to three of water, as the solvent medium, and to employ the smallest possible quantity of the tincture of iodine as the reagent, and after applying heat for a short time, to set in repose. On spontaneous evaporation or cooling, the optical crystals deposit themselves, and may be recognized by the polarizing microscope, according to the description given of this substance in a former notice to the Society in June last.

You may remember that this proposition was also contained in my paper on iodo-strychnia, which was withdrawn from the Royal Society by me in June last in consequence of a necessity for revision and the completion of experiments requisite to settle the formula of that peculiar substance, and the introduction of an abstract of the literature concerning it.

I remain, &c.,
W. Bird Herapath.

IV. "Dynamical Illustrations of the Magnetic and the Heliçoidal Rotatory Effects of Transparent Bodies on Polarized Light." By Professor W. Thomson, F.R.S. Received May 10, 1856.

The elastic reaction of a homogeneously strained solid has a character essentially devoid of all heliçoidal and of all dipolar asymmetry. Hence the rotation of the plane of polarization of light passing through bodies which either intrinsically possess the heliçoidal property (syrup, oil of turpentine, quartz crystals, &c.), or have the magnetic property induced in them, must be due to elastic reactions dependent on the heterogeneousness of the strain through the space of a wave, or to some heterogeneousness of the luminous motions* dependent on a heterogeneousness of parts of the matter of lineal dimensions not infinitely small in comparison with the wave length. An infinitely homogeneous solid could not possess either of those

* As would be were there different sets of vibrating particles, or were Rankine's important hypothesis true, that the vibrations of luminiferous particles are directly affected by pressure of a surrounding medium in virtue of its inertia.

properties if the stress at any point of it was influenced only by parts of the body touching it; but if the stress at one point is directly influenced by the strain in parts at distances from it finite in comparison with the wave length, the heliçoidal property might exist, and the rotation of the plane of polarization, such as is observed in many liquids and in quartz crystals, could be explained as a direct dynamical consequence of the statical elastic reaction called into play by such a strain as exists in a wave of polarized light. It may, however, be considered more probable that the matter of transparent bodies is really heterogeneous from one part to another of lineal dimensions not infinitely small in comparison with a wave length, than that it is infinitely homogeneous and has the property of exerting finite direct "molecular" force at distances comparable with the wave length: and it is certain that any spiral heterogeneousness of a vibrating medium must, if either right-handed or left-handed spirals predominate, cause a finite rotation of the plane of polarization of all waves of which lengths are not infinitely great multiples of the steps of the structural spirals. Thus a liquid filled homogeneously with spiral fibres, or a solid with spiral passages through it of steps not less than the forty-millionth of an inch, or a crystal with a right-handed or a left-handed geometrical arrangement of parts of some such lineal dimensions as the forty-millionth of an inch, might be certainly expected to cause either a right-handed or a left-handed rotation of ordinary light (the wave length being $\frac{1}{40,000}$th of an inch for homogeneous yellow).

But the magnetic influence on light discovered by Faraday depends on the direction of motion of moving particles. For instance, in a medium possessing it, particles in a straight line parallel to the lines of magnetic force, displaced to a helix round this line as axis, and then projected tangentially with such velocities as to describe circles, will have different velocities according as their motions are round in one direction (the same as the nominal direction of the galvanic current in the magnetizing coil), or in the contrary direction. But the elastic reaction of the medium must be the same for the same displacements, whatever be the velocities and directions of the particles; that is to say, the forces which are balanced by centrifugal force of the circular motions are equal, while the luminiferous motions are unequal. The absolute circular motions being therefore either equal or such as to transmit equal centrifugal forces to the particles initially considered, it follows that the luminiferous motions are only components of the whole motion; and that a less luminiferous component in one direction, compounded with a motion existing in the medium when transmitting no light, gives an equal resultant to that of a greater luminiferous motion in the contrary direction compounded with the same non-luminous motion. I think it is not only impossible to conceive any other than this dynamical explanation of the fact that circularly polarized light transmitted through magnetized glass parallel to the lines of magnetizing force, with the same quality, right-handed always, or left-handed always, is propagated at different rates according as its course is in the direction or is contrary to the direction in which a north magnetic pole is drawn; but I believe it can be demonstrated that no other explanation of that fact is possible. Hence it appears that Faraday's optical discovery affords a demonstration of the reality of Ampère's explanation of the ultimate nature of magnetism; and gives a definition of magnetization in the dynamical theory of heat. The introduction of the principle of moments of momenta ("the conservation of areas") into the mechanical treatment of Mr. Rankine's hypothesis of "molecular vortices," appears to indicate a line perpendicular to the plane of resultant rotatory momentum ("the invariable plane") of the thermal motions as the magnetic axis of a magnetized body, and suggests the resultant moment of momenta of these motions as the definite measure of the "magnetic moment." The explanation of all phenomena of electro-magnetic attraction or repulsion, and of electro-magnetic induction, is to be looked for simply in the inertia and pressure of the matter of which the motions constitute heat. Whether this matter is or is not electricity, whether it is a continuous fluid interpermeating the spaces between molecular nuclei, or is itself molecularly grouped; or whether all matter is continuous, and molecular heterogeneousness consists in finite vortical or other relative motions of contiguous parts of a body; it is impossible to decide, and perhaps in vain to speculate, in the present state of science.

I append the solution of a dynamical problem for the sake of the illustrations it suggests for the two kinds of effect on the plane of polarization referred to above.

Let the two ends of a cord of any length be attached to two *points at the ends of a horizontal arm made to rotate round a vertical axis through its middle point at a constant angular velocity, ω, and let a second cord bearing a weight be attached to the middle of the first cord. The two cords being each perfectly light and flexible, and the weight a material point, it is required to determine its motion when infinitely little disturbed from its position of equilibrium*.*

Let l be the length of the second cord, and m the distance from the weight to the middle point of the arm bearing the first. Let x and y be, at any time t, the rectangular coordinates of the position of the weight, referred to the position of equilibrium O, and two rectangular lines OX, OY, revolving uniformly in a horizontal plane in the same direction, and with the same angular velocity as the bearing arm; then, if we choose OX parallel to this arm, and if the rotation be in the direction with OY preceding OX, we have, for the equations of motion,

$$\frac{d^2x}{dt^2}-\omega^2x-2\omega\frac{dy}{dt}=-\frac{g}{l}x,$$

$$\frac{d^2y}{dt^2}-\omega^2y+2\omega\frac{dx}{dt}=-\frac{g}{m}y.$$

If for brevity we assume

$$\frac{1}{2}\left(\frac{g}{l}+\frac{g}{m}\right)=n^2,\text{ and }\frac{1}{2}\left(\frac{g}{l}-\frac{g}{m}\right)=\lambda^2,$$

we find, by the usual methods, the following solution :—

$$x=\text{A}\cos\{[\omega^2+n^2+(\lambda^4+4n^2\omega^2)^{\frac{1}{2}}]^{\frac{1}{2}}t+\alpha\}$$
$$+\text{B}\cos\{[\omega^2+n^2-(\lambda^4+4n^2\omega^2)^{\frac{1}{2}}]^{\frac{1}{2}}t+\beta\},$$

$$y=-\frac{2\omega^2-\lambda^2+(\lambda^4+4n^2\omega^2)^{\frac{1}{2}}}{2\omega[\omega^2+n^2+(\lambda^4+4n^2\omega^2)^{\frac{1}{2}}]^{\frac{1}{2}}}\text{A}\sin\phi-\frac{2\omega^2-\lambda^2-(\lambda^4+4n^2\omega^2)^{\frac{1}{2}}}{2\omega[\omega^2+n^2-(\lambda^4+4n^2\omega^2)^{\frac{1}{2}}]^{\frac{1}{2}}}\text{B}\sin\psi,$$

where A, α, B, β are arbitrary constants, and ϕ and ψ are used for brevity to denote the arguments of the cosines appearing in the expression for x.

The interpretation of this solution, when ω is taken equal to the component of the earth's angular velocity round a vertical at the

* By means of this arrangement, but without the rotation of the bearing arm, a very beautiful experiment, due to Professor Blackburn, may be made by attaching to the weight a bag of sand discharging its contents through a fine aperture.

locality, affords a full explanation of curious phenomena which have been observed by many in failing to repeat Foucault's admirable pendulum experiment. When the mode of suspension is perfect, we have $\lambda=0$; but in many attempts to obtain Foucault's result, there has been an asymmetry in the mode of attachment of the head of the cord or wire used, or there has been a slight lateral unsteadiness in the bearings of the point of suspension, which has made the observed motion be the same as that expressed by the preceding solution, where λ has some small value either greater than or less than ω, and n has the value $\sqrt{\frac{g}{l}}$. The only case, however, that need be considered as illustrative of the subject of the present communication is that in which ω is very great in comparison with n. To obtain a form of solution readily interpreted in this case, let

$$[\omega^2+n^2+(\lambda^4+4n^2\omega^2)^{\frac{1}{2}}]^{\frac{1}{2}}=\omega+\rho, \qquad [\omega^2+n^2-(\lambda^4+4n^2\omega^2)^{\frac{1}{2}}]^{\frac{1}{2}}=\omega-\sigma,$$

$$\frac{2\omega^2-\lambda^2+(\lambda^4+4n^2\omega^2)^{\frac{1}{2}}}{2\omega[\omega^2+n^2+(\lambda^4+4n^2\omega^2)^{\frac{1}{2}}]^{\frac{1}{2}}}=1+e, \qquad \frac{2\omega^2-\lambda^2-(\lambda^4+4n^2\omega^2)^{\frac{1}{2}}}{2\omega[\omega^2+n^2-(\lambda^4+4n^2\omega^2)^{\frac{1}{2}}]^{\frac{1}{2}}}=1-f.$$

The preceding solution becomes

$$\begin{aligned} x&=\mathrm{A}\cos\{(\omega+\rho)t+\alpha\}+\mathrm{B}\cos\{(\omega-\sigma)t+\beta\} \\ y&=-\mathrm{A}\sin\{(\omega+\rho)t+\alpha\}-\mathrm{B}\sin\{(\omega-\sigma)t+\beta\} \\ &\quad -e\mathrm{A}\sin\{(\omega+\rho)t+\alpha\}+f\mathrm{B}\sin\{(\omega-\sigma)t+\beta\}. \end{aligned}$$

To express the result in terms of coordinates ξ, η, with reference to fixed axes, instead of the revolving axes OX, OY, we may assume

$$\xi=x\cos\omega t-y\sin\omega t, \qquad \eta=x\sin\omega t+y\cos\omega t.$$

Then we have

$$\begin{aligned} \xi&=\mathrm{A}\cos(\rho t+\alpha)+\mathrm{B}\cos(\sigma t-\beta) \\ &\quad +\left(e\mathrm{A}\sin\{(\omega+\rho)t+\alpha\}-f\mathrm{B}\sin\{(\omega-\sigma)t+\beta\}\right)\sin\omega t \\ \eta&=-\mathrm{A}\sin(\sigma t+\alpha)+\mathrm{B}\sin(\sigma t-\beta) \\ &\quad +\left(-e\mathrm{A}\sin\{(\omega+\rho)t+\alpha\}+f\mathrm{B}\sin\{(\omega-\sigma)t+\beta\}\right)\cos\omega t. \end{aligned}$$

When ω is very large, e and f are both very small, and the last two terms of each of these equations become very small periodic terms, of very rapidly recurring periods, indicating a slight tremor in the resultant motion. Neglecting this, and taking $\alpha=0$ and $\beta=0$, as we may do without loss of generality, by properly choosing the axes of reference, and the era of reckoning for the time, we have finally, for an approximate solution of a suitable kind,

$$\xi = \mathrm{A} \cos \rho t + \mathrm{B} \cos \sigma t,$$
$$\eta = -\mathrm{A} \sin \rho t + \mathrm{B} \sin \sigma t.$$

The terms B, in this expression, represent a circular motion of period $\frac{2\pi}{\sigma}$, in the positive direction (that is, from the positive axis of ξ to the positive axis of η), or in the same direction as that of the rotation ω; and the terms A represent a circular motion, of period $\frac{2\pi}{\rho}$, in the contrary direction. Now, ω being very great, ρ and σ are very nearly equal to one another; but ρ is rather less than σ, as the following approximate expressions derived from their exact values expressed above, show:—

$$\rho = n + \frac{1}{8}\frac{\lambda^4}{\omega^2 n} - \frac{1}{8}\frac{\lambda^4}{\omega^3}, \qquad \sigma = n + \frac{1}{8}\frac{\lambda^4}{\omega^2 n} + \frac{1}{8}\frac{\lambda^4}{\omega^3}.$$

Hence the form of solution simply expresses that circular vibrations of the pendulum in the contrary directions have slightly different periods, the shorter, $\frac{2\pi}{\sigma}$, when the motion of the pendulum follows that of the arm supporting it, and the longer, $\frac{2\pi}{\rho}$, when it is in the contrary direction. The equivalent statement, *that if the pendulum be simply drawn aside from its position of equilibrium, and let go without initial velocity, the vertical plane of its motion will rotate slowly at the angular rate* $\frac{1}{2}(\sigma - \rho)$, is expressed most shortly by taking A=B, and reducing the preceding solution to the form

$$\xi = 2\mathrm{A} \cos \varpi t \cos n' t,$$
$$\eta = 2\mathrm{A} \sin \varpi t \cos n' t,$$

where

$$n' = \frac{1}{2}(\sigma + \rho), \text{ or, approximately, } n' = n + \frac{1}{8}\frac{\lambda^4}{\omega^2 n},$$

and

$$\varpi = \frac{1}{2}(\sigma - \rho), \text{ or, approximately, } \varpi = \frac{1}{8}\frac{\lambda^4}{\omega^3}.$$

It is a curious part of the conclusion thus expressed, that the faster the bearing arm is carried round, the slower does the plane of a simple vibration of the pendulum follow it. When the bearing arm is carried round infinitely fast, the plane of a vibration of the pendulum will remain steady, and the period will be n; in other words, the motion of the pendulum will be the same as that of a simple pendulum whose length is $\frac{2}{\frac{1}{e}+\frac{1}{m}}$, or a harmonic mean between the effective lengths in the two principal planes of the actual pendulum.

It is easy to prove from this, that if a long straight rod, or a stretched cord possessing some rigidity, unequally elastic or of unequal dimensions, in different transverse directions, be made to rotate very rapidly round its axis, and if vibrations be maintained in a line at right angles to it through any point, there will result, running along the rod or cord, waves of sensibly rectilineal transverse vibrations, in a plane which in the forward progress of the wave, turns at a uniform rate in the same direction as the rotation of the substance; and that if $\frac{2\pi}{\omega}$ be the period of rotation of the substance, and l and m the lengths of simple pendulums respectively isochronous with the vibrations of two plane waves of the same length, a, in the planes of maximum and of minimum elasticity of the substance, when destitute of rotation, the period of vibration in a wave of the same length in the substance when made to rotate will be

$$\frac{2\pi}{n\left(1+\frac{1}{8}\frac{\lambda^4}{\omega^2 n^2}\right)};$$

and the angle through which the plane of vibration turns, in the propagation through a wave length, will be

$$\frac{\pi}{4}\frac{\lambda^4}{n\omega^3};$$

or the number of wave lengths through which the wave is propagated before its plane turns once round, will be

$$\frac{8n\omega^3}{\lambda^4};$$

where, as before,

$$n=\sqrt{g\cdot\frac{1}{2}\left(\frac{1}{l}+\frac{1}{m}\right)}, \qquad \lambda=\sqrt{g\cdot\frac{1}{2}\left(\frac{1}{l}-\frac{1}{m}\right)},$$

and ω denotes the angular velocity with which the substance is made to rotate.

If next we suppose the rod or cord to be slightly twisted about its axis, so that its directions of maximum and minimum elasticity shall lie on two rectangular heliçoidal surfaces (*heliçoïdes gauches*), and if, while regular rectilineal vibrations are maintained at one point of it with a period to which the wave length corresponding is a very large multiple of the step of the screw, the substance be made to rotate so rapidly as to make the velocity of a point carried along one of the screw surfaces in a line parallel to the axis be equal to the velocity of propagation of a wave, it is clear that a series of sensibly plane waves will run along the rod or cord with no rotation of the plane of vibration. The period of vibration of a particle will be, approximately, the same as before, that is, approximately, equal to $\frac{2\pi}{n}$. Its velocity of propagation will therefore be $\frac{na}{2\pi}$, and, if s be the step of the screws, the period of rotation of the substance, to fulfil the stated condition, must be $\frac{2\pi s}{na}$, or its angular velocity $\frac{na}{s}$. Now it is easily seen that the effects of the rapid rotation, and the effects of the slight twist, may be considered as independently superimposed; and therefore the effect of the twist, with no rotation of the substance, must be to give a rotation to the plane of vibration equal and contrary to that which the rotation of the substance would give if there were no twist. But the effect on the plane of vibration, due to an angular velocity ω, of rotation of the substance, is, as we have seen, one turn in $\frac{8n\omega^3}{\lambda^4}$ wave lengths; and therefore it is one turn in $8\frac{n^4}{\lambda^4}\frac{a^3}{s^3}$ wave lengths when the angular velocity is $\frac{na}{s}$. Hence the effect of a twist amounting to one turn in a length, s, a small fraction of the wave length, is to cause the plane of vibration of a wave to turn round with the forward propagation of the wave, at the rate of one turn in $8\frac{n^4}{\lambda^4}\frac{a^3}{s^3}$ wave lengths, in the same direction as that of a point kept on one of the screw surfaces.

From these illustrations it is easy to see in an infinite variety of ways how to make structures, homogeneous when considered on a large enough scale, which (1) with certain rotatory motions of component parts having, in portions large enough to be sensibly homogeneous, resultant axes of momenta arranged like lines of magnetic force, *shall have the dynamical property by which the optical phenomena of transparent bodies in the magnetic field are explained*; (2) with spiral arrangements of component parts, having axes all ranged parallel to a fixed line, *shall have the axial rotatory property corresponding to that of quartz crystal*; and (3) with spiral arrangements of component groups, having axes totally unarranged, *shall have the isotropic rotatory property possessed by solutions of sugar and tartaric acid, by oil of turpentine, and many other liquids.*

V. "Researches on the Action of Sulphuric Acid upon the Amides and Nitriles, with Remarks on the Conjugate Sulpho-acids." By GEORGE B. BUCKTON, Esq., F.L.S., F.C.S., and A. W. HOFMANN, Ph.D., F.R.S. Received May 13, 1856.

(Abstract.)

Since we had the honour of addressing the Royal Society upon the subject of the behaviour of acetamide and acetonitrile towards sulphuric acid, we have completed our experiments upon the amides and nitriles, and extended our researches to other groups of bodies. The results of these additional inquiries we now beg to present in the form of a second short summary, the analytical details and the more extended description of the new compounds being given in the complete memoir, which, at the same time, we have the honour of submitting to the Society.

Before proceeding, however, to give an account of our new compounds, it may be desirable to state that several considerations, suggested by the progress of our inquiry, have induced us finally to adopt the name of Disulphometholic acid instead of the provisional term Tetrasulphomethylic acid under which we have described, in our first communication, the new acid generated by the action of sulphuric acid upon acetamide and acetonitrile.

ETHYL-SERIES.

Action of Sulphuric Acid upon Propionitrile.

Considerable difficulty is experienced in preparing this nitrile in a