account for it, such, for example, as that the shell "yawed" from its path to a degree varying from gun to gun, the "yaw" being supposed to affect the pressure at the escape holes, and therewith the time of burning. The true explanation, however, proved to be the hitherto unsuspected effect of "spin"—*i.e.* the angular velocity of the shell about its axis, and this factor has since proved practically the most important one in the behaviour of a powder train fuze. The shell, in order to secure stability in its flight, is given a high angular velocity by the rifling of the gun working on the copper driving-band. In all the guns employed (varying in velocity from 900 f.s. to 2500 f.s.) the twist of the rifling was 1 turn in 30 calibres—*i.e.* in 30 times 3 in. or 7½ ft. This gave angular velocities varying from 7200 to 20,000 revolutions per minute in the five guns. The angular velocity of a shell falls off comparatively slowly in flight, so that it could be regarded as approximately constant along the trajectory of each gun. The peculiar differences observed in the gun trials could be explained only as an effect of spin, and it was clearly necessary to carry out spinning trials on fuzes "at rest"—*i.e.* without forward velocity—to see if the effect of spin could be isolated. Such trials were carried out at speeds up to 30,000 r.p.m., and an enormous effect of spin was established. It was possible to double the time of burning of a fuze, or even to make it cease burning altogether, merely by spinning it. The effects of a fall of pressure also were exaggerated by spin, as was shown in the laboratory at University College, by spinning a fuze under reduced pressure.

The explanation of this effect of spin is interesting. It could not be due to any "dynamic pressure" effect at the escape holes, or to a centrifugal effect on the gases in the groove; these were investigated and found to be far too small. The real explanation is the centrifugal effect on the slag produced by the gunpowder in its combustion. When the spin is high the gunpowder, warmed, softened, and just ignited by the combustion of the previous layer, is "spun" outwards to the outer edge of the groove before it has had time properly to burn and to ignite the next layer; consequently, combustion is slower, and may fail altogether. The absence of any effect of spin in the case of a special powder giving no slag, as well as the fact that "blind" fuzes are found to have failed first on the *inside* edge of the ring, make it clear that the centrifugal effect on the slag is the prime cause of the trouble. At 30,000 r.p.m., a spin reached in fuzes fired from small guns, it is almost impossible to attain any accuracy at all. The rapid increase of fuze-trouble with spin is due to the fact that the centrifugal effect varies as the *square* of the spin.

One obvious means of avoiding the excessive effect of spin was to reduce the rifling of the gun and therewith the rotation of the shell. The possibility of doing this is strictly limited, as with too low a spin the shell becomes unstable. Two similar guns were rifled respectively 1 turn in 30 and 1 turn in 40 calibres, and in all respects the fuzes fired from the latter were found to behave more satisfactorily, thus confirming the results and predictions of laboratory trials. All similar guns were provided thereafter with the smaller rifling, with good effects.

Another factor affecting the behaviour of fuzes is their temperature. This effect, also previously unknown, is a smaller one, but by no means negligible. A fuze burns more quickly at a higher temperature, and allowance must be made for this in accurate firing. A curious phenomenon arises in connection with this. It was usual to test a fuze at rest as well as in the gun, and in the case of some long-burning fuzes at rest the fuze heats itself by its own combustion to such an extent that its time of burning is seriously decreased. This "self-heating" effect does not occur in a fuze fired from a gun, which is cooled by its passage through the air. Consequently, for accurate comparison with gun trials the fuze fired at rest must be cooled while it burns—*e.g.* by subjecting it to a rapid spray of water. This was actually done in later trials, the fuze being rotated in a closed box at any required spin and pressure, and subjected the while to a rapid jet of water to ensure the constancy of its temperature.

We may summarise as follows: The rate of burning of a fuze is a function of the total pressure at its escape holes, which is made up of the atmospheric pressure A and some function $f(v/V)$ of v its velocity and V the velocity of sound. It is a function also of the spin S and of the temperature T. Expressed mathematically, the rate of burning is equal to $F[\{A+pf(v/V)\}, S, T]$, where F is some complicated function of the three variables. It is easy to see that fuzes are likely to cause trouble when subjected to conditions, as they were in the late war, far exceeding in severity any under which they had previously been used; and to foretell that in the next war—if there be one—reliance will be placed mainly on clockwork fuzes unaffected by these various factors.

The Iridescent Colours of Insects.[1]

By H. ONSLOW.

III.—SELECTIVE METALLIC REFLECTION.

IN the two preceding articles various insects have been described and illustrated, which owe their principal iridescent effects to the colours of "thin plates" and to the diffraction of ribbed structures or "gratings." However, more than one physicist of repute has stated that most insect colours are due to selective metallic reflection. The arguments against this theory, as applied to scales, were considered in the first article; briefly, they are due to the facts that both reflected

---

[1] Continued from p. 183.

and transmitted colours disappear when scales are immersed in fluids of a highly refractive index, and that all colours vanish when scales are subjected to pressure, as could scarcely be the case if the colours were due to some molecular structure, such as a film of aniline dye.

Now in the case of scaleless beetles and in many other iridescent structures, including bees and dragon-flies with bright, metallic wings, (1) the colour does not disappear on exerting pressure; (2) the reflected colour does not disappear on immersion in fluids of high refractive index, even when penetration is facilitated by a vacuum; and (3) the transmitted colour, so far as this can be seen, also persists. It is worth noting that the data which Michelson relies on to show the similarity in the behaviour of polarised light, when reflected from iridescent insect structures and films of aniline dye, fit the wing-cases of beetles much more closely than they do the wings of butterflies or the feathers of birds.

Sections *1* and *2* of Fig. 1 show typical iridescent wing-cases. Section *1* is that of the common green Rose Beetle (*Cetonia aurata*) and section *2* that of a beetle with a peculiar sheen (*Anomala dussumieri*), due to the numerous dome-shaped protuberances, *b*, seen in section. The surface of the chitin is protected by a thin cuticle, *c*, 0·5μ thick, but there appears to be no structure likely to produce colour. It is clear that this film cannot cause the colour, because the wing must have a protective sheath of some sort, otherwise the colour would disappear as soon as the surface came into optical contact with a refractive fluid. Consequently it is very important to determine exactly at what depth the colour-producing layer is situated, in order to decide whether there is room for an adequate structure to exist above it.

For this purpose a wing-case was carefully polished under the microscope with a paste of the finest carborundum and cedar-wood oil. On removing the surface-layer, a very remarkable change of colour was observed to have taken place. Sections were cut from suitable portions of the polished area, the exact colour and position of which could be determined. A composite picture of three different sections is shown in *3* (Fig. 1). To the extreme right of section *o* the cuticle, *c*, is untouched, but further on it is partly removed, and the lowest point seems to have been reached near *b*, in section *n*. Somewhere here the colour changes to magenta, but as soon as the irregular dark line dividing the cuticle from the lower layers is passed all colour vanishes, and the black chitin is exposed, as at *a*, in section *m*. Thus it appears that this line running underneath the cuticle is the seat of the colour-producing layer, and its extreme depth is about 0·5μ below the surface. This figure, which was obtained with the microscope, was checked by an indirect method of measurement, and the two results were found to agree with sufficient accuracy.

There appears to be a choice between two alternatives: (1) the colour may be due to a single thin film, which must lie under a protective sheath of some description, or (2) it may be produced by a layer having properties similar to an aniline dye. Although it is possible to show that under suitable conditions single films could, by interference, produce colours as bright as those shown by beetles, the second alternative appears the more probable. This is principally because of the exceedingly small distance between the surface of the wing-case and the lowest limit of the colour-producing layer. Within the space of 0·5μ, room must be made both for the protective cuticle and for the thin film itself. This might, indeed, be just possible, but is unlikely, because of the peculiar sequence of the colours caused by reducing the thickness of the iridescent film in polishing.

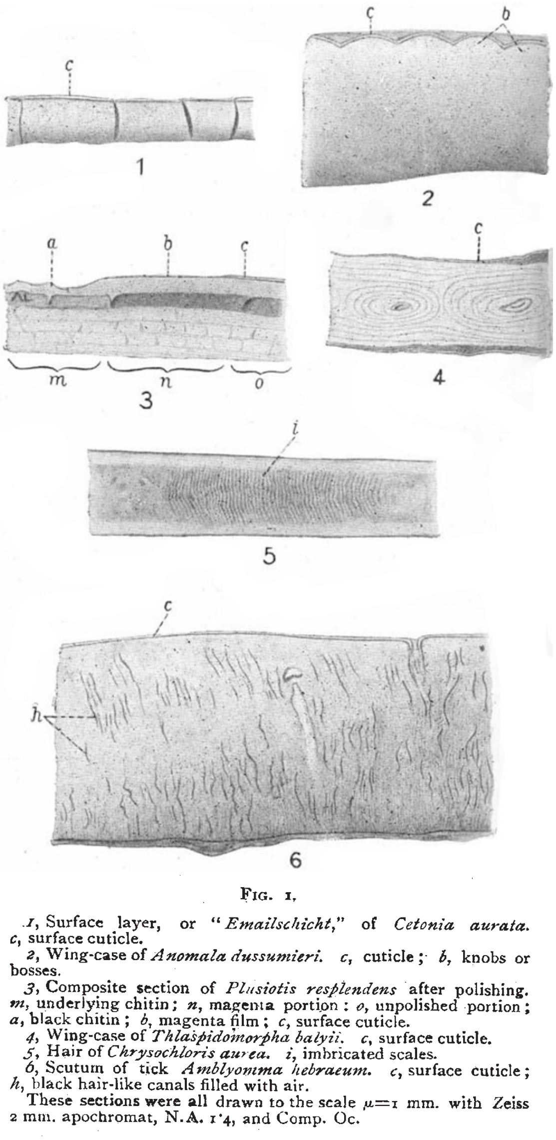

Fig. 1.

1, Surface layer, or "*Emailschicht*," of *Cetonia aurata*. *c*, surface cuticle.
2, Wing-case of *Anomala dussumieri*. *c*, cuticle; *b*, knobs or bosses.
3, Composite section of *Plusiotis resplendens* after polishing. *m*, underlying chitin; *n*, magenta portion: *o*, unpolished portion; *a*, black chitin; *b*, magenta film; *c*, surface cuticle.
4, Wing-case of *Thlaspidomorpha balyii*. *c*, surface cuticle.
5, Hair of *Chrysochloris aurea*. *i*, imbricated scales.
6, Scutum of tick *Amblyomma hebraeum*. *c*, surface cuticle; *h*, black hair-like canals filled with air.
These sections were all drawn to the scale $\mu = 1$ mm. with Zeiss 2 mm. apochromat, N.A. 1·4, and Comp. Oc.

This appearance is difficult to describe, and must be seen to be appreciated fully. On polishing the brilliant gold beetle *Plusiotis resplendens*, no effect is at first seen, except perhaps a slight dulling of the lustre. The golden surface, scarred and scratched by the polishing crystals, remains unaltered for a period, which appears to depend on the thickness of the cuticle. Then, at a certain depth, the gold is suddenly replaced by a metallic magenta, and where this is seen to shine through a very thin film of gold, a silvery-blue effect is produced. On continuing to polish, the magenta rapidly disappears, revealing the black underlying chitin. These changes may be closely imitated by gently polishing a thin film of gold deposited electrolytically on copper. Similar effects are also seen when a copper sheet is gently heated in the steam-oven until films of oxide are formed. It is worth mentioning that Mallock has shown, by means of polishing experiments, that the coloured films of steel oxide are not due to interference in the manner usually supposed.

In the case of these beetles it may be objected that the colour of a thin film *would* change if its thickness were reduced by polishing in the above way. The change of colour, however, would be gradual, and not abrupt as is the case. Moreover, the sequence of colours would be different from that which actually occurs, as, for instance, when bluish-green and green wing-cases change to crimson or scarlet.

Some Iridescent Colours which Depend on Moisture.

The small beetles, forming the group known as Tortoise Beetles, throw considerable light on the question of surface colours by their behaviour in various fluids. Many of these beetles are golden when alive, or when preserved in spirit, but brown when dry. The colour, however, returns on soaking them in alcohol, but not in all other organic fluids. Section *4* (Fig. 1) is cut from a wing-case which has a thin cuticle, *c*, and is in other respects almost exactly like that of an ordinary scaleless beetle that retains its colour after drying. Moreover, the colour does not disappear under pressure, but here the resemblance ceases, for, curiously enough, the golden glitter remains, even after the cuticle has been polished away, so long as the surface is kept moist. In fact, almost the whole wing-case may be ground away before the metallic lustre disappears. It is obvious, from this curious behaviour, that the whole thickness of the surface layer of chitin is concerned, when in a moist condition, in reflecting a lustre, somewhat in the same way as pebbles on a beach glitter in the sunshine when washed by an advancing wave. Even vertical cracks in the chitin are seen to have golden sides. The reason for this behaviour is clear. When dry, aqueous alcohol and certain fluids can penetrate the cuticle, but other organic fluids cannot. The colour does not return immediately after immersing the beetle, but it must soak, because the protecting cuticle is pervious only with some difficulty. For the same reason, once it is wet, the colour takes some time to disappear, because the cuticle prevents the moisture from evaporating, as it must no doubt do when the beetle is alive. The fact that the whole thickness of the chitin layer reflects metallic colour suggests that, in scaleless beetles, colour may be due to a skin of chitin having the same properties as that of the Tortoise Beetles, but with the surface so polished that moisture is not necessary for the development of the colour.

Some of the most interesting beetles of this group are those which, though colourless when dry, develop a brilliant iridescence on being moistened with a wet brush. There is a remarkable bug with these properties, named *Pycanum rubens*, which is a bright apple-green when alive or in spirit, but a dull purple-brown when dry. Experiments were made in various fluids, and it was found that in alcohol, which was completely dehydrated by metallic calcium, immersion produced no colour. But the slightest trace of water caused the colour to return, and dilute acid had the effect of making it more or less permanent. Pressure experiments showed that there was no surface colour due to a molecular structure, because the colour completely disappeared, to return again as soon as the pressure was removed, just as the colours of thin films should do. These and other observations made it probable that the colour arose in a thin membrane with, like gelatin, a specific power of absorbing water, but not other organic solvents. When dry, the membrane must be too uneven to cause regular reflection, but as soon as it is swollen with water it can give the colours of thin films.

The third example of this type of iridescence was found in certain metallic ticks first described by Prof. Nuttall. When dry, they are a dull ochre, and in most anhydrous fluids a matt silver, like freshly cut aluminium, but in aqueous fluids they show bright metallic colours, both green and red. Reference to a section of the scutum, *6* (Fig. 1), shows that a protective cuticle, *c*, covers a thick layer of chitin interpenetrated by innumerable tiny air-canals, *h*. It is probable that, when dry, the white light reflected from this air renders all structural colours invisible; but when an aqueous fluid, which can penetrate the cuticle, fills these canals, the dark background produced clearly shows up the colours which may, or may not, be due to an absorbent membrane, as in the case of *P. rubens*.

In the course of these investigations many other very interesting iridescent structures were examined, for a description of which there is here no space. Many of these revealed no adequate colour-producing structure, and they present a most interesting field for further research. Among the most striking objects are the green metallic wings of certain bees and dragon-flies, such as some of the Carpenter bees, and *Neurobasis chinensis*. These very brilliant and thin structures behaved in many ways like the wing-cases of scaleless beetles. There are also the iridescent eyes of many Diptera, and the amazing iridescent hairs of a mammal, the Cape Golden Mole, *Chrysochloris aurea*, 5 (Fig. 1), showing the fine imbricated scales, *i*. In addition there are the brilliant *setae* of the "sea-mouse," a marine worm (*Aphrodite aculeata*). In plants not many iridescent structures are found, with the exception of the beautiful Pteridophyte, *Selaginella Wildenovii*, which glistens with a very strong blue and purple metallic sheen.

Obituary.

ARTHUR SIDGWICK AS NATURALIST.

THE admirable notice of the late Arthur Sidgwick in the *Times* of September 28 describes him as "naturalist," as well as "scholar" and "politician." It is a true and just description. The love of natural history developed early, and was always one of the strong and essential elements in his intellectual life.

Sidgwick was twenty-seven, and had been a master at his old school—Rugby—for three years, when Wallace's article "On Mimicry and other Protective Resemblances among Animals" appeared in the *Westminster Review* for July, 1867, and it had the same effect upon him as, in its later form, reprinted in the "Essays on Natural Selection," it had on the present writer. A few months after reading it, Sidgwick, on November 9, read his paper "On Protective Resemblances among Insects" before the Rugby School Natural History Society (pp. 23–26 of the report for 1867), in which he not only gave an admirable review of the article, but was also able to draw on his own past experience as a naturalist for illustrations. There is one slip in his reference to Wallace's account of Bates's epoch-making paper, for he spoke of the Heliconidæ and their Leptalis mimics as "white," whereas they are brightly coloured, while the Leptalis, abandoning an ancestral white, have become brightly coloured also.

Among Sidgwick's original observations in the paper, the following are quoted by Wallace in his revised essay (p. 45 of the 1875 edition):—

> I myself have more than once mistaken *Cilix compressa*, a little white and grey moth, for a piece of bird's dung dropped upon a leaf, and *vice versa* the dung for the moth. *Bryophila glandifera* and *perla* are the very image of the mortar walls on which they rest; and only this summer, in Switzerland, I amused myself for some time in watching a moth, probably *Larentia tripunctaria*, fluttering about quite close to me, and then alighting on a wall of the stone of the district, which it so exactly matched as to be quite invisible a couple of yards off.

Observations of this kind were far from well known in those days, only a few years after the appearance of the "Origin of Species."

Sidgwick was a man of strong opinions; what he believed he believed intensely. Yet, with all this, he was exceptionally modest. I recall a later paper of his on the same subject as the earlier, read before the recently established Oxfordshire Natural History Society. In the discussion some criticisms were passed upon the relative value of the destructive agencies of which he had spoken. He accepted the remarks of much younger members with perfect kindliness, and ended by saying that he hoped "to do better next time."

These memories lead naturally to thoughts of his simplicity, and with it his delightful and infectious boyishness. One came in to ask for his ever-ready help in coining some scientific term, and found him testing his latest toy, a little typewriter, and then everything must give way to a race between the player and the writer—the latter much handicapped by the banging of the machine; or a simple form of billiard table had displaced the heaps of books, and a game must be played; or a chunk of marzipan emerged and must be shared.

Sidgwick's sympathy with the aims of science in university life was not bounded by his love of natural history. In the conflicts which often arose, and were bound to arise, between the old, which is really modern, and the new, which is a return to the ancient ways, Sidgwick always supported science. I never knew an exception in the years when we were closely associated.

Among the notices and memories of Arthur Sidgwick I have seen, there has been no reference to the two volumes of "School Homilies," addressed, from 1870 onwards, to the boys in Canon J. M. Wilson's House at Rugby. The addresses deal, as Canon Wilson says in his introduction, "with apparently commonplace subjects, but they lifted every subject out of the commonplace." They should be read by everyone who wishes to know the man and all that he stood for. E. B. P.

BY the death of M. LOUIS DUCOS DU HAURON we lose one of the foremost pioneers in the photography of colour. M. du Hauron was born on December 8, 1837, and died on August 31 last. *La Nature* of September 25 publishes a portrait taken in 1877, and the *British Journal of Photography*, Colour Supplement, of October 1 gives the portrait by which he is generally known, taken evidently some years after the other, and a useful chronology of his work. It seems that he began the study of luminous sensations in 1859, and that by 1862 he had worked out a method of colour photography by means of three colour filters and complementary printing; but his chief contributions to the subject are contained in two small volumes, which, unfortunately, are now very rare—"Les Couleurs en Photographie: Solution du Problème," published in 1869, and "Les Couleurs en Photographie et en particulier l'Héliochromie au Charbon," published in the following year. In these publications he enunciated