)	Compens. (deg.)	Ellipticity $\times 10^3$.
408	-48	...	...	-48	-275	-708	-20	-118	-303
417	-61	...	...	-53	-298	-754	-25	-107	-272
431	-74	-210	-519	-57	-216	-535	-22	-083	-205
440	-76	-138	-328	-57	-189	-441	-23	-054	-149
450	-74	-078	-188	-58	-129	-309	-24	-027	-064
460	-61	+063	+150	-54	-020	-046	-21	-006	-014
470	-52	+142	+328	-47	+037	-084	-18	+038	+087
480	-45	+192	+435	-40	+091	+205	-13	+055	+124
500	-25	+258	+561	-25	+152	+331	-08	+065	+140
520	-10	+280	+585	-15	+193	+404	-04	+072	+150
540	+03	+311	+640	-03	+231	+475	+02	+084	+173
560	+14	+313	+619	+17	+244	+483	+05	+092	+181
580	+25	+296	+568	+17	+230	+442	+08	+087	+167
600	+33	+255	+475	+24	+210	+390	+10	+079	+146
630	+40	+194	+344	+32	+185	+330	+14	+073	+130
660	+47	+142	+242	+37	+145	+246	+18	+061	+104
680	+43	+119	+198	+42	+123	+204		+056	+092

TABLE II.—*Dark Iron.*
Field: 7,500 c.g.s.

Wave-length.	Rotation Thickness $\times 10^{-3}$.			Ellipticity Thickness			Transmission (per cent.).		Extinction $\times 10^{-4}$.	Refractive Index.
	No. 2.	No. 3.	No. 4.	No. 2.	No. 3.	No. 4.	No. 3.	No. 4.		
408	— 8·8	— 4·9	— 9·4	...	— 142	— 143				2·39
417	— 11·2	— 9·8	— 11·4	— 92	— 150	— 129			8·3	2·38
431	— 13·6	— 11·6	— 10·3	— 61	— 89	— 69	1·3	14·4		2·36
440	— 14·0	— 11·7	— 10·7	— 35	— 63	— 30	..	..	7·3	...
450	— 13·7	— 11·0	— 11·0	— 98	— 9	— 7	1·9	15·9	...	2·35
460	— 12·0	— 11·0	— 9·8	— 120	— 17	— 41	3·0	19·2	6·4	2·34
470	— 9·5	— 9·6	— 8·4	— 61	— 17	— 41	4·7	21·3	5·7	2·32
480	— 8·2	— 8·2	— 6·1	— 80	— 42	— 59	6·9	29·2	5·0	2·31
500	— 4·6	— 5·1	— 3·7	— 102	— 67	— 67	9·7	33·0	4·2	2·29
520	— 1·7	— 3·1	— 1·7	— 106	— 83	— 72	12·6	36·3	3·7	...
540	— 0·5	— 0·6	— 0·7	— 116	— 96	— 85	15·3	39·2	3·2	2·26
560	— 2·5	— 1·9	— 2·3	— 113	— 97	— 88	18·0	41·9	2·9	2·24
580	— 4·6	— 3·5	— 3·7	— 103	— 88	— 77	20·7	44·7	2·7	...
600	— 6·1	— 4·9	— 4·7	— 87	— 78	— 69	...	...	...	2·21
620	...	...	...	...	...	...	...	...	...	2·20
630	— 7·3	— 6·5	— 6·4	— 63	— 66	— 61	23·4	47·0	2·4	...
640	...	...	...	— 45	— 50	— 49	26·1	49·2	2·2	...
660	— 8·6	— 7·4	— 8·2	— 37	— 41	— 44	28·0	56·6	1·9	...
680	— 7·8	— 8·5	...	...	...	...	30·9	51·3	1·7	...
700	— 8·5	...	...	...	...	...				...

corresponding film. These show that both rotation and ellipticity are approximately proportional to the thickness of the film, the approximation being on the whole as near as one could expect from the conditions of the experiment. These values for films 3 and 4 are plotted in fig. 5, the results from 3 being indicated by the black dots, from 4 by the circles. The transmission values for the same films, given also in Table II., serve for calculating the extinction coefficients by using the formula

$$\frac{I_3}{I_4} = e^{-K(d_3-d_4)},$$

in which I_3 , I_4 refer to the ratio in percent. of transmitted to the incident light of the two films respectively; d_3 and d_4 the thickness of the films in centimetres; and K the extinction coefficient sought. These extinction coefficients are also given in Table II. Finally, in the last column of this table are given the refractive indices of film 3 as obtained according to the method described in § 3. They are represented in the upper plot of fig. 5, and the extinction coefficients in the lower.

The rotation, ellipticity, and extinction curves are consistent with each other; but it appears strange that the refractive-index curve shows no corresponding anomaly in form in this region. Its slope is, however, opposite in direction to that given by other investigators for normal iron. The magnitude (2.2 to 2.4) is about the same here as in normal iron.

In Table III. are recorded the observations of rotation and ellipticity of film 2 with various field-strengths, the magnitude of the latter being determined by the rotation produced in a given length of carbon bisulphide. The bottom line of this table gives the ratio of the mean of the magnitudes contained in each two vertical columns (obtained by ignoring algebraic signs). This shows that, within experimental errors, the ellipticity bears the same ratio to the rotation for all field-strengths. Assuming, as has been shown in some cases by Du Bois*, that the rotation is proportional to the magnetization of the film, we may conclude that the ellipticity produced by the film is also proportional to its magnetization.

Observations on light reflected from these films in a magnetic field gave no conclusive results, arising partly from the fact that so much light is returned from the back surface of the film, especially in the red end of the spectrum.

* Du Bois, Wied. *Ann.* xxxi. p. 941.

TABLE III.—*Dark Iron.*

Field	2,800.		6,300.		7,500.		14,100.	
Wave-length.	Rotation.	Ellipticity × 10 ³ .	Rotation.	Ellipticity × 10 ³ .	Rotation.	Ellipticity × 10 ³ .	Rotation.	Ellipticity × 10 ³ .
417	-.49	...	-.61	-6.20	-.61	...	-.67	-4.03
431	-.55	-3.65	-.76	-5.14	-.74	-5.24	-.71	-4.65
440	-.55	-2.52	-.73	-3.51	-.76	-3.40	-.74	-2.58
450	-.57	-1.18	-.70	-1.78	-.75	-1.89	-.71	-1.37
460	-.49	+1.05	-.64	+0.75	-.66	+1.49	-.69	+1.37
470	-.43	+2.02	-.55	+2.98	-.52	+3.32	-.57	+3.15
480	-.32	+2.86	-.41	+4.53	-.45	+4.38	-.45	+4.27
500	-.18	+3.87	-.25	+5.36	-.25	+5.66	-.24	+5.47
520	-.07	+4.29	-.11	+5.73	-.10	+5.93	-.08	+6.02
540	+.01	+4.52	+.03	+6.09	+.03	+6.46	+.01	+6.58
560	+.12	+4.52	+.15	+5.85	+.14	+6.25	+.19	+6.46
580	+.18	+4.03	+.24	+5.38	+.25	+5.73	+.29	+5.97
600	+.23	+3.49	+.31	+4.52	+.33	+4.79	+.39	+4.90
630	+.29	+2.49	+.38	+3.31	+.40	+3.48	+.46	+3.47
660	+.33	+1.79	+.42	+2.43	+.47	+2.44	+.51	+2.13
680	+.33	+1.21	+.44	+2.12	+.43	+2.00	+.54	+1.79
Ratio of Magnitudes }	9.4		9.7		9.9		9.2	

This fact was made evident by the coefficient of reflexion being of a wave form in the red end of the spectrum (arising from interference between front and back reflexions) and a flat curve in the blue (where the absorption is large).

About 11 per cent. of the light is reflected at normal incidence from the front surface of these films, this value being practically the same for all colours.

7. *Electrolytic Iron.*

As already stated, the electrolytic films were deposited on microscope cover-glasses which had been platinized after the method of Kundt. As nearly as could be measured, these platinum films were about $6 \cdot 10^{-7}$ cm. thick in all cases. As a convenient method for measuring the thickness of the various iron films with the greatest accuracy, a comparatively thick film was deposited, its magnetic rotation observed for the more sensitive region of the spectrum ($520 \mu\mu$), and its thickness obtained by subtracting the thickness of the platinum from the combined thickness as measured according to § 2. The following table gives the values obtained, the thinner film merely serving to furnish check-values.

TABLE IV.

Film.	Thickness $\times 10^7$ (cm.).			Rotation (degrees).	Rotation Thickness.
	Pt + Fe.	Pt (approx.).	Fe.		
24	41	6	35	·92	263000
29	67	6	61	1·57	257000

The field-strength used for these measurements was 13,700 (c.g.s.).

From the above value of the rotation divided by the thickness, the thickness of the other films was calculated after measuring their rotation under the same conditions. This assumes that the various films are identical in structure, which assumption later results show to be not rigidly correct. However, the accuracy obtained by this procedure is probably much greater than if the thickness of the thinner films used had been measured directly.

Values of the rotation and ellipticity produced by two different electrolytic films are found in Table V. and the corresponding curves in fig. 6 (Pl. XXIV.). The form of the

TABLE V.—*Electrolytic Iron.*

Thickness : No. 24, 35×10^{-7} ; No. 26, 41.5×10^{-7} cm.

Wave-length.	No. 24—Field, 14,700.			No. 26—Field, 14,600.		
	Rotat. (deg.).	Compens. (deg.).	Ellipt. $\times 10^3$.	Rotat. (deg.).	Compens. (deg.).	Ellipt. $\times 10^3$.
440 ...	57	5.6	13.3	66	6.4	15.5
460 ...	61	...	...	...	...	...
480 ...	65	6.2	13.6	78	7.3	16.2
500 ...	70	...	...	...	...	...
520 ...	78	7.1	14.4	91	8.3	17.0
540 ...	81	...	...	...	...	...
560 ...	89	7.8	15.0	104	9.2	17.5
600 ...	98	8.3	15.1	120	9.4	16.9
630 ...	105	8.5	14.7	129	9.4	16.2
660 ...	107	8.6	14.3	127	9.3	15.2

rotation curve is practically the same in both, but there is an evident difference in the ellipticity, which indicates that the metal giving the upper curve has the centre of its resonance region slightly nearer the visible spectrum than the other. Both indicate the resonance region of electrolytic iron as being much further out in the violet than that of dark iron.

The values of rotation and ellipticity divided by the thickness of the corresponding films are given in Table VI., and

TABLE VI.—*Electrolytic Iron.*

Field, 14,600 c.g.s.

Wave-length.	$\frac{\text{Rotation}}{\text{Thickness}} \times 10^{-3}$.		$\frac{\text{Ellipticity}}{\text{Thickness}}$.		Extinction, $\times 10^{-5}$.
	No. 24.	No. 26.	No. 24.	No. 26.	
440 ...	163	159	3820	3740	...
460 ...	174	...	...	...	...
480 ...	189	187	3880	3920	8.1
500 ...	199	...	...	...	7.5
520 ...	221	219	4140	4080	7.0
540 ...	230	...	...	...	6.5
560 ...	254	249	4300	4220	6.3
580 ...	270	...	...	...	6.3
600 ...	280	288	4330	4100	6.1
620 ...	...	...	...	...	6.0
630 ...	299	310	4230	3920	...
640 ...	...	...	...	...	6.2
660 ...	306	305	4070	3660	6.0

their curves in fig. 7. The rotation is proportional to the thickness throughout, but with the ellipticity this is true only in the blue end of the spectrum, a considerable divergence being evident in the red. A more remarkable variation in these electrolytic films is found on comparing the rotation curve in this figure with that plotted from Lobach's results (*l. c.*) which is also given. The magnitudes are not only greatly different, but the rotation in our films increases more rapidly toward the red than in his, thus showing that the difference in values cannot be accounted for by assuming an error in thickness measurements.

The extinction coefficients of this type of iron were obtained by measuring the transmission of a very thin film of definite thickness, then repeating the measurements after depositing over this. Two films were thus tested, giving as mean results the values found in Table VI. The corresponding curve is plotted in fig. 7. Compared with dark iron it is noticed that this extinction-curve is much flatter than that of fig. 5, a fact we should expect from the great difference in form of the curves of rotation and ellipticity. Another remarkable difference between these films and those of the dark iron is the relative magnitudes of rotation, ellipticity, and extinction. With the same thickness the magnetic effects of electrolytic iron are about forty times that of the dark, while the extinction ranges from ten to thirty times.

The effect on rotation and ellipticity of varying the strength of the magnetic field is shown in the following table, obtained from film 24 with a wave-length of 520 $\mu\mu$.

TABLE VII.

Field-strength (c.g.s.).	Rotation (deg.).	Ellipticity $\times 10^3$.	Ellipticity Rotation $\times 10^3$.
9,500	60	12.7	21.2
10,800	65	13.8	21.2
12,800	69	14.8	21.5
15,000	77	16.2	21.2

As with dark iron, the ellipticity changes with the magnetizing force at the same rate as the rotation, as shown by the last column of this table.

Light reflected from an electrolytic film (No. 22) was

tested for both rotation and ellipticity in a field of about 13,000 lines. The results are given in the following table:—

TABLE VIII.

Wave-length	440	480	520	560	600	630	660
Rotation (deg.)	−·16	−·17	−·19	−·19	−·18	−·14	−·18
Ellipticity $\times 10^3$...	−·06	−·23	−·42	−·45	−·50	−·90	−·70

These results show that the rotation of reflected light is about the same for all colours, but the ellipticity—on the whole small—increases slightly with the wave-length. We find here that the negative rotation is also accompanied by a negative ellipticity, both being positive in the case of transmitted light.

8. *Metallic Iron.*

The type of films designated as *metallic*, to distinguish them from the other type obtained from cathode deposit *in vacuo*, seem to be produced by sublimation of the cathode. They are probably nearer normal iron in their structure than either of the other types. This is indicated by their appearance, and also suggested by their magnetic characteristics.

The reflexion coefficients as measured are practically constant throughout the spectrum, an average of 37 per cent. of the light being reflected. Their absorption is so great that only very thin specimens could be investigated, the thickest being 19×10^{-7} cm., from which the thickness of the others was obtained by measuring their magnetic rotation. This film (No. 15) was very carefully measured, following the method described in § 2, by two observers independently, whose mean results differed by only three per cent.

In Table IX. are found the magnetic rotation and ellipticity produced by two different films of this type in a field of 13,200 units. The results from film 15 are plotted in fig. 8 (Pl. XXIV.). The form of the rotation curve is very similar to that from electrolytic iron, but the ellipticity curve is distinctly different, the ellipticity, decreasing instead of increasing, with the wave-length. The form of the latter indicates the resonance region as being farther out in the ultra-violet than that of the electrolytic iron type. A more marked difference in the two types becomes evident when the ratio of

TABLE IX.—*Metallic Iron.*Thickness: No. 11, 15.4×10^{-7} ; No. 15, 19×10^{-7} cm.

Field: 13,200 c.g.s.

Wave-length.	No. 11.			No. 15.		
	Rotat. (deg.).	Compens. (deg.).	Ellipt. $\times 10^3$.	Rotat. (deg.).	Compens. (deg.).	Ellipt. $\times 10^3$.
406 ...	.78	...	...	...	...	...
417 ...	.83	7.2	17.7	.98	...	...
431 ...	.85	...	...	...	...	...
440 ...	.87	7.2	17.0	1.07	8.8	20.8
460 ...	.92	7.3	16.7	...	...	...
480 ...	.95	7.3	16.0	1.22	8.7	19.0
500 ...	1.06	7.2	15.2	...	...	...
520 ...	1.08	7.2	14.6	1.30	8.8	17.9
540 ...	1.06	7.3	14.6	...	...	...
560 ...	1.15	7.1	13.7	1.43	8.8	16.9
580 ...	1.17	7.1	13.2	...	...	...
600 ...	1.20	7.0	12.6	1.50	8.8	15.9
630 ...	1.20	7.0	12.1	...	8.6	14.8
660 ...	1.17	7.0	11.5	1.59	...	...
680 ...	1.20	7.3	11.8	..	...	...

rotation and ellipticity to the thickness is considered. Table X. gives these for the two films represented in Table IX. Both possess about the same rotatory power which is three times that of the electrolytic films. The ratio of ellipticity to the thickness is also two to three times as large in the metallic type as in the electrolytic.

The results in Table X. and corresponding curves in fig. 9 show that the ellipticity is not proportional to the thickness, if the two films are of exactly the same type. This inconsistency becomes more marked with thinner films, and leads to the suggestion (discussed below) that an observable part of the ellipticity of the transmitted light arises from reflexion effects, an explanation put forward by Righi* for the existence of ellipticity in the transmitted light.

Table X. also gives the transmission measurements on two films (Nos. 11 and 16) from which the extinction coefficients in the adjacent column are calculated. The transmission curve of film 11 is plotted in fig. 8. It reveals only a slightly greater transparency in the red over that in the blue. The extinction curve, plotted in fig. 9, is practically straight and nearly horizontal. Compared with electrolytic films the extinction here is about five times the magnitude obtained from them.

* Righi, *Mem. R. Accad. Sc. d. Bologna*, 1886, p. 443.

TABLE X.—*Metallic Iron.*

Thickness: No. 11, 15.4×10^{-7} ; No. 15, 19×10^{-7} ;
No. 16, 7×10^{-7} cm. Field: 13,200 c.g.s.

Wave-length.	Rotation Thickness $\times 10^{-3}$.		Ellipticity Thickness.		Transmission (per cent.).		Extinct. $\times 10^{-6}$.
	No. 11.	No. 15.	No. 11.	No. 15.	No. 11.	No. 16.	
406 ...	520						
417 ...	535	520	12000				
431 ...	550	...	...				
440 ...	570	560	11500	10700			
460 ...	600	...	11200	...			
480 ...	610	640	10700	9800	.88	8.5	3.3
500 ...	690	...	10300	...	.92	9.0	3.3
520 ...	700	680	10000	9200	.97	8.7	3.2
540 ...	690	...	9800	...	1.01	8.6	3.1
560 ...	740	750	9300	8700	1.03	8.9	3.1
580 ...	760	...	9000	...	1.04	9.3	3.2
600 ...	780	790	8700	8300	1.06	9.2	3.1
620 ...	...	...	...	...	1.06	9.2	3.1
630 ...	780	...	8500	8000	...	...	...
640 ...	...	...	...	...	1.04	9.0	3.1
660 ...	760	830	7800	...	1.06	9.1	3.1
680 ...	780	...	8000	...	1.01	8.5	3.1

The variation of both magnetic rotation and ellipticity with field-strength is given, for film 15, in Table XI. The ratio of the mean ellipticity to the mean rotation for those

TABLE XI.—*Metallic Iron.*

Film No. 15.

Field:	2800	2700	5800	5700	7500	7600	13200	13200	15500	15500
Wave-length.	Rot.	Ellipt. $\times 10^3$.	Rot.	Ellipt. $\times 10^3$.	Rot.	Ellipt. $\times 10^3$.	Rot.	Ellipt. $\times 10^3$.	Rot.	Ellipt. $\times 10^3$.
440...	.29	5.05	.68	10.2	.74	14.5	1.06	20.4	1.17	
480...	.33	4.7	.66	9.6	.86	13.4	1.21	18.7	1.22	
520...	.34	4.5	.72	9.1	.91	12.5	1.30	17.6	1.34	18.2
560...	.40	4.1	.79	8.4	1.00	11.8	1.43	16.6	1.47	17.1
600...	.35	3.9	.79	8.4	1.08	11.2	1.50	15.6	1.52	16.4
630...	...	3.7	...	7.8	...	...	...	14.6	...	15.1
660...	.40	...	.82	...	1.13	...	1.58	...	1.65	
Ratio of Means }	11.8		11.4		11.8		11.8		11.3	

wave-lengths for which values were obtained for all fields, is given at the bottom of the table (corrections having first been made for difference in field-strength). As with both the *dark* and the *electrolytic* types, this shows also the ellipticity proportional to the rotation, hence we assume it to be proportional to the magnetization of the iron.

Fig. 10 shows the variation in magnetic rotation of the three types of films with the strength of field. The curves for *electrolytic* and *metallic* films (plotted from Tables VII. and XI.) are quite parallel; that for the *dark* (Table III.) reaches practically a maximum magnitude at an intensity as low as 5000 lines, though the others still show an observable increase at 15,000.

The effect of reflexion in a magnetic field is given for film 15 in the following table:—

TABLE XII.
Field: 13,200 c.g.s.

Wave-length	440	480	520	560	600	660	680
Rotation (deg.)	-.12	-.12	-.13	-.12	-.11	-.15	-.13
Ellipticity $\times 10^3$...	...	-2.34	-2.20	-2.12	-2.16	-1.92	-2.01

The rotation and ellipticity are both negative, as found in the case of electrolytic films, the rotation in both being of about the same magnitude.

The ellipticity of the *metallic* type (which was found to be the same on both air and glass faces of the film) decreases slightly with increasing wave-length, and averages about four times that obtained from the electrolytic type. The results in Table XII. are plotted in fig. 8.

9. *Elliptic Polarization produced by Transmission should be Proportional to the Thickness.*

It may be easily proved that any ellipticity arising from differential absorption, of the two circular components into which the light is assumed to be resolved, should, for the magnitudes observed here, be simply proportional to the thickness of the film.

Let A_r and A_l be the amplitudes of the "right" and "left" vibrations respectively. These superposed produce an elliptic vibration whose major axis is twice their sum,

and minor axis twice their difference. The ratio of minor to major axis is then

$$E = \frac{A_r - A_l}{A_r + A_l}.$$

This we designate the ellipticity of the vibration. If A_r and A_l be equal we have zero ellipticity, a plane vibration. After passing a distance x through a medium possessing the extinction coefficients k_r and k_l (defined in terms of the amplitude) the two vibrations will have the amplitudes respectively

$$A_r e^{-k_r x} \quad \text{and} \quad A_l e^{-k_l x},$$

and will combine to form an elliptic vibration possessing as ratio between the axes the value

$$E = \frac{A_r e^{-k_r x} - A_l e^{-k_l x}}{A_r e^{-k_r x} + A_l e^{-k_l x}}.$$

For A_r and A_l equal, which is the case at the incident face of the film, when there is no ellipticity of the reflected light, this equation readily takes the form

$$\begin{aligned} E &= \frac{e^{+\frac{k_l - k_r}{2}x} - e^{-\frac{k_l - k_r}{2}x}}{e^{+\frac{k_l - k_r}{2}x} + e^{-\frac{k_l - k_r}{2}x}} \\ &= \tanh \frac{k_l - k_r}{2} x. \end{aligned}$$

For values of $E \leq .15$ we may write this (within an error of less than one per cent.)

$$E = \frac{k_l - k_r}{2} x.$$

Within the accuracy of our measurements (which do not exceed an ellipticity of .02) *the ellipticity arising from differential absorption in the films should therefore be proportional to their thickness.* For those films in which the ellipticity is proportional to the thickness, the tabulated values of the ellipticity divided by the thickness represent therefore

$$\frac{k_l - k_r}{2}.$$

10. *Effect of Elliptic Polarization by Reflexion on that of the Transmitted Component.*

Let R_r^2 and R_l^2 be the ratio of the intensity of the reflected light to the incident for the "right" and "left" components respectively. The corresponding ratio of amplitudes will then be R_r and R_l . The ellipticity of the reflected light when the incident is plane polarized is therefore

$$E_R = \frac{R_r - R_l}{R_r + R_l}.$$

In the measurements given this ellipticity is a very small quantity, that is $R_r - R_l$ is small. Since the reflexion in a magnetic field is not appreciably different from that without it, we may also consider $R_r + R_l = 2R$, in which R^2 is the reflexion coefficient of the metal as commonly determined. The above ellipticity then becomes

$$E_R = \frac{1}{R} \cdot \frac{R_r - R_l}{2}.$$

The ellipticity of the penetrating component is given by

$$E_P = \frac{(1 - R_r^2)^{\frac{1}{2}} - (1 - R_l^2)^{\frac{1}{2}}}{(1 - R_r^2)^{\frac{1}{2}} + (1 - R_l^2)^{\frac{1}{2}}},$$

which becomes, by substituting R as above,

$1 - R^2$ for $(1 - R_r^2)^{\frac{1}{2}}(1 - R_l^2)^{\frac{1}{2}}$, and $2R^2$ for $R_r^2 + R_l^2$:

$$\begin{aligned} E_P &= -\frac{R_r^2 - R_l^2}{4(1 - R^2)} \\ &= -\frac{R^2}{1 - R^2} E_R. \end{aligned}$$

For the magnitudes dealt with in this investigation the ellipticity of the transmitted light is obtained by simply adding to the ellipticity produced by differential absorption that produced by differential reflexion. Assuming that the effect of reflexion at both air and glass surfaces of the film is the same, as indicated by the results obtained from film 15 (p. 852), we have for the ellipticity of the transmitted light

$$\begin{aligned} E_T &= E + 2E_P \\ &= \frac{1}{2}(k_l - k_r)x - 2\frac{R^2}{1 - R^2}E_R. \end{aligned}$$

By measuring E_T , E_R , R^2 , and x the difference of the absorption coefficients $(k_l - k_r)$ may be calculated from this

equation. By measuring E_T and α for two films of different thickness the term containing R^2 and E_R may be eliminated.

To test this formula a series of very careful observations were made on three different films, of which the mean results are given in the following table, the "right" vibration being given the positive value:—

TABLE XIII.

Wave-length, 500 $\mu\mu$. Field-strength, 13,600.

Film.	Double Rotation.	Thickness (calc.).	Ellipt. $\times 10^3$.	$\frac{k_l - k_r}{2}$.
16	·99	7.5×10^{-7}	9.41	9.0×10^3
11	2.21	16.6 „	16.1	8.0 „
15	2.61	19.6 „	18.8	8.1 „

The above values of $\frac{k_l - k_r}{2}$ are calculated by using $E_R = -2.07 \times 10^{-3}$ and $R^2 = .37$, as found in the case of film 15. By eliminating these last two quantities, however, films 16 and 11 give 7.3×10^3 ; films 16 and 15, 7.8×10^3 ; and films 11 and 15, 9.1×10^3 as values for the same expression. The two methods give results which agree as well as the experimental conditions warrant.

11. *Light transmitted at Right Angles to the Magnetic Field.*

To test the possibility of the optical effects in the magnetic field being produced by the presence of free ions (as in the Hall effect), light plane-polarized at an azimuth of forty-five degrees to the field was sent at right angles to the field through the film, and tested for the presence of elliptic polarization. Film 15 was used for this test as it gave the largest effects in the foregoing experiments. *No ellipticity could be detected*, although about one per cent. of that produced on the light transmitted along the lines of force could have been seen.

12. *Dark Cobalt.*

Cobalt films, designated from their appearance by reflected light as *dark*, were obtained in the same manner as the corresponding of iron, that is, deposited from the cathode

in hydrogen under a comparatively low current-density. Compared with iron, they are remarkably transparent but correspondingly less active in the magnetic field. Fig. 11 (Pl. XXIV.) gives curves for the magnetic rotation and ellipticity of two different films, 1870×10^{-7} and 3470×10^{-7} cm. thick respectively. They are strikingly different from all other types of films investigated. The rotation is positive but decreases with increasing wave-length; the ellipticity is negative throughout and increases in magnitude with increasing wave-length. On comparing these curves with those of dark iron (fig. 4) we are inclined to think that the latter would take this form in the region of the spectrum below about $380 \mu\mu$.

Table XIV. contains the values of magnetic rotation

TABLE XIV.—*Dark Cobalt.*

Thickness: No. 2, 1870×10^{-7} ; No. 3, 3470×10^{-7} cm.
Field: 14,000 c.g.s.

Wave-length.	Rotation Thickness $\times 10^{-3}$.		Ellipticity Thickness		Transmission (per cent.).		Extinct. $\times 10^{-3}$.	Refrac. Index.
	No. 2.	No. 3.	No. 2.	No. 3.	No. 2.	No. 3.		
440	...	1.37	...	...	.5	...	...	1.98
460	...	1.28	- 7.6	- 9.2	.7	.2	...	1.99
480	1.01	1.17	- 6.4	- 9.7	1.0	.2	10.2	1.98
500	1.10	1.07	- 7.6	-10.2	1.5	.3	9.6	1.96
520	1.07	1.05	- 7.0	-11.7	2.1	.5	9.0	1.96
540	.96	.97	- 8.0	-12.2	3.1	.75	8.6	1.96
560	.88	.97	- 8.8	-11.8	4.0	1.1	8.1	1.96
580	.91	.91	- 9.2	-12.8	5.0	1.3	7.6	1.94
600	.94	.89	-10.0	-13.2	6.5	2.0	6.9	1.98
620	...	...	...	...	8.7	2.9	6.7	...
630	.70	.80	- 9.6	-13.5	...	...	...	1.94
640	...	...	...	...	10.6	3.7	6.3	...
660	.61	.76	-10.0	-14.2	11.5	4.0	6.1	1.94
680	...	...	...	...	10.7	5.4	5.6	...
690	.60	.61	...	-14.8	...	...	...	1.94

and ellipticity divided by the thickness (plotted in figure 12), and of the transmission of the two films. The rotation is proportional to the thickness, but the ellipticity increases more rapidly than the thickness. Were this caused by elliptic polarization of the reflected light, this latter should be over 4.10^{-3} , but a test revealed that one-fortieth of that magnitude was not present. This indicates that the

differential absorption coefficient ($k_r - k_l$) was not the same in the two films.

The coefficients of extinction and the refractive indices of these films are also given in Table XIV. and plotted in fig. 12. The extinction is much less than that of *dark* iron, and also increases much less rapidly with decreasing wave-lengths. The refractive index rises very slightly in passing from red to blue.

13. Electrolytic Cobalt.

Films of electrolytic cobalt were deposited on platinized glass from a solution of cobalt-ammonium-sulphate. They proved remarkably more active in a magnetic field than those of Lobach (*l.c.*). Our experience showed that the concentration of the solution and the rate of deposit affects the hardness of the electrolytic films of both iron and cobalt, and we are inclined to believe that it also affects their magnetic activity as well, though this was not tested. These films hold less closely to a definite type than either the *dark* or the *metallic* films.

Two thick films were produced for the purpose of obtaining their rotatory power for the brightest region of the spectrum. The measurements are given in the following table.

TABLE XV.

Wave-length, $520 \mu\mu$. Field, 13,600 c.g.s.

Film.	Thickness $\times 10^7$ (cm.).			Rotation.	Rotation Thickness*
	Pt + Co.	Pt. (approx.).	Co.		
30	76	6	70	2.31	330,000
32	66	6	60	1.80	300,000

The mean of these values of the rotation divided by the thickness was used for determining the thickness of the other films studied.

Table XVI. contains results from film 31 possessing a thickness of 31×10^{-7} cm. The quantitative results from different films did not agree well enough to warrant a more extended study, especially in reference to their elliptic polarization. Two films as measured gave the same value for ellipticity while their rotation differed by more than thirty per cent. The results from film 31 are, however, typical as regards the variation with wave-length. The curves

are given in fig. 13 (Pl. XXIV.). The rotatory power as shown in the table is more than double that obtained by Lobach.

TABLE XVI.—*Electrolytic Cobalt.*

Thickness, 31×10^{-7} cm. Field, 13,500 c.g.s.

Wave-length.	Rotation (deg.).	Ellipticity $\times 13^3$.	$\frac{\text{Rotat.}}{\text{Thick.}} \times 10^{-5}$.	Extinction $\times 10^{-5}$.
440	·94	9·6	3·03	
480	·99	9·5	3·19	9·0
500 .....		.....	.....	9·0
520	1·00	8·9	3·23	9·1
540 .....		.....	.....	9·0
560	1·10	8·4	3·55	8·9
580 .....		.....	.....	9·0
600	1·19	7·4	3·84	8·9
620 .....		.....	.....	8·7
630	1·22	6·6	3·94	...
640 .....		.....	.....	8·8
660	1·25	5·7	4·03	8·9

The extinction (also more than twice that given by Lobach) was obtained in the same manner as that of electrolytic iron, by measuring the transmission of a film of definite thickness, then depositing over this and repeating the measurements. The results as given are the mean of two sets obtained from different films. The extinction curve (fig. 13) is flatter than that of electrolytic iron. The form of the ellipticity curve appears to indicate also that the absorption region is effectively farther out in the ultra-violet than that of the iron. The difference in the results from this form of cobalt and the *dark* is nearly as striking as that between the corresponding types of iron.

14. *Metallic Cobalt.*

Films of cobalt designated as *metallic* were readily obtained by deposit from a very hot cathode with a glow current through hydrogen. Like iron they are brilliant mirrors, though for the same thickness much more transparent. Also like the iron they impart no tint to transmitted light.

In figure 14 are plotted the curves of rotation, ellipticity, transmission, and rotation by reflexion of a representative film. Only a slight trace of ellipticity by reflexion was observed. The forms of the curves are very similar to those of the corresponding type of iron (fig. 8).

Table XVII. and figure 15 embody the results from two films, one of measured thickness (48×10^{-7} cm.), the other calculated from its magnetic rotation (24×10^{-7} cm.). The results show that the ellipticity is proportional to the thickness, as should be expected since there is no appreciable ellipticity in the reflected light. The extinction values are found to be only about one-third those of the corresponding type of iron. The refractive indices as given were obtained from one series of observations. They could be only approximately determined owing to the small magnitudes involved. They are about fifty per cent. higher than those of *dark* cobalt, and like them remain about the same value throughout the spectrum.

TABLE XVII.—*Metallic Cobalt.*

Thickness : No. 7, 48×10^{-7} ; No. 8, 24×10^{-7} cm.

Field : 14,000 c.g.s.

Wave-length.	Rotation Thickness $\times 10^{-5}$		Ellipticity Thickness		Transmission (per cent.).		Extinct. $\times 10^{-6}$.	Refrac. Index.
	No. 7.	No. 8.	No. 7.	No. 8.	No. 7.	No. 8.		
440	.....	5.6	.....	5050	.....	1.9		
460	5.6	5.8	4800	4800	.....	2.0		
480	.....	5.8	.....	4600	.....	2.1		
500	5.7	5.8	4400	4450	.17	2.2	1.11	2.8
520	.....	5.9	.....	4300	.19	2.3	1.08	2.8
540	6.0	6.0	3960	4100	.20	2.3	1.06	3.2
560	.....	6.2	.....	3850	.22	2.5	1.05	3.3
580	6.3	6.3	3740	3780	.23	2.6	1.05	3.6
600	.....	6.4	.....	3430	.25	2.6	1.02	3.1
620	.....	.....	.....	.....	.27	2.7	1.00	3.2
630	6.8	6.6	.....	3200	.....	.....	.....	.....
640	.....	.....	.....	.....	.29	2.8	0.98	2.7
660	.....	6.8	.....	2880	.30	2.9	0.98	3.1

15. Nickel.

As already stated only electrolytic nickel showed more than a mere trace of optical activity in the magnetic field. This is rather remarkable, for brilliant nickel mirrors are produced by the glow current, and by varying the temperature, films of any hardness, all of which show metallic reflexion, may be obtained.

Table XVIII. (p. 860) contains the results obtained from two different films of electrolytic nickel, one (No. 40) possessing a measured thickness of 71×10^{-7} cm., the other (No. 41) a calculated thickness of 37.4×10^{-7} . The thickness of the second film, as calculated from its rotation, is considered

TABLE XVIII.—*Electrolytic Nickel.*Thickness: No. 40, 71×10^{-7} cm. (meas.);No. 41, 37.4×10^{-7} cm. (calc.).

Field: 13,800 c.g.s.

Wave-length.	No. 40.			No. 41.			Extinct. $\times 10^{-6}$.
	Rot.	Rotat. Thick. $\times 10^{-5}$.	Ellipt. $\times 10^3$.	Rot.	Rotat. Thick. $\times 10^{-5}$.	Ellipt. $\times 10^3$.	
440	74	1.04	.....	41	1.10		
480	85	1.20	.....	42	1.12	9.7	1.82
520	90	1.27	12.7	47	1.27	9.2	1.82
560	99	1.39	.....	50	1.34	9.0	1.83
600	1.07	1.51	.....	55	1.48	8.9	1.84
630	.....	.....	.....	61	1.65	9.0	.....
640	.....	.....	.....	.....	.....	.....	1.87

reliable because this ratio is practically the same for all colours. The ellipticity is evidently not proportional to the thickness, shown by comparing the values obtained from the two films at a wave-length of $520 \mu\mu$. A third film (No. 42) was deposited somewhat differently from the others and tested for magnetic rotation and ellipticity. The results are found in Table XIX. The thickness measured was 35×10^{-7} cm. It may be noted by comparison with film No. 41 of the preceding table that while the rotation of 42 is greater than that of 41, its ellipticity is somewhat smaller. A more striking difference is observed on comparing the rotatory power of the two films. No. 42 exhibits on the average fifty

TABLE XIX.—*Electrolytic Nickel.*Thickness, 35×10^{-7} cm. (meas.). Field, 13,800 c.g.s.

Wave-length.	Rotation (deg.).	Rotation Thickness $\times 10^{-5}$.	Ellipticity $\times 10^3$.
440	52	1.50	9.1
480	57	1.64	8.6
520	55	1.57	8.9
560	63	1.80	8.8
600	72	2.06	9.2
630	79	2.23	

per cent. greater values for the rotation divided by the thickness than No. 41. The magnitudes of both are again, as in iron and cobalt, greatly in excess of those obtained by Lobach for the corresponding type of films.

The extinction coefficients recorded in Table XVIII. were obtained by measuring the transmission and magnetic rotation of a thin deposit, then depositing over this and repeating the measurements. The thickness was calculated from the mean rotatory power of films 41 and 42, hence the values obtained for the extinction are consequently of questionable accuracy.

16. Summary and Conclusions.

(a) Three types of both iron and cobalt have been investigated with respect to their magneto-optical activity, their optical extinction, and also in part their refractive indices and reflexion. These types are found to differ essentially in the period of their optical resonance; and further also in the magnitude of their optical extinction, which appears to be largely a friction phenomenon. In the *dark* type the resonance region is in or very near the visible spectrum, so that *dark* iron gives a marked anomaly in both magnetic rotation and ellipticity; and *dark* cobalt gives curves for the same of such a form as to suggest, when combined with those of the *dark* iron, the typical form of the rotation and ellipticity on both sides of the resonance region. These hypothetical curves possess positive values for the magnetic rotation outside the resonance region changing through zero to negative within it; and negative ellipticity in the region of periods shorter than that of resonance, changing to positive in the region of longer periods. The rotation increases toward a maximum value on leaving the resonance region in both directions; the ellipticity increases to a maximum magnitude, then appears to decrease asymptotically toward zero on both sides. The hypothetical rotation curve appears to have the general form of that given by Elias* for erbium chloride, but with values opposite in sign.

(b) No corresponding anomaly exists in the refractive index curves, leading to the conclusion that the ions producing magnetic anomaly do not appreciably contribute to the refractive index.

(c) In the *electrolytic* films the magneto-optical effects indicate that the resonance region lies in the ultra-violet. The magnetic rotatory power, the differential optical

* *Physik. Zeitschr.* ix. p. 931 (1906).

extinction in the magnetic field, and the optical extinction of these films are all many times larger than those of the dark type. These properties also vary considerably in magnitude with different samples.

(d) In the *metallic* films the shift of the resonance region into the ultra-violet, the magnitudes of the magneto-optical properties, and the optical extinction are again all greater than in the *electrolytic*.

(e) There appears to be a relation between the granular structure of these films and their period of resonance. Electrolytically deposited metals are known to be granular. The *dark* films are far softer and less tenacious than these. It is therefore natural to suppose them to be made up of larger structural units. The metallic films, on the other hand, produced by cathode sublimation, appear more like the fused metal. Their structure should be of smaller units than either of the other types; they should therefore possess the shortest period of resonance, as the results seem to indicate.

(f) All films giving magnetic rotation impart also, under the same conditions, ellipticity to the transmitted light. In some cases an ellipticity was observed in the reflected light. Like the magnetic rotation, the ellipticity produced is proportional to the magnetization of the medium.

Eliminating the ellipticity arising from reflexion, that of the transmitted light was found in several cases to be proportional to the thickness of the film. The exceptions to this rule are considered to arise from a difference in structure of the films.

No ellipticity was observed in cases of light transmitted at right angles to the magnetic field.

(g) Films of electrolytic nickel showed marked magneto-optical properties, those obtained from the cathode *in vacuo* scarcely a trace.

(h) The extinction coefficients of both *electrolytic* and *metallic* films are greatly in excess of those obtained by other observers.

(i) Existing theories do not appear to lend themselves to explain the results obtained.

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FIG. 4.—DARK IRON.

FIG. 5.—DARK IRON.

FIG. 6.—ELECTROLYTIC IRON.

FIG. 7.—ELECTROLYTIC IRON.

FIG. 8.—METALLIC IRON.

FIG. 9.—METALLIC IRON.

FIG. 10.

FIG. 13.—ELECTROLYTIC COBALT.

FIG. 11.—DARK COBALT.

FIG. 12.—DARK COBALT.

FIG. 14.—METALLIC COBALT.

FIG. 15.—METALLIC COBALT.