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latter so as to form a very acute angle with the blade. The "ligament" will then be observed to fall from the point perpendicularly to the apparent edge of the knife. If the point of the pin be now slipped down behind the knife, the acute angle will appear to be partly filled up; and on moving the pin so as gradually to increase the angle (pivoting the pin round its point which is held below the edge), it will seem as if connected with the blade by a glutinous substance.

XLVIII. *On the Motions of Camphor and of certain Liquids on the Surface of Water.* By CHARLES TOMLINSON, *F.R.S.**

1. ON a former occasion I contributed to this Magazine two papers on the Motions of Camphor and of certain Liquids on the Surface of Water[1]. These papers contain a large number of references to phenomena which during nearly two centuries have cropped up in the Transactions and Proceedings of various scientific societies at home and abroad, and in many of the foreign and domestic journals devoted to science. Having studied these varied phenomena during a number of years and published many papers thereon, it was with sincere pleasure that I recognized in the same field of research a fellow-labourer who, armed with a new theoretical instrument, succeeded in gathering in the abundant crop which had been so widely scattered during so long a period.

By means of the principle of the surface-tension of liquids, Professor G. Van der Mensbrugghe, of the University of Ghent, has not only succeeded in binding together a magnificent sheaf of facts, but in doing so has contributed to the bundle a number of full and ripe ears of his own growing[2].

I must also take this opportunity of thanking him for the very kind terms in which he refers to my labours[3].

* Communicated by the Author.

[1] Phil. Mag. for December 1869 and January 1870.

[2] I must also associate with Professor Van der Mensbrugghe's name that of Professor Carlo Marangoni, of the R. Liceo Dante of Florence. In 1865 he published a pamphlet, *Sull' espansione delle goccie d'un liquido galleggianti sulla superficie di altro liquido*, in which he adopts the principle of surface-tension in studying the conditions under which a drop of one liquid spreads upon the surface of another.

[3] "M. Tomlinson avait étudié depuis plus de dix ans le phénomène de l'extension des huiles et les mouvements de certains corps solides sur l'eau; aussi je n'hésite pas à voir en lui le physicien qui a le mieux préparé la vraie théorie de ces phénomènes, grâce aux soins scrupuleux avec lesquels il a décrit les faits, en même temps qu'au nombre et à la variété de ses expériences; je me plais à ajouter que la lecture de ses travaux a le plus contribués à me suggérer les idées développées dans mon premier mémoire."

2. The object of his second memoir[4] is (I.) to furnish an additional number of facts by observers of repute bearing on the subject in hand (for which the author is in great measure indebted to the Royal Society's Catalogue of Scientific Papers), (II.) to meet certain objections that have been advanced against the theory, and (III.) to supply a few more experimental proofs.

3. In noticing the more remote facts, which are for the most part stated by Professor Van der Mensbrugghe in a very brief form, I must on several occasions enlarge considerably, since my own labours, begun so long ago as 1838, have in some cases anticipated more recent results. Many of my experiments have been already given in the two papers referred to above (see note [1]), so that in the present communication I shall endeavour as far as possible to avoid repetition.

4. And first as to the additional facts, omitting mere guesses, such as that of San Martino[5], who, in 1793, attributed the motions of camphor to electrical action, we come to Sir H. Davy[6], who, in 1802, noticed that fragments of acetate of potash (then called acetite) move on the surface of water somewhat after the manner of camphor. The more irregular fragments rotate most quickly, whence it is concluded that the shifting of the centre of gravity had something to do with the phenomena, while the rectilinear movements were attributed to currents descending from the salient points of each fragment and so producing on it unequal pressures.

5. Carradori, in 1805, noticed[7] that when a large drop of the milky juice of a euphorbiaceous plant is placed on the surface of water in a large vessel, a portion of the drop spreads, while another portion descends in threads which accumulate at the bottom. If, then, the vessel be inclined so as to spill some of the water and so renew the surface, on returning the vessel to its first position the agitation will cause some of the milky filaments to rise to the surface, where they spread like the first portion.

6. These and a multitude of other phenomena, as noticed in my first Experimental Essay[8], were attributed by Carradori to a

[4] "Sur la Tension superficielle des Liquides considérée au point de vue de certains mouvements observés à leur surface," second mémoire, extrait du tome xxxvii. des *Mémoires Couronnés* &c., publiés par l'Acad. Roy. des Sci. de Belgique, 1873.

[5] *Nuovo Giorn. Enciclopedico d'Italia,* Marzo 1793.

[6] Journal of the Royal Institution, vol. i. p. 314.

[7] "Dell' attrazione di superficie, Mem. II.," *Mem. di Matem. et di Fisica della Soc. Ital. delle Scienze,* vol. xii. parte 2ª. Many of Carradori's results and some account of his contest with Prevost are given in the first of the two papers referred to in note [1].

[8] Experimental Essays, published in Weale's Series, 1863. Essay I. On the Motions of Camphor on Water.

"superficial attraction" (*attrazione di superficie*), which Dutrochet afterwards developed into the "epipolic force" (*force épipolique*).

7. In 1819 Barlocci[9] covered fragments of camphor with gold leaf, and found that they did not move on the surface of water. The idea was that by preventing the formation of vapour, Venturi's theory, which attributed the motions to the escape of vapour, would be supported. It is further stated that perfect cubes of camphor do not move on the surface of water, on account of their perfect symmetry. This, however, is a mistake which several observers have fallen into; and we suspect that the cutting and shaping and handling of the camphor so as to confer upon it a geometrical form made it dirty, and that this was really the cause of its want of motion. I have frequently placed beautifully formed oblate spheroids of camphor on the surface of water; and these have continued to move about during some hours: but these figures were absolutely clean; for they were formed by dissolving camphor in strong sulphuric acid, and depositing a drop of the solution from the end of a clean glass rod upon the surface of clean water in a catharized glass $3\frac{1}{2}$ inches in diameter. The acid dialyzes off and leaves the camphor in a compact well-shaped button. Two or three drops may be deposited on the same surface; and the resulting buttons will sport about for a long time without interfering with each other's motions.

8. In 1824 a writer in Thomson's 'Annals'[10] attributes the motions of camphor on water to the fact that the centre of gravity of each fragment and the centre of support are not in the same vertical. Another anonymous writer[11] rejects this idea, on the ground that, if true, every irregular floating body ought to present the same phenomena as camphor.

9. I may here remark that during the many years in which the motions of camphor puzzled even the best observers, the idea was not seldom started that the shifting of the centre of gravity had something to do with the phenomenon. In 1863 Mr. Trachsel[12] quotes an experiment by M. Gingembre (without reference), in which a cylinder of camphor, ballasted at one end with lead, was placed in water reaching halfway up the little pillar. After twelve hours' contact the camphor was cut half through at the level of the water, but not equally all round. This experiment (which really originated with Venturi[13]) is quoted to show "the unequal power of solution in certain directions of the crystalline mass," and "this being one of the pro-

[9] *Giorn. Accad. di Sci. Roma*, vol. ii. p. 226.

[10] Second Series, vol. viii. p. 75.

[11] Ibid.

[12] Chemical News, August 22, 1863.

[13] *Annales de Chimie*, tome xxi. p. 262.

perties of camphor pointed out by Mr. Lightfoot, and from which he derives his well-written explanation of the cause of these motions when he says, 'the water upon which it floats, being capable of diffusing this vapour more readily in certain directions of the crystalline axis, thereby removes sufficient vapour-pressure at these points for the opposite side to drive about (by recoil) the nicely suspended particle.' "

10. In my reply to Mr. Trachsel[14], I state that nearly two years before I had pointed out the more rapid solution of camphor on a broken than on a natural surface, and also that the vapour theory was three quarters of a century old. It was first started by Volta in 1787, adopted by Prevost in 1799 under the term *jet gazeux*, and is now being revived without any experimental basis being provided for it.

11. As to the disturbance of the centre of gravity being the cause of motion in a floating and partly soluble mass, we have only to secure a crystal of some soluble salt to a slice of cork by means of an india-rubber ring, so as to be a little lighter than water; and if this be set floating, the waste will be constantly disturbing the centre of gravity of the mass, so as to produce a rolling over and a slow progressive motion. But no explanation of this kind suffices to explain the gyrations of camphor, benzoic acid, citric acid, &c., which are so rapid under the most favourable conditions (namely, chemically clean glass and water, and a bright, warm, dry day) as to extinguish the form of the fragments and make them appear like a grey cloud on the water.

12. In 1825 the brothers Weber[15] examined the subject of the camphor motions, and showed that a downy feather smeared with oil at the two ends will rotate on the surface of water. But other observers had already pointed out that an indifferent substance, such as sulphur, glass, earth, sugar, paper, &c. (as indicated by Carradori in 1808[16]), smeared with a fixed oil will rotate on the surface of water. But the first observation of this fact is older still. Franklin, in his celebrated letter to Brownrigg[17], on the action of oil in stilling the waves, dated November 7, 1773, states that while visiting Smeaton near Leeds, he was about to show what he calls "the smoothing experiment" on a pond, when Mr. Jessop, one of Smeaton's pupils, spoke of an odd appearance on that same pond. "He was about to clean a little cup in which he kept oil, and he threw upon the water

[14] Chemical News, September 12, 1863.

[15] *Wellenlehre.* Leipzig, 1825.

[16] *Giornale di Fisica &c.* vol. i. Pavia, 1808.

[17] Memoirs of the Life and Writings of Benjamin Franklin, edited by his grandson, W. T. Franklin (Lond. 1819), vol. ii. p. 268. Also Phil. Trans. 1774.

some flies that had been drowned in the oil. These flies presently began to move, and turned round on the water very rapidly as if they were vigorously alive." The experiment was repeated before Dr. Franklin, who says, "To show that it was not any effect of life recovered by the flies, I imitated it by little bits of oiled chips and paper cut in the form of a comma of the size of a common fly, when the stream of repelling particles issuing from the point made the comma turn round the contrary way." The Doctor adds that "this is not a chamber experiment; for it cannot well be repeated in a bowl or dish of water on a table." The reason for this is want of chemical purity in the bowl or dish. The effect may be well shown in a clean glass 5 or 6 inches in diameter, by moulding small coracles of paper on the rounded end of a glass rod, pouring into one of these coracles a few drops of a volatile oil, and placing it on the surface of water. The paper-comma experiment is sometimes referred to as originating with the brothers Weber; but in truth their labours added nothing to the subject, nor does it appear that they intended to do more than glance at it. They do not settle any thing, but, on the contrary, declare that the varied phenomena connected with the subject still remain unexplained[18]. They are even inclined to fall back upon an electrical theory in order to explain the rapidity with which a drop of oil spreads on the surface of water.

13. In 1828 August[19] described an experiment by Wirth, in which a metal ball is suspended at a short distance from the surface of water sprinkled over with powdered sealing-wax. On closing the hands over the metal ball the fragments of sealing-wax are set in motion, an effect attributed by Wirth to the magnetism of the human body, but by August to currents of air due to differences in temperature. He supports this view by showing that the effect can be produced by the action of a heated cylinder[20].

14. In 1836 Challis[21] endeavoured to account for the spreading of a drop of oil on the surface of water by considering that the angle formed by the free surface of this drop and the com-

[18] They say:—"Die ganze Erscheinung ist noch gar nicht erklärt."

[19] Pogg. *Ann.* S. 2. vol. xiv. p. 429.

[20] This class of experiment originated with B. Prevost at the beginning of the present century (*Ann. de Chim.* vol. xxiv. p. 31). These experiments (of which the following is the leading one) are remarkable, and excited a good deal of attention at the time. If near the edge of a disk of tinfoil floating on the surface of water we present obliquely a rod of heated metal, or the focus of solar rays by means of a burning-glass, the disk moves away from the source of heat. This experiment, now so easily explained on the principle of surface-tension, led Prevost into some very elaborate speculations.

[21] Phil. Mag. vol. viii. p. 288.

mon surface of the two liquids must be very small, and that consequently a thin film of oil must spread over the whole surface of the water, while a second drop would assume the lenticular form. I give Professor Challis's own words, since a similar theory was published by Du Bois-Reymond[22] in 1858. He says:—"The angle of actual contact between two fluids is determined by the hydrostatical equilibrium resulting from the molecular attractions of the two substances, the fluids being treated as incompressible. It thence appeared that this is an exceedingly small angle in cases in which the bodies in contact are not of very different specific gravities. Hence in the instance before us, the angle of contact (that is, the angle which the surface of contact of the oil and water makes with the upper free surface of the oil) is very small. But since the drop is convex both at its upper and under surfaces, this is apparently an angle of considerable magnitude. In fact the theoretical angle of contact, or that which the upper surface of the oil makes with an imaginary surface drawn parallel to its under surface, and just beyond the sphere of the molecular action of the water, would be found by calculation to be of sensible magnitude. Consequently, that the angle of actual contact may be exceedingly small, the portion of the upper surface of the oil that lies within the sphere of the molecular action of the water must undergo a flexure near the visible periphery of the drop. Now in fulfilling this condition it seems probable that a very thin film of the oil spreads over the whole water surface (as there is no force to counteract), and gives rise at the same time to the visible spreading of the first drop. The film itself, being of less thickness than the radius of the sphere of the molecular action of the water, will not be perceptible to the senses. Such a circumstance having happened to the drop that first comes in contact with the water will prevent any that succeed from being similarly affected."

15. It is remarkable that Professor Challis should have thought it theoretically probable that a thin [invisible] film of the oil spreads over the whole surface of the water and assists the visible [and slower] spreading of the first drop, because in some oils (such as oil of cinnamon) this thin film is visible. On depositing a drop of this oil on the surface of clean water in a clean glass $3\frac{1}{2}$ inches in diameter, an exceedingly thin but visible film is instantly drawn over the whole surface of the water, while the denser film, which does not cover half the surface, spreads much more slowly. In the case of freshly distilled oil of coriander (the very remarkable cohesion-figures of which are given in one of my papers[23]), the first thin film is accompa-

[22] Pogg. *Ann.* vol. civ. p. 193.

[23] Phil. Mag. S. 4. vol. xxxiii. plate iv., June 1867.

nied by volleys of minute globules which extend to the edge of the water in radial lines. Other similar cases of essential oils might be cited; and even in the case of solid fats the evidence of a thin invisible film covering the surface and arresting the camphor motions, seemed to be irresistible before the promulgation of the surface-tension theory. A stick of common mottled soap, or of tallow or lard, lowered into a large surface of water previously dusted over lightly with lycopodium powder, instantly clears away a large circular space (extending nearly to the edge of the glass). This effect is much more satisfactorily explained on the surface-tension theory than on the existence of a thin invisible film. But in the case of oils, whether volatile or fixed, it must be considered that a much greater tensile force is exerted in spreading some oils than others. When a film formed by a drop of a volatile oil nearly covers the surface of the water, there is still a sufficient residual amount of surface-tension to cause fragments of camphor to perform their evolutions; they skate through the film, cutting it up in all directions. But in the case of a film formed by so large a quantity as a drop of any fixed oil, the camphor fragments are motionless, whether on the film itself or on the adjacent water-surface. This was formerly supposed to prove the existence of a fatty film which, though invisible, destroyed contact between the water and the camphor; but now, in accordance with the new theory, the fatty-oil film so far reduces the tension as to leave no residual force sufficient to give motion to the fragments.

16. But if, as I have shown, a freshly distilled volatile oil does not prevent the motion of the camphor fragments, some deductions must be made from the statements of the earlier observers, which savour of the marvellous. Thus Volta, writing in 1787, says:—"If the water be defiled with any foreign substance, or its surface only slightly fouled with oily matter, if only the dust of the room or of one's clothes be upon it, the looked-for motions of camphor and of benzoin will not take place, or will be so feeble as to be scarcely sensible[24]. So also Prevost[25], writing in 1797, remarks that "if the surface of the water be touched with a pin previously dipped in oil, the motion of the camphor fragments instantly ceases, just as if they had been struck by lightning (*comme foudroyées*)." Venturi[26] also, in 1797, says, "Touch the surface with oil, and an almost imperceptible film instantly advances over the whole surface, repels the fragments, and strikes them motionless as if by magic."

[24] Volta's Latin letter to Frank is contained in the *Delectus Opusculorum Medicorum*. Ticini, 1787. An English translation of this letter is given in my 'Experimental Essays.' See note [8].

[25] *Ann. de Chim.* vol. xxi. p. 254. [26] Ibid. p. 262.

17. Now in all these cases I venture to say that the experiment was not performed under the most favourable conditions. It was known that the water must be free from grease; but I know of no reference on the part of these early inquirers to show that they took special means to make the vessel containing the water chemically clean, any more than the surface of the camphor or the knife with which it was cut or scraped. Hence, the initial tension of the water not being at a maximum, contact with a very slight portion of grease or oily matter would so far further lower it as to produce the sudden effects described. But if the experiment be repeated under the most favourable conditions, in which the surface-tension of the water is at its maximum, the water may be touched with a fixed oil, and the iridescent film resulting therefrom, though lowering the tension, will not do so to a sufficient amount to arrest the motions of the camphor fragments. For example, a shallow glass 4 inches in diameter was filled first with strong sulphuric acid and then rinsed out with tap-water and filled with the same. Fragments of camphor were extremely active on the surface, which was now touched with the point of a clean penknife that had been dipped into refined East-India rape-oil; a film of a splendid deep-blue colour was produced, which instantly opened into a sort of lace-pattern; but the fragments of camphor continued to rotate, not so vigorously as at first, but still with vigour. If the film of oil be first formed on the surface and the camphor fragments thrown upon it, they will also rotate. If instead of using the point of a knife to deposit the oil, a glass rod be employed and a drop be deposited, this, especially if the oil be heated, will flash out into a film, completely covering the surface of water in a vessel 6 inches in diameter. Under these conditions fragments of camphor do not rotate; but there is sufficient residual tensile force to give motion to creosote. A drop of this instantly repels the oil-film, cuts it up in all directions, and moves over the surface with great vigour, the only sign of diminished tension being that the cohesion-figure does not open out into the usual brittle arc and so break up into a number of figures, but preserves one parent figure, from which volleys of small globules are discharged[27].

18. In the paper just referred to[28] I give a number of cases in which a volatile-oil film arrests the motions of creosote, and then evaporating, the water (according to the new theory) so far recovers its tension that the creosote suddenly starts into life and increases in vigour as evaporation proceeds.

[27] Figures representing this action are given in the plate accompanying the paper referred to in note [23].

[28] See note [23].

19. Considering the mode in which surface-tension acts, it will naturally be supposed that the motions in question are not confined to camphor and a few other solids, nor to creosote and a few other liquids. In fact fragments of any body that act by suddenly lowering the surface-tension at the spot on which they fall are liable to these camphor motions. Many salts act in this way, the last that I have observed being sulphate of aniline. The following solids also rotate:—Borneol, naphthol, thymol, nitrotoluol: this was inactive on water at 56° F., but very active on water at 90°, a crystalline needle sweeping over the surface at right angles to the length of the crystal. Binitrotoluol on water at 96°. Hydrochlorate of toluidin: a crystalline fragment darted to and fro in short jerks, as if surprised at the novelty of its situation, and then, accepting the conditions, moved rapidly over the surface in circular sweeps and quickly disappeared. Acetamid behaved in a similar manner. Lactid and oxamethan also rotate rapidly. Sulphaldehyd rotates rapidly in wide sweeps and soon becomes motionless. The same phenomena are exhibited by benzoic anhydride. Amidobenzoic acid also rotates rapidly, and quickly disappears; while the crystalline portion of nitrobenzoic ether sails round and round near the edge, and continues to do so for a long time.

Among liquids, a drop of toluidin on the surface of water, in a vessel 4 inches in diameter, affords an instructive illustration of surface-tension: the drop forms a figure for an instant something like that of creosote; it then bursts as with an explosion, dotting the whole surface with smaller figures, each of which also explodes; and the smaller particles resulting therefrom rapidly disappear amid lively agitations. A drop of phenyl-mustard oil quickly spreads into a large ragged film, which is torn into numerous fragments, covering the surface; and then each fragment gathers itself up into a well shaped lens. A second drop rests as a lens. A drop of monochloracetic ether spreads rapidly over the surface and rebounds to the centre, breaks up into numerous ovoid masses, with colour, which rapidly disappear with a remarkable opening out. When the whole has disappeared, the motes on the surface rush wildly to and fro. Formiate of ethyl produces a very pretty rose-engine figure with a central boss. Oxalate of ethyl forms a wide film with iridescent edges, and then, in waving figures, quickly disappears. Iodide of allyl gives a colourless film over the whole surface, then exhibits a magnificent display of iridescence, breaks up and instantly disappears. The following liquids also present interesting phenomena:—Nitrobenzol, nitrobenzoic ether, nitrotoluol, and cymol. It would be easy to extend the list both of solids and liquids that afford instructive illustrations of surface-tension, whether on the surface of water or on that of other liquids. A drop of oil of lavender on the surface of liquid acetic acid forms a wonderfully active figure, which I have already noticed[29], together with the figures of various liquids on the surfaces of sulphuric acid, cocoa-nut oil, castor-oil, paraffin, spermaceti, white wax, olive-oil, lard, and sulphur, heated, where necessary, so as to render them sufficiently fluid[30].

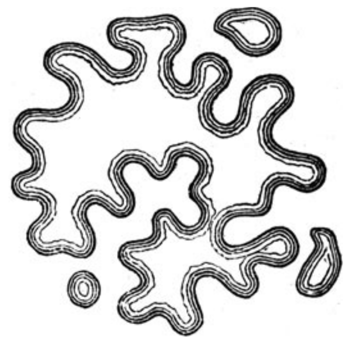
20. In 1837 Dr. Pietro Savi[31] had his attention directed to the following statements by De Candolle[32] with reference to the contractile motions of plants:—"Si l'on place sur l'eau des folioles, ou des fragmens de folioles, du *Schinus Molle*, on voit l'huile volatile, contenue dans certaines cellules du tissu, s'echapper, non par un flux continu, mais par des saccades intermittentes, qu'on ne peut, ce me semble, rapporter à d'autres causes qu'à quelque contraction des cellules qui renferment ce suc." And again at page 287 of the same volume, with reference to the sudden and singular movements of the leafy fragments:—"ces mouvemens sont dus à des jets intermittens d'huile essentielle, qui sortent des cellules, frappent l'eau, et determinent dans le foliole un mouvement de recul semblable à celui de l'éolipyle. On voit ici assez clairement un effet vital."

Dr. Savi shows, by a microscopical examination of the leaves in question, that no provision is made for the exertion of a contractile force, that fragments of the dried leaves move, that the motions are common to leaves of the *Terebintaceæ, Euphorbiaceæ, Urticaceæ, Asclepiadaceæ*, and some others, and that the true explanation of these phenomena (which are physical, not physiological) is to be found in Carradori's attraction of surface, as explained in his memoirs[33].

21. In 1838 Morren[34] showed that a leaf of the *Schinus Molle*, or American pear, placed on water had a jerking motion, while the surface became covered with a film of a sweet-smelling oil. Another plant, the *Passiflora fœtida*, is furnished with hairs, one of which, plunged into water, discharges a small drop of oil, which, rising to the surface, expands and contracts several times, and then apparently bursts with violence, the smaller portions going through similar changes. These are well-known effects of surface-tension common to several oils and other liquids, as is also an experiment by Zantedeschi[35], in which a

[29] Phil. Mag. for March 1862.
[30] Phil. Mag. for November 1864.
[31] *Mem. Valdarnesi*, 1837, vol. ii. p. 117.
[32] *Phys. Végét.* vol. i. p. 38.
[33] He refers to *Mem. della Soc. Ital.* vols. xi., xii., and xv.
[34] *Corresp. Mathém. et Phys. de* M. Quetelet, 1838, vol. x. p. 339.
[35] Given by Luvini in his *Saggio di un Corso di Fisica Elementare*

few drops of valerianic acid poured into water rise to the surface, go through a variety of contortions and evolutions, and excite the astonishment of the observer that dead matter should thus of itself become endowed with such active motion. Some years ago I performed this experiment, and had a drawing made of one stage of the contortions. If the annexed figure is supposed to be in rapid motion, constantly changing into simi-



lar figures, and detaching pear-shaped lenses which immediately become circular, a good idea will be formed of the behaviour of this liquid on the surface of water. A drop of isobutylic alcohol forms a similar figure, only more rapid in its action.

22. In 1838 I published a new method of producing Newton's rings[36]. Referring to the facility with which oil spreads over the surface of water, it is stated that any oil, balsam, varnish, or essence not soluble in water will answer the purpose, or, if the oil or balsam &c. be too viscid, it may be made sufficiently fluid by the action of heat. A single drop of oil &c. may form a circular film from 2 to 5 inches in diameter with or without colour, depending on the thickness. Supposing the film to be without colour, the finger dipped in ether (or a piece of porous wood, or a camel's-hair pencil, or, as was afterwards adopted, a bit of sponge tied over the end of a glass rod) and held over the film, "we instantly see a repulsion or recession of particles; a black spot is formed; and round it the seven orders of rings appear in all their lustre and beauty. The rings remain just so long as the finger is wet with ether, which having evaporated, or the wet finger being removed, the rings contract in diameter and disappear altogether. These rings can be formed at any part of the surface of the film, and any number of times while the film endures."

Among the conditions enumerated are:—"the glass and the water must be perfectly clean and free from grease; the surface of the water must be perfectly tranquil; a clean glass rod must be dipped into the oil, and a single drop only be placed

(Torino, 1868), p. 236. Professor Luvini has copied, at pp. 238, 239, the figures of creosote and coriander referred to in notes [23] and [27].

[36] The Student's Manual of Natural Philosophy, London, 1838. In the chapter entitled "The Soap-bubble," at p. 545.

upon the surface of the water; the ether must not touch the film, or it will destroy it, while if the ether be taken up by a body that has not a pointed or rounded termination the rings will not be formed, and there will only result a series of concentric figures, depending for form upon that of the end of the substance held over the film. Instead of ether we may employ solution of ammoniacal gas, pyroligneous ether, alcohol, or naphtha. Strong ammonia sometimes breaks up the film and scatters it over the surface of the water."

A turpentine film, which is at first colourless, soon begins to display colour as the film becomes thinner by evaporation—a remark that does not apply to a film formed by a drop of the fixed oils of olive, rape, castor, nut, &c.

Films that exhibit some of the most splendid colours of thin plates may be formed from a drop of balsam of Peru or a turpentine varnish, such as copal varnish, carriage-varnish, gold size, black japan, &c. If the ether be held over one of these coloured films, "we immediately get a series of rings as before, quite independent of the large rings which occupy the surface of the water. That part of the film subjected to the action of the ether no longer forms a portion of the original film, but is subject to the systematic arrangement which the ether produces. A film showing the colours of the 5th, 6th, and 7th orders only is, at that particular part which is subjected to the action of the ethereal vapour, made sufficiently thin to exhibit the rings of the 1st, 2nd, 3rd, and 4th orders, or of the 2nd and 3rd, or of the 3rd and 4th,—all depending on the quantity of ether taken up, the rate of evaporation, and the proximity of the ether to the film—in other words, on the comparative thinness of the film. Should the drop of oil &c. form a lens instead of a film, the ether vapour will drive it with great energy over the surface of the water."

If the water be dusted over with a dry powder, the vapours of ether &c. will powerfully repel the particles. "Turpentine and some of the volatile oils produce a similar effect upon powders; and one volatile oil frequently repels a film formed by another."

The above details refer to the repulsion of films. "A strong and decided attraction may be exhibited by presenting to the film a drop of an acid of low boiling-point, such as nitric or pyroligneous acid. By such means an oil-film of the size of a crown-piece may be reduced to the size of a sixpence; and a film exhibiting colour will have all colour destroyed by the proximity of the acid, whose influence is to thicken the film. Sulphuret of carbon and an aqueous solution of chlorine produce a similar result" (pp. 545–549).

23. In 1841 Sir David Brewster[37] reproduced some of my results, probably without suspecting that he had been anticipated, although a full abstract of them was given in a then popular Journal of wide circulation[38]. Brewster formed a film of oil of laurel on water placed in a black vessel, or on the surface of diluted or real ink. He justly describes the rings produced as being splendid beyond description. He says:—"These thin plates of oil of laurel exhibit some curious phenomena which I believe have not been noticed. If we wet with water, alcohol, or the oil of laurel itself, the extremity of a short piece of wire, such as a large pin, and hold the pin in the hand so that its head may be above and almost touching the film, the film will recede in little waves of circular shape which form a new system of coloured rings; and they become covered with the vapour from the fluid on the head of the pin in such small particles that they reflect no light, and the rings appear to be blackened. By withdrawing the pin the film is restored to its former state. The same effect is produced by heating the pin or the fluid upon it to promote evaporation" (p. 51, note).

24. We now come to the time when Dutrochet published his elaborate essays on what he termed the epipolic force; and as this forms a kind of middle term between the earlier and the more recent history of this wide subject, we may here conveniently pause for a time.

Highgate, N.
7th October, 1873.

XLIX. *On Integrating Differential Equations by Factors and Differentiation, with Applications in the Calculus of Variations.* *By* Professor CHALLIS, *M.A., F.R.S., F.R.A.S.**

THE method of integrating differential equations discussed in this communication depends on the following general theorem, which, as far as I am aware, has not been previously enunciated:—

The differential coefficients $\frac{dy}{dx}, \frac{d^2y}{dx^2}, \frac{d^3y}{dx^3}$, &c. being represented by p, q, r, &c., let F be a function of x, y, p, q, r, &c. of any order and degree, and suppose that we have

$$\psi\left(x, y, p, q, \text{\&c. } \mathrm{F}, \frac{d\mathrm{F}}{dx}, \frac{d^2\mathrm{F}}{dx^2}, \text{\&c.}\right)=0,$$

[37] Phil. Trans. Part I. p. 43.

[38] The Mechanics' Magazine, Sept. 8, 1838, vol. xxix. p. 394.

* Communicated by the Author.