

CHAPTER VI

FARADAY EFFECT IN DIAMAGNETIC CRYSTALS

1. INTRODUCTION

In 1845 Faraday (21) discovered that a transparent substance, placed in a magnetic field, rotates the plane of polarisation of light traversing it along the magnetic lines of force. This is now known as the Faraday effect. It differs from natural optical activity in that the sense of the rotation depends only on the direction of the magnetic field and not on the direction in which light passes through the medium. The magneto-optic rotation is considered positive when the rotation is in the direction of the amperean electric current which would be necessary to produce the magnetic field that causes the rotation. The rotation is found to be proportional to the thickness of the material traversed and the magnetisation intensity. For diamagnetics the magnetisation intensity is almost equal to the applied magnetic intensity and hence the rotation.

$$\alpha = V \int_0^L H_1 dl = V (\phi_L - \phi_0)$$

where L is the length of the specimen and H_1 represents the magnetic intensity at l and ϕ_L and ϕ_0 the magnetic potentials at $l = L$ and $l = 0$. If the field happens to be uniform and the direction of the magnetic field makes an angle θ with the direction of the light.

$$\alpha = VHL \cos \theta \quad (1)$$

$$\text{and if } \theta = 0, \alpha = VHL$$

where V is called the Verdet constant after the French physicist Verdet (58) who established all these quantitative laws. V represents the magnetic rotation in minutes of arc per centimetre per oersted.

To avoid errors due to inhomogenities in the field it is customary to evaluate the Verdet constant of a substance by comparing the rotation observed in it with that in a standard substance of the same thickness under identical conditions. The standard substances that are used are water and carbon disulphide. The values for these substances for λ 5893 (Na) together with the formula for the temperature variation are given below (Rodger and Watson (47)).

$$\text{Water : } V_D = 0.01311 (1 - 0.0000305t - 0.00000305t^2) \text{ minutes/cm./Oersted.}$$

$$\text{CS}_2 : V_D = 0.04347 (1 - 0.01696t) \text{ minutes/cm./Oersted.}$$

It is necessary to specify the wavelength and the temperature at which the Verdet constant is measured as it varies when either of these parameters is changed.

The actual measurements are made using some of the well known techniques that have been evolved for visual or spectroscopic polarimetry. Excellent reviews on this subject are available (2, 11, 22, 29, 31, 49) and we shall not dilate upon them. It may be remarked that the half shadow method is the most popular one for visual and spectrographic measurements. In recent years the photoelectric

methods (1, 23, 25, 52, 55, 56) have become so accurate and reliable that they are slowly replacing the photographic method for the measurements in the far ultraviolet.

2. VARIATION OF MAGNETO-OPTIC ROTATION WITH WAVELENGTH

The variation of the magnetic rotation with wavelength is one of the striking effects that was observed immediately after the original discovery of Faraday. The first empirical formula suggested for this was that V varied as $1/\lambda^2$ (E. Becquerel (3)). A notable advance in the subject was made in 1897 when H. Becquerel (6) basing himself on the simple electron theory and the concept of the Larmor's precession, derived the following formula connecting the Faraday rotation with the refractive dispersion.

$$V = \frac{e}{2mc^2} \lambda \frac{dn}{d\lambda} \quad (2)$$

This relation cannot obviously be expected to hold good in most cases as the Larmor's theorem is known to fail in the case of molecules. However in the modified form (18)

$$V = \gamma \frac{e}{2mc^2} \lambda \frac{dn}{d\lambda} \quad (3)$$

where γ is a constant factor, the Becquerel formula was found to fit the experimental data much better. Immediately after this penetrating analysis into the cause of the Faraday rotation by Becquerel, it became quite clear that the study of the dispersion of the magnetic rotation would be a powerful method for the understanding of the spectroscopic behaviour of a substance.

The Becquerel formula was soon followed by two formulae derived by Drude, (20), the first obtained on the hypothesis of "molecular currents" and the second on the concept of Hall effect. The formulae are

$$V = \sum_i \frac{A_1 v^2}{v_1^2 - v^2} \quad \text{---type A} \quad (4)$$

$$\text{and} \quad V = \sum_i \frac{A_1 v^3}{(v_1^2 - v^2)^2} \quad \text{---type B} \quad (5)$$

Here v_1 's represent the frequencies responsible for refractive dispersion. Since the publication of these formulae, there has been a considerable discussion as to the exact type of formula to be used for magneto-optic dispersion.

We shall now give in the briefest outline the derivation of the most general formula for magneto-optic dispersion and then discuss the actual nature of the formula to be used for diamagnetic substances.

The experiments on the velocity of light in a medium placed in a magnetic field (5, 40, 33, 10) have definitely established that Faraday rotation in isotropic substances, owes its origin to the fact that plane polarised light splits up into two circular vibrations which are propagated with different velocities in a magneto-optic medium. From Fresnel's theory

$$V = \frac{\pi v}{c} (n_- - n_+) \quad (6)$$

where n_- and n_+ are the refractive indices for the two circular components and c

is the velocity of light. This formula could be combined with a simple formula for refractive dispersion of the type

$$n^2 - 1 = \sum_i \frac{A_i N_i f_i}{\nu_i^2 - \nu^2} \quad (7)$$

where N_i, f_i , and ν_i represent the number, strength and the frequency of the dispersion electron. The magnetic field would affect ν_i, f_i , and N_i because of the Zeeman splitting and the accompanying changes in the transition probabilities and populations associated with the absorption frequency. Therefore,

$$n_+ - n_- = \delta n = \frac{1}{2n} \sum_i \frac{\delta n}{\delta \nu_i} \delta \nu_i + \frac{\delta n}{\delta f_i} \delta f_i + \frac{\delta n}{\delta N_i} \delta N_i \quad (8)$$

where $\delta \nu_i, \delta f_i$ and δN_i represent the differences in the frequency, oscillator strength and the number of oscillators for the two circular components. These quantities have been evaluated and are respectively equal to $2\gamma_1 \mu_0, 2f_i b_1 \mu_0$ and $2N_i \mu_B/KT$. Here μ_0 is the frequency of the normal Zeeman splitting, γ_1 is a measure of the deviation of the Zeeman splitting of ν_i from the normal value and b_1 is a factor dependent on the multiplet splitting, (Darwin (17)) and μ_B is the Bohr magneton. From these values and from equations (6) and (8) one gets (49)

$$V = \frac{e}{2mc^2 n} \sum_i \left[\frac{\gamma_1 A_i \nu^2}{(\nu_i^2 - \nu^2)^2} + \frac{B_i \nu^2}{\nu_i^2 - \nu^2} + \frac{C_i}{\Gamma} \frac{\nu^2}{\nu_i^2 - \nu^2} \right] \quad (9)$$

The last term is effective only in paramagnetics. One notices therefore that the most general magneto-optic rotation formula for a diamagnetic substance is a combination of the two types of formulae A and B suggested by Drude. In a series of classical papers on this subject Darwin (17, 18) has most critically examined the nature of the dispersion formula to be used for magneto-optic rotation. He concludes that the effect of the change in the oscillator strength due to the magnetic field would indeed be small, if not negligible, when the observations are confined to regions quite removed from the absorption wavelength. He has also been able to derive a formula of the type B using the general principles enunciated in Kramer's theory of dispersion.

In attempting to find which type of formula is most satisfactory experimentally, it is necessary to construct an adequate formula for refractive dispersion using either observed or at least reasonable absorption frequencies and then to test out which of the two formulae fits the magneto-optic dispersion best. At the time when Darwin wrote his memoir there were only four crystals for which accurate dispersion data were available both for refraction and Faraday rotation. These were NaCl, KCl, CaF₂ and quartz. Even so he concluded that there was little evidence for a formula of type A. Now we have accurate data on LiF, MgO, KBr, KI, CaCO₃, NaClO₃, Pb(NO₃)₂, Sr(NO₃)₂, Ba(NO₃)₂, fused silica and a series of optical glasses. In all these without exception the magneto-optic rotation can be well expressed by a formula (type B)

$$V = \frac{e}{2mc^2 n} \sum_i \frac{\gamma_1 A_i \lambda^2 \lambda_i^2}{(\lambda^2 - \lambda_i^2)^2} \quad (10)$$

The constants of these formulae for various substances are given in Table III.

It may be noticed that formula (10) is nothing but the modified Becquerel formula (2) in which the anomaly factor γ is different for different absorption frequencies. It must be remembered that in testing out the general formula (9) the variation with wavelength of the B term is very much faster than that of the (A) term. Hence as one approaches the ultraviolet, the effect of the B terms would predominate. Hence accurate values of the magneto rotation over the entire range of wavelengths, right from the infra-red to the extreme ultra-violet would be necessary before we can completely rule out the existence of an A term.

It is also pertinent to remark here that as the infra-red frequencies are due to atomic movements they cannot contribute much to magneto-optic rotation. Hence it is customary to omit the infra-red frequencies in the computations of magneto-optic rotation.

3. VARIATION OF MAGNETO-OPTIC ROTATION WITH TEMPERATURE

It has been noticed that the Verdet constant of a crystal increases with temperature while that of a liquid usually decreases with temperature. Unfortunately there is very little data on the temperature variation of Faraday rotation in crystals. The only crystal for which some data could be traced in the literature is quartz. The positive temperature coefficient obviously indicates that the temperature variation cannot be explained as a density change alone. Let

$$V = \frac{1}{n} \sum_i \frac{\gamma_i A_i N_i f_i v^2}{(v_1^2 - v^2)^2} \quad (11)$$

Following Chandrasekhar (12) who explained the temperature variation of optical activity, differentiating this equation and assuming no change in the oscillator strength, we have

$$\frac{dV}{dT} = \sum_i \frac{4 V_i \gamma_i^2}{\gamma_i^2 - \gamma^2} X_i + \sum_i \frac{1}{N_i} \frac{dN_i}{dT} V_i - \frac{V}{n} \frac{dn}{dT} \quad (12)$$

where $X_i = -\frac{1}{\gamma_i} \frac{d\gamma_i}{dT}$ and V_i is the contribution due to the frequency γ_i to the Verdet constant V . Since $\frac{1}{N_i} \frac{dN_i}{dT} = -\gamma$ the coefficient of cubical expansion, if the dispersion of the substance is controlled by one absorption frequency then

$$\frac{1}{V} \frac{dV}{dT} = \frac{4\lambda^2}{\lambda^2 - \lambda_1^2} X_0 - \gamma - \frac{1}{n} \frac{dn}{dT} \quad (13)$$

In the case of quartz an absorption wavelength at $\lambda 0.0925\mu$ is found to explain the dispersion and the magneto-optic dispersion fairly satisfactorily. From the temperature variation of refractive index (dn/dT), the values of X_0 and $1/n dn/dT$ are respectively found to be 4.5×10^{-5} and -0.42×10^{-5} . The cubical expansion for quartz is about 4.0×10^{-5} . Substituting these values one gets the value for $\frac{1}{V} \frac{dV}{dT}$ as 14.9×10^{-5} for $\lambda 5000$. The observed value (Borel 9) for the region $\lambda 6700 - \lambda 4700$ is 14.2×10^{-5} . The agreement seems to be quite satisfactory indicating that in a crystal the change in frequency due to temperature can to a large extent, explain the temperature variation of Faraday rotation.

4. THE EFFECT OF DENSITY ON THE FARADAY ROTATION

We shall next take up the question of the effect of density on Faraday rotation. Here again we have very little data on substances in the solid state. The only case where there is any satisfactory data is that of crystalline and fused quartz. When quartz which has a density of 2.65 is melted it becomes a glass and in doing so its density decreases to 2.208. X-ray and other studies indicate that the internal structure of quartz and fused silica are very similar. It is well known that the additive constant in the case of refractive index obtained from polarisability is the refractivity and its magnitude is either $\frac{n^2 - 1}{n^2 + 2} \times \frac{1}{d}$ or $\frac{n^2 - 1}{d}$ depending on whether the Lorentz-Lorenz polarisation field is present inside the crystal or not. In the same manner the additive constant for magneto-optic rotation is the magnetic rotativity defined as $\frac{9n}{(n^2 + 2)^2} \frac{V}{d}$ or $\frac{nV}{d}$. The significance of rotativity is, it must be reiterated, that for a substance it remains constant even when its density changes. The following Table gives all the optical and magneto-optic constants for quartz and fused silica. One notices that while there is a variation of only 2% in the values of nV/d for the two substances, the variation in $9n/(n^2 + 2)^2 V/d$ is almost 14%. This is rather disconcerting as these figures seem to throw a serious doubt on the very existence of the Lorentz-Lorenz polarisation field in solids or at least in quartz.

Substance	Density	Refractive index	Verdet Constant	Refractivity		Rotativity	
		$\lambda 5780$	$\lambda 5780$	Drude	L.L.	Drude	L.L.
Crystalline quartz	1.651	1.5447	0.01714	0.5228	0.1191	.00100	.00467
Fused quartz	2.208	1.4590	0.01540	0.5111	0.1238	.00107	.00537

5. FARADAY EFFECT AND ACCIDENTAL BIREFRINGENCE

The measurement of the Faraday rotation in cubic crystals is in principle quite a simple procedure. The only difficulty that prevents the collection of data in a large number of cubic crystals is the lack of proper specimens for experimental study. Only a few crystals like NaCl and KCl are obtained as large perfect specimens. The specimens that one usually comes across are quite small and as a rule they exhibit a small amount of strain birefringence. The smallness of the crystal by itself is no serious difficulty, as the use of fairly powerful magnetic fields together with accurate photoelectric techniques is capable of yielding very precise values of the magnetic rotation over quite a wide range of wavelength. The problem is therefore, one of eliminating the effects of the strain birefringence. A very thorough study of the effect of birefringence in Faraday rotation has been made (35, 44, 41, 53) and simple methods have been devised for evaluating the true rotation from observations of the apparent rotations in strained crystals.

It must be remembered that when measuring the rotation in a solid with a small amount of birefringence using a conventional apparatus, what is determined is the position of the major axis of the emergent elliptic vibration with respect to the planes of polarisation of the incident light. This could be called the apparent rotation. It is found that the apparent rotation is smaller or larger than the true rotation depending on the relative angle between the plane of the incident vibration and the axis of strain. When the birefringence is small

$$2\rho = 2\psi_0 \left(1 - \frac{\delta^2}{6}\right) \quad (14)$$

and

$$2\rho = 2\psi_{45} \left(1 + \frac{\delta^2}{3}\right) \quad (15)$$

where ρ is the true rotation and ψ_0 and ψ_{45} are the rotations when the plane of the incident vibration is parallel and at 45° to the axis of strain. Therefore the true rotation can be evaluated from the equation

$$\rho = \frac{2\psi_0 + \psi_{45}}{3} \quad (16)$$

The advantage of this method is that the magnitude of the birefringence need not be known at all. Fortunately as most melt grown and solution grown crystals exhibit a preferred axis of strain, this method is of great utility in the accurate measurement of the Verdet constant in small crystals. It is probably worthwhile to point out that if the error in the Faraday rotation due to birefringence at λ 6000 is about 1% that at λ 2500 A would be as great as 6% and hence the necessity for the birefringence correction.

6. FARADAY EFFECT IN ANISOTROPIC MEDIA

The theory of magnetic rotation in anisotropic crystals has been the subject of a series of investigations (13, 61, 34, 35). If plane polarised light is incident on an anisotropic medium placed in a magnetic field, it splits up into two elliptic vibrations of opposite senses, lying crossed to each other, which travel with different velocities. These two vibrations being coherent, they combine at every point to produce an elliptic vibration whose major axis is rotated with respect to the plane of polarisation of the incident light. The magnitude of this rotation and also the ellipticity of the emergent vibration are determined by the thickness of the crystal, its birefringence and its magneto-optic rotation. The exact formulae relating these quantities are known. Hence the evaluation of the Faraday effect in an anisotropic solid finally reduces to the accurate determinations of the constants of the elliptic vibrations emergent from the crystal when the magnetic field is on and off. Normally as the total phase retardation introduced by the magnetic rotation is very small compared to that due to birefringence, the measurement of the rotation along any direction other than the optic axis presents a good deal of experimental difficulty. Along the optic axis, however, apart from the problem of sending the light exactly along it, the measurement is very similar to that in an isotropic crystal.

In spite of the practical difficulty the rotations have been measured for directions slightly inclined to the optic axis for two crystals, calcite [Chauvin (13) maximum inclination 2°] and alumina [Ramaseshan (43) maximum inclination 10°]. The latter investigation was solely undertaken to find out whether the Verdet constant of an anisotropic substance does change with the direction or not. The analysis of the results in these two experiments indicated that within the limits of experimental error, no sensible change could be detected for these small inclinations.

Realising the difficulty of measuring the magneto-optic rotation along directions away from the optic axis, Voigt (59) considered the problem of the variation of the Verdet constant with direction from a completely new and definitely more satisfactory point of view. Using the simple electron theory and the concept of the anisotropic polarisability tensor, he has shown that in certain types of monoclinic crystals (those in which the optic axes lie in the optical symmetry plane) the magnetic rotation for light travelling along the two optic axes are different for the same applied magnetic fields. This is true even in diamagnetic crystals. He found experimental confirmation for this when he discovered that the magneto-optic rotation in cane sugar along the two optic axes are significantly different. Values of the optical rotation and magneto-optic rotation are given in the Table below.

OPTICAL AND MAGNETO-OPTIC ROTATION IN CANE SUGAR

Wavelength in Å	Optical rotation in degrees per/mm.		Magneto-optic rotation in min. per cm. per oers.	
	Optic axis I	Optic axis II	Optic axis I	Optic axis II
6260	$15^\circ 2'$	$47^\circ 50'$	0.0132	0.0150
5770	$17^\circ 22'$	$56^\circ 2'$	0.0154	0.0168
4860	$22^\circ 53'$	$79^\circ 56'$	0.0206	0.0220
4510	$26^\circ 40'$	$97^\circ 33'$	0.0246	0.0258

From the equations he derived, Voigt also foresaw the possibility of the Verdet constant varying with direction in paramagnetic anisotropic crystals, where due to the perceptible magnetisability, the external field causes internal fields of different strengths in different directions. This effect was experimentally demonstrated by J. Becquerel (7,8), who showed by an ingenious experiment that the Verdet constant, of the paramagnetic crystal Tysonite was $-0.3705' \text{ cm.}^{-1} \text{ gauss}^{-1}$ along the optic axis and -0.3068 perpendicular to it.

The measurements of the Faraday rotation in anisotropic crystals have therefore been confined to the case of light travelling along the optic axis. Even so the number of crystals that have been investigated is not large. They are cane sugar, apophyllite, apatite, dolomite (59), quartz (9), calcite (45) and alumina (43) and the results for these are given in Table I.

7. FARADAY ROTATION IN OPTICALLY ACTIVE CRYSTALS

Wiedemann (60) found in the case of liquids an empirical rule that the ratio of the magneto-optic to natural rotation was constant for different wavelengths.

It was later shown that most substances did not obey this rule very well. In the case of quartz however the Wiedemann rule was found to hold quite well (30) but it failed in NaClO_3 , (39). We shall now consider from the theory of dispersion whether there should be any relationship between the magneto-optic and optical rotation.

Recently Chandrasekhar (12) has shown that the rotatory dispersion in a crystal could be well expressed by a formula of the type

$$\rho = \sum_i \frac{A \nu^2}{(\nu_1^2 - \nu^2)^2} \quad (19)$$

where ν_1 's are the absorption frequencies responsible for all optical effects. He has also adduced most convincing theoretical arguments for the choice of such a dispersion formula, in preference to a formula of the Drude type (A).

In such a formula the contribution made to optical activity by each one of the absorption frequencies may be in quite a different proportion to those made by them to refraction. Indeed it has been shown that in NaClO_3 one of the absorption frequencies actually makes a -ve contribution to rotation.

The Faraday rotation in any crystal can be represented by the formula,

$$V = \frac{1}{n} \sum_i \frac{\gamma_1 B_1 \nu_1}{(\nu_1^2 - \nu^2)^2}$$

Here again the contribution made to magneto-optic rotation is proportional to the magneto-optic anomaly factor γ_1 which may vary from frequency to frequency. Therefore as the variation of n with wavelengths is small, the ratio of the contribution to magneto-optical rotation due to each one of the absorption frequencies would be a constant. In other words the Wiedemann rule holds good for the magnetic and optical rotation contributed by each of absorption frequencies of the substance.

8. MAGNETO-OPTIC ANOMALY FACTOR

In a paramagnetic substance, the anomaly factor γ can vary with the wavelength of the incident light, even if there is only one absorption frequency contributing to dispersion (equation 9). This, however, is not the case in diamagnetic crystals. If one finds that in a diamagnetic crystal the mean γ factor, calculated from the observed values of rotation and dispersion, varies with wavelength, it signifies that the different absorption frequencies that contribute to refractive dispersion have different γ factors, *i.e.*, different Zeeman splitting. This is actually found to be the case in nitrates of lead, barium and strontium, calcite, NaClO_3 etc. (See Table II), that is in crystals with highly anisotropic groups.

In the original formula that Becquerel derived he assumed that the Zeeman splitting of the absorption frequency is normal. This assumption will only be strictly true in the case of atoms and ions that have the inert gas configuration *i.e.*, the S state. In these cases the value of the anomaly factor (which is a ratio of the actual Zeeman splitting to the normal Zeeman splitting) would be unity (48, 27, 57, 50). Hence any deviation from the ideal inert gas configuration would obviously decrease the magnitude of the γ factor. Hence γ could be taken as a measure of this deviation from the inert gas structure (36).

Experiments (40, 51) have shown that the γ factor of alkali halide ions in solution is greater than that of these ions in the crystalline state, but the γ factor of the ions in solutions never attains the theoretical value of unity. This is probably, because of the other complicating factors like solvation, association etc., in the case of solutions. It is rather interesting to find that the γ factors of the crystalline alkali halides which are known to be highly ionic are less than unity, indicating that the ions even in these cases are not completely spherical. One notices also that the γ factor in crystals which are known to have covalent bonds, is very low as can be seen from the case of diamond. It is significant that in crystals with highly anisotropic groups, like nitrates, carbonates, chlorates the absorption frequency corresponding to the covalent groups (NO_3 , CO_3 , ClO_3) has a much lower γ factor than that for the other frequencies.

However for a complete understanding of the nature of the anomaly factor and to establish a definite correlation between the anomaly factor, the strength of the binding, and the electronic structure it is necessary to have more exhaustive data not only on the dispersion of the magneto-optic rotation but also on the absorption frequencies of different substances.

9. EXPERIMENTAL DATA

Table I gives the Verdet constants of different crystals. The values of the refractive indices and the magneto-optic anomaly for the corresponding wavelengths are also given. Column 6 gives the references to the different observers who made the observations while column 7 indicates the references wherein the dispersion of magnetic rotation are available.

Table II gives the values of the magneto-optic rotation for various wavelengths for different crystals and Table III gives the constants of the magneto-optic dispersion formula

$$V_n = \sum_i \frac{A_i \gamma_i \lambda^2 \lambda_i^2}{(\lambda^2 - \lambda_i^2)^2}$$

It must be remembered that the same constants can be used to fit the formula for refractive dispersion, the formula being

$$n^2 - 1 = A + \sum_i \frac{A_i \lambda^2}{\lambda^2 - \lambda_i^2}$$

In the case of NaCl and CaF_2 γ values have been calculated from the data of both Landau (28) and Meyer (32). This has been done because of the considerable differences in the experimental values reported. The first figure, in the last column of this table gives the reference to the investigators who have fitted up the formulae the second figure being the reference of the worker whose data have been used.

TABLE I

Substance	Wavelength λ in Å	Refractive Index	VERDET CONSTANT mins/cm/ Oersted	Anomaly Factor γ	Reference	Dispersion of V
LiF	5780	1.3919	0.00935	0.842	(52)	(52)
NaCl	5893	1.5443	0.0328	0.86	(32)	(32), (39), (28)
			0.0355	0.93	(39), (28), (4)	
NaBr	5461	1.6462	0.0621	0.86	(42)	
KCl	5780	1.4914	0.0277	0.80	(32)	(32), (52), (39)
			0.0294	0.85	(52), (39)	
KBr	5780	1.5591	0.04422	0.85	(52), (39)	(52), (39)
KI	5780	1.6656	0.0753	0.87	(52), (39)	(52)
NH ₄ Cl	5893	1.6397	0.0367	0.72	(39)	
NH ₄ Br	5893	1.7157	0.0449	0.69	(39)	
CaF ₂	5893	1.4339	0.00897	0.68	(32), (38)	(32), (28), (38)
	4358	1.4395	0.01751	0.696	(28)	
MgO	5461	1.7422	0.0427	0.92	(52), (39)	(52)

TABLE I—(Continued)

Substance	Wavelength λ in Å	Refractive Index	VERDET CONSTANT mins/cm/ Oersted	Anomaly Factor $\bar{\gamma}$	Reference	Dispersion of V
ZnS	5893	2.3683	0.225	0.92	(4), (36), (15)	(36), (15)
Diamond	5893	2.4172	0.0128	0.17	(4)	
Pb(NO ₃) ₂	5780	1.7833	0.0223	0.30	(36)	(36)
Ba(NO ₃) ₂	5780	1.5701	0.0491	0.505	(52)	(52)
Sr(NO ₃) ₂	5780	1.5908	0.0124	0.24	(52)	(52)
NaClO ₃	5780	1.5908	0.0179	0.22	(52)	(52)
	5780		0.0179	0.67	(45)	(45), (59), (16)
			0.0176*	0.65	(59)	
NaBrO ₃	5893	1.5943	Relative		(16)	(16)
Strontium dithionate	5893		Relative		(16)	(16)
Ammonium Alum	5893	1.4594	0.0128	0.55	(39), (26)	(26)
Potassium Alum	5893	1.4560	0.0124	0.54	(39), (26)	(26)
Fused Quartz	5780	1.4590	0.01540	0.79	(52)	(52)
			0.0148	0.76	(15), (37)	

Crystalline quartz	5780	1.5447	0.0171	0.78	(14)	(9), (19), (24)
	5893	1.5443	0.01664	0.78	(9)	(30), (54)
Calcite	5893	1.6584	0.0185	0.49	(45)	(45)
Apatite	5400	1.6393	0.0192*	0.53	(59)	(59)
Apophyllite	5900	1.5342	0.0179*	0.68	(59)	(59)
Dolomite	5400	1.6836	0.0127*	0.27	(59)	(59)
Corundum (Al ₂ O ₃)	5893	1.7685	0.0210	0.62	(43)	(43)
Cane sugar Optic axis I	5770		0.0154*		(59)	(59)
			-Do- II	0.0168*		(59)

* The values given by Voigt have been multiplied by 2 as there appears to be a numerical error in his computation.

TABLE III
VALUES OF THE CONSTANTS IN THE DISPERSION FORMULAE

$$n^2 - 1 = A + \sum \frac{A_1 \lambda^2}{(\lambda^2 - \lambda_1^2)} \quad V = \frac{1}{n} \frac{e}{2mc^2} \sum \frac{\gamma_1 A_1 \lambda^2 \lambda_1^2}{(\lambda^2 - \lambda_1^2)^2}$$

	A	A ₁	A ₂	A ₃	λ ₁	λ ₂	λ ₃	γ ₁	γ ₂	γ ₃	Reference
LiF	0.2650	0.6596			0.0865			0.836			(52)
NaCl	0.15599	0.85546	0.31779		0.1107	0.1563		0.93	0.93		(52), (28)
								0.859	0.859		(52), (32)
KCl	0.24341	0.35736	0.37616	0.19808	0.1000	0.1310	0.1620	0.854	0.854	0.854	(52)
KBr	0.24236	0.41169	0.42657	0.2808	0.1100	0.1460	0.1800	0.850	0.850	0.850	(52)
KI	0.4532	0.2150	0.8027	0.1780	0.1290	0.1805	0.2190	0.871	0.871	0.871	(52)
CaF ₂	0.25910	0.61667	0.16404		0.0820	0.1115		0.696	0.696		(52), (28)
								0.682	0.682		(52), (32)
MgO		0.7537	1.2034		0.0400	0.1300		0	0.963		(52)
ZnS	2.0221	2.0998			0.2532			0.92			(36)
Diamond		4.3356	0.3306		0.1060	0.1750		0.30	0.30		(36)
Pb(NO ₃) ₂		1.4610	0.5740		0.1048	0.2250		0.850	0.36		(52)
Ba(NO ₃) ₂		1.768	0.2172		0.0950	0.2250		0.51	0.043		(52)
Sr(NO ₃) ₂		1.2417	0.21174		0.1010	0.2250		0.40	0.061		(52)
NaClO ₃		1.1825	0.07992		0.0900	0.1850		0.74	0.46		(45)
Fused Quartz		0.5320	0.4151	0.1570	0.0600	0.1060	0.1190	0.793	0.793	0.793	(52)
Crystalline Quartz		0.66340	0.51785	0.17591	0.0600	0.1060	0.1190	0.776	0.776	0.776	(52), (9)
CaCO ₃ (Calcite)		0.43257	0.8293	0.4337	0.0500	0.1000	0.1535	0.825	0.825	0.20	(45)

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