ON IRIDESCENT SHELLS.

Part III. Body-Colours and Diffusion-Haloes.

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1. *Introduction.*

Paper II of this series[1] which appeared under the sub-title "Colours of Laminar Diffraction" dealt with various optical effects exhibited by nacre which owed their origin primarily to the laminated structure of this substance. Owing to the circumstance that the laminations are, in practice, not quite parallel to the external surface of the substance but intersect it, the phenomena cease to be identical with the simple interference effects exhibited by stratified films in which the laminations are parallel to the external surfaces. Instead of the familiar coloured reflections exhibited by films of the latter description, we obtain a series of diffraction-spectra produced by the grating-like structure of the external surface due to the laminations meeting it obliquely. The characteristic iridescence of the shell manifests itself in one or other of these diffraction spectra being specially intense and approximately monochromatic in character, besides also influencing neighbouring orders of spectra in their intensity and colour distribution. The distribution of intensity in the spectra is found to depend greatly on the condition of the external surface and especially the degree of its optical polish.

In the present paper, we shall concern ourselves with a group of optical effects exhibited by nacre which have till now received little or no attention in the literature of the subject and which are nevertheless of interest and importance as they play an essential part in the appearance and colours of nacreous shells as ordinarily observed. These effects have no analogue in the optics of transparent stratified films and owe their origin to the granular and colloidal structure of the nacreous substance. As was remarked in Paper I of the series[2], the laminæ of which the nacreous substance is composed are not continuous but consist of a great many individual crystalline particles arranged in some kind of order and cemented together by the organic substance conchyolin. These individual particles in their environment

[1] C. V. Raman, *Proc. Ind. Acad. Sci.*, 1935, 1, 574.

[2] C. V. Raman, *Proc. Ind. Acad. Sci.*, 1935, 1, 567.

should obviously be capable of diffracting or diffusing light in a manner determined by their size, shape, orientation and grouping relatively to each other in the laminæ. Direct evidence that such diffraction effects occur is furnished by the "diffusion-haloes" exhibited by thin plates of nacre which we shall describe in the course of the paper and which will be found illustrated in Figs. 1 to 10 in the accompanying plates. These diffusion-haloes form a unique method of revealing the structure of the nacreous substance, and indicate that this structure is entirely different in the three great divisions of the mollusca, namely, the Bivalves, the Gastropods and the Cephalopods, and that it also exhibits notable variations as between individual families and species. The recognition of the great differences in the structure of nacre in different kinds of shell and a consideration of the important part played by the structure in determining the optical properties of nacre are fundamental to our subject. It will be seen in the sequel that the phenomena considered in this paper all arise, in one way or other, as consequences of the diffusion of light within the substance of nacre.

2. *Translucency of Nacreous Shells.*

One of the most beautiful properties of the nacreous substance is its "translucency" to light, a property which, it may be added, is also exhibited by shells which do not contain nacre but are porcelain-like in appearance, *e.g.*, the Indian Chank (*Turbinella Pirum*). The translucency of nacre is however specially remarkable in consequence of the fact that the light which diffuses through the substance exhibits colours which in many cases, *e.g.*, with shells of *Turbo*, *Haliotis* or *Nautilus*, rival in richness the colours observed in reflection. To observe these diffusion colours, it is necessary to expose the nacre by removing the superincumbent conchyolin and prismatic layers and desirable also to polish the external surface formed by such removal. The shell should be viewed interposed between the eye and the source of illumination. The effects are most striking when the observations are made in a dark room and the shell is held up against an aperture illuminated by a powerful source, *e.g.*, sunlight. *The penetration of light through the substance of the shell accompanied by diffusion which is observed in these circumstances should not be confused with the phenomenon of transparency or regular transmission.* When a beam of light enters the substance of the shell, the extinction of its energy due to diffusion is so rapid that its path as a coherent pencil of radiation travelling in a specific direction is practically very limited, and the light that penetrates the shell, except in the case of relatively thin layers, consists almost entirely of diffuse radiation. Light which diffuses through and exhibits colours may readily be observed with shells which are much too thick to transmit any light in the regular way.

Large shells of *Nautilus pompilius* and of *Turbo* form most beautiful objects when examined in the manner described in the preceding paragraph. Fig. 11 reproduces a photograph of the shell of *Nautilus pompilius* seen in a dark room when held against an aperture illuminated by sunlight. The photograph, of course, does not reproduce the beautiful colours actually seen. The internal septa characteristic of the *Nautilus* shell and the thickening of the walls of the shell at the regions of attachment of the septa are however strikingly visible in the photograph. It must not be imagined from this photograph that the shell of the *Nautilus* is transparent to light; on the contrary it is remarkably opaque even compared with other nacreous shells, and does not allow any light to be transmitted through it in the regular optical way except in the thinnest layers. Fig. 12 reproduces a photograph of a *Turbo* shell taken in similar circumstances. The most noticeable feature in this photograph is the progressive weakening due to the spiral structure of the shell, of the light that diffuses through as we approach the vertex of the shell.

Gorgeous colours are exhibited by the nacreous shells of many species of *Haliotis* when held up against a window and viewed as "translucencies". The Californian species of the Haliotidæ (known as abalone) which exhibit remarkably rich colours by reflected light form however a noteworthy exception. A shell of abalone when held up against a window illumined by sunlight is observed to allow very little light to diffuse through. Of three different species of shell which have been examined, the one which exhibits the most striking colours of all by reflection on both sides of the nacreous layer (Fig. 1 in Plate XV accompanying Paper I of the series) is completely opaque in some areas and only allows a little deep red light to filter through in other areas. A second species exhibiting rippled markings on the convex side, and richer colours on the concave than on the convex side (Fig. 2 in Plate XV of Paper I) behaves very similarly, but is somewhat less opaque, and in some relatively more translucent areas gives hints of diffusion colours other than a deep red. A third species which is the least striking in respect of the colours shown by reflection (weak and almost silvery-white on the convex side, stronger on the concave side) is the least opaque of all, and allows some smoky-red light to filter through almost everywhere. Thin sections cut transversely through the nacre of the three species of abalone and examined under the microscope disclose the existence of dark layers traversing the nacre which appear to be responsible for the exceptional optical behaviour of these shells.

The diffusion colours of translucent nacreous shells are found to depend both on the angle at which the incident light falls on the first surface and on the *angle at which the second surface is viewed.* The simplest case is that in which the light is incident normally on the first surface and is observed in a direction nearly normal to the second. The colours are best seen under these conditions, and if the plate is of moderate thickness, are roughly complementary to the colour of the iridescence at the first surface. This is readily understood, if we assume that the part of the spectrum which is strongest in the iridescent reflection is missing in the light which diffuses through the shell. This does not, however, account for the richness of colour of the light that diffuses through, nor for the change of this colour with the direction of observation when the angle of incidence remains constant. It is evident that for a full understanding of the phenomena, we have to consider the changes in spectral character which occur in the process of diffusion through the substance of the shell, especially those which occur in the layers adjacent to the second surface prior to emergence of the light from it. A fuller consideration of these matters may conveniently be deferred to a later paper describing spectroscopic observations on the colours of nacreous shells. Meanwhile, it will be sufficient to draw attention to two important features. Firstly, the colours of diffusion, besides shifting their position in the spectrum when the directions of incidence or of observation are altered, tend to weaken and disappear as these directions are made more oblique. Secondly, when the thickness of the shell is very considerable, the light that diffuses through it tends to assume a pronounced reddish hue, submerging the characteristic colours arising from the laminated structure of the shell.

3. *Body-Colours.*

The diffusion of light by the granular structure of the shell naturally occurs in all directions with reference to the incident beam, namely, *forwards, backwards* and *laterally*. The preceding section dealt with the colours in the light diffused *forwards* and observed after it has penetrated through the thickness of the shell. We may reserve the designation of "diffusion colours" for the phenomena arising from such forward diffusion, and indicate by the term "body-colours," the very significant effects due to *backward* diffusion of the light which are observable on the same side of the shell as the iridescent reflection. The phenomenon of body-colour is shown by all varieties of iridescent nacre, including *Margaratifera, Turbo, Trochus, Haliotis* and *Nautilus pompilius*, and its recognition is essential to an understanding of the colour-effects exhibited by nacre. The body-colours are, in fact, quite striking when observed in directions adjacent to that of the iridescent reflection and are then complementary to it in hue. They determine to a surprising extent the appearance of mother-of-pearl as seen in ordinary circumstances. Either the iridescence or the complementary body-colour may reach the eye from any given part of the surface of a mother-of-pearl object depending on the optical conditions, namely, the relative positions of the source of the light, the object, and the eye, as well as the inclination of the internal laminations responsible for the iridescence and the degree of polish of the external surface. If the conditions are favourable, the iridescent reflection reaches the eye, while if they are unfavourable, it is the complementary body-colour that is perceived. When a mother-of-pearl object, *e.g.*, a polished *Turbo* shell, is viewed inside a room, the reflections of the window or of the lamps in the room by the internal laminations exhibit the iridescence, while the shell as a whole exhibits the complementary body-colours. The complementarity of the colours is readily observed and appreciated in such circumstances.

Fig. 13 illustrates a polished bowl made of *Turbo* shell when viewed with the light behind the observer. The upper portion of the bowl exhibits a brilliant arch of light (just over the fret-work) due to a fold in the internal laminations which reflects the light in the direction of observation and shows the characteristic iridescence. The rest of the surface of the bowl is so greatly inclined to the direction of observation that the coloured reflections cannot reach the observer's eye. The bands so strikingly visible on the lower part of the shell are, in fact, bands of body-colour. Bands having the same configuration but of complementary colours and exhibiting the brilliant iridescent reflections are seen when the bowl is moved to a position between the eye and the source of light.

Figs. 14 (*a*) and (*b*) are intended to illustrate the complementarity of the iridescence and the body-colours exhibited by a shell of *Margaratifera*. Seen from inside the room, the light from a door or a window reflected by the shell exhibits brilliant bands of colour, while if the shell be slightly tilted so that the reflection does not reach the eye, the complementary body-colours are observed over the whole surface of the shell. An attempt has been made to exhibit this complementarity by photographing the shell in the two positions with a panchromatic plate and a red filter covering the lens of the camera. The exposure given in taking picture (*b*) was considerably greater than that required for picture (*a*). On carefully comparing the two pictures, especially the bands of light and darkness seen to the left of the central elliptic area, it will be noticed that the areas which appear dark in (*a*) are bright in (*b*) and *vice versa*. Some complications however arise from the irregularity of the internal structure of the shell which is very evident in the photograph, especially in picture (*a*), and which does not exist in the smoothly worked exterior surface of the shell.

When, as is generally the case, an extended source of light is employed and its reflection at the surface of a shell is observed, the iridescence and the body-colour would in general be seen superposed, and since they are complementary in hue, they tend to neutralise each other's colours. The striking extent to which the iridescence and body-colour dilute one another is most clearly realised when a fairly flat plate of nacre such as that illustrated in Figs. 14 (*a*) and (*b*) is viewed, first inside a room and then is taken outside and viewed under the open sky. *An astonishing change is observed; the gorgeous colours observed within the room disappear, and the plate appears dead white and flat under the open sky.* The explanation of this result is that the iridescent reflection of a particular part of the sky, and the body-colour due to the illumination of the plate by the whole hemisphere of the sky are seen superposed. Since, in these circumstances, no colour is observed, we may draw the inference that the two phenomena are essentially complementary to each other, in other words, *that a plate of nacre returns as a body-colour diffused in various directions the whole of the light that falls upon it and is not specularly reflected as the characteristic iridescence.*

We must here recognise two limitations to the correctness of the foregoing statement. It is obviously necessary that a plate of nacre should be of sufficient thickness if the whole of the light that falls upon it is to be returned either as iridescence or as body-colour. Secondly, we must assume that no material absorbing light *per se* is present in the nacre, as otherwise the light that penetrates would disappear by absorption before it can be returned by diffusion. The thickness necessary for the full development of the body-colour would be considerable for relatively clear varieties of nacre, *e.g.*, *Mytilus viridis* and may not actually be available, while small thicknesses may be quite sufficient in the case of strongly diffusing varieties of nacre, *e.g.*, *Nautilus pompilius*. It is significant in this connection that the shell of *Nautilus pompilius*, though comparatively thin, exhibits on its surface the stripes of body-colour complementary to the iridescent reflections in a most conspicuous manner. For the same reason, it follows that if we wish to observe the iridescence of any variety of nacre with the maximum of spectral purity, we should work with comparatively thin plates of the material so as to reduce to a minimum the intensity of the complementary body-colour which appears superposed on it.

It has already been remarked that the shells of the Californian abalone contain layers of some darker material traversing their nacreous substance and that these layers appear to be responsible for the remarkable opacity of these shells. The presence of absorbing layers within the nacre must, as remarked above, greatly diminish the intensity of the body-colour. This appears to be actually the case, as is indicated for instance by the fact that the abalone box illustrated in Paper II (unlike the shell of *Margaratifera*) exhibits under the open sky, an iridescence which is perceptibly but not greatly inferior to that visible under less extended illumination. These remarks and observations suggest that the richness of the reflection colours shown by the abalone shells is at least partially to be ascribed to the presence in their nacre of absorbing layers and the consequent weakening of the complementary body-colours.

A detailed study of the spectral characters of the body-colours is reserved for a future paper. It may be remarked that the colours naturally vary with the angle of incidence of the light on the surface of shell, and also it may be noted, to an appreciable extent with the angle of observation. The complementarity with the iridescence-colours for directions adjacent to that in which the latter colours are observed appears however to be maintained in all cases. The body-colours of nacre may be exhibited in an objective manner on a screen by allowing a narrow beam of sunlight to fall on the surface of the shell and receiving the reflected and diffused light on a white bristol board. The effects observed naturally depend on a variety of circumstances including especially the variety of nacre employed, the degree of its optical polish and the angle of incidence of light. With shells of *Turbo*, a disk of diffuse light having a well-defined outer margin and exhibiting a colour complementary to that of the iridescent spectrum appears surrounding it. That this disk of diffuse radiation is due to the internal structure of the nacre and not to external surface irregularities is indicated by the fact that it does not disappear when the surface is covered with a layer of canada-balsam and a cover-slip of glass. Other varieties of nacre also exhibit similar phenomena but differing in detail and not always so well-defined.

An alternative method of studying the body-colours and their angular distribution is to observe the surface of the shell under the hollow-cone illumination provided by the Leitz ultra-opak microscope as described in Paper II, using for this purpose, one or the other of the series of objectives with varying angles of illumination and, if desired, also the sector diaphragm provided with this instrument. The change from iridescence to body-colour is readily demonstrated by slightly tilting the specimen under the microscope so as to bring one or the other into view. Effects of surprising brilliance may be observed in this way with suitable specimens.

4. *Diffusion-Haloes.*

We now pass on to consider the diffusion-haloes already mentioned in the introductory section of the paper and illustrated in Figs. 1 to 10. To observe them, all that is necessary is to rub down a piece of nacre to a sufficient degree of thinness, polish both its faces with the finest rouge on chamois leather, and then to mount the piece in canada-balsam between cover-slips of glass, and thus minimise the disturbances due to the imperfections of the external surfaces. The diffusion-haloes may then be studied either subjectively or objectively. For subjective observation, all that is necessary is to hold the mounted specimen in front of the eye and view a bright source of light, *e.g.*, a filament lamp from a distance in a dark room. For objective demonstration of the diffusion-haloes, a thin pencil of sunlight is allowed to pass through the specimen and is received on a white piece of bristol board held at a suitable distance from the specimen. The haloes may also be readily photographed using a small aperture illuminated by an electric arc as the source and placing the specimen close to the lens of the camera.

The photographs reproduced in Figs. 1 to 10 disclose a remarkable variety in the configuration of the diffusion-haloes. It will be noticed that the Gastropod shells, *Turbo, Trochus* and *Haliotis* give haloes that form more or less complete circles. The halo of the Cephalopod *Nautilus pompilius* is of very peculiar form, consisting of two roughly circular but incomplete arcs of about 60° angle on either side of the direct beam. The bivalve shells, of which five different species have been studied, give again quite a different type of halo, namely, two spots or rather diffraction-spectra, one on either side of the central diffraction disk and distinctly separated from it. It will thus be seen that the three great groups of molluscan shells are strikingly differentiated by the general type of diffusion-haloes exhibited by their nacreous layers.

Closer study reveals further and very interesting differences in the character of the haloes obtained with the nacre of individual families and species of molluscs. Perhaps the most striking type of halo is that given by the nacre of the species of *Turbo* examined (Fig. 1). This consists of a well-defined circular halo which with white light exhibits the regular colour-sequence corresponding to a proportionality of the size of the halo to the wave-length employed. The halo is separated from the image of the source of light by a dark region, and there is hardly any corona seen surrounding the source. It should be mentioned that to obtain a symmetric circular halo with the nacre of *Turbo*, it is necessary to carefully orientate the specimen in front of the eye till the complete circle is obtained. With an incorrect orientation, only parts of the circle are observed. It is to be inferred from the effects noticed that the complete circular halo is obtained when the plane of the internal laminations containing the diffracting particles is exactly normal to the line joining the source of light and the eye.

The diffusion-haloes given by the nacre of *Trochus* and of *Haliotis*, though resembling that of *Turbo* in having circular symmetry, differ strikingly in detail. With *Trochus*, the central corona surrounding the image of the source is much more marked, and the outer ring is therefore much less clearly separated from the latter. The halo of *Haliotis* is intermediate in type between those of *Turbo* and *Trochus*. (The transverse bar of light seen running across the halo in Fig. 3 is due to scratches on the surface of the specimen not having been removed during polishing). The halo of the species of Californian abalone examined is of very curious form, being of distinctly elliptic shape, with a dark bar running along the major axis. This type of halo evidently deserves further examination with more specimens and other species of abalone.

Though the five different species of bivalves examined show the same general type of diffusion-halo, they differ considerably in such details as the angular separation of the two spectra and their brightness, both absolutely and relatively to the central corona surrounding the image of the source. In some bivalves, *e.g.*, the species of *Parreysia* examined (Fig. 7), the two spectra are very bright and clear, and rather close together. In others, *e.g.*, *Pinctada lentigunosa* (Fig. 8), they are weak and rather further apart, while with the nacre of *Mytilus viridis*, the spectra are so weak and so widely separated that it is not easy to observe or photograph them.

It is not difficult to infer in a general way, the size and arrangement of the crystalline particles in the laminæ which give rise to the diffusion phenomena, from the observed angular size of the haloes as well as their general character. For instance, in the case of *Turbo*, we may infer that the crystal particles are about 4μ in diameter and are arranged with a considerable approach to regularity and circular symmetry. On the other hand, in the bivalves, the particles are distinctly smaller in size and are evidently arranged in a manner which simulates the lines of a coarsely ruled grating. Since the crystalline particles in nacre are accessible to microscopic observation, it should be possible to check the foregoing inferences directly and to closely correlate the observed form of the diffusion-haloes with the microscopically determined orientation and arrangement of the particles. Meanwhile, it is gratifying to note that an X-ray examination of different species of nacre, carried out by Dr. Rama Swamy and published in the same issue of these *Proceedings* (see following paper) indicates differences of the crystal orientation in the nacre of Gastropods, Cephalopods and Bivalves, closely analogous to and evidently connected with the differences in the spatial arrangement of the particles deduced from the foregoing observations of the optical haloes. A fuller discussion of the optical and X-ray results may advantageously be reserved for a future occasion.

5. *Transmission Colours.*

In the second section of the paper, we have already had occasion to remark on the rapid extinction of the primary beam of light which occurs as the result of diffusion in its passage through the substance of nacre, and also on the great difference between different species as regards the transparency of their nacre. How small is the actual transparency of shells will be readily appreciated on attempting to view through them a bright source of light, *e.g.*, the sun or the electric arc. It will be found that except when relatively thin layers of the order of a few tenths of a millimeter are employed, the image of the source is either invisible or else is seen very feebly with a deep red colour. The observations clearly indicate that the colours of the transmitted light are a composite phenomenon and are a function of the thickness of the shell. *Firstly*, owing to the iridescent reflection at the surface of the shell, certain well-defined regions of the spectrum are removed and are consequently missing in the transmitted light. *Secondly*, there is a rapid attenuation of the beam in passing through the substance of the shell as the result of scattering or diffusion of light. Observations with thin sections of nacre suggest that such scattering or diffusion is only in part due to the relatively coarse crystalline particles present in the laminæ of the nacre, and that a much finer colloidal structure is also present in the nacre which is responsible for a selective scattering through large angles of the shorter waves in the spectrum. On this view, we should expect a rapid extinction of the blue end of the spectrum in the transmitted light in its progress through the specimen. *Thirdly*, we must also consider the possibility of a genuine absorption of light in the substance of the nacre, particularly in the case of those species where a marked colour, independent of the angles of incidence and observation is exhibited by the nacre.

It is clear from what has been said above that the colour of the transmitted light must progressively alter with increasing thickness of the specimen, and that only with comparatively thin pieces can we expect it to be roughly complementary to the colour of the reflected light. Such a progressive change of colour in the transmission is actually observed with all varieties of nacre; as already remarked, the colour of the transmitted light tends to a deep red with increasing thickness of the nacre, irrespective of what the colour is for relatively thin pieces of the same nacre. One curious consequence of this is that pieces of nacre which have their characteristic reflection in the red region of the spectrum transmit much less light for the same thickness than pieces which exhibit a blue or green reflection; the reason obviously is that in the former case, two causes of extinction operate simultaneously in the same region of the spectrum.

Further details regarding the spectral character of the transmitted light and the relative importance of the three causes of extinction specified above in different species of nacre are reserved for future consideration.

6. *Lateral or Transverse Diffusion of Light.*

We may conclude this paper by a brief discussion of some remarkable effects which are observed in a very simple experiment with a plate of nacreous shell. A small aperture, say 5 millimeters in diameter, is illuminated with sunlight, and the plate of nacre is pressed closely against it. The observations are conveniently made in a dark room. When the plate employed is a millimeter or two thick, the incident beam of light is unable to penetrate the shell. The light is however observed to diffuse laterally in the plate through surprisingly large distances. For instance, with a shell of *Margaratifera* two or three millimeters thick, the light penetrates laterally to a distance of twenty or more millimeters in all directions. The phenomenon is illustrated* in Figs. 15 (*a*) and (*b*). The latter, in particular, shows clearly the central spot which is the portion of the plate in contact with the illuminated aperture as also an extended area of fainter luminosity surrounding it. The central spot corresponds to the area of nacre illuminated by the incident beam and by the forward diffusion, while the outer luminosity represents the regions illuminated by lateral diffusion. As already remarked, the ordinary transmission of light through nacre is limited to a few tenths of a millimeter, while its penetration by forward diffusion is limited to a few millimeters. The lateral diffusion to distances up to twenty millimeters or more must therefore be regarded as a very remarkable phenomenon.

The natural interpretation of the effects described above is that nacre considered as a diffusing medium is very anisotropic in its properties, and that light can penetrate by diffusion to far greater distances parallel to the laminations than perpendicular to them. Why this should be so is a question, the answer to which may be reserved for a future occasion. We may however point out that the interpretation given above is favoured by several of the observed details regarding the phenomenon. We have already remarked (sections 2 and 5) that the colour of the transmitted light tends to a deep red with increasing thickness of the nacre, and the same feature is also shown by the forward diffusion. In the experiment described in the present section, the same feature is noticed as regards the colour of the central spot which tends to a deep red with increasing thicknesses of the nacre employed. The laterally diffused light shows however quite a different

* Fig. 15 (*a*) reproduces a photograph taken in a lighted room, and the whole of the shell is visible. The central spot is submerged in the lateral diffusion.

colour, except in its outermost edges where it tends again to a deep red. This observation indicates that the lateral diffusion is quite a distinct phenomenon and possesses characters different from that of the forward or backward diffusion. It may be remarked that different types of nacre differ greatly in this as in other properties. The phenomenon of lateral diffusion is, for example, hardly to be observed with the shell of *Nautilus pompilius*.

7. *Summary.*

The paper describes a group of interesting optical phenomena which have their origin in the granular and colloidal structure of nacre and have no analogue in the optics of transparent stratified films. Section 1 points out that the crystalline particles present in nacre diffract or diffuse light in a manner determined by their size, shape and arrangement and in consequence give rise to various optical effects. Section 2 describes the forward diffusion of light through nacre and the colours arising therefrom exhibited by iridescent shells observed as "translucencies". These colours depend both on the angles of incidence and of observation. Section 3 describes the phenomena of backward diffusion of light or body-colours which are complementary to the iridescent reflections and tend to dilute the latter to an extent determined by the circumstances of observation. Section 4 describes the diffusion-haloes observed when a source of light is viewed through a thin polished plate of nacre. These haloes assume very different forms for the three great groups of molluscs, namely, the Gastropods, the Bivalves and the Cephalopods, and indicate that the arrangements of the crystalline particles in nacre are very different in these three groups and also show distinct differences as between individual families and species. Section 5 deals with the colours of the transmitted light which are a function of the thickness of the nacre and indicates the existence of three distinct factors which determine the extinction coefficient. Section 6 deals with the phenomena of lateral or transverse diffusion of light which occurs through surprisingly great thickness in several kinds of nacre and which indicates that nacre is a highly anisotropic medium in this respect.

Numerous photographs of the diffusion-haloes and other phenomena illustrate the paper.

In conclusion, I have to express my thanks to Mr. C. S. Venkateswaran who assisted me in these studies and obtained the photographs illustrating the paper, as also to Mr. P. Pattabhiramayya who prepared numerous thin sections of nacre for optical and microscopic observation. The Research Assistant of the Fisheries Department at Ennur has been very helpful in the supply of suitable specimens for the work.

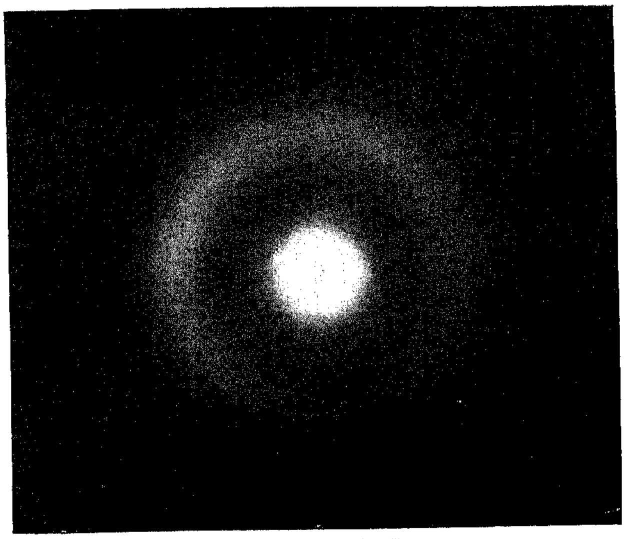


FIG. 1. *Turbo* Sp.

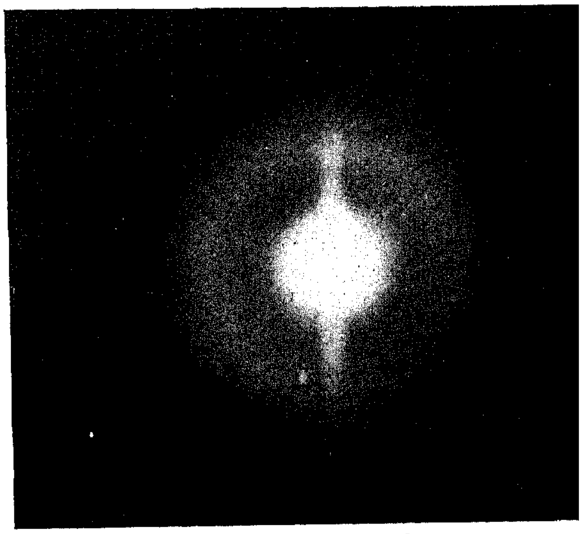


FIG. 2. *Haliotis* Sp.


FIG. 3. *Trochus* Sp.


FIG. 4. *Abalone* Sp.


FIG. 5. *Nautilus pompilius.*

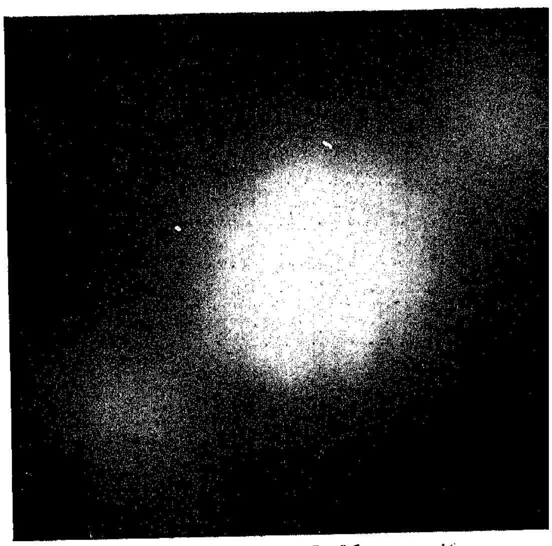


FIG. 6. *M. Margaratifera.*

FIGS. 1—6. Diffusion-Haloes of Iridescent Shells.

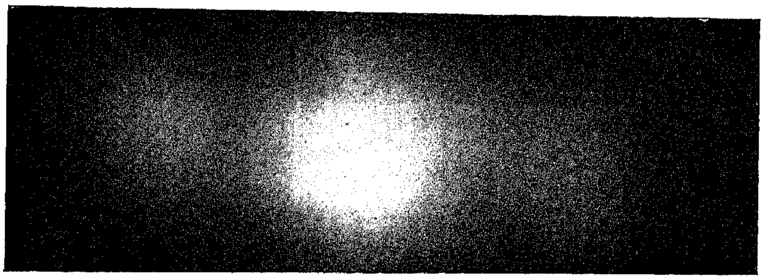


FIG. 7. *Parreysia* Sp.

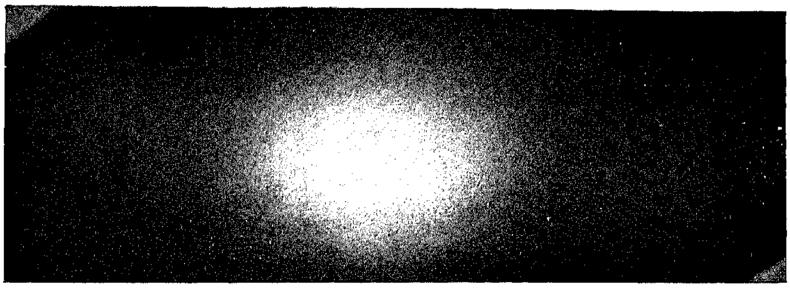


FIG. 8. *Pinctada lentiginosa.*

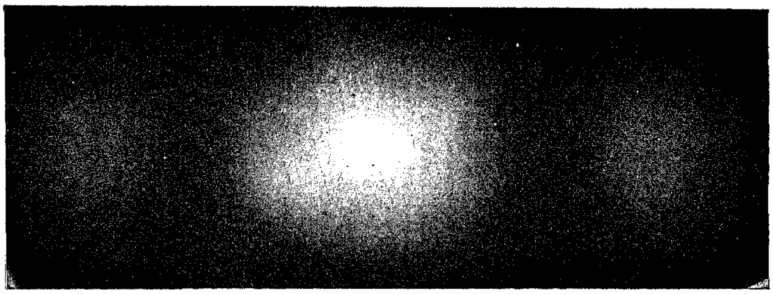


FIG. 9. *Lamellidens marginalis.*

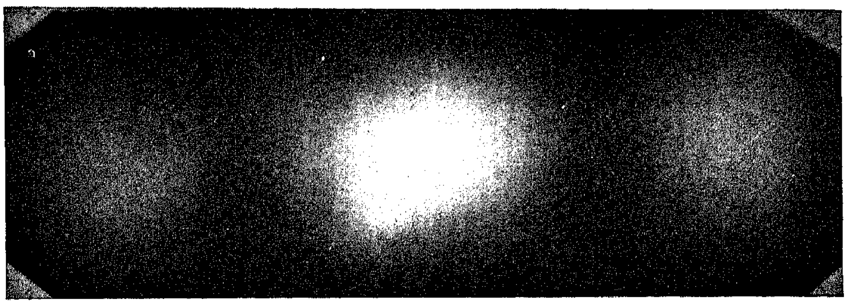


FIG. 10. *Pinctada vulgaris.*

FIGS. 7—10. Diffusion-Haloes of Iridescent Shells.

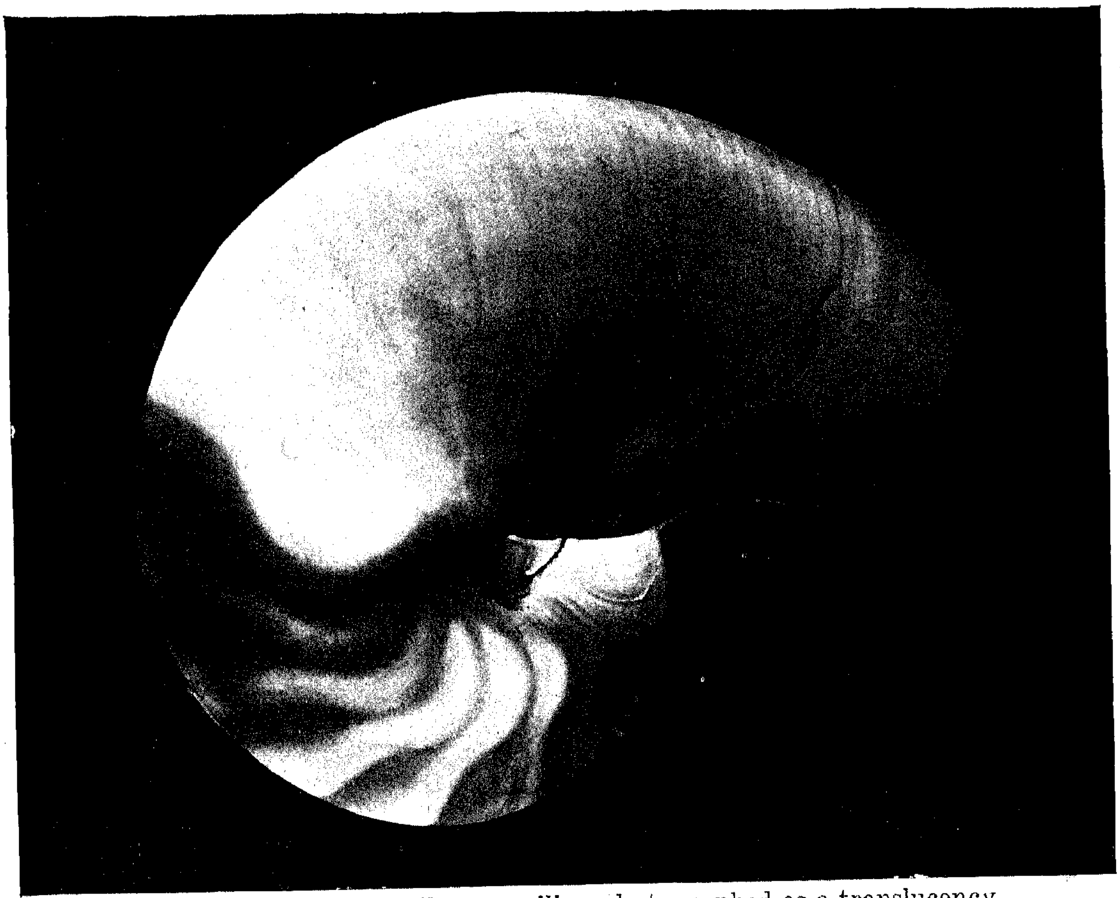


FIG. 11. Shell of *Nautilus pompilius* photographed as a translucency.

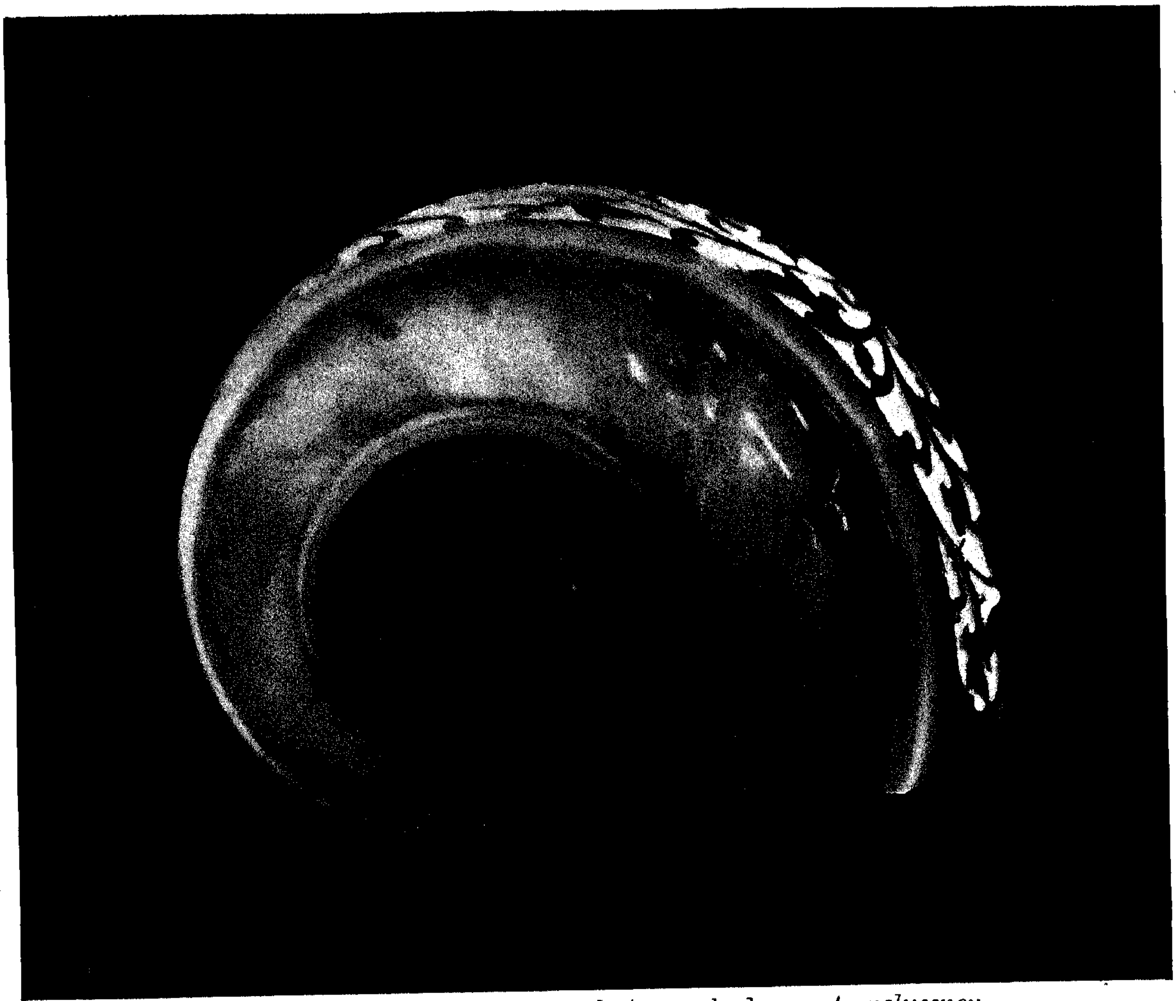


FIG. 12. Shell of *Turbo* sp. photographed as a *translucency*.

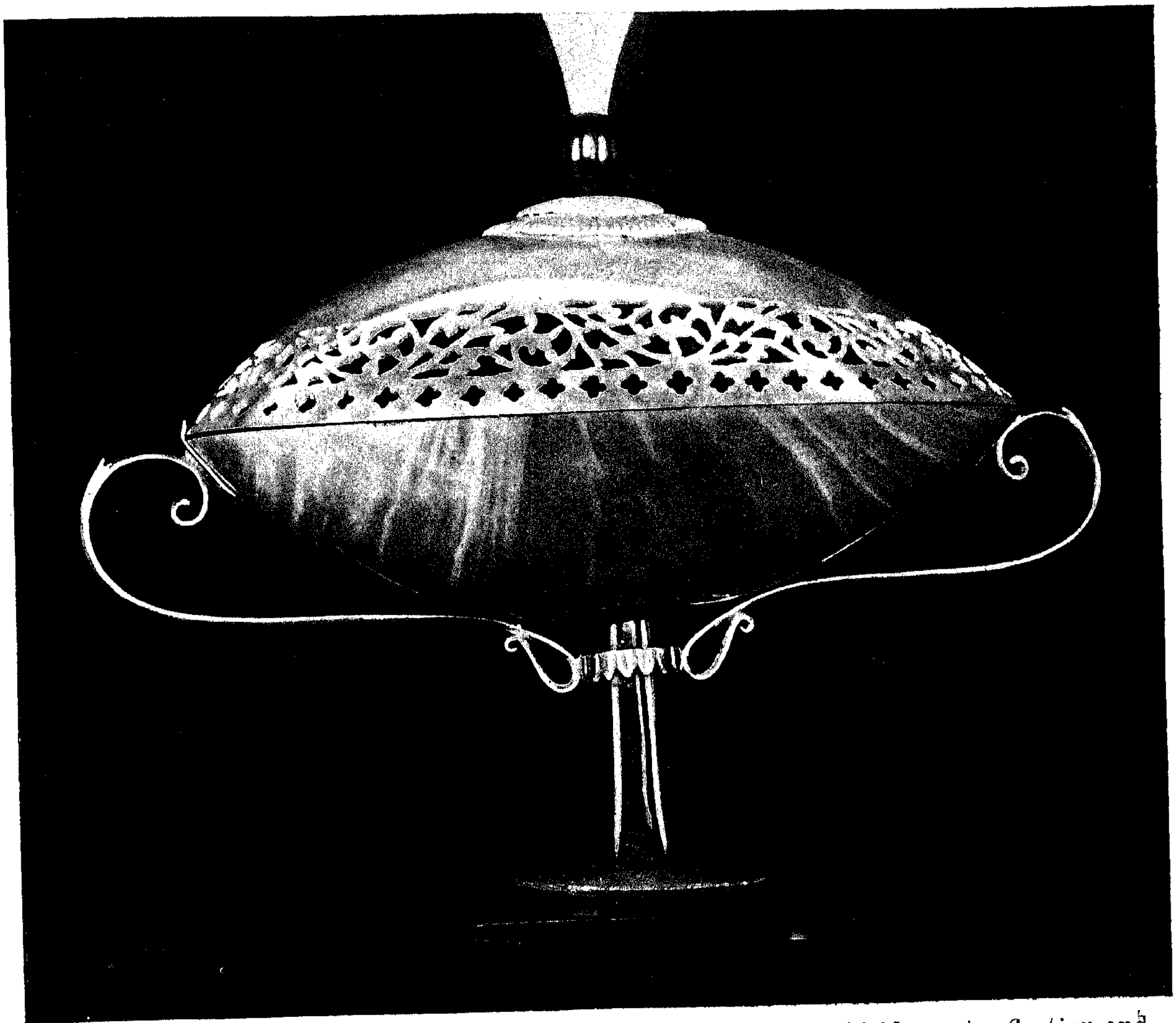
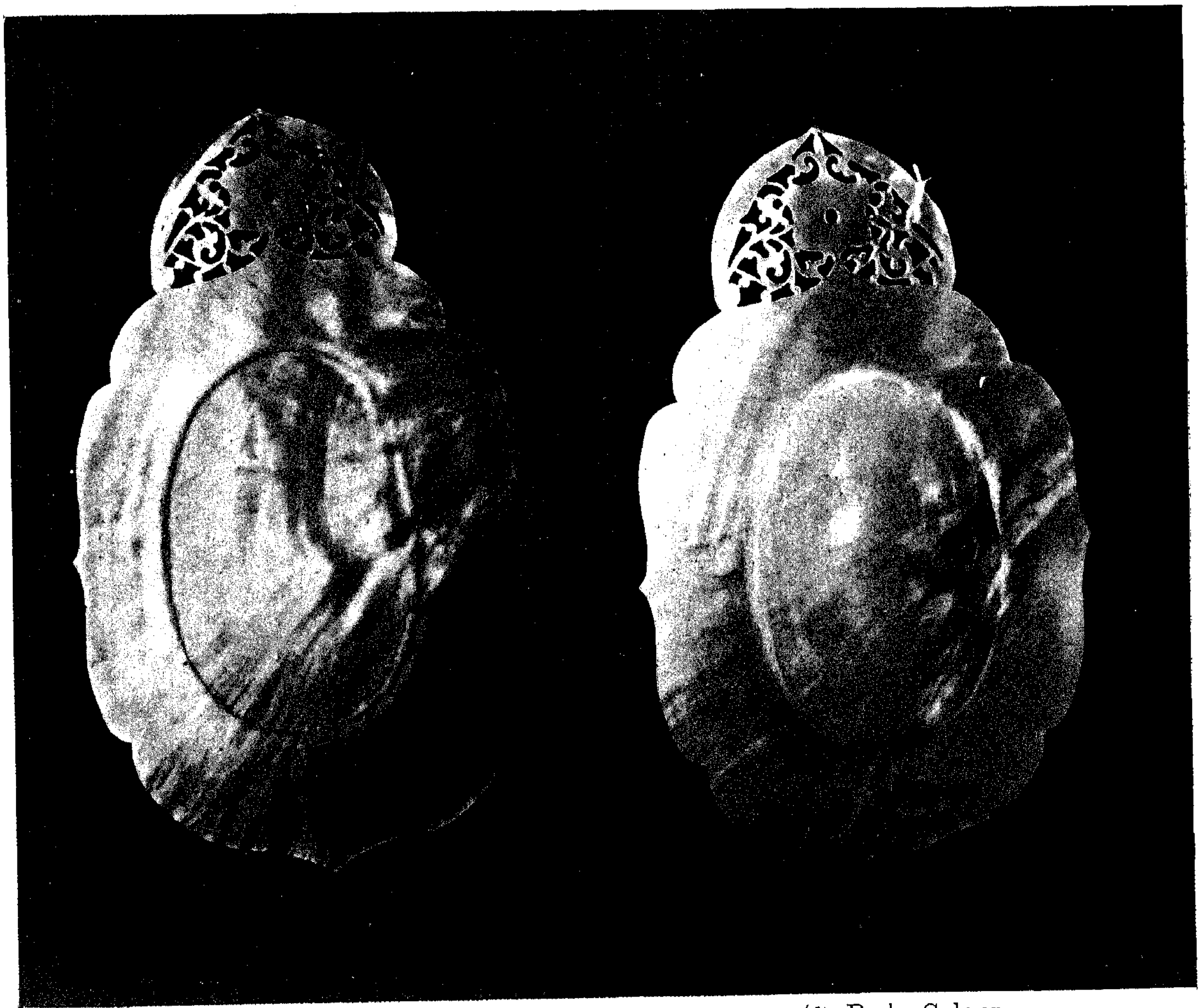
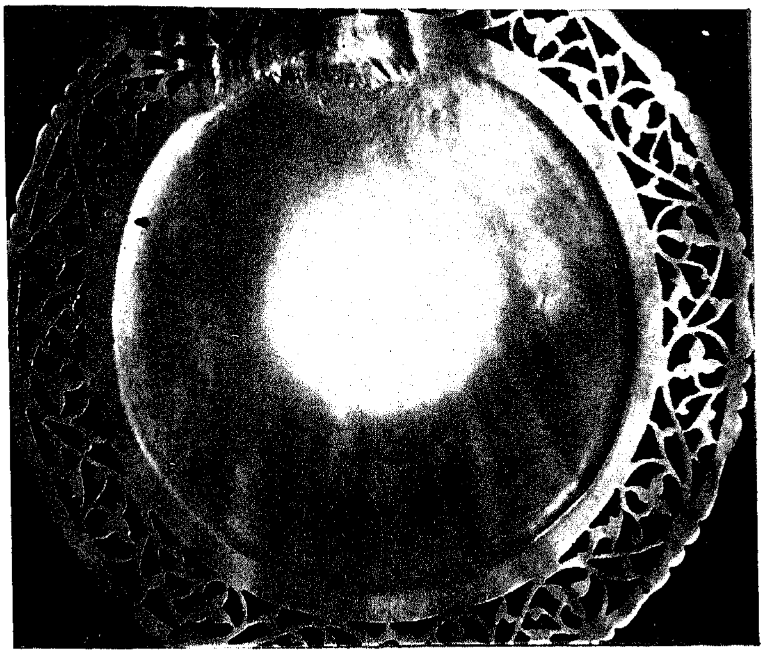


FIG. 13. Bowl of *Turbo* Shell: Upper surface showing bright arc of iridescent reflection and lower surface, bands of body-colour.

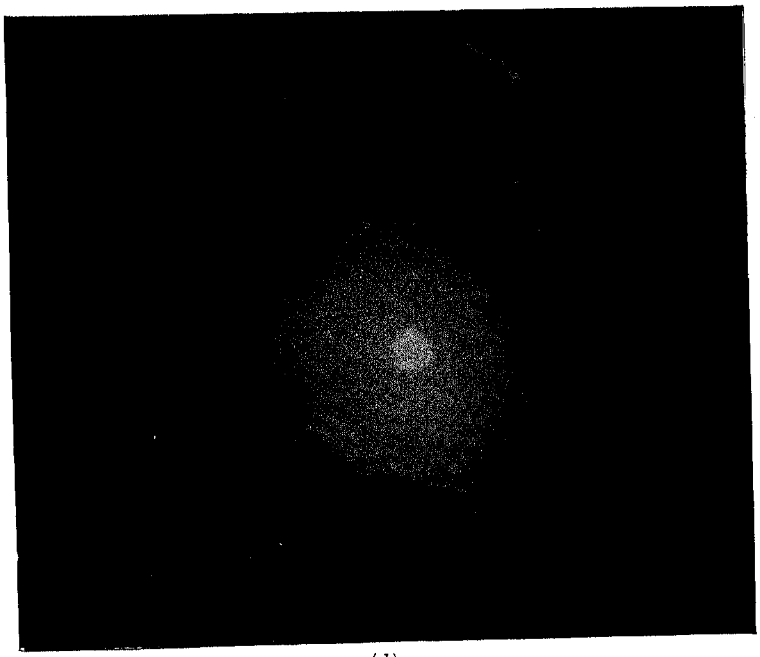


(*a*) Iridescence. (*b*) Body-Colour.

FIG. 14. Plate of iridescent shell of *M. Margaratifera* photographed with panchromatic plate and red filter.



(*a*)



(*b*)

FIG. 15. Shell of *M. Margaratifera* showing lateral diffusion of light.