

Understanding Rate of Diffusion between Two Liquids in a Christiansen Cell in Terms of Time Evolutions of Diffraction Halos

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ABSTRACT: When laser radiation is allowed to pass through the diffusion region separating the two liquids in a Christiansen cell, beautiful circular halo is observed on the screen. The pattern of this diffraction halo changes with time. In the present work we have studied this diffraction halo and its time evolution. It has been observed that there is a definite co-relation between the shape of the diffraction halo and width of the diffusion region. The time evolution of this diffraction halo indicates that as diffusion region increases the circular halo becomes elliptical and finally straight. It may be noted that this type of diffraction halo and its time evolution is not reported in any earlier works in connection with Christiansen effect. It is believed that the time evolution of this diffraction halo will have practical application in diffusion study between two molecules.

KEY WORDS: Christiansen effect, Diffraction halo, Diffusion, Chromatic pattern.

I. INTRODUCTION

When an optically isotropic solid like glass is powdered and put inside a flat sided cell which is then filled with a liquid and its refractive index of the latter is adjusted suitably by varying its composition or altering its temperature, beautiful chromatic effects are observed when the refractive index of the liquid is brought into coincidence with that of the powder for some chosen wavelength of the spectrum. The cell becomes transparent for that particular wavelength while rest of the incident light passing through the cell is diffused out in various directions and appears as a halo surrounding the light source. This is known as the Christiansen effect observed by Christiansen. It is evident that this effect has its great practical application in designing optical filter, capable of isolating narrow region of the spectrum with minimum loss of light. It was Raman and co-workers [1-3] who gave adequate explanations to the observed facts of Christiansen effect through a series of papers on the basis of wave front corrugation concept. Christiansen effect has found its applications in diverse field of science and technology; mainly in IR study[4,5,], in glass technology[6], heat transfer and flow through porous media[7], in atmospheric study[8,9], to build optical power limiter and sensor[10,11], colloids and polymer study[12], and also in microgravity research [13]. In a recent work Mahanta et al.[14,15] have described in detail about the role of diffusion on the chromatic patterns associated with Christiansen effect. The present work is concerned with some salient features of Christiansen cell observed without glass spherules and using laser beam. It is observed that when laser radiation is allowed to pass through the diffusion region separating the two liquids in a Christiansen cell, beautiful circular halo is observed on the screen. Studies on the time evolution of diffraction halos may lead to the development of an optical technique for diffusion study.

II. MATERIALS AND METHODS

We have used the experimental setup similar to that used by Raman and co-workers [2] but the source of light in the present case is He- Ne laser source ((5mW, 675nm))and also green laser (diode laser). Also, we have not used any

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transparent solid powder in liquid combination as done by earlier workers. Laser radiation is allowed to fall on the Christiansen cell containing liquids through an iris and the diffraction halos are observed on a white screen. DSLR camera has been used to photograph the chromatic patterns under different circumstances. Here we use different types of liquids combination like acetone and CS_2 , acetone and benzene, acetone and CCl_4 etc. Square culettes as well as test tubes of diameter 0.5 cm and 1.0 cm and 30 cm long have been used as sample cells. In our experiment the cell was first half filled with heavier liquid. The lighter liquid of equal volume is introduced very carefully to avoid any convection currents. The observed chromatic patterns are projected on a white screen at distance of 15 cm. and the pattern is recorded by the DSLR camera.

III. EXPERIMENTAL

When laser radiation is allowed to pass through the boundary separating the two liquids, beautiful circular halo is observed on the screen. The photograph of the halo patterns are recorded after a specific interval of time. It is seen that the shapes of the halo pattern changes with time. It is instructive to record the diffraction haloes in the region of diffusion at different instant of time from the beginning and at successive stages of its development till a stage of saturation is attained. They are reproduced in Fig.1. It is worthwhile to note that the circular halo does not appear on the screen when the light is transmitted through other parts of the sample cell. It is worthy of remark that the diffraction halos are also observed when coherent light from green or other laser radiation is used. But in this case the haloes are not well focused as compared to red laser.

IV. RESULTS AND DISCUSSION

Fig.1 (a, b, c,.....i) shows the optical patterns at different times. At the beginning of the experiment, approximately circular halo is observed and as time evolves, the halo become more and more elliptical. In case of acetone and CS_2 the elliptical pattern becomes almost straight after few hours. The development of the elliptical halos from circular takes places at a quicker rate when the process of diffusion is rapid. It is worthwhile to note that the fringe patterns move upward. This indicates that diffusion is more towards lower side due to gravitation. The displacement of the center against time yields a curve as shown in Fig. 2.

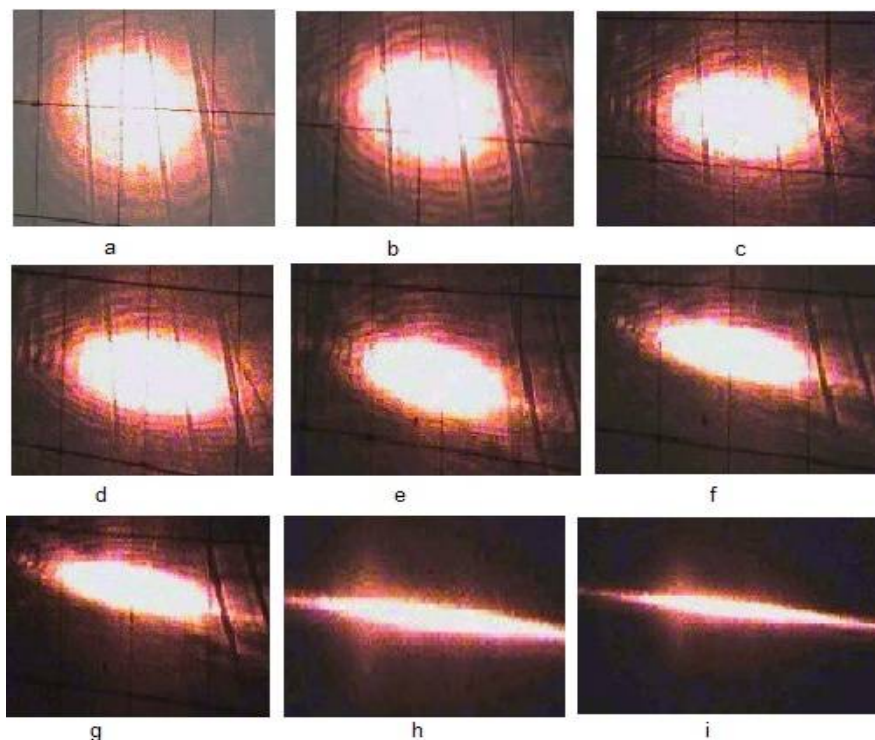


Fig. 1: Time evolution diffraction halo pattern in Christiansen cell. The horizontal and vertical dark lines are the reference mark on the screen.

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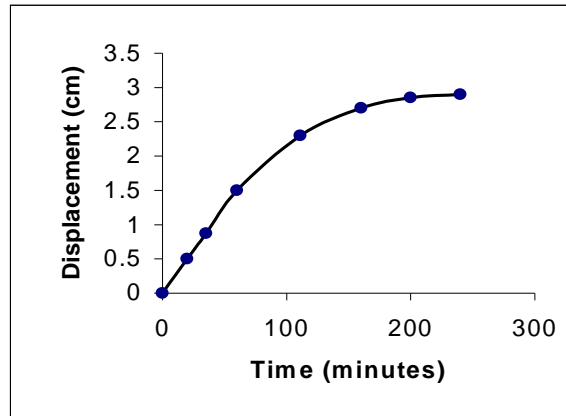


Fig. 2: Displacement of the centre of diffraction halos with time.

It is mentioned earlier that these types of halos observed in diffusion region and its time evolution is not reported yet. However in a recent work the method of multiple beam intererometry has been used to determine diffusion co-efficient [16]. The types of fringes observed by these workers are attributed to the change in the path traveled by the incident light with its position inside the experimental cell.

Why the phenomenon described above manifests itself is not difficult to understand if we consider the process of diffusion which is taking place between two liquids to both sides of the boundary separating them. The appearance of diffraction halo patterns is due to diffusion between the liquids which is taking place between acetone and CS₂ to both sides of the boundary separating them. The density of the liquid at the boundary and in the region of diffusion is more than that lying above and is less than that lying below it. In our experiment the cell was first half filled with heavier liquid (heavier concentration). The lighter liquid (lower concentration) of equal volume is introduced very carefully to avoid any convection currents. The process of diffusion starts after the cell is filled.

The free diffusion process is governed by Fick's second law, and for one-dimensional diffusion along the z-axis it is given by [17],

$$\frac{dC(z,t)}{dt} = D \frac{d^2C(z,t)}{dz^2}$$

where C(z, t) is the concentration at z at time t, D is the diffusion coefficient and z is the direction of diffusion. Inside the diffusion cell and for the range of concentrations over which the experiments were conducted, the refractive index is a linear function of concentration (Fig.3) [16].

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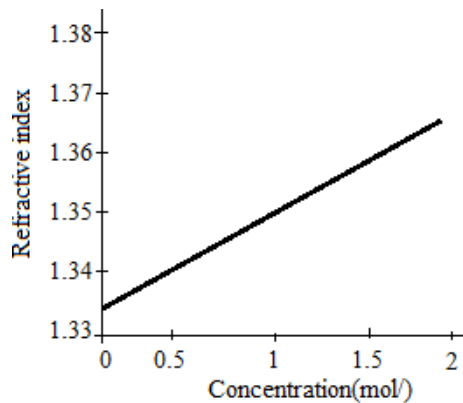


Fig. 3: Change in refractive index with concentration. [16]

Then one can write,

$$n(z,t) = mC(z,t) + n_o,$$

where m is the slope of the concentration versus refractive index curve in the applied concentration range and n_o is the constant. There will be change in refractive index at a particular plane perpendicular to the direction of diffusion with time. Since the refractive index at different planes in the cell is different the light passing through the cell will have different optical paths at different planes given by

$$\Delta_1(z_1) = n_1(z_1)L, \quad \Delta_2(z_2) = n_2(z_2)L, \dots$$

where $\Delta_1, \Delta_2, \dots$ are the optical paths of the light rays through different planes situated at z_1, z_2, \dots and n_1, n_2, \dots are the corresponding refractive indices of the planes and L is the thickness of the cell. The orientation of the experimental cell and change in the path length of the light traveling through the cell is shown in fig. 4.

From Fig. 4 it is clear that the optical paths through different planes are different. Hence refractive index gradient due to concentration gradient is taking place in this region, which is responsible for the optical pattern. It is evident that in this case the diffusion region between two liquids acts as a narrow slit suitable for diffraction. It is evident that in this case the diffusion band between two liquids acts as a narrow slit suitable for diffraction. When the depth of the diffusion is small (up to 5 mm in this case) we get the circular fringes. Initially diffusion in both sides of the boundary takes place equally. So during this time we get the circular fringes. But with passage of time diffusion is more towards lower side due to gravitation and hence the fringe pattern becomes more elliptical and eventually straight. However, it may be noted that the nature of optical pattern observed here does not depend on the shape of the sample cell. We have observed these patterns in square culettes also.

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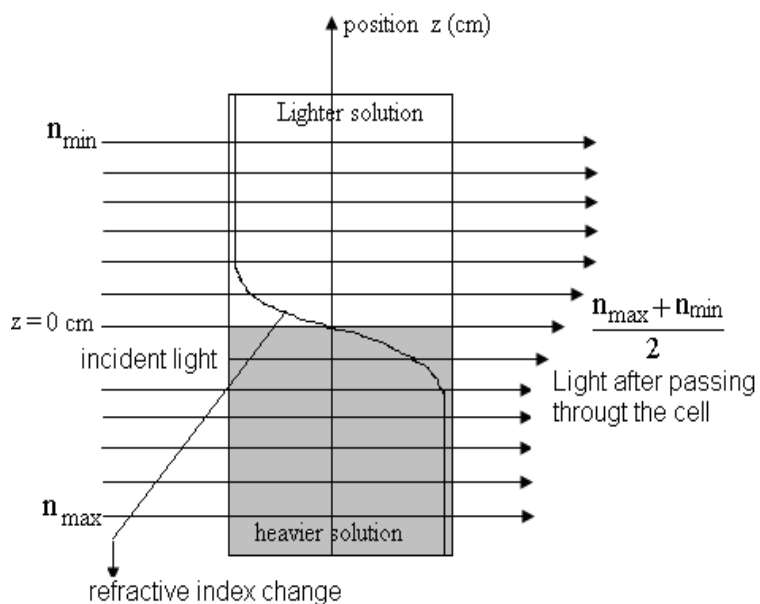


Fig. 4: Change in path traveled by the incident light with its position inside the cell.

Table 1 shows The nature of halo with the depth of diffusion and Fig. 5 shows the change of depth of diffusion with time between the liquids; acetone and CS₂ (vol. 1:1) . Interesting is that this is analogous to the curves as shown in Fig 2 which indicates that there is a definite co-relation between the change of shape of the diffraction halo and rate of diffusion. Table 2 indicates few liquid mixtures where it is shown that fringes are observed only when diffusion exists.

Table 1: The nature of halo pattern with the depth of diffusion

Time in minute	Depth in diffusion in mm	Shape of halo
0.03	1	Circular
20	5	Circular
40	8.5	Elliptical
60	12	Elliptical
110	18	Elliptical
160	23	Elliptical
200	25.5	Elliptical
250	28	Straight
300	29.5	Straight

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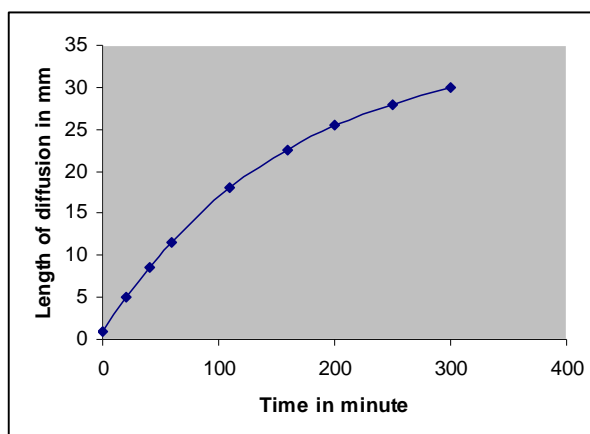


Fig. 5: A plot of diffusion length with time between acetone and CS₂(vol. 1:1). The length of experimental cell is 10 cm and thickness is 1 cm.

Table 2: Nature of boundary layers between two liquids

Sl no	Liquid mixture	Diffusion observed	circular halo observed
1	Acetone and CS ₂	Yes	Yes
2	Water and acetone	Yes	Yes
3	CS ₂ and water	No	No
4	Benzene and water	No	No
5	Petroleum spirit and water	No	No
6	Benzene and CS ₂	Yes	Yes

V. CONCLUSIONS

The halo pattern, which is observed when a monochromatic and coherent beam of light is passed through the region of diffusion, gives sufficient information about the region separating two liquids, which are capable of mixing through diffusion. Since Christiansen effect utilizes this region so it is believed that these diffraction halo patterns will throw much needed light on the theory of the Christiansen effect. Further we have observed that the circular halo transformed to elliptical halos as time evolves. It is reasonable to believe that this observation will give quantitative information about the rate of diffusion between two liquids and hence it will be new optical metrological technique.

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