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"Nec aranearum sane textus ideo melior quia ex se fila gignunt, nec noster vilior quia ex alienis libamus ut apes." JUST. LIPS. *Polit.* lib. i. cap. 1. Not.

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"Meditationis est perscrutari occulta; contemplationis est admirari perspicua . . . . . Admiratio generat quæstionem, quæstio investigationem, investigatio inventionem."—*Hugo de S. Victore.*



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Erratum in Mr. FARADAY's paper, vol. xxxi.

Page 416, line 12 from top, *for* equally *read* axially.

Erratum in Mr. J. Cockle's paper, vol. xxxii.

Page 363, line 15 from the bottom, *for* 64 *read* 62; *for* 83 *read* 77; and *for* 84 *read* 82.

distinguished philosophers as Wollaston, Young, and Sir William and Sir John Herschel, I feel assured that my Analysis of the Spectrum will be confirmed by future observers who may repeat my experiments with the same care with which they were made, and without any prejudice in favour of their own speculations.

St. Leonard's College, St. Andrews,
May 8, 1848.

LXV. *On the Velocity of Sound, in Reply to the Remarks of the* Astronomer Royal. *By the* Rev. J. Challis, *M.A., F.R.A.S., Plumian Professor of Astronomy in the University of Cambridge*.*

THE mathematical investigation of the velocity of sound which I gave in the Philosophical Magazine for last April, has elicited Remarks from the Astronomer Royal, on which I must make a few observations, before I proceed to defend the principles of my investigation against the arguments which the Astronomer Royal has brought forward.

The not giving a reason for attaching a negative sign to b^2, was an omission on my part, which Mr. Airy has supplied exactly according to my views.

After allowing that the constant b^2 is admissible and may be introduced for trial, Mr. Airy adds, "It is accordingly introduced and tried, and we immediately perceive that if it has a value different from zero, the result of non-divergence of vibrations cannot be obtained. Most reasoners would conclude, either that such a result is not legitimately to be expected, or that a last trial should be made by supposing $b^2=0$." The result of non-divergence of vibrations is obtained by that part of my reasoning which terminates at line 8 of page 280, in which Mr. Airy "sees no ground for questioning any important step." I am not, therefore, chargeable with acting differently from "most reasoners" in not coming to the conclusion that such a result is not to be expected. Respecting the case in which $b^2=0$, which is that of plane-waves, I propose to speak shortly.

In the next sentence Mr. Airy goes on to say, "Instead of this, Professor Challis has recourse to *another* equation extracted from *another* memoir, and not demonstrated here, which he considers more accurate than his equation (4.), and he then uses this new equation in conjunction with equation (3.), and thus obtains the startling results to which I have alluded."

* Communicated by the Author.

The results alluded to, viz. the non-divergence of the vibrations, and a greater velocity of propagation than the value a, are obtained by the part of the reasoning terminating, as already specified, in page 280, *before* the introduction of the new equation, which is first mentioned towards the bottom of page 281. This equation in no way applies, unless the reasoning be carried beyond the first order of approximation.

I admit that there is inconvenience in referring to a separate investigation, contained in another work, and undertaken for a different purpose; and for this reason, as well as for another which I shall mention hereafter, I will omit all consideration of the equation against the introduction of which Mr. Airy protests. If, however, the results derived from the approximate equations (3.) and (4.) be liable to objection because those equations are approximate, it will be proper to investigate and to use the corresponding exact equations, which I am prepared to do in the pages of this Journal. The course of the argument will thus be clear, and equations (3.) and (4.) will be employed together as "fairly and honestly" as Mr. Airy can desire.

I now maintain that I have proved, supposing b^2, or e, to have a value different from zero, that the waves are non-divergent, and that the velocity of propagation is greater than a. At the bottom of page 279 of my paper, the following equation is obtained by reasoning which has not been objected to,

$$\varphi = m \cos \frac{2\pi}{\lambda}\left(z - at\sqrt{1+\frac{e\lambda^2}{\pi^2}} + c'\right);$$

from which, since

$$u = \varphi\frac{df}{dx}, \quad v = \varphi\frac{df}{dy}, \quad w = f\frac{d\varphi}{dz}, \text{ and } as = -\frac{f}{a}\cdot\frac{d\varphi}{dt},$$

it follows that

$$u = m\frac{df}{dx}\cos\frac{2\pi}{\lambda}\left(z - at\sqrt{1+\frac{e\lambda^2}{\pi^2}} + c'\right)$$

$$v = m\frac{df}{dy}\cos\frac{2\pi}{\lambda}\left(z - at\sqrt{1+\frac{e\lambda^2}{\pi^2}} + c'\right)$$

$$w = -\frac{2\pi mf}{\lambda}\sin\frac{2\pi}{\lambda}\left(z - at\sqrt{1+\frac{e\lambda^2}{\pi^2}} + c'\right)$$

$$as = -\frac{2\pi mf}{\lambda}\sqrt{1+\frac{e\lambda^2}{\pi^2}}\sin\frac{2\pi}{\lambda}\left(z - at\sqrt{1+\frac{e\lambda^2}{\pi^2}} + c'\right).$$

As f is a function of x and y only, these equations show that the velocity and density at all points of any *plane* perpendi-

cular to the axis of z, are propagated unaltered in a direction parallel to that axis with the uniform velocity $a\sqrt{1+\frac{e\lambda^2}{\pi^2}}$; in other words, the waves are non-divergent, and the velocity of propagation is greater than a.

I shall next maintain that e must have a value different from zero.

In p. 277 I have come to a conclusion which has not been disputed, and which is expressed in these words: "It is thus shown that the condition that $udx+vdy+wdz$ be an exact differential, must be satisfied in a manner which shall equally apply whatever be the original disturbance of the fluid." The supposition that u, v, and w are functions of the distance from a fixed plane, is one of a general nature, by which $udx+vdy+wdz$ becomes an exact differential, and which, consequently, is as much entitled to consideration as that which I have adopted. This is, in fact, the case of plane-waves, and coincides with the supposition that $b^2=0$. If the motion be parallel to the axis of z, $w=\frac{d\varphi}{dz}$, and the exact equation applicable to plane-waves is

$$\frac{d^2\varphi}{dt^2}-\left(a^2-\frac{d\varphi^2}{dz^2}\right)\frac{d^2\varphi}{dz^2}+2\frac{d\varphi}{dz}\cdot\frac{d^2\varphi}{dz\,dt}=0, \quad . \quad . \quad \text{(A.)}$$

which, as is known, is satisfied by the equation

$$w=f(z-(a+w)t).$$

The function f being quite arbitrary, we may give it a particular form. Let, therefore,

$$w=m\sin\frac{2\pi}{\lambda}(z-(a+w)t).$$

This equation shows that at any time t_1 we shall have $w=0$ at points on the axis of z, for which

$$z-(a+w)t_1=\frac{n\lambda}{2},$$

or

$$z=at_1+\frac{n\lambda}{2}.$$

At the same time w will have the value $\pm m$ at points of the axis for which

$$z-(a+m)t_1=\left(\frac{n}{2}-\frac{1}{4}\right)\lambda,$$

or

$$z=at_1+\frac{n\lambda}{2}+mt_1-\frac{\lambda}{4}.$$

Here it is observable that no relation exists between the points of no velocity and the points of maximum velocity. As m, t_1, and λ are arbitrary constants, we may even have

$$mt_1 - \frac{\lambda}{4} = 0,$$

in which case the points of no velocity are also points of maximum velocity. This is a manifest absurdity. No step, however, of the reasoning by which this result has been obtained can be controverted. What then is the meaning of it? Clearly the analysis rejects the supposition of plane-waves, by giving an integral which admits of no physical interpretation. Plane-waves are thus shown to be physically impossible.

Another way in which $udx+vdy+wdz$ becomes an exact differential, is to suppose the velocity to be a function of the distance from a fixed centre, that is, to suppose the waves to be spherical. In this case an exact integral is not obtainable. But it may be shown by an integral of the known approximate equation

$$\frac{d^2.r\varphi}{dt^2} = a^2.\frac{d^2.r\varphi}{dr^2},$$

that the analysis rejects this supposition also. The equation is satisfied if $r\varphi = f(r-at)$; whence

$$as = -\frac{d\varphi}{adt} = \frac{f'(r-at)}{r}.$$

We may therefore have

$$as = \frac{m}{r}\sin\frac{2\pi}{\lambda}(r-at);$$

and putting $r-at=c$, it follows that a given phase of the wave is carried with the uniform velocity a, the condensation (s) varying inversely as the distance r. This conclusion is generally adopted: but a very simple application of the principle of constancy of mass will prove that it is false. For if σ_1, σ_2 be the condensations in spherical shells of indefinitely small thickness α, at corresponding parts of the same wave when at different distances r_1, r_2, the above-named principle requires that $2\pi r^2{}_1\sigma_1\alpha$ should be equal to $2\pi r^2{}_2\sigma_2\alpha$, so that $r^2{}_1\sigma_1 = r^2{}_2\sigma_2$, and the condensation varies inversely as the *square* of the distance. The inevitable conclusion from this reasoning is, that the analysis rejects the supposition of spherical waves.

There remains the supposition which I have adopted to satisfy the condition that $udx+vdy+wdz$ be an exact differential ($d\psi$), viz. that ψ is the product of a function of x and y,

and a function of z and t; according to which, if b^2 have a value different from zero, the waves are neither plane nor spherical. No incompatibility here presents itself, at least, as far as to the first order of approximation. We may even explain, on this hypothesis, the contradictions met with in the other two. For supposing non-divergence to be the normal condition of waves, a plane-wave, or a spherical wave, is possible only when it is compounded of an unlimited number of non-diverging waves: and in the case of a spherical wave so compounded, the variation of condensation is inversely as the *square* of the distance from the centre, as we have shown that it ought to be.

The argument respecting this third supposition is evidently incomplete, unless it be proved that no incompatibility is met with when the reasoning is conducted by exact equations. I propose in another communication to consider this part of the subject, which requires a mode of treatment different from that in my paper on Luminous Rays (Camb. Phil. Trans., vol. viii. part 3, p. 365). I have there made use of equation (A.), not being at the time aware of what is the true interpretation of its integral. Consequently the equation which Mr. Airy has objected to, though not upon a consideration of its merits, and which I have avoided introducing into this communication, is as yet unsupported.

What I have said above will suffice for an answer to Mr. Airy's arguments in paragraphs (β.) and (γ.). In the former, the motion results from two systems of plane-waves propagated in directions making an angle whose cosine is $\frac{n-\frac{e}{n}}{n+\frac{e}{n}}$ with the axis of z on opposite sides, and therefore diverging from that axis. In the latter, the motion results from systems of plane-waves also. I have nothing to urge against the mathematical reasoning: my sole answer is, that plane-waves are physically impossible.

The difficulty respecting the augmentation of the velocity of sound by the development of heat, cannot be so summarily disposed of as Mr. Airy appears to imagine. I shall perhaps succeed better in conveying my meaning by using symbols. If θ be the temperature where the pressure is p and density ρ, and θ_1 the temperature in the quiescent state of the fluid, we have, by a known equation,

$$p = a^2\rho(1+\alpha(\theta-\theta_1)).$$

Hence

$$\frac{d^2z}{dt^2} = -\frac{dp}{\rho dz} = -\frac{a^2 d\rho}{\rho dz} - a^2\alpha(\theta - \theta_1)\frac{d\rho}{\rho dz} - a^2\alpha\frac{d\theta}{dz}.$$

The usual theory explains how the third term of the right-hand side of this equation may be in a given ratio to the first; but my difficulty is to conceive how the same can be the case also with the *second* term, since it changes sign with the change of sign of $\theta - \theta_1$.

Cambridge Observatory,
May 19, 1848.

LXVI. *On some New Lines in the Solar Spectrum.* *By* Professor Elie Wartmann*.

THE study of the spectrum has long occupied the attention of philosophers. As early as 1802 Wollaston made known the existence of some obscure rays perpendicular to its length. Twelve years later Fraunhofer again discovered them, and gave an analysis of them, which is a masterpiece of patience and skill. We know that he used these lines as extremely valuable marks for the construction of achromatic refractive systems. Having been sought for in spectra produced with different sources of illumination, and with prisms and absorbing media of various kind, they have likewise become of considerable interest, as affording geometricians an opportunity of discussing the comparative merits of the theories of light.

In 1840 I made a series of experiments on the spectrum with an excellent prism of flint-glass, the last cut by the illustrious Bavarian optician. These experiments led me to several results, which I communicated to my pupils and showed to some amateurs; but I desired to increase their number before publishing them in a connected form. At present, not having the apparatus which I employed any longer at my disposal, it is useless to make further delay. Notwithstanding their imperfection, I may be allowed to make known some details that I believe to be new. I extract them briefly from the note-book of my laboratory, dated April and May 1841.

"The lecture-room of the Academy of Lausanne having been darkened, a beam of solar light, thrown by a tinned or blackened mirror, was made to pass through a vertical slit of $0^{mm}{\cdot}8$ in width. This beam is refracted in Fraunhofer's prism fixed in a vertical position at the distance of eight metres. Directly behind this instrument is placed an achromatic theodolite of $0^{m}{\cdot}04$ aperture, made at Aarau, or a comet seeker

* Communicated by the Author.