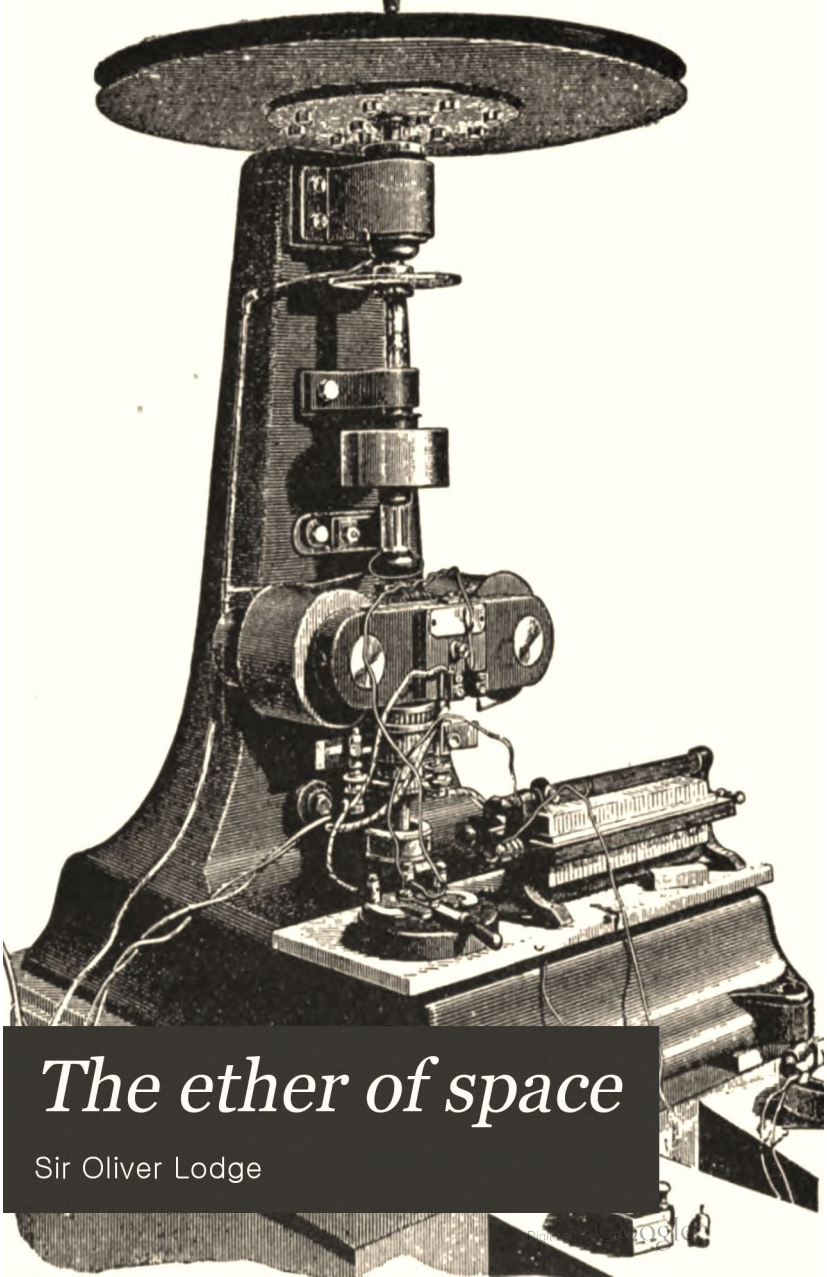
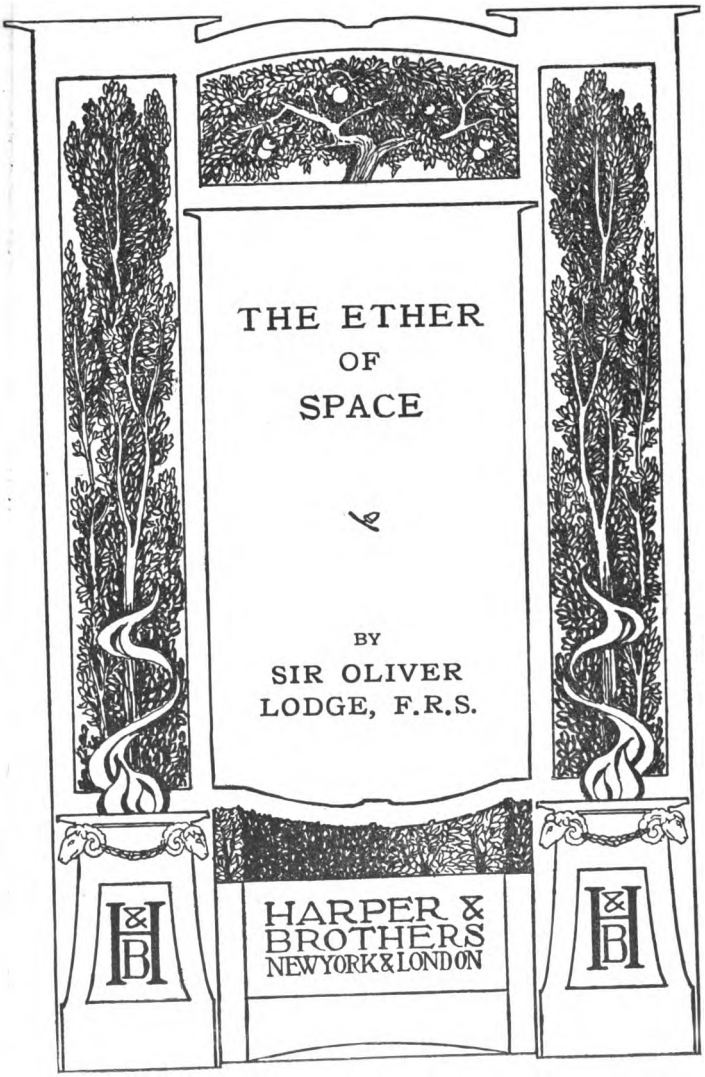


The ether of space

Sir Oliver Lodge



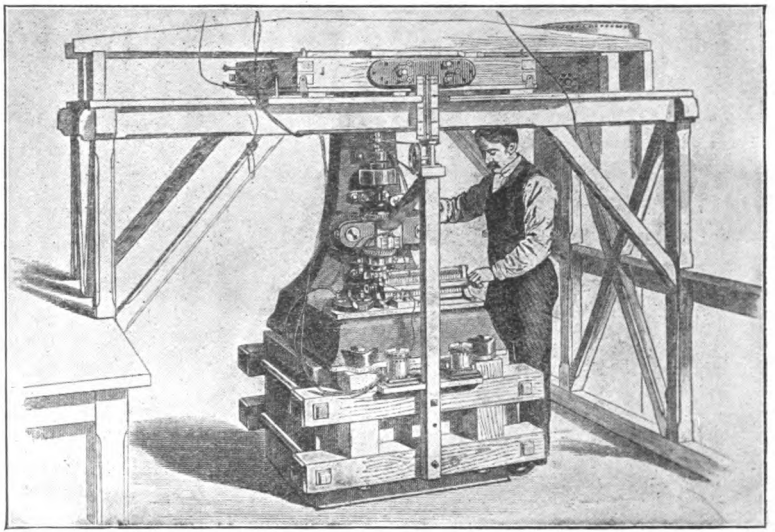


FIG. 15.—View of Ether machine complete and in action.
(See Chapter V, and Figs. 12 and 13.)

THE ETHER OF SPACE

BY

R OLIVER LODGE, F.R.S.

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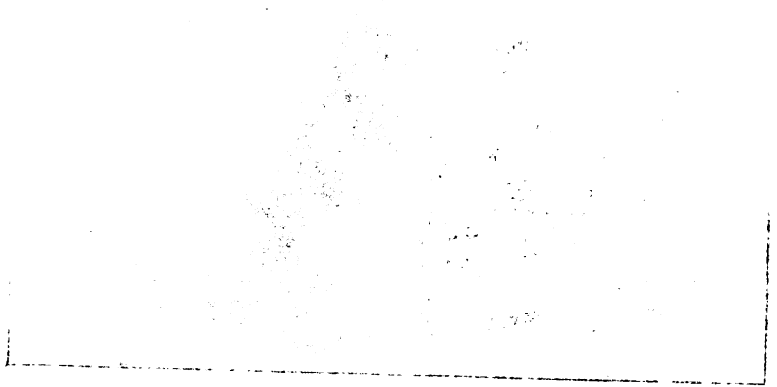

FIG. 15.—View of Fiber machine complete and in action.
(See Chapter V, and Figs. [illegible])

THE ETHER OF SPACE

BY

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INTRODUCTION

To lead up to and justify the idea of the reality and substantiality, and vast though as yet largely unrecognized importance, of the Ether of Space, the following chapters have been written. Some of them represent the expanded notes of lectures which have been given in various places —chiefly the Royal Institution; while the first chapter represents a lecture before the Ashmolean Society of the University of Oxford in June, 1889. One chapter (*viz.*, Chap. II) has already been printed as part of an appendix to the third edition of *Modern Views of Electricity*, as well as in the *Fortnightly* and *North American Reviews;* but no other chapters have yet been published, though parts appear in more elaborate form in Proceedings or Transactions of learned societies.

The problem of the constitution of the Ether, and of the way in which portions of it are modified to form the atoms or other constituent units of ordinary matter, has not yet been solved. Much work has been done in this direction by various mathematicians, but much more remains to be done. And until it is done, some scepticism is reasonable—perhaps laudable. Meanwhile there are few physicists who will

THE ETHER OF SPACE

I

THE LUMINIFEROUS ETHER AND THE MODERN THEORY OF LIGHT

THE oldest and best known function for an ether is the conveyance of light, and hence the name "luminiferous" was applied to it; though at the present day many more functions are known, and more will almost certainly be discovered.

To begin with, it is best to learn what we can concerning the properties of the Interstellar Ether from the phenomena of Light.

For now well-nigh a century we have had a wave theory of light; and a wave theory of light is quite certainly true. It is directly demonstrable that light consists of waves of some kind or other, and that these waves travel at a certain well-known velocity, achieving a distance equal to seven times the circumference of the earth every second; from New York to London

to be able to store up energy and effect recoil; inertia, in order to enable the disturbed substance to overshoot the mark and oscillate beyond its place of equilibrium to and fro. Any medium possessing these two properties can transmit waves, and unless a medium possesses these properties in some form or other, or some equivalent for them, it may be said with moderate security to be incompetent to transmit waves. But if we make this latter statement, one must be prepared to extend to the terms elasticity and inertia their very largest and broadest signification, so as to include any possible kind of restoring force, and any possible kind of persistence of motion, respectively.

These matters may be illustrated in many ways, but perhaps a simple loaded lath, or spring, in a vise will serve well enough. Pull it to one side, and its elasticity tends to make it recoil; let it go, and its inertia causes it to overshoot its normal position. That is what inertia is: power of overshooting a mark, or, more accurately, power of moving for a time even against driving force—power to rush up hill. Both causes together make it swing to and fro till its energy is exhausted. This is a disturbance simply periodic in time. A regular series of such springs, set at equal intervals and started vibrating at regular intervals of time one after the other, would be periodic in space too; and

so they would, in disconnected fashion, typify a wave. A series of pendulums will do just as well, and if set swinging in orderly fashion will furnish at once an example and an appearance of wave motion which the most casual observer must recognise as such. The row of springs obviously possesses elasticity and inertia; and any wave-transmitting medium must similarly possess some form of elasticity and some form of inertia.

But now proceed to ask what is this Ether which in the case of light is thus vibrating? What corresponds to the elastic displacement and recoil of the spring or pendulum? What corresponds to the inertia whereby it overshoots its mark? Do we know these properties in the ether in any other way?

The answer, given first by Clerk-Maxwell, and now reiterated and insisted on by experiments performed in every important laboratory in the world, is:—

> The elastic displacement corresponds to electrostatic charge—roughly speaking, to electricity.
>
> The inertia corresponds to magnetism.

This is the basis of the modern electromagnetic theory of light.

Let me attempt to illustrate the meaning of this statement, by reviewing some fundamental electrical facts in the light of these analogies:—

A violent flash occurs if the stoppage is sudden enough—a flash which means the bursting of the insulating air partition by the accumulated electromagnetic momentum. The scientific name for this electrical inertia is "self-induction."

Briefly we may say that nearly all electromagnetic experiments illustrate the fact of etherial inertia.

Now return to consider what happens when a charged conductor (say a Leyden jar) is discharged. The recoil of the strained dielectric causes a current, the inertia of this current causes it to overshoot the mark, and for an instant the charge of the jar is reversed; the current now flows backward and charges the jar up as at first; back again flows the current; and so on, charging and reversing the charge, with rapid oscillations, until the energy is all dissipated into heat. The operation is precisely analogous to the release of a strained spring, or to the plucking of a stretched string.

But the discharging body, thus thrown into strong electrical vibration, is imbedded in the all-pervading ether; and we have just seen that the ether possesses the two properties requisite for the generation and transmission of waves—*viz.*, elasticity, and inertia or density; hence, just as a tuning-fork vibrating in air excites aerial waves, or sound, so a discharging Leyden jar in ether excites etherial waves, or light.

Etherial waves can, therefore, be actually produced by direct electrical means. I discharge here a jar, and the room is for an instant filled with light. With light, I say, though you can see nothing. You can see and hear the spark, indeed; but that is a mere secondary disturbance we can for the present ignore—I do not mean any secondary disturbance. I mean the true etherial waves emitted by the electric oscillation going on in the neighbourhood of the recoiling dielectric. You pull aside the prong of a tuning-fork and let it go: vibration follows and sound is produced. You charge a Leyden jar and let it discharge: vibration follows and light is excited.

It is light, just as good as any other light. It travels at the same pace, it is reflected and refracted according to the same laws; every experiment known to optics can be performed with this etherial radiation electrically produced—and yet you cannot see it. Why not? For no fault of the light; the fault (if there be a fault) is in the eye. The retina is incompetent to respond to these vibrations—they are too slow. The vibrations set up when this large jar is discharged are from a hundred thousand to a million per second, but that is too slow for the retina. It responds only to vibrations between 400 billion and 700 billion per second. The vibrations are too quick for the ear, which re-

sponds only to vibrations between 40 and 40,000 per second. Between the highest audible and the lowest visible vibrations there has been hitherto a great gap, which these electric oscillations go far to fill up. There has been a great gap simply because we have no intermediate sense organ to detect rates of vibration between 40,000 and 400,000,000,000,000 per second. It was therefore an unexplored territory. Waves have been there all the time in any quantity, but we have not thought about them nor attended to them.

It happens that I have myself succeeded in getting electric oscillations so slow as to be audible—the lowest I had got in 1889 were 125 per second, and for some way above this the sparks emit a musical note; but no one has yet succeeded in directly making electric oscillations which are visible—though indirectly everyone does it when they light a candle.

It is easy, however, to have an electric oscillator which vibrates 300 million times a second, and emits etherial waves a yard long. The whole range of vibrations between musical tones and some thousand million per second is now filled up.

With the large condensers and self-inductances employed in modern cable telegraphy, it is easy to get a series of beautifully regular and gradually damped electric oscillations, with a period of

two or three seconds, recorded by an ordinary signalling instrument or siphon recorder.

These electromagnetic waves in space have been known on the side of theory ever since 1865, but interest in them was immensely quickened by the discovery of a receiver or detector for them. The great though simple discovery by Hertz, in 1888, of an "electric eye," as Lord Kelvin called it, made experiments on these waves for the first time easy or even possible. From that time onward we possessed a sort of artificial sense organ for their appreciation — an electric arrangement which can virtually "see" these intermediate rates of vibration.

Since then Branly discovered that metallic powder could be used as an extraordinarily sensitive detector; and on the basis of this discovery, the "coherer" was employed by me for distant signalling by means of electric or etheric waves, until now when many other detectors are available in the various systems of wireless telegraphy.

With these Hertzian waves all manner of optical experiments can be performed. They can be reflected by plain sheets of metal, concentrated by parabolic reflectors, refracted by prisms, and concentrated by lenses. I have made, for instance, a large lens of pitch, weighing over three hundredweight, for concentrating

them to a focus.[1] They can be made to show the phenomenon of interference, and thus have their wave-length accurately measured. They are stopped by all conductors, and transmitted by all insulators. Metals are opaque; but even imperfect insulators, such as wood or stone, are strikingly transparent; and waves may be received in one room from a source in another, the door between the two being shut.

The real nature of metallic opacity and of transparency has long been clear in Maxwell's theory of light, and these electrically produced waves only illustrate and bring home the well-known facts. The experiments of Hertz are, in fact, the apotheosis of Maxwell's theory.

Thus, then, in every way, Clerk-Maxwell's brilliant perception or mathematical deduction, in 1865, of the real nature of light is abundantly justified; and for the first time we have a true theory of light—no longer based upon analogy with sound, nor upon the supposed properties of some hypothetical jelly or elastic solid, but capable of being treated upon a substantial basis of its own, in alliance with the sciences of Electricity and of Magnetism.

Light is an electromagnetic disturbance of the ether. Optics is a branch of electricity. Out-

[1] See Lodge and Howard, *Philosophical Magazine* for July, 1889. See also *Phil. Mag.*, August, 1888, page 229.

and best worked department of Physical Science —*viz.*, that explored by the Newtonian method. Though in truth there is every reason to suppose that we should have had Newton with us in these modern developments.

There is, I believe, a general tendency to underrate the certainty of some of the convictions to which natural philosophers have gradually, in the course of their study of nature, been impelled; more especially when those convictions have reference to something intangible and occult. The existence of a continuous space-filling medium, for instance, is probably regarded by most educated people as a more or less fanciful hypothesis, a figment of the scientific imagination—a mode of collating and welding together a certain number of observed facts, but not in any physical sense a reality, as water and air are realities.

I am speaking purely physically. There may be another point of view from which all material reality can be denied, but with those questions physics proper has nothing to do; it accepts the evidence of the senses, regarding them as the tools or instruments wherewith man may hope to understand one definite aspect of the universe; and it leaves to philosophers, equipped from a different armory, the other aspects which the material universe may—nay, must—possess.

By a physical "explanation" is meant a clear

statement of a fact or law in terms of something with which daily life has made us familiar. We are all chiefly familiar, from our youth up, with two apparently simple things, *motion* and *force*. We have a direct sense for both these things. We do not understand them in any deep way, probably we do not understand them at all, but we are accustomed to them. Motion and force are our primary objects of experience and consciousness; and in terms of them all other less familiar occurrences may conceivably be stated and grasped. Whenever a thing can be so clearly and definitely stated, it is said to be explained, or understood; we are said to have "a dynamical theory" of it. Anything short of this may be a provisional or partial theory, an explanation of the less known in terms of the more known, but Motion and Force are postulated in physics as the completely known: and no attempt is made to press the terms of an explanation further than that. A dynamical theory is recognized as being at once necessary and sufficient.

Now, it must be admitted at once that of very few things have we at present such a dynamical explanation. We have no such explanation of matter, for instance, or of gravitation, or of electricity, or ether, or light. It is always conceivable that of some such things no purely dynamical explanation will ever be forthcoming,

cannot find a trace of mechanical connection between matter and ether, of the kind known as viscosity or friction.

Why, then, if it is so impalpable, should we assert its existence? May it not be a mere fanciful speculation, to be extruded from physics as soon as possible? If we were limited for our knowledge of matter to our sense of touch, the question would never even have presented itself; we should have been simply ignorant of the ether, as ignorant as we are of any life or mind in the universe not associated with some kind of material body. But our senses have attained a higher stage of development than that. We are conscious of matter by means other than its resisting force. Matter acts on one small portion of our body in a totally different way, and we are said to *taste* it. Even from a distance it is able to fling off small particles of itself sufficient to affect another delicate sense. Or again, if it is vibrating with an appropriate frequency, another part of our body responds; and the universe is discovered to be not silent but eloquent to those who have ears to hear. Are there any more discoveries to be made? Yes; and already some have been made. All the senses hitherto mentioned speak to us of the presence of ordinary matter—gross matter, as it is sometimes called—though when appealing to our sense of smell, and more especially to a dog's sense of

ethereal disturbances themselves, but other disturbances excited by them in our tissues, that our heat nerves feel; and the same assertion can be made for our more highly developed and specialised sight nerves. All nerves must feel what is occurring next door to them, and can directly feel nothing else; but the "radiation," the cause which excited these disturbances, travelled through the ether—not through any otherwise known material substance.

It should be a commonplace to rehearse how we know this. Briefly, thus: Radiation conspicuously comes to us from the sun. If any free or ordinary matter exists in the intervening space, it must be an exceedingly rare gas. In other words, it must consist of scattered particles of matter, some big enough to be called lumps, some so small as to be merely atoms, but each with a considerable gap between it and its neighbor. Such isolated particles are absolutely incompetent to transmit light. And, parenthentically, I may say that no form of ordinary matter, solid, liquid, or gaseous, is competent to transmit a thing travelling with the speed and subject to the known laws of light. For the conveyance of radiation or light all ordinary matter is not only incompetent, but hopelessly and absurdly incompetent. If this radiation is a thing transmitted by anything at all, it must be by something *sui generis*.

But it is transmitted; for it takes time on the journey, travelling at a well-known and definite speed; and it is a quivering or periodic disturbance, falling under the general category of wave-motion. Nothing is more certain than that. No physicist disputes it. Newton himself, who is commonly and truly asserted to have promulgated a rival theory, felt the necessity of an ethereal medium, and knew that light consisted essentially of waves.

Sight.

A small digression here, to avoid any possible confusion due to the fact that I have purposely associated together temperature nerves and sight nerves. They are admittedly not the same, but they are alike in this, that they both afford evidence of radiation; and, were we blind, we might still know a good deal about the sun, and if our temperature nerves were immensely increased in delicacy (not all over, for that would be merely painful, but in some protected region), we might even learn about the moon, planets, and stars. In fact, an eye, consisting of a pupil (preferably a lens) and a sunken cavity lined with a surface sensitive to heat, could readily be imagined, and might be somewhat singularly effective. It would be more than a light recorder; it could detect all the ethereal quiverings caused

Except for an occasional volcano, or a flash of lightning, only gigantic bodies like the sun and stars have energy enough to produce these higher flute-like notes; and they do it by sheer main force and violence—the violence of their gravitative energy—producing not only these, but every other kind of radiation also. Glow-worms, so far as I know, alone have learned the secret of emitting the physiologically useful waves, and none others.

Why these waves are physiologically useful—why they are what is called "light," while other kinds of radiation are "dark," is a question to be asked, but, at present, only tentatively answered. The answer must ultimately be given by the Physiologist; for the distinction between light and non-light can only be stated in terms of the eye, and its peculiar specialised sensitiveness; but a hint may be given him by the Physicist. The ethereal waves which affect the eye and the photographic plate are of a size not wholly incomparable with that of the atoms of matter. When a physical phenomenon is concerned with the ultimate atoms of matter, it is often relegated at present to the field of knowledge summarized under the head of Chemistry. Sight is probably a chemical sense. The retina may contain complex aggregations of atoms, shaken asunder by the incident light vibrations, and rapidly built up again by the living tissues

that closely. Not yet do we fully realise what we are doing. Not yet have we any dynamical theory of electric currents, of static charges, and of magnetism. Not yet, indeed, have we any dynamical theory of light. In fact, the ether has not yet been brought under the domain of simple mechanics—it has not yet been reduced to motion and force: and that probably because the *force* aspect of it has been so singularly elusive that it is a question whether we ought to think of it as material at all. No, it is apart from mechanics at present. Conceivably it may remain apart; and our first additional category, wherewith the foundations of physics must some day be enlarged, may turn out to be an ethereal one. And some such inclusion may have to be made before we can attempt to annex vital or mental processes. Perhaps they will all come in together.

Howsoever these things be, this is the kind of meaning lurking in the phrase that we do not yet know what electricity or what the ether is. We have as yet no dynamical explanation of either of them; but the past century has taught us what seems to their student an overwhelming quantity of facts about them. And when the present century, or the century after, lets us deeper into their secrets, and into the secrets of some other phenomena now in course of being rationally investigated, I feel as if it would be

no merely material prospect that will be opening on our view, but some glimpse into a region of the universe which Science has never entered yet, but which has been sought from far, and perhaps blindly apprehended, by painter and poet, by philosopher and saint.

Note on the Spelling of Ethereal.

The usual word "ethereal" suggests something unsubstantial, and is so used in poetry; but for the prosaic treatment of Physics it is unsuitable, and etheric has occasionally been used instead. No just derivation can be given for such an adjective, however; and I have been accustomed simply to spell etherial with an *i* when no poetic meaning was intended. This alternative spelling is not incorrect; but Milton uses the variant "ethereous," in a sense suggestive of something strong and substantial (*Par. Lost*, vi, 473). Either word, therefore, can be employed to replace "ethereal" in physics: and in succeeding chapters one or other of these is for the most part employed.

of a star is shifted from its true place by an angle $\frac{1}{10,000}$th of a "radian,"[1] or about 20 seconds of arc.

This is called Astronomical Aberration, and is extremely well known. But a number of other problems open out in connection with it, and on these it is desirable to enter into detail. For if the ether is stationary while the earth is flying through it—at a speed vastly faster than any cannon-ball, as much faster than a cannon-ball as an express train is faster than a saunter on foot—it is for all practical purposes the same as if the earth were stationary and the ether streaming past it with this immense velocity in the opposite direction. And some consequence of such a drift might at first sight certainly be expected. It might, for instance, seem doubtful whether terrestrial surveying operations can be conducted, with the extreme accuracy expected of them, without some allowance for the violent rush of the light-conveying medium past and through the theodolite of the observer.

Let us therefore consider the whole subject further.

Aberration.

Everybody knows that to shoot a bird on the wing you must aim in front of it. Every one will

[1] *Radian* is the name given by Prof. James Thomson to a unit angle of circular measure, an angle whose arc equals its radius, or about 57°.

direction of the observer's notion. This is common aberration. It is the simplest thing in the world. The easiest illustration of it is that when you run through a vertical shower, you tilt your umbrella forward; or, if you have not got one, the drops hit you in the face; more accurately, your face as you run forward hits the drops. So the shower appears to come from a cloud ahead of you, instead of from one overhead.

We have thus three motions to consider, that of the source, of the receiver, and of the medium; and, of these, only motion of receiver is able to cause an aberrational error in fixing the position of the source.

So far we have attended to the case of projectiles, with the object of leading up to light. But light does not consist of projectiles, it consists of waves; and with waves matters are a little different. Waves crawl through a medium at their own definite pace; they cannot be *flung* forward or sideways by a moving source; they do not move by reason of an initial momentum which they are gradually expending, as shots do; their motion is more analogous to that of a bird or other self-propelling animal, than it is to that of a shot. The motion of a wave in a moving medium may be likened to that of a rowing-boat on a river. It crawls forward with the water, and it drifts with the water;

To prove this let us attend to what is happening at the target. The first shot is supposed to be entering at A, and if the target is stationary will leave it at Y. A marker looking along Y A will see the position whence the shot was fired. This may be likened to a stationary observer looking at a moving star. He sees it where and as it was when the light started on its long journey. He

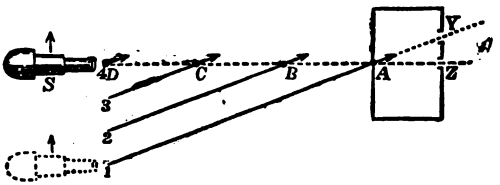


FIG. 1.—Shots or Disturbances with Momentum from a Moving Gun.

does not see its present position, but there is no reason why he should. He does not see its physical state or anything as it is now. He sees it as it was when it sent the information which he has just received. There is no aberration caused by motion of source.

But now let the receiver be moving at same pace as the gun, as when two grappled ships are firing into each other. The motion of the target carries the point Y forward, and the shot A leaves it at Z, because Z is carried to where Y was. So in that case the marker looking along

normal. Now, *if the motion of the medium inside the receiver is the same as it is outside*, the wave will pass straight on along the slant to Z, and the true direction of the source is fixed. But if the medium inside the target or telescope is stationary, the wave will cease to drift as soon as it gets inside—under cover, as it were; it will proceed along the path it has been really pursuing *in the medium* all the time, and make its exit at Y. In this latter case—of different motion of the medium inside and outside the telescope—the apparent direction, such as Y A, is not the true direction of the source. *The ray is in fact bent where it enters the differently moving medium* (as shown in Fig. 4).

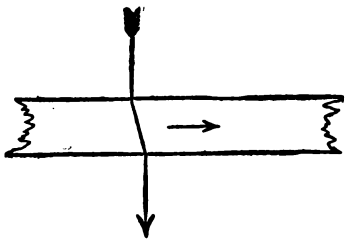


FIG. 4.—Ray through a Moving Stratum.

A slower moving stratum bends an oblique ray, slanting with the motion, in the same direction as if it were a denser medium. A quicker stratum bends it oppositely. If a

out as simple spheres from the then position of source as centre. Wave-normal and ray now coincide: S M is not a ray, but only the locus of successive disturbances. A stationary telescope

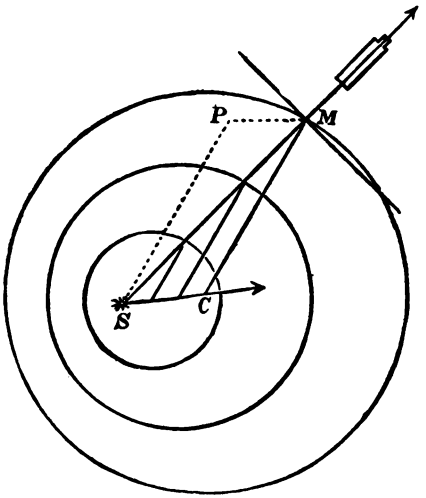


FIG. 5.—Successive Wave Fronts in a Moving Medium.

would look not at S, but along M C to a point where the source was when it emitted the wave M; a moving telescope, if moving at same rate as source, will look at S. Hence S M is sometimes called the *apparent* ray. The angle S M C is the

aberration angle, which in Chap. X we denote by ϵ.

Fig. 6 shows normal reflection for the case of a moving medium. The mirror M reflects light received from S_1 to a point S_2 just in time to catch the source there if that is moving with the medium.

Parenthetically, I may say that the time taken on the double journey, S_1 M S_2, when the medium is moving, is not quite the same as the double journey S M S, when all is stationary; and that this is the principle of Michelson's great experiment; which must be referred to later.

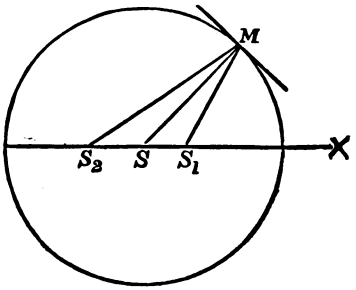


FIG. 6.—Normal Reflection in Moving Medium.
The angle M S X is the angle θ in the theory of Michelson's experiment described in Chapter IV.

The ether stream we speak of is always to be considered merely as one relative to matter. Absolute velocity of matter means velocity through

the ether—which is stationary. If there were no such physical standard of rest as the ether—if all motion were relative to matter alone—then the contention of Copernicus and Galileo would have had no real meaning.

ought to be able to detect some evidence of its existence.[1]

It is not so easy a thing to detect as you would imagine. We have seen that it produces no deviation or error in direction. Neither does it cause any change of colour or Doppler effect; that is, no shift of lines in spectrum. No steady wind can affect pitch, simply because it cannot blow waves to your ear more quickly than they are emitted. It hurries them along, but it lengthens them in the same proportion, and the result is that they arrive at the proper frequency. The precise effects of motion on pitch are summarised in the following table:—

Changes of Frequency due to Motion

Source approaching shortens waves.

Receiver approaching alters relative velocity.

Medium flowing alters both wave-length and velocity in exactly compensatory manner.

What other phenomena may possibly result from motion? Here is a list:—

Phenomena resulting from Motion

(1) Change or apparent change in direction; observed by telescope, and called aberration.

[1] The word "stationary" is ambiguous. I propose to use "stagnant," as meaning stationary with respect to the earth—*i.e.*, as opposed to stationary in *space*.

(2) Change or apparent change in frequency; observed by spectroscope, and called Doppler effect.

(3) Change or apparent change in time of journey; observed by lag of phase or shift of interference fringes.

(4) Change or apparent change in intensity; observed by energy received by thermopile.

What we have arrived at so far is the following:—

Motion of either source or receiver can alter frequency; motion of receiver can alter apparent direction; motion of the medium can do neither.

But the question must be asked, can it not hurry a wave so as to make it arrive out of phase with another wave arriving by a different path, and thus produce or modify interference effects?

Or again, may it not carry the waves down stream more plentifully than up stream, and thus act on a pair of thermopiles, arranged fore and aft at equal distances from a source, with unequal intensity?

And once more, perhaps the laws of reflection and refraction in a moving medium are not the same as they are if it be at rest. Then, moreover, there is double refraction, colours of thin plates and thick plates, polarisation angle, rotation of the plane of polarisation; all sorts of optical phenomena that need consideration.

It is not to be supposed that there is any *destruction* of light, or any dissipation of energy: it is merely a case of redistribution.

The bright parts are brighter just in proportion as the dark parts are darker. The screen is illuminated in stripes and no longer uniformly, but its total illumination is the same as if there were no interference.

Projection of Interference Bands.

It is not easy to project these interference bands on a screen so as to make them visible to an audience, partly because the bands or stripes of darkness are exceedingly narrow; indeed, I had not previously seen the experiment attempted. But by means of what I call an interference kaleidoscope, consisting of two mirrors set at an angle with a third semi-transparent mirror between them, it is possible to get the bands remarkably clear and bright, so that they can readily be projected: and I showed these at a lecture to the Royal Institution of Great Britain in 1892.

Each mirror is mounted on a tripod with adjustable screw feet, which stand on a thick iron slab, which again rests on hollow india-rubber balls. Looking down on the mirrors the plan is as in the diagram Fig. 7, which indicates sufficiently the geometry of the arrangement,

wind is a bodily transfer of air; hence, of course, gives the sound a ride. Whereas light does not really travel in water, but always in ether; and it is by no means obvious whether a stream of water can help or hinder it. Experiment decides, however, and answers in the affirmative. It helps it along with just about half the speed of the water; not with the whole speed, which is curious and important, and really means that the moving water has no effect whatever on the ether of space, though we must defer explaining how this comes about. Suffice for present purposes the fact that the velocity of light inside moving water, and therefore presumably inside all transparent matter, is altered to some extent by motion of that matter.

Does not this fact afford an easy way of detecting a motion of the earth through the ether? Every vessel of stagnant water is really travelling along through the ether at the rate of nineteen miles a second. Send a beam of light through it one way, and it will be hurried; its velocity, instead of being 140,000 miles a second, will be 140,009 miles. Send a beam of light the other way, and its velocity will be 139,991; just as much less. Bring these two beams together; surely some of their wave-lengths will interfere. M. Hoek, Astronomer at Utrecht, tried the experiment in this very form; here is a diagram of

with an appropriate zenith-sector full of water. Stars were seen through the water-telescope precisely as through an air telescope. A negative result again! (The theory is fully dealt with in Chapter X and Appendix 3.)

Stellar observations, however, are unnecessarily difficult. Fresnel had pointed out that a terrestrial source of light would do just as well. He had also (being a man of exceeding genius) predicted that nothing would happen. Hoek has now tried it in a perfect manner and nothing did happen.

But these facts are not at all disconcerting; they are just what ought to be anticipated, in the light of true theory. The absence of all effect caused by stagnant dense matter inserted in the path of a beam of light, that is of dense transparent matter not artificially moved with reference to the earth—or rather with reference to source and receiver—is explicable on Fresnel's theory concerning the behaviour of ether inside matter.

If the index of refraction of the matter is called μ, that means that the speed of light inside it is $\frac{1}{\mu}$ th of the speed outside or in vacuo. And that is only another way of saying that the virtual etherial density inside it is represented by μ^2, since the velocity of waves is inversely as the square root of the density of the medium which conveys them; the elasticity being reckoned as constant, and the same inside as out.

But if, instead of running water, stagnant water is used—that is stationary with respect to the earth, though still moving violently through the ether—then the (μ^2-1) effect of the load will be fixed to the matter, and can produce no extra or motile effect. The only part that could produce an effect of that kind would be the free ether, of density 1. But then this—on the above view—is absolutely stationary, not being carried along by the earth at all; hence this can give no effect either. Consequently the whole effect of an ether-drift past the earth is zero, on optical experiments, according to the theory of Fresnel; and that is exactly what all the experiments just described have confirmed.

Since then Professor Mascart, with great pertinacity, has attacked the phenomena of thick plates, Newton's rings, double refraction, and the rotatory phenomenon of quartz; but he has found absolutely nothing attributable to a stream of ether past the earth.

The only positive result ever supposed to be attained was in a very difficult polarisation observation by Fizeau in 1859. Unless this has been repeated, it is safest to ignore it; but I believe that Lord Rayleigh has repeated it, and obtained a negative result.

Fizeau also suggested, but did not attempt, what seems an easier experiment, with fore and aft thermopiles and a source between them, to

observe the drift of a medium by its convection of energy; but arguments based on the law of exchanges[1] tend to show, and do show as I think, that a probable alteration of radiating power due to motion through a medium would just compensate the effect otherwise to be expected.

We may summarise most of these statements as follows:—

Summary.

Source alone moving produces . . .	A real and apparent change of wave-length. A real but not apparent error in direction. No lag of phase or change of intensity, except that appropriate to altered wave-length.
Medium alone moving, or source and receiver moving together, produces . . .	No change of frequency. No error in direction. A real lag of phase, but undetectable without control over the medium. A change of intensity corresponding to different distance, but compensated by change of radiating power.

[1] Lord Rayleigh, "Nature," March 25, 1892.

a little longer than the motion across, though everything else was accurately the same, some shift of the interference bands might be expected as the slab rotated.

But whereas in all the experiments previously described the effect looked for was a first-order effect, of magnitude one in ten or twenty thousand—depending, that is to say, on the first power of the ratio of speed of earth to speed of light—the effect now to be expected depends on the *square* of that same ratio, and therefore cannot be greater, even in the most favourable circumstances, than 1 part in a hundred million.

It is easy to realise, therefore, that it is an exceptionally difficult experiment, and that it required both skill and pertinacity to perform it successfully.

That it is an exceptionally difficult experiment will be realised when I say that it would fail in conclusiveness unless one part in 400 millions could be clearly detected.

Mr. Michelson reckons that by his latest arrangement he could see 1 in 4000 millions if it existed (which is equivalent to detecting an error of $\frac{1}{1000}$th of an inch in a length of 60 miles); but he saw nothing. Everything behaved precisely as if the ether was stagnant; as if the earth carried with it all the ether in its immediate neighbourhood. And that was his conclusion.

brilliantly worked it into his system. It may be explained briefly thus:—

Electric charges in motion constitute an electric current. Similar charges repel each other, but currents in the same direction attract. Consequently two similar charges moving in parallel lines will repel each other less than if stationary—less also than if moving one after the other in the same line. Likewise two opposite charges, a fixed distance apart, attract each other less when moving side by side than when chasing each other. The modification of the static force, thus caused, depends on the squared ratio of their joint speed to the velocity of light.

Atoms of matter are charged; and cohesion is a residual electric attraction (*see* end of Appendix 1). So when a block of matter is moving through the ether of space its cohesive forces across the line of motion are diminished, and consequently in that direction it expands, by an amount proportioned to the square of aberration magnitude.

A light journey, to and fro, across the path of a relatively moving medium is slightly quicker than the same journey, to and fro, along (*see* p. 67). But if the journeys are planned or set out on a block of matter, they do not remain quite the same when it is conveyed through space: the journey across the direction of motion becomes longer than the other journey, as we have just seen. And the extra distance compensates or neutralises the extra speed; so that light takes the same time for both.

V

SPECIAL EXPERIMENT ON ETHERIAL VISCOSITY

THE balance of evidence at this stage seems to incline in the sense that there is no ether drift, that the ether near the earth is stagnant, that the earth carries all or the greater part of the neighbouring ether with it—a view which, if true, must singularly complicate the theory of ordinary astronomical aberration: as is explained at the beginning of the last chapter.

But now put the question another way. *Can* matter carry neighbouring ether with it when it moves? Abandon the earth altogether; its motion is very quick but too uncontrollable, and it always gives negative results. Take a lump of matter that you can deal with, and see if it pulls any ether along.

That is the experiment which I set myself to perform, and which in the course of the years 1891–97 I performed. It may be thus described in essence:—

Take a steel disk, or rather a couple of large steel disks a yard in diameter clamped together

The thing to observe is whether the motion of the disks is able to replace a bright band by a dark one, or vice versa. If it does, it means

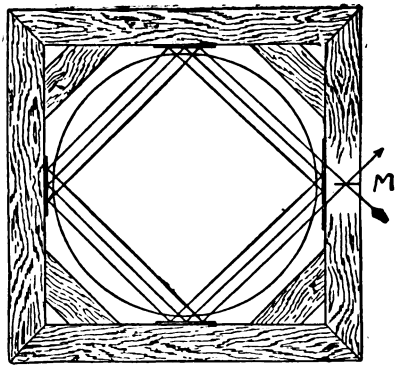


FIG. 11.—Diagrammatic Plan of Optical Frame for Ether Machine; with Steel Disks, one yard in diameter, inside the frame. (The actual apparatus is shown in Figs. 13 and 14 and Fig. 12.)

M is a semi-transparent mirror, reflecting half an incident beam and transmitting the other half. The two half beams each go three times round the square contour, in opposite directions, and then reunite. It is an extension of the idea of Fig. 7.

that one of the half beams—*viz.*, that which is travelling in the same direction as the disks—is helped on a trifle, equivalent to a shortening of journey by some quarter millionth of an inch or so in the whole length of 30 feet; while the other half beam—*viz.*, that travelling against the

motion of the disks—is retarded, or its path virtually lengthened, by the same amount.

If this acceleration and retardation actually occur, waves which did not interfere on meeting before the disks moved, will interfere now; for one will arrive at the common goal half a length behind the other.

Now a gradual change of bright space to dark, and vice versa, shows itself, to an observer looking at the bands, as a gradual change of position of the bright stripes, or a shift of the bands. A shift of the bands, and especially of the middle white band, which is much more stable than the others, is what we look for. The middle band is, or should be, free from the "concertina"-like motion which is liable to infect the others.

At first I saw plenty of shift. In the first experiment the bands sailed across the field as the disks got up speed until the crosswire had traversed a band and a half. The conditions were such that had the ether whirled at the full speed of the disks I should have seen a shift of three bands. It looked very much as if the light was helped along at half the speed of the moving matter, just as it is inside water.

On stopping the disks the bands returned to their old position. On starting them again in the opposite direction, the bands ought to have shifted the other way too, if the effect was

genuine; but they did not; they went the same way as before.

The shift was therefore wholly spurious; it was caused by the centrifugal force of the blast of air thrown off from the moving disks. The mirrors and frame had to be protected from this. Many other small changes had to be made, and gradually the spurious shifts have been reduced and reduced, largely by the skill and patience of my assistant, Mr. Benjamin Davies, until presently there was barely a trace of them.

But the experiment is not an easy one. Not only does the blast exert pressure, but at high speeds the churning of the air makes it quite hot. Moreover, the tremor of the whirling machine, in which from four to nine horse-power is sometimes being expended, is but too liable to communicate itself to the optical part of the apparatus. Of course elaborate precautions are taken against this. Although the two parts, the mechanical and the optical, are so close together, their supports are entirely independent. But they have to rest on the same earth, and hence communicated tremors are not absent. They are the cause of most of the slight residual trouble.

The whole experiment is described in fairly full detail in the *Philosophical Transactions of the Royal Society* for 1893 and 1897. And there also are described some further modifications where-

by the whirling disks are electrified—likewise without optical effect, and are also magnetised; or rather a great iron mass, strongly magnetised by a current, is used to replace the steel disks.

The effect was always zero, however, when spurious results were eliminated; and it is clear that at no practicable speed does either electrification or magnetisation confer upon matter any appreciable viscous grip upon the ether. Atoms *must* be able to throw it into vibration, if they are oscillating or revolving at sufficient speed; otherwise they would not emit light or any kind of radiation; but in no case do they appear to drag it along, or to meet with resistance in any uniform motion through it. Only their acceleration is effectual.

In the light of Larmor's electron theory, we know now that acceleration of atoms, or rather of a charge upon an atom, necessarily generates radiation, proportional in amount to the *square* of the acceleration—whether that be tangential or normal. There is no theoretical reason for assuming any influence on uniform velocity. And even the influence on acceleration is exceedingly small under ordinary circumstances. Only during the violence of collision are ether waves freely excited. The present experiment, however, has nothing to do with acceleration: it is a test of viscosity. An acceleration term exists in motion through even a perfect fluid.

mounted. The whirling machine strongly bolted down to a stone pier independent of the floor; the optical frame independently supported by a gallows frame from other piers. The centrifugal mercury speed-indicator is visible in front, and Mr. Davies is regulating the speed. At the back is seen a boiler-plate screen for the observer with his eye at the telescope. (*See* Frontispiece.)

The expense of the apparatus was borne by my friend, the late George Holt, shipowner, of Liverpool.

Fig. 16 exhibits something like the appearance seen in the eye-piece, with the interference bands on each side of the middle band, and with the

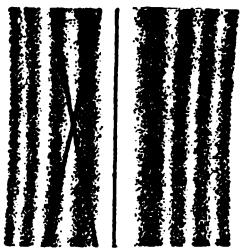
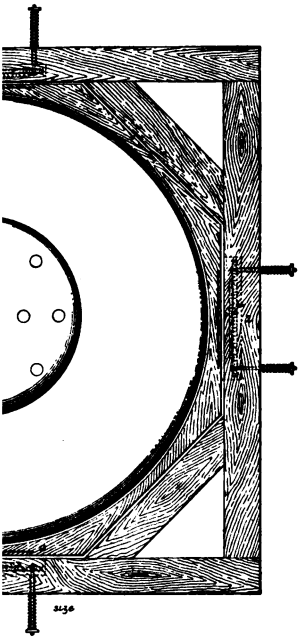


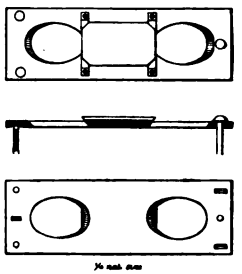
FIG. 16.—Approximate appearance of the interference bands and micrometer Tires as seen in the eye-piece of the telescope of the Ether machine.

micrometer wires set in position—each moved by an independent micrometer head. The straight vertical wire was usually set in the centre of the



1/4 real size

Mode of mounting the semitransparent mirror M so as to give altitude and azimuth movement to the reflected beam



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Details of brass plate supporting back mirror. Front, ends and back views
Back view shows the three slots in which the ends of the supporting screws rest giving a fine adjustment, the plate being supported by three rigid pushes and three elastic pulls

...id glazed drum to isolate them from the ...es. Supports of telescope and collimator also ..., three of them let into recesses in the wooden ... by three finely cut screws against which M is the semi-transparent mirror

middle white band, and the X wire on the yellow of the first coloured band on one side or the other.

The method of observation now consists in setting a wire of the micrometer accurately in the centre of the middle band, while another wire is usually set on the first band to the left. Then the micrometer heads are read, and the setting repeated once or twice to see how closely and dependably they can be set in the same position. Then we begin to spin the disks, and when they are going at some high speed, measured by a siren note and in other ways, the micrometer wires are reset and read—reset several times and read each time. Then the disks are stopped and more readings are taken. Then their motion is reversed, the wires set and read again; and finally the motion is once more stopped and another set of readings taken. By this means the absolute shift of middle band, and its relative interpretation in terms of wave-length, are simultaneously obtained; for the distance from the one wire to the other, which is often two revolutions of a micrometer head, represents a whole wave-length shift.

In the best experiments I do still often see something like a fiftieth of a band shift; but it is caused by residual spurious causes, for it repeats itself with sufficient accuracy in the same direction when the disks are spun the other way round.

Of real reversible shift, due to motion of the

ether, I see nothing. I do not believe the ether moves. It does not move at a five-hundredth part of the speed of the steel disks. Further experience confirms and strengthens this estimate, and my conclusion is that such things as circular-saws, flywheels, railway trains, and all ordinary masses of matter do not appreciably carry the ether with them. Their motion does not seem to disturb it in the least.

The presumption is that the same is true for the earth; but the earth is a big body—it is conceivable that so great a mass may be able to act when a small mass would fail. I would not like to be too sure about the earth—at least, not on a strictly experimental basis. What I do feel sure of is that if moving matter disturbs ether in its neighbourhood at all, it does so by some minute action, comparable in amount perhaps to gravitation, and possibly by means of the same property as that to which gravitation is due—not by anything that can fairly be likened to etherial viscosity. So far as experiment has gone, our conclusion is that the viscosity or fluid friction of the ether is zero. And that is an entirely reasonable conclusion.

Magnetisation.

For testing the effect of magnetism, an oblate spheroid was made of specially selected soft iron,

cordingly in the eyepiece the iron surfaces could be seen, above and below, as well as the interference bands in the luminous gap. The whole appearance is depicted in Fig. 18.

Electrification.

For the electrification experiment, a third and insulated disk was clamped between the two steel disks and kept electrified to sparking tension. The arrangement is shown diagrammatically on a smaller scale in Fig. 19.

Fig. 19.—Arrangement for electrifying a third or middle steel disk to sparking potential while spinning.

The electrification test was exceptionally easy to apply by connecting the insulated charging pin to a Voss machine in action: because when the disks were spinning and the bands in good condition, the electrification could be instantaneously applied, taken off, reversed, or whatever was desired; and the effect of the sudden lowering of potential by sparks passing between the revolving plates could be exactly looked for.

The conclusion of my second *Philosophical Transactions* paper—that of 1897—is that *neither*

an electric nor a magnetic transverse field confers viscosity upon the ether, nor enables moving matter to grip and move it rotationally.

Question of a Possible Longitudinal Magnetic Drift.

Later I tried a longitudinal magnetic field also; arranging a series of four large electric bobbins or long coils along the sides of a square inscribed at 45° in the optical square (Figs. 11 and 13), so that the light went along their axes.

The details of this experiment have been only partially recorded, but the salient points are to be found stated in the *Philosophical Magazine* for April, 1907, pages 495–500.

The result was again negative; that is to say, a magnetic field causes no perceptible acceleration in a beam of light sent along the lines of force. The extra velocity that could have been observed would have been $\frac{1}{9}$th of a millimeter per second, or 16 miles per hour, for each c.g.s. unit of field intensity.

Another mode of expressing the result is that the difference of magnetic potential applied, namely, a drop of two million c.g.s. units of magnetic potential, does not hurry light along it by so much as $\frac{1}{60}$th part of a wave-length.

There may be reasons for supposing that some much slower drift or conveyance than this

is really caused in the ether by a magnetic field; but if so, the ether must be regarded as so excessively dense that the amount of such a drift for any practicable magnetic field seems almost hopelessly beyond experimental means of detection.

VI

ETHERIAL DENSITY

THIS leads us to enter upon the question of whether it is possible to determine with any approach to accuracy the actual density or massiveness of the ether of space, compared with those forms of matter to which our senses have made us accustomed.

The arguments on which an estimate may be made of the density or massiveness of the ether as compared with that of matter depend on the following considerations, the validity of which again is dependent upon an electrical theory of matter. In this theory, or working hypothesis, an assumption has to be made: but it is one for which there is a large amount of justification, and the reasons for it are given in many books—among others in my book on *Electrons*, and likewise at the end of the new edition of *Modern Views of Electricity*, also in my *Romanes Lecture*, published by the Clarendon Press in 1903. Put briefly, the assumption is that matter is composed, in some way or other, of electrons; which

But without repeating arguments here, it will suffice to say that although the estimates may be made in various ways, differing entirely from each other, yet the resulting differences are only slight; the calculated densities come out all of the same order of magnitude—namely, something comparable to 10^{12} c.g.s. units; that is to say, a million million grammes per cubic centimeter, or, in other words, a thousand tons to the cubic millimeter.

But, throughout, we have seen reason to assert that the ether is incompressible; arguments for this are given in *Modern Views of Electricity*, Chapter I. And, indeed, the fundamental medium filling all space, if there be such, ***must***, in my judgment, be ultimately incompressible; otherwise it would be composed of parts, and we should have to seek for something still more fundamental to fill the interstices.

The ether being incompressible, and an electron being supposed composed simply and solely of ether, it follows that it cannot be either a condensation or a rarefaction of that material, but must be some singularity of structure, or some portion otherwise differentiated. It might, for instance, be something analogous to a vortex ring, differentiated kinetically—*i.e.*, by reason of its rotational motion, from the remainder of the ether; or it might be differentiated statically, and be something which would have to be called

a strain-centre or a region of twist, or something which cannot be very clearly at present imagined with any security; though various suggestions have been made in that direction.

The simplest plan for us is to think of it somewhat as we think of a knot on a piece of string. The knot differs in no respect from the rest of the string, except in its tied-up structure; it is of the same density with the rest, and yet it is differentiated from the rest; and, in order to cease to be a knot, would have to be untied—a process which as yet we have not yet learned how to apply to an electron. If ever such a procedure becomes possible, then electrons will thereby be resolved into the general body of the undifferentiated ether of space—that part which is independent of what we call "matter."

The important notion for present purposes is merely this: that the density of the undifferentiated or simple ether, and the density of the tied-up or beknotted or otherwise modified ether constituting an electron, are one and the same. Hence the argument above given, at least, when properly worked out, tends to establish the etherial density as of the order 10^{12} times that of water.

There ought to be nothing surprising (though I admit that there is something very surprising) in such an estimate; inasmuch as many converging lines of argument tend to show that ordinary

matter is a very porous or gossamer-like substance, with interspaces great as compared with the spaces actually occupied by the nuclei which constitute it. Our conception of matter, if it is to be composed of electrons, is necessarily rather like the conception of a solar system, or rather of a milky way; where there are innumerable dots here and there, with great interspaces between. So that the average density of the whole of the dots or material particles taken together—that is to say, their aggregate mass compared with the space they occupy—is excessively small.

In the vast extent of the Cosmos, as a whole, the small bulk of actual matter, compared with the volume of empty space, is striking—as we shall show directly; and now on the small scale, among the atoms of matter, we find the conditions to be similar. Even what we call the densest material is of extraordinarily insignificant massiveness as compared with the unmodified ether which occupies by far the greater proportion of its bulk.

When we speak of the density of *matter*, we are really though not consciously expressing the group-density of the modified ether which constitutes matter—not estimated per unit, but per aggregate; just as we might estimate the group or average density of a cloud or mist. Reckoned per unit, a cloud has the density of water; reckoned per aggregate, it is an impal-

pable filmy structure of hardly any density at all. So it is with a cobweb, so perhaps it is with a comet's tail, so also with the Milky Way, with the cosmos—and, as it now turns out, with ordinary matter itself.

For consider the average density of the material cosmos. It comes out almost incredibly small. In other words, the amount of matter in space, compared with the volume of space it occupies, is almost infinitesimal. Lord Kelvin argues that ultimately it must be really infinitesimal (*Philosophical Magazine*, Aug., 1901, and Jan., 1902); that is to say that the volume of space is infinitely greater than the total bulk of matter which it contains. Otherwise the combined force of gravity—or at least the aggregate gravitational potential—on which the velocity generated in material bodies ultimately depends, would be far greater than observation shows it to be.

The whole visible universe, within a parallax of $\frac{1}{1000}$ second of arc, is estimated by Lord Kelvin as the equivalent of a thousand million of our suns; and this amount of matter, distributed as it is, would have an average density of 1.6×10^{-23} grammes per c.c. It is noteworthy how exceedingly small is this average or aggregate density of matter in the visible region of space. The estimated density of 10^{-23} c.g.s. means that the visible cosmos is as much rarer

than a "vacuum" of a hundred millionths of an atmosphere, as that vacuum is itself rarer than lead.

It is because we have reason to assert that any ordinary mass of matter consists, like the cosmos, of separated particles, with great intervening distances in proportion to their size, that we are able to maintain that the aggregate density of ordinary stuff, such as water or lead, is very small compared with the continuous medium in which they exist, and of which all particles are supposed to be really composed. So that lead is to the ether, as regards density, very much as the "vacuum" above spoken of is to lead. The fundamental medium itself must be of uniform density everywhere, whether materialised or free.

selves of what they mean by the average or aggregate density of any discontinuous system, such as a powder, or a gas, or a precipitate, or a snow-storm, or a cloud, or a milky way.

If it be urged that it is unfair to compare an obviously discrete assemblage like the stars, with an apparently continuous substance like air or lead, the answer is that it is entirely and accurately fair; since air, and every other known form of matter, is essentially an aggregate of particles, and since it is always their average density that we mean. We do not even know for certain their individual atomic density.

The phrase "specific gravity or density of a powder" is ambiguous. It may mean the specific gravity of the dry powder as it lies, like snow; or it may mean the specific gravity of the particles of which it is composed, like ice.

So also with regard to the density of matter; we might mean the density of the fundamental material of which its units are made—which would be ether; or we might, and in practice do, mean the density of the aggregate lump which we can see and handle; that is to say, of water or iron or lead, as the case may be.

In saying that the density of matter is small—I mean, of course, in the last, the usual, sense. In saying that the density of ether is great—I mean that the actual stuff of which these highly porous aggregates are composed is of immense, of

well-nigh incredible, density. It is only another way of saying that the ultimate units of matter are few and far between—*i.e.*, that they are excessively small as compared with the distances between them; just as the planets of the solar system, or worlds in the sky, are few and far between—the intervening distances being enormous as compared with the portions of space actually occupied by lumps of matter.

It may be noted that it is not unreasonable to argue that the density of a *continuum* is necessarily greater than the density of any disconnected aggregate: certainly of any assemblage whose particles are actually composed of the material of the *continuum*. Because the former is "all there," everywhere, without break or intermittence of any kind; while the latter has gaps in it—it is here and there, but not everywhere.

Indeed, this very argument was used long ago by that notable genius Robert Hooke, and I quote a passage which Professor Poynting has discovered in his collected posthumous works and kindly copied out for me:—

"As for *matter*, that I conceive in its essence to be immutable, and its essence being expatiation determinate, it cannot be altered in its quantity, either by condensation or rarefaction; that is, there cannot be more or less of that power or reality, whatever it be, within the same expatiation or content; but every equal expatiation

with equally dense *materia*. Gold fills only a small fraction of the space assigned to it, and yet has a big mass. How much greater must be the total mass filling that space."

The tacit assumption here made is that the particles of the aggregate are all composed of one and the same continuous substance—practically that matter is made of ether; and that assumption, in Hooke's day, must have been only a speculation. But it is the kind of speculation which time is justifying, it is the kind of truth which we all feel to be in process of establishment now.[1]

We do not depend on that sort of argument, however; what we depend on is experimental measure of the mass, and mathematical estimate of the volume, of the electron. For calculation shows that however the mass be accounted for—whether electrostatically, or magnetically, or hydrodynamically—the estimate of ratio of mass to effective volume can differ only in a numerical coefficient, and cannot differ as regards order of magnitude. The only way out of this conclusion would be the discovery that the negative electron is not the real or the main matter-

[1] It does not seem to have been noticed that in Query 22, quoted in the Introduction to the present book, Newton seems to throw out a curious hint in this same direction, though he immediately abandons it again. He does not appear to have carefully *edited* his queries; probably they were published posthumously.

unit, but is only a subsidiary ingredient; whereas the main mass is the more bulky positive charge. That last hypothesis, however, is at present too vague to be useful. Moreover, the mass of such a charge would in that case be unexplained, and would need a further step; which would probably land us in much the same sort of etherial density as is involved in the estimate which I have based on the more familiar and tractable negative electron. (*See* Appendix 2.)

It may be said, Why assume any definite density for the ether at all? Why not assume that, as it is infinitely continuous, so it is infinitely dense —whatever that may mean—and that all its properties are infinite? This might be possible were it not for the velocity of light. By transmitting waves at a finite and measurable speed, the ether has given itself away, and has let in all the possibilities of calculation and numerical statement. Its properties are thereby exhibited as essentially finite—however infinite the whole extent of it may turn out to be. Parenthetically, we may remark that "gravitation" has not yet exhibited any similar kind of finite property; and that is why we know so little about it.

Etherial Energy.

Instead, then, of saying that the density of the ether is great, the clearest mode of expression

the nature of locomotion, but circulation in closed curves, returning upon itself—vortex motion of a kind far more finely grained than any waves of light or any atomic or even electronic structure.

Now if the elasticity of any medium is to be thus explained kinetically, it follows, as a necessary consequence, that the speed of this internal motion must be comparable to the speed of wave propagation; that is to say that the internal squirming circulation, to which every part of the ether is subject, must be carried on with a velocity of the same order of magnitude as the velocity of light.

This is the theory then—this theory of elasticity as dependent on motion—which, in combination with the estimate of density, makes the internal energy of the ether so gigantic. For in every cubic millimeter of space we have, according to this view, a mass equivalent to what, if it were matter, we should call a thousand tons, circulating internally, every part of it, with a velocity comparable to the velocity of light, and therefore containing—stored away in that small region of space—an amount of energy of the order 10^{29} ergs, or, what is the same thing, 3×10^{11} kilowatt centuries; which is otherwise expressible as equal to the energy of a million horsepower station working continuously for forty million years.

Summarised Brief Statements Concerning the Ether

(As communicated by the author to the British Association at Leicester, 1907.)

1. The theory that an electric charge must possess the equivalent of inertia was clearly established by J. J. Thomson in the *Philosophical Magazine* for April, 1881.

2. The discovery of masses smaller than atoms was made experimentally by J. J. Thomson, and communicated to Section A at Dover in 1899.

3. The thesis that the corpuscles so discovered consisted wholly of electric charges was sustained by many people, and was clinched by the experiments of Kaufmann in 1902.

4. The concentration of the ionic charge, required to give the observed corpuscular inertia, can be easily calculated; and consequently the size of the electric nucleus, or electron, is known.

5. The old perception that a magnetic field is kinetic has been developed by Kelvin, Heaviside, FitzGerald, Hicks, and Larmor, most of whom have treated it as a flow along magnetic lines; though it may also, perhaps equally well, be regarded as a flow perpendicular to them and along the Poynting vector. The former doctrine is sustained by Larmor, as in accordance with the

principle of Least Action, and with the absolutely stationary character of the ether as a whole; the latter view appears to be more consistent with the theories of J. J. Thomson.

6. A charge in motion is well known to be surrounded by a magnetic field; and the energy of the motion can be expressed in terms of the energy of this concomitant field—which again must be accounted as the kinetic energy of ethereous flow.

7. Putting these things together, and considering the ether as essentially incompressible—on the strength of the Cavendish electric experiment, the facts of gravitation, and the general idea of a connecting continuous medium—the author reckons that to deal with the ether dynamically it must be treated as having a density of the order 10^{12} grammes per cubic centimeter. (*See* Appendix 2.)

8. The existence of transverse waves in the interior of a fluid can only be explained on gyrostatic principles—*i.e.*, by the kinetic or rotational elasticity of Lord Kelvin. And the internal circulatory speed of the intrinsic motion of such a fluid must be comparable with the velocity with which such waves are transmitted.

9. Putting these things together, it follows that the intrinsic or constitutional vortex energy of the ether must be of the order 10^{33} ergs per cubic centimeter.

VIII

ETHER AND MATTER

THE MECHANICAL NECESSITY FOR A CONTINUOUS MEDIUM FILLING SPACE

IN this chapter I propose to summarise in simple and consecutive form most of the arguments already used. Thirty years ago Clerk-Maxwell gave to the Royal Institution of Great Britain a remarkable address on "Action at a Distance." It is reported in the Journal R.I., Vol. VII, and to it I would direct attention. Most natural philosophers hold, and have held, that action at a distance across empty space is impossible; in other words, that matter cannot act where it is not, but only where it is. The question "Where is it?" is a further question that may demand attention and require more than a superficial answer. For it can be argued on the hydro-dynamic or vortex theory of matter, as well as on the electrical theory, that every atom of matter has a universal though nearly infinitesimal prevalence, and extends everywhere; since there is no definite sharp

gate, near such a body as a planet, it becomes enormous.

The force with which the moon is held in its orbit would be great enough to tear asunder a steel rod four hundred miles thick, with a tenacity of 30 tons per square inch; so that if the moon and earth were connected by steel instead of by gravity, a forest of pillars would be necessary to whirl the system once a month round their common centre of gravity. Such a force necessarily implies enormous tension or pressure in the medium. Maxwell calculates that the gravitational stress near the earth, which we must suppose to exist in the invisible medium, is 3000 times greater than what the strongest steel could stand; and near the sun it should be 2500 times as great as that.

The question has arisen in my mind, whether, if the whole sensible universe—estimated by Lord Kelvin as equivalent to about a thousand million suns—were all concentrated in one body of specifiable density,[1] the stress would not be so great as to produce a tendency toward etherial disruption; which would result in a disintegrating explosion, and a scattering of the particles once more as an enormous nebula and other fragments into the depths of space. For the

[1] On doing the arithmetic, however, I find the necessary concentration absurdly great, showing that such a mass is quite insufficient. (*See* Appendix 1.)

tension would be a maximum in the interior of such a mass; and, if it rose to the value 10^{33} dynes per square centimeter, something would have to happen. I do not suppose that this can be the reason, but one would think there must be *some* reason, for the scattered condition of gravitative matter.

Too little is known, however, about the mechanism of gravitation to enable us to adduce it as the strongest argument in support of the existence of an ether. The oldest valid and conclusive requisition of an ethereous medium depends on the wave theory of light, one of the founders of which was the Royal Institution Professor of Natural Philosophy at the beginning of last century, Dr. Thomas Young.

No ordinary matter is capable of transmitting the undulations or tremors that we call light. The speed at which they go, the kind of undulation, and the facility with which they go through vacuum, forbid this.

So clearly and universally has it been perceived that waves must be waves of something —something distinct from ordinary matter— that Lord Salisbury, in his presidential address to the British Association at Oxford, criticised the ether as little more than a nominative case to the verb to undulate. It is truly *that*, though it is also truly more than that; but to illustrate that luminiferous aspect of it, I will quote a

confidence as the result of a great part of Lord Kelvin's work.

It may be illustrated by a few experiments.

A wheel of spokes, transparent or permeable when stationary, becomes opaque when revolving, so that a ball thrown against it does not go through, but rebounds. The motion only affects permeability to matter; transparency to light is unaffected.

A silk cord hanging from a pulley becomes rigid and viscous when put into rapid motion; and pulses or waves which may be generated on the cord travel along it with a speed equal to its own velocity, whatever that velocity may be, so that they appear to stand still. This is a genuine case of kinetic rigidity; and the fact that the wave-transmission velocity is equal to the rotatory speed of the material, is typical and important, for in all cases of kinetic elasticity these two velocities are of the same order of magnitude.

A flexible chain, set spinning, can stand up on end while the motion continues.

A jet of water at sufficient speed can be struck with a hammer, and resists being cut with a sword.

A spinning disk of paper becomes elastic like flexible metal, and can act like a circular saw. Sir William White tells me that in naval construction steel plates are cut by a rapidly revolving disk of soft iron.

matter called *inertia*, which can, to a certain extent, be explained electromagnetically, provided the ethereous density is granted as of the order 10^{12} grammes per cubic centimeter. The elasticity of the ether would then have to be of the order 10^{33} c.g.s.; and if this is due to intrinsic turbulence, the speed of the whirling or rotational elasticity must be of the same order as the velocity of light. This follows hydrodynamically; in the same sort of way as the speed at which a pulse travels on a flexible running endless cord, whose tension is entirely due to the centrifugal force of the motion, is precisely equal to the velocity of the cord itself. And so, on our present view, the intrinsic energy of constitution of the ether is incredibly and portentously great; every cubic millimeter of space possessing what, if it were matter, would be a mass of a thousand tons, and an energy equivalent to the output of a million-horse-power-station for 40 million years.

The universe we are living in is an extraordinary one; and our investigation of it has only just begun. We know that matter has a psychical significance, since it can constitute *brain*, which links together the physical and the psychical worlds. If any one thinks that the ether, with all its massiveness and energy, has probably no psychical significance, I find myself unable to agree with him.

IX

STRENGTH OF THE ETHER

TO show that the ether cannot be the slight and rarefied substance which at one time, and indeed until quite lately, it was thought to be, it is useful to remember that not only has it to be the vehicle of light and the medium of all electric and magnetic influence, but also that it has to transmit the tremendous forces of gravitation.

Among small bodies gravitational forces are slight, and are altogether exceeded by magnetic and electric or chemical forces. Indeed, gravitational attraction between bodies of a certain smallness can be more than counterbalanced even by the pressure which their mutual radiation exerts—almost infinitesimal though that is; so that, as a matter of fact, small enough bodies of any warmth will repel each other unless they are in an enclosure of constant temperature—*i.e.*, unless the radiation pressure upon them is uniform all round.

The size at which radiation repulsion overbalances gravitational attraction, for equal

a force which is felt over millions of miles. The force is not only felt indeed, but must be reckoned as one of prodigious magnitude.

When dealing with bodies of astronomical size, the force of gravitation overpowers all other forces; and all electric and magnetic attractions sink by comparison into insignificance.

These immense forces must be transmitted by the ether, and it is instructive to consider their amount.

Some Astronomical Forces which the Ether has to Transmit.

Arithmetical Calculation of the Pull of the Earth on the Moon.

The mass of the earth is 6000 trillion (6×10^{21}) tons. The mass of the moon is $\frac{1}{80}$th that of the earth. Terrestrial gravity at the moon's distance (which is 60 earth radii) must be reduced in the ratio $1 : 60^2$; that is, it must be $\frac{1}{3600}$th of what it is here.

Consequently the pull of the earth on the moon is

$$\frac{6 \times 10^{21}}{80 \times 3600} \text{ tons weight.}$$

A pillar of steel which could transmit this force, provided it could sustain a tension of 40 tons to the square inch, would have a diameter of about 400 miles; as stated in the text, page 112.

If this force were to be transmitted by a forest of weightless pillars each a square foot in cross-section, with a tension of 30 tons to the square inch throughout, there would have to be 5 million million of them.

Arithmetical Calculation of the Pull of the Sun on the Earth.

The mass of the earth is 6×10^{21} tons. The intensity of solar gravity at the sun's surface is 25 times ordinary terrestrial gravity.

At the earth's distance, which is nearly 200 solar radii, solar gravity will be reduced in the ratio of 1 : 200 squared.

Hence the force exerted by the sun on the earth is

$$\frac{25 \times 6 \times 10^{21}}{(200)^2} \text{ tons weight.}$$

That is to say, it is approximately equal to the weight of 37×10^{17} ordinary tons upon the earth's surface.

Now steel may readily be found which can stand a load of 37 tons to every square inch of cross-section. The cross-section of a bar of such steel, competent to transmit the sun's pull to the earth, would therefore have to be

10^{17} square inches;
or, say, 700×10^{12} square feet.

by the square of its angular velocity, multiplied by the radius of its orbit; that is to say,

$$F = M \left(\frac{2\pi}{T}\right)^2 r$$

where T is the length of a year.

The process of evaluating this is instructive, owing to the manipulation of units which it involves:—

$$F = 6 \times 10^{21} \text{ tons} \times \frac{4\pi^2 \times 92 \times 10^6 \text{ miles}}{(365\frac{1}{4} \text{ days})^2}$$

which of course is a mass multiplied by an acceleration. The acceleration is—

$$\frac{40 \times 92 \times 10^6}{133300 \times (24)^2} \text{ miles per hour per hour}$$

$$= \frac{3680 \times 10^6 \times 5280}{133300 \times 576 \times (3600)^2} \text{ feet per sec. per sec.}$$

$$= \frac{115 \times 5280}{133300 \times 576 \times 12.96} \times 32 \text{ feet per sec. per sec.}$$

$$= \frac{g}{1640}$$

Hence the Force of attraction is that which, applied to the earth's mass, produces in it an acceleration equal to the $\frac{1}{1640}$th part of what ordinary terrestrial gravity can produce in falling bodies; or

$$F = 6 \times 10^{21} \text{ tons} \times \frac{g}{1640}$$

$$= \frac{6}{1640} \times 10^{21} \text{ tons weight;}$$

which is the ordinary weight of 37×10^{17} tons, as before.

The slight numerical discrepancy between the above results is of course due to the approximate character of the data selected, which are taken in round numbers as quite sufficient for purposes of illustration.

If we imagine the force applied to the earth by a forest of round rods, one for every square foot of the earth's surface—*i.e.*, of the projected earth's hemisphere or area of equatorial plane—the force transmitted by each would have to be 2700 tons; and therefore, if of 30-ton steel, they would each have to be eleven inches in diameter, or nearly in contact, all over the earth.

Pull of a Planet on the Earth.

While we are on the subject, it seems interesting to record the fact that the pull of any planet on the earth, even Neptune, distant though it is, is still a gigantic force. The pull of Neptune is $\frac{1}{20000}$th of the sun's pull; *i.e.*, it is 18 billion tons weight.

Pull of a Star on the Earth.

On the other hand, the pull of a fixed star, like Sirius—say a star, for example, which is 20 times the mass of the sun and 24 light years distant—is comparatively very small.

It is easily found by dividing 20 times the sun's pull by the squared ratio of 24 years to 8 minutes; and it comes out as 30 million tons weight.

Such a force is able to produce no perceptible effect. The acceleration it causes in the earth and the whole solar system, at its present speed through space, is only able to curve the path with a radius of curvature of length thirty thousand times the distance of the star.

Force required to hold together the Components of some Double Stars.

But it is not to be supposed that the transmission of any of these forces gives the ether the slightest trouble, or strains it to anywhere near the limits of its capacity. Such forces must be transmitted with perfect ease, for there are plenty of cases where the force of gravitation is vastly greater than that. In the case of double stars, for instance, two suns are whirling round each other; and some of them are whirling remarkably fast. In such cases the force holding the components together must be enormous.

Perhaps the most striking case, for which we have substantially accurate data, is the star β Aurigæ; which, during the general spectroscopic survey of the heavens undertaken by Professor Pickering, of Harvard, in connection

equal bodies, revolving about a common centre of gravity midway between them, in nearly circular orbits.

The speed and period together easily give the radius of the circular orbit as about 8 million miles.

Equating centrifugal and centripetal forces

$$\frac{m v^2}{r} = \gamma \frac{m^2}{(2r)^2}$$

and comparing the value of $4r^3/T^2$ so obtained with the r^3/T^2 of the earth, we find the mass of each body must be about 30,000 times that of the earth, or about $\frac{1}{10}$th that of the sun.

(This is treating them as spheres, though they must really be pulled into decidedly prolate shapes. Indeed it may seem surprising that the further portions can keep up with the nearer portions as they revolve. If they are of something like solar density their diameter will be comparable to half a million miles, and the natural periods of their near and far portions will differ in the ratio $(\frac{7}{6})^{3/2} = 1.1$ approximately. Tenacity could not hold the parts together, but gravitational coherence would.)

This, however, is a digression. Let us continue the calculation of the gravitative pull.

We have masses of $3 \times 10^4 \times 6 \times 10^{21}$ tons, re-

4. In all cases the line of vision depends on motion of the observer, and on that alone. If the observer is stationary, his line of vision is a ray. If he moves at the same rate as the ether, his line of vision is a wave-normal.

5. Line of vision depends not at all on the motion of the ether, so long as it has a velocity-potential. Hence, if this condition is satisfied the theory of aberration is quite simple.

General Statement as to Negative Results in the Subject.

It is noteworthy that almost all the observations which have been made with negative results as to the effect of the earth's orbital motion on the ether are equally consistent with complete connection and complete independence between ether and matter. If there is complete connection, the ether near the earth is relatively stagnant, and negative terrestrial results are natural. If there is complete independence, the ether is either absolutely stationary or has a velocity-potential, and the negative results are, as has been shown, thereby explained. Direct experiment on the subject of etherial viscosity proves that that is either really or approximately zero, and substantiates the "independence" explanation.

Definition of a Ray.

A ray signifies the path of a definite or identical portion of radiation energy—the direction of energy-flux. In other words, it may be considered as the path of a labelled disturbance; for it is some special feature which enables an eye to fix direction: it is that which determines the line of collimation of a telescope.

Now in order that a disturbance from A may reach B, it is necessary that adjacent elements of a wave front at A shall arrive at B in the same phase; hence, the path by which a disturbance travels must satisfy this condition from point to point. This condition will be satisfied if the time of journey down a ray and down all infinitesimally differing paths is the same.

The equation to a ray is therefore contained in the statement that the time taken by light to traverse it is a minimum; or

$$\int_{A}^{B} \frac{ds}{V} = \text{minimum}$$

If the medium, instead of being stationary, is drifting with the velocity v, at angle θ to the ray, we must substitute for V the modified velocity V cos $\epsilon + v \cos \theta$; and so the function

Hence some slight modification of interference effects by reason of drift would seem to be possible; since the time of a to and fro light-journey depends subordinately on the inclination of ray to drift.

The above expression applies to Michelson's remarkable experiment[1] of sending a split beam to and fro, half along and half across the line of the earth's motion; and is, in fact, a theory of it. There ought to be an effect due to the difference between $\theta=0$ and $\theta=90°$. But none can be detected. Hence, either something else happens, or the ether near the earth is dragged with it so as not to stream through our instruments.

Alternative Explanation.

But if the ether is dragged along near moving matter, it behaves like a viscous fluid, and all idea of a velocity-potential must be abandoned. This would complicate the theory of aberration (pp. 47 and 64), and moreover is dead against the experimental evidence described in Chapter V.

The negative result of Mr. Michelson's is, however, explicable in another way—namely, by the FitzGerald-Lorentz theory that the linear dimensions of bodies are a function of their motion through the ether. And such an effect it is reasonable to expect; since, if cohesion forces are

[1] *Philosophical Magazine*, December, 1887.

flected—refracted or diffracted—by an amount corresponding to its frequency of vibration or wave-length.

Motion of the medium, so long as it is steady, affects neither frequency nor wave-length, and accordingly is without influence on the result. It produces no Doppler effect except when waxing or waning.

Motion of the source alone crowds the waves together on the advancing side and spreads them out on the receding side. An observer, therefore, whom the source is approaching receives shorter waves, and one from whom the source is receding receives longer waves, than normal. At any fixed point waves will arrive, therefore, with modified frequency.

So long as a source is stationary the wave-lengths emitted are quite normal, but motion of an observer may change the frequency with which they are *received*, in an obvious way; they are swept up faster if the receiver is approaching, they have a stern chase if it is receding.

All this is familiar, and was geometrically illustrated in Chapter III, but there are some minor and rather curious details which are worthy of brief consideration.

Grating Theory.

For suppose a "grating" is used to analyse the light. Its effect can depend on nothing kinetic;

it must be regulated by the merely geometric width of the ruled spaces on it. Consequently it can only directly apprehend wave-lengths, not frequencies.

In the case of a moving *source*, therefore, when the wave-length is really changed, a grating will appreciate the fact, and will show a true Doppler effect. But in the case of a moving *observer*, when all the waves received are of normal length, though swept up with abnormal frequency, the grating must still indicate wave-length alone, and accordingly will show no true Doppler effect.

But inasmuch as the telescope or line of vision is inclined at the angle of disperson to the direction of the incident ray, ordinary aberration must come in, as it always does when an observer moves athwart his line of vision; and so there will be a spurious or apparent Doppler effect due to common aberration. That is to say a spectrum line will not be seen in its true place, but will appear to be shifted by an amount almost exactly imitative of a real Doppler effect —the imitation being correct up to the second order of aberration magnitude. The slight outstanding difference between them is calculated in my *Philosophical Transactions* paper, 1893, page, 787. It is too small to observe.

It is not an important matter, but as it is rather troublesome to work out the diffraction observed by a grating advancing toward the

depend directly upon frequency—*i.e.*, upon a time relation between the period of a light vibration and the period of an atomic or electronic revolution or other harmonic excursion.

Let us say, therefore, that prismatic dispersion directly indicates frequency. It cannot depend upon wave-length, for the wave-length inside different substances is different, and though refractive index corresponds to this, dispersive power does not.

In the case of a prism, therefore, no distinction can be drawn between motion of source and motion of receiver; for in both cases the frequency with which the waves are received will be altered—either because they are really shorter, though arriving at normal speed, or because they are swept up faster, although of normal length.

Achromatic Prism.

It must be noticed that the observation of Doppler effect by a prism depends entirely on dispersion—*i.e.*, on waves of different length being affected differently. But prisms can be constructed whose dispersion is corrected and neutralised. Such achromatic prisms, if perfectly achromatic, will treat waves of all sizes alike; and, accordingly, the shortening of the waves from a moving source will not produce any effect. Achromatic prisms will therefore

So the equivalent air thickness, instead of being $(\mu-1)z$, is

$$\frac{\mu z}{\cos\epsilon+\frac{a}{\mu}\cos\theta}-z=\left(\frac{\mu\cos\epsilon-a\cos\theta}{\left(1-\frac{a}{\mu}\right)^2}-1\right)z,$$

or, to the first order of minutiæ,

$$(\mu-1)z-az\cos\theta;$$

θ being the angle between ray and ether drift inside the medium.

So the extra equivalent air layer *due to the motion* is approximately $\pm a\,z\cos\theta$, a quantity independent of μ.

Hence, no plan for detecting this first order effect of motion is in any way assisted by the use of dense stationary substances; their extra ether, being stationary, does not affect the lag caused by motion, except indeed in the second order of small quantities, as shown above.

Direct experiments made by Hoek,[1] and by Mascart, on the effect of introducing tubes of water into the path of half beams of light, are in entire accord with this negative conclusion.

Thus, then, we find that no general motion of the entire medium can be detected by changes in direction, or in frequency, or in phase; for on

[1] *Archives Néerlandaises* (1869), Vol. IV, p. 443, or *Nature*, Vol. XXVI, p. 500. Also Chapter IV, above.

none of them has it any appreciable (*i.e.*, first order) effect, even when assisted by dense matter.

Another mode of stating the matter is to say that the behaviour of ether inside matter is such as to enable a potential-function,

$$\int \mu^2 v \cos\theta ds,$$

to exist throughout all transparent space, so far as motion of ether alone is concerned (*see* Appendix 3).

The existence of this potential function readily accounts for the absence of all effect on direction due to the general drift of the medium, whether in the presence of dense matter (such as water-filled telescopes) or otherwise. Whatever may be the path of a ray by reason of reflection or refraction in a stationary ether, it is precisely the same in a moving one if this condition is satisfied, although the wave-normals and wave-fronts are definitely shifted.

However matter affects or loads the ether inside it, it cannot on this theory be said either to hold it still, or to carry it with it. The general ether stream must remain unaffected, not only near, but inside matter, if rays are to retain precisely the same course as if it were relatively stationary.

fundamental substance or perfect fluid, with what is equivalent to an inertia-coefficient of 10^{12} grammes per c.c.; that *matter* is composed of modified and electrified specks, or minute structures of ether, which are amenable to mechanical as well as to electrical force and add to the optical or electric density of the medium; and that elastic-rigidity and all potential energy are due to excessively fine-grained etherial circulation, with an intrinsic kinetic energy of the order 10^{33} ergs per cubic centimeter.

APPENDIX 1.

ON GRAVITY AND ETHERIAL TENSION

IN the arithmetical examples of Chapter IX we reckon merely the force between two bodies; but the Newtonian tension mentioned in Chapter VIII does not signify that force, but rather a certain condition or state of the medium, to variations in which, from place to place, the force is due. This Newtonian tension is a much greater quantity than the force to which it gives rise; and, moreover, it exists at every point of space, instead of being integrated all through an attracted body.

It rises to a maximum value near the surface of any spherical mass; and if the radius be R and the gravitational intensity is g, the tension at the surface is $T_0 = gR$. At any distance r, further away, the tension is $T = gR^2/r$.

This follows at once thus:—

Stating the law of gravitation as $F = \gamma \frac{m\,m'}{r^2}$, the meaning here adopted for etherial tension at the surface of the earth is

$$T = \int_R^\infty \frac{\gamma E}{r^2}\,dr = \frac{\gamma E}{R};$$

so that the ordinary intensity of gravity is

$$g = -\frac{dT}{dR} = \frac{\gamma E}{R^2} = \frac{4}{3}\pi\rho\gamma R.$$

Accordingly, near the surface of a planet the tension

is $T_0 = gR$, or for different planets is proportional to σR^2.

The velocity of free fall from infinity to such a planet is $\sqrt{(2\,T_0)}$; the velocity of free fall from circumference to centre, assuming uniform distribution of density, is $\sqrt{(T_0)}$; and from infinity to centre it is $\sqrt{(3T_0)}$.

Expanding all this into words:—

The etherial tension near the earth's surface, required to explain gravity by its rate of variation, is of the order 6×10^{11} c.g.s. units. The tension near the sun is 2500 times as great (p. 112). With different spheres in general, it is proportional to the density and to the superficial area. Hence, near a bullet one inch in diameter, it is of the order 10^{-6}; and near an atom or an electron about 10^{-21} c.g.s.

If ever the tension rose to equal the constitutional elasticity or intrinsic kinetic energy of the ether—which we have seen is 10^{33} dynes per square centimeter (or ergs per c.c.) or 10^{22} tons weight per square millimeter—it seems likely that something would give way. But no known mass of matter is able to cause anything like such a tension.

A smaller aggregate of matter would be able to generate the velocity of light in bodies falling toward it from a great distance; and it may be doubted whether any mass so great as to be able to do even that can exist in one lump.

In order to set up a tension equal to what is here suspected of being a critical, or presumably disruptive, stress in the ether (10^{33} c.g.s.), a globe of the density of the earth would have to have a radius of eight light years. In order to generate a

velocity of free fall under gravity equal to the velocity of light, a globe of the earth's density would have to be equal in radius to the distance of the earth from the sun, or say 26,000 times the earth's radius. If the density were less, the superficial area would have to be increased in proportion, so as to keep ρR^2 constant.

The whole visible universe within a parallax of $\frac{1}{1000}$ second of arc, estimated by Lord Kelvin as the equivalent of 10^9 suns, would be quite incompetent to raise etherial tension to the critical point 10^{33} c.g.s. unless it were concentrated to an absurd degree; but it could generate the velocity of light with a density comparable to that of water, if *mass* were constant.

If the average density of the above visible universe (which may be taken as 1.6×10^{-28} grammes per c.c.) continued without limit, a disruptive tension of the ether would be reached when the radius was comparable to 10^{13} light years; and the velocity of light would be generated by it when the radius was 10^7 light years. But heterogeneity would enable these values to be reached *more* easily.

Gravitation is thus supposed to be the result of a mechanical tension inherently, and perhaps instantaneously, set up throughout space whenever the etherial structure called an electric charge comes into existence; the tension being directly proportional to the square of the charge and inversely as its linear dimensions. *Cohesion* is quite different, and is due to a residual electrical attraction between groups of neutral molecules across molecular distances; a variant or modification of chemical affinity.

APPENDIX 2.

CALCULATION IN CONNECTION WITH ETHER DENSITY

JUST as the rigidity of the ether is of a purely electric character, and is not felt mechanically —since mechanically it is perfectly fluid—so its density is likewise of an electro-magnetic character, and again is not felt mechanically, because it cannot be moved by mechanical means. It is by far the most stationary body in existence; though it is endowed with high intrinsic energy of local movement, analogous to turbulence, conferring on it gyrostatic properties.

Optically, its rigidity and density are both felt, since optical disturbances are essentially electromotive. Matter loads the ether optically, in accordance with the recognised fraction $\frac{\mu^2-1}{\mu^2}$; and this loading, being part and parcel of the *matter*, of course travels with it. It is the only part amenable to mechanical force.

The mechanical density of matter is a very small portion of the etherial density; whereas the optical or electrical density of matter—being really that of ether affected by the intrinsic or constitutional electricity of matter—is not so small. The relative optical virtual density of the ether inside matter

generating circular lines of magnetic induction, by reason of some rotational property of the ether, and if we attribute all the magnetic inertia to the magnetic whirl thus caused round its path—provisionally treating this whirl as an actual circulation of fluid excited by the locomotion—then we shall proceed thus:—

Let a spherical electron e of radius a be flying at moderate speed u, so that the magnetic field at any point, $r\theta$, outside, is

$$H = \frac{eu \sin\theta}{r^2},$$

and the energy per unit volume everywhere is $\mu H^2/8\pi$.

But a magnetic field has been thought of by many mathematicians as a circulation of fluid along the lines of magnetic induction—which are always closed curves—at some unknown velocity w.

So consider the energy per unit volume anywhere: it can be represented by the equivalent expressions

$$\tfrac{1}{2}\rho w^2 = \frac{\mu H^2}{8\pi} = \frac{\mu}{8\pi} \cdot \frac{e^2 u^2 \sin^2\theta}{r^2};$$

wherefore

$$\frac{w}{u} = \sqrt{\left(\frac{\mu}{4\pi\rho}\right)} \cdot \frac{e \sin\theta}{r^2}.$$

The velocity of the hypothetical circulation must be a maximum at the equator of the sphere, where $r = a$ and $\theta = 90$; so, calling this w_o,

$$\frac{w_o}{u} = \sqrt{\left(\frac{\mu}{4\pi\rho}\right)} \frac{e}{a^2},$$

tangential stress called out by such strain is of the order 10^{11} atmospheres.

The hypothetical luminous circulation-velocity, conferring momentum on a wave-front, in accordance with Poynting's investigation, comes out 10^{-22} cm. per sec. These calculations are given in the concluding chapter of the new edition of *Modern Views of Electricity*.

The supposed magnetic ethereal drift, along the axis of a solenoid or other magnetic field, if it exist, is comparable to .003 centim. per sec., or 4 inches an hour, for a field of intensity 12,000 c.g.s.

But it is not to be supposed that this hypothetical velocity is slow everywhere. Close to an electron the speed of magnetic drift is comparable to the locomotion-velocity of the electron itself, and may therefore rise to something near the speed of light; say $\frac{1}{30}$th of that speed: but in spite of that, at a distance of only 1 millimeter away, it is reduced to practical stagnation, being less than a millimicron per century.

In any solenoid, the ampere-turns per linear inch furnish a measure of the speed of the supposed magnetic circulation along the axis—no matter what the material of the core may be—in millimicrons per sec.

[1 micron$=10^{-6}$ meter; 1 millimicron is 10^{-9} meter $=10^{-7}$ centimeter, or a millionth of a millimeter.]

To get up an ethereal speed of 1 centimeter per second—such as might be detected experimentally by refined optical appliances, through its effect in

accelerating or retarding the speed of light sent along the lines of magnetic force—would need a solenoid of great length, round every centimeter of which 1000 amperes circulated 3000 times. That is to say, a long field of four million c.g.s. units of intensity.

In other words, any streaming along magnetic lines of force, such as could account for the energy of a magnetic field, must be comparable, in centimeters per second, to one four-millionth of the number of c.g.s. units of intensity in the magnetic field.

The μ^2-1 portion is that which we call "matter," and this portion is readily susceptible to locomotion, being subject to—that is, accelerated by—mechanical force. The free portion of normal density 1 is absolutely stationary as regards locomotion, whether it be inside or outside a region occupied by ordinary matter, for it is not amenable to either mechanical or electric forces. They are transmitted by it, but never terminate upon it; except, indeed, at the peculiar structure called a wave-front, which simulates some of the properties of matter.

(If free or unmodified ether can ever be moved at all, it must be by means of a magnetic field; along the lines of which it has, in several theories, been supposed to circulate. Even this, however, is not real locomotion.)

Fizeau tested that straightforward consequence of this theory which is known as Fresnel's law, and ascertained by experiment that a beam of light was accelerated or retarded by a stream of water, according as it travelled with or against the stream. And he found the magnitude of the effect precisely in accordance with the ratio of the locomotive portion of the ether to the whole—the fraction $(\mu^2 - 1)/\mu^2$ of the speed of the water being added to or subtracted from the velocity of light, when a beam was sent down or up the stream.

But even if another mode of expression be adopted, the result to be anticipated from this experiment would be the same.

For instead of saying that a modified portion of the ether is moving with the full velocity of the

body while the rest is stationary, it is permissible for some purposes to treat the whole internal ether as moving with a fraction of the velocity of the body.

On this method of statement the ether outside a moving body is still absolutely stationary, but, as the body advances, ether may be thought of as continually condensing in front, and, as it were, evaporating behind; while, inside, it is streaming through the body in its condensed condition at a pace such that what is equivalent to the normal quantity of ether in space may remain absolutely stationary. To this end its speed backward relatively to the body must be u/μ^2 and accordingly its speed forward in space must be $u\,(1 - 1/\mu^2)$.

For consider a slab of matter moving flatways with velocity u; let its internal etherial density be μ^2, and let the external ether of density 1 be stationary. Let the forward speed of the internal ether through space be xu, so that a beam of light therein would be hurried forward with this velocity. Then consider two imaginary parallel planes moving with the slab, one in advance of it and the other inside it, and express the fact that the amount of ether between those two planes must continue constant. The amount streaming relatively backward through the first plane as it moves will be measured by u times the external density, while the amount similarly streaming backward through the second plane will be $(u - xu)$ times the internal density. But this latter amount must equal the former amount. In other words,

$u \times 1$ must equal $(u - xu) \times \mu^2$.