



Philosophical Magazine Series 5

ISSN: 1941-5982 (Print) 1941-5990 (Online) Journal homepage: <http://www.tandfonline.com/loi/tphm16>

LXVII. Remarks on a new theory of dew

Charles Tomlinson F.R.S.

To cite this article: Charles Tomlinson F.R.S. (1886) LXVII. Remarks on a new theory of dew , Philosophical Magazine Series 5, 21:133, 483-494, DOI: [10.1080/14786448608627882](https://doi.org/10.1080/14786448608627882)

To link to this article: <http://dx.doi.org/10.1080/14786448608627882>



Published online: 29 Apr 2009.



Submit your article to this journal [↗](#)



Article views: 2



View related articles [↗](#)

Therefore the chance that the angle COp shall lie between ϕ and $\phi + d\phi$ is proportional to $\sin \phi d\phi$. And therefore, as stated in (1), for any given direction of $p\text{O}q$ all directions of OC are in Maxwell's distribution equally probable.

If Maxwell's distribution does not exist, then for any direction of $p\text{O}q$ some directions of OC are more probable than others before collision. After collision all are equally probable; I think it follows that collisions tend to bring about Maxwell's distribution.

LXVII. *Remarks on a new Theory of Dew.*

By CHARLES TOMLINSON, F.R.S.*

MR. AITKEN read before the Royal Society of Edinburgh, on the 21st of December last, a paper in which a new theory of Dew is promulgated in opposition to that of Dr. Wells, "who," he says, "has justly been considered the great master of this subject." An abstract of the paper, presumably by the author himself, was given in the number of 'Nature' for the 14th of January last, preparatory to the publication of the memoir in the 'Edinburgh Transactions.'

Many years ago I showed that the chief points which Dr. Wells is said to have established had already been demonstrated by his predecessors; and in noticing his essay in the 'Quarterly Review' for 1814, Dr. Thomas Young enters a protest against "the total novelty of the opinions which Dr. Wells's laborious series of experiments had so amply illustrated and confirmed; for while the author affords us complete information respecting the sentiments of Aristotle and Theophrastus as to the nature and causes of dew, some of the works of the most distinguished philosophers of modern times have most unaccountably escaped his attention."

The fact is there is a considerable difference between a scientific worker and a scientific writer. The worker is generally too intent on his own share in discovery to do more than accept the conditions of the question in hand from some writer who may have compiled from earlier books and not taken the trouble to consult original memoirs. There are not many writers who work at scientific literature with the same zeal with which literary men pursue their labours; and the reason is to be found in the marked difference between literature and science. A literary work bears the impress of *mind*, scientific work bears the stamp of *nature*.

* Communicated by the Author.

The one is individual and proper to the man ; the other is general and has no individuality. A work by Shakspeare remains for all time untouched, unchanged (except to make the text more correct, and thus augment the author's individuality); a work by Davy may be taken up by Faraday, and Faraday's work may be carried forward by his contemporaries or successors. And this is probably what Lord Bacon meant when he said that his inductive method of philosophizing tended rather "to level wit and intellect."

The interest that is felt in literary history, contrasted with the comparative indifference to scientific history, rests on the fact that a Chaucer, a Shakspeare, a Dryden, a Gibbon is each an intellect rounded, complete, fixed, and final. But, without meaning the slightest disrespect to such great men as Newton, Davy, and Faraday, it must be admitted that they are but parts of a great whole, and that whole is Nature. We care more about the laws of Nature than about their discoverers ; but every one feels an interest in a great writer because he and his works are inseparably connected. An unpublished poem or letter by one of the great writers of the past would excite the ardour of the literary world ; a new fact in the history of oxygen or of the composition of water would fail to receive more than a passing glance from scientific men. They consider that all the main known facts are embodied in textbooks, while that which is not so embodied is of no consequence. They consider that we have the names of the discoverers and the dates of all important facts in the main correct. They want to pursue discovery, not its history ; and hence they feel but little interest in the light thrown by old memoirs on the progress of the past.

Sir John Herschel, writing a scientific treatise, refers to Wells's Essay as "one of the most beautiful specimens of inductive experimental inquiry," and earnestly recommends it to the student "as a model with which he will do well to become familiar." Dr. Whewell, writing scientific history, is more cautious : he refers to Wells's Essay as "one of those books which most drew attention to the true doctrine."

Wells, in his essay, writes with an air of authority. His tone is everywhere that of a man announcing his own discoveries. For example, he says :—"I have frequently seen, during nights that were generally clear, a thermometer lying on the grass-plot rise several degrees upon the zenith being occupied only a few minutes by a cloud." Most of the important steps in the theory are thus stated as if for the first time, and we find only a loose and general reference to authorities, and a very scant acknowledgment of other men's

labours. Nevertheless, most of Wells's results had been published long before the author commenced his labours, and the theory for which he has obtained so much credit was also similarly indicated, in brief but unmistakable terms*.

The chief points which Dr. Wells is said to have established may be thus stated :—

I. That on clear and serene nights the surface of the earth is colder than the air some feet above it.

II. That on such nights dew or hoar-frost is formed.

III. That in cloudy weather the temperature of the ground approaches, and is often identical with, that of the air ; and under such circumstances little or no dew is formed.

IV. That screens, even of the lightest material, interposed between the ground and the clear sky, and, in general, whatever interrupts the view of the sky, prevents that portion of the ground thus protected from cooling below the temperature of the air.

V. That different bodies exposed to the clear sky become colder than the air ; the times and amounts of cooling being, in general, different in different bodies.

VI. That all these varied phenomena are to be accounted for on the principles of radiation and condensation, by the first of which the surface of the earth after sunset, provided the sky be clear, cools down below the temperature of the air ; and by the second of which, the vapour suspended in the air is reduced to the liquid state by contact with a body cooler than itself. But should the sky be clouded or the ground be protected by means of screens, the heat radiated from the earth is reflected back again, and thus maintains the surface at or about the same temperature as that of the air.

Mr. Aitken, in his theory of dew, states :—

I. That the ground below the surface is always hotter than the air over it, and that, so long as this excess keeps the surface above the dew-point of the air, it will, if moist, give off vapour, which will condense on the grass and form dew, and not the vapour that was previously present in the air.

II. That vapours rising from the ground during dewy nights are thus trapped by the herbage, or within tin trays inverted on the ground.

III. That on weighing a small area of the exposed surface

* The details are given in my essay, "On the Claim of Dr. Wells to be regarded as the Author of the Theory of Dew," published in the 'Edinburgh New Philosophical Journal,' for January 1861 ; and in a somewhat enlarged form in 'Experimental Essays,' published in 1863, in Weale's Series. See also a notice from my pen in the 'Chemical News' of the 12th April, 1867, of a reprint of Wells's Essay.

of the ground, such as a turf six inches square that had been exposed for some hours while dew was forming, it was always found to have lost weight.

IV. That bare soil loses nearly as much in weight as grass-land.

V. That pieces of blackened glass placed on the ground remain clear of vapour, thereby showing the soil to be always giving off vapour because the surface is above the dew-point.

VI. That even where radiation is strong and vapour is condensed on the soil, such vapour is supposed to proceed from below, and to be trapped by the cold surface-soil. Thus the under surface of clouds are often covered with hoar-frost, while there is little on the upper surface; and in roads the under surface of stones may be wet as well as the under sides of slates placed on gravelly roads.

VII. That the leaves of plants apparently wet with dew are not really so, but the moisture is an exudation from the plants themselves*.

VIII. That the radiating powers of different bodies have hitherto been erroneously stated. Black and white cloths were found to radiate equally well; soil and grass were also almost exactly equal to each other; lampblack was equal to whitening; sulphur was about two thirds that of black paint; snow in the shade on a bright day was at mid-day 7° colder than the air, while a black surface at the same time was only 4° colder; but at night both radiated almost equally well.

Such is the new theory of dew, which, if accepted, must go far to render nugatory the results obtained by some of the most celebrated observers. It would occupy too much time and space to examine the above eight propositions minutely, and to compare their statements with already received results. It will, perhaps, be sufficient for our purpose to give a few details from those researches upon which we have hitherto most relied, and leave the reader to contrast them with Mr. Aitken's ingenious speculations.

That "the ground at a short distance below the surface is always hotter than the air over it," is not a new observation. In 1779 Pictet† found that a thermometer suspended 5 feet from the ground marked a lower temperature on clear nights than one suspended at the height of 75 feet; he also placed a thermometer with its bulb buried in the earth, and found it to

* Muschenbroeck regarded dew as a real perspiration of plants.

† *Lettres Physiques* &c. of M. de Luc, La Haye and Paris, 1779; also *Essais de Physique*, by M. Pictet, Geneva, 1790.

indicate a higher temperature than the air above it. He had supposed the cold of evening to descend from above, and could scarcely believe his eyes when he found the thermometer at the height of 75 feet to read more than 2° R. above one at 5 feet. "It is then from the ground that this coldness proceeds, for the thermometer at 4 lines from the ground generally read lower than the one at 5 feet." All this is correctly observed; but the buried thermometer led him astray; for this naturally indicating a higher temperature than any of the other instruments, he supposed that the earth retained a considerable portion of the heat it had acquired during the day, that a layer of air cooled by evaporation from the surface produced the cold to the height of four lines, while at higher elevations the warmer air escaped this chilling influence.

In January 1781 Professor Patrick Wilson noticed at the Glasgow Observatory, between 1 and 3 A.M., the temperature of the air 24 feet from the ground to be 7° F., while the snow in the Park at the depth of 6 inches was 24° . He also noticed the effect of clouds and screens in raising the temperature, and Dr. Black suggested a screen of gauze, which was tried, with a like effect.

That dew rose out of the ground is a very old notion. Mr. Aitken refers it to Gersten; but his Treatise appeared so lately as 1748, under the title *Exercitationes recentiores circa Roris meteora*. In a volume in my library, entitled *De Rore disquisitio physica D. Joannis Nardii* (Florentiæ, 1642), it is stated:—"Rorem observant hi fieri exhalitu è terra elevato, silente vento, celo sereno, anni tempore, loco, et regione temperatis."

The Florentine Academicians were the first to show that the moisture which supplied dew already existed in the air. The Hon. Robert Boyle, in his 'Experimental History of Cold' (1665), showed that the beautiful exhibition of frost on the window-pane is condensed from the vapour of the air in the room, and he attempted to estimate, by weighing, the amount of vapour condensed within a given time upon a phial containing a mixture of salt and snow. Boyle distinctly recognized the fact that dew and hoar-frost are formed by the precipitation of the vapour of the air upon a colder body.

In 1752 M. le Roi, of Montpellier, doubting the received notion that dew rose from the ground, sealed up a bottle of white glass containing air at 20° R. (77° F.), and he noticed that as the temperature cooled down there was a considerable deposit of dew within the bottle, which again disappeared as the temperature became higher. Le Roi made a number of admirable observations, among others the method of deter-

mining the dew-point, which has generally been assigned to Dalton under the date 1801.

But probably among all the researches into the phenomena of dew those of M. Melloni are best adapted to furnish an answer to Mr. Aitken. His observations were made in the autumn of 1846 in the valley of La Lava, situate between Naples and Salerno. It is curious to note that the Austrian and Bourbon Governments, in their dread of novelty, would not allow a new text-book on Physics to be introduced into colleges and schools; so that the old theory was taught, namely, that dew rose from the earth. Melloni, in order to show that the laws of radiation are the same in Italy as in other countries, where there is more political liberty, undertook these researches*.

The early experimentalists seemed to pride themselves on the great differences between the thermometers on the grass and other substances, and the thermometer suspended in the air above them, as when Wells assumes a kind of injured tone in noticing that Six had obtained a greater difference than he had done, viz. 16° F. †; whereas Melloni rather prides himself on the smallness of this difference, and maintains that the great depression of temperature, as observed by Wells and others, arose quite as much from the radiation of the glass and other materials of the thermometers, as from that of the substance under examination ‡. Nor does he find it necessary, in the economy of nature, that vegetation should cool down so much below the temperature of the air as had hitherto been supposed; since a difference of one or two degrees C. would, in most cases, suffice to condense the moisture of the air upon grass and the tender surfaces of leaves. He answers the theory which supposes that, as the cold varies from 1° to 10° C. with the amount of shelter or exposure, so certain plants are bedewed while others are quite dry, by denying the fact; for we have either the entire absence of

* "On the Nocturnal Cooling of Bodies exposed to a Free Atmosphere in Calm and Serene Weather, and on the resulting Phenomena near the Earth's Surface," read to the Royal Academy of Naples on the 23rd February, and 9th and 16th March, 1847. A French translation of these Memoirs was made under the Author's superintendence for the *Annales de Chimie et de Physique* for February and April 1848. An excellent English translation appeared in Taylor's 'Scientific Memoirs,' vol. v. 1852.

† Mr. Aitken also notices a difference on dewy nights of from 10° to 18° F. between two thermometers, one placed on the grass and the other under the surface among the stems, but on the top of the soil.

‡ Melloni took extraordinary pains to prevent his thermometers from sharing in the radiation of the bodies, the amount of whose cooling they had to measure.

dew, or its diffusion in quantities sensibly equal on all low-growing plants, whatever their position with respect to the sky. He also insists that dew is never formed except when the air is nearly saturated : also that radiation under a clear sky is always a fixed quantity, whatever the temperature may be ; so that in nights equally serene the same substance always cools to the same extent, whatever the temperature of the air at the time.

The nocturnal differences in heat, moisture, and aqueous condensation do not proceed, as hitherto supposed, from the direct action of the cold due to the radiation of plants and of exposed portions of the soil, but most of the phenomena which precede and accompany the formation of dew result from the more or less prolonged sojourn of the air around the radiating surfaces. In a meadow while dew is forming under a clear sky and a calm air, let us divide the lower region of the atmosphere into two strata—the *lower*, which scarcely rises above the grass ; the *higher*, which extends upwards from it 30 or 40 metres ; and suppose the cold due to the nocturnal radiation of the herbage to be only 1° ; this degree of cold will always remain the same whatever the temperature of the atmosphere. If the air be at 20° , the higher portions of the grass will descend to 19° a few minutes after sunset ; the air in contact with them will be cooled, will descend into the interior of the meadow, and reach the ground. This movement of descent along the leaves and stems will necessarily restore to the air a portion of the lost heat, and will force it to reascend towards the higher part of the meadow, where it will undergo a fresh cooling which will cause a second descent, and so on ; so that the air of the meadow or of the lower stratum, impelled by two opposite influences, will soon take a circulating or convective motion. The cold produced at the surface of the meadow will be gradually transmitted by this aerial circulation to the lower parts, which will also be cooled ; and, on the other hand, both by radiation and by their contact with the superior portion of the stems, the temperature of the whole mass of air which is put in motion will fall. If it be at $19^{\circ}\cdot5$, the grass will sink to $18^{\circ}\cdot5$. By repeating the process the air will fall to 19° , and the grass to 18° ; the air to $18^{\circ}\cdot5$, the grass to $17^{\circ}\cdot5$, and so on ; so that by the action of the grass on the air and the reaction of the air on the grass, the temperature of the lower stratum will be gradually diminished by several degrees, and the space occupied by the herbage retaining its vapour will approach the state of saturation. A thermometer introduced into this space will mark a temperature much lower than that of the higher stratum ; the hygrometer will

there be kept near its maximum of humidity ; and the slightest degree of cold will suffice to precipitate the aqueous vapour on the bodies which are immersed therein.

In the same way may be explained the large amount of cooling which takes place when a thermometer loosely enveloped in wool, or cotton-wool, is exposed to the clear nocturnal sky. The air cooled by coming in contact with these envelopes penetrates into them, and tends to fall by virtue of its greater density ; but the mechanical resistance and the attraction offered by the innumerable tangled fibres retain it for some time in the midst of those parts which are radiating towards the sky. A series of actions and reactions similar to those just described then takes place, and the mixture of air and of wool cools much more than a simple layer of varnish or of lampblack applied to the thermometer. In the same way plants with velvety leaves acquire a somewhat lower temperature than plants with smooth ones, and consequently become covered with a greater quantity of dew. Now in studying the phenomena of cooling in the meadow, if the greatest cold be produced at the top of the grass, the cooler air would, by its superior density, soon sink to a lower level. We may imagine three layers of air—one in contact with the points of the grass ; the second immediately below it, where the blades are more numerous, and more or less exposed to the zenith ; and the third entangled in the matted portion, which is entirely sheltered from the sky. The points of the grass are in a condition most favourable for free radiation, but the blades are there fewer in number, and the air is exposed to slight disturbances which diminish the radiating effect ; but the middle portion, where the blades are most numerous and the disturbance less, radiates most powerfully and produces the greatest cooling. The lowest layer of air being sheltered, will at first have a higher temperature than the other two ; but these, being cooler and denser, will descend and react on the radiating portions of the grass, and the more so in proportion as the movement is slow. In time the middle portion will contract the greatest cold, and in descending will displace the somewhat warmer air, and in the end the lower stratum will be colder than the first, so that the blades and stems which are least exposed to the aspect of the sky will be colder than the points of the blades, and the thermometer buried in the grass will mark a lower temperature than one in contact with the surface. And here, too, the formation of dew will be most abundant, not on the surface, but just below it. But as the cooling goes on, the lower layer of air will be again displaced, and radiation continuing from the soil, a

certain amount of dryness will be produced, evaporation will take place, and the vapour thus formed will be again precipitated on the upper parts of the blade. But in order to effect this, the ground must be comparatively dry. *This appearance of dew on the upper parts of plants led to the idea that dew rose out of the earth.*

The process above described will of course be disturbed or destroyed by wind. On the other hand, what is called "a perfectly calm night" does not exist in nature. Air is so very mobile a fluid, that the least difference in temperature sets it in motion in the form of imperceptible currents; and there are always numerous inequalities of temperature depending on the nature of the soil, the greater or less amount of vegetation, the degree of cultivation, the presence of houses, all of which prevent equilibrium from being attained in the air. But supposing the air to be tranquil so far as our perceptions are concerned, then the processes of radiation, convection, and condensation sufficiently account for the presence of dew, whether on the herbage or on the inner surface of Mr. Aitken's thin metal trays.

But let us hear Melloni. He says:—"Some have pretended to discover proofs of the existence of a *current of warm vapour exhaled by the earth*, and an objection against the principle of nocturnal radiation in the different proportions of water deposited during calm and clear nights on the two surfaces of a bell-glass inverted on the ground; for it often happens that the dew is more copiously formed on the inside than on the outside of the vessel. But this fact by no means justifies the conclusion; for the phenomena of circulation and aqueous precipitation just described with reference to the air and grass of a meadow are also produced in the interior of the vessel, the sides of which are cooled by radiation. These actions become even more intense in this case, because the imprisoned air is sheltered from the least atmospheric disturbance; and we have just seen that the quantity of water condensed on the outside depends, on the contrary, on the degree of calm in the atmosphere. Hence the slightest degree of wind will suffice to render more abundant the precipitation on the interior of the bell-glass, without leading to the conclusion of an increase favouring the pretence of an exhalation of vapour from the earth, and contrary to the theory of dew founded on the cold produced by nocturnal radiation.

"Nothing, then, is simpler now than to comprehend why a radiating body such as a piece of wood or stone, placed on a moist soil towards sunset, is abundantly covered with dew on

its lower side before a single drop of liquid appears on the upper surface. The body submitted to the frigorific action of the sky is in contact with two masses of air—the one at rest and humid, because it is sheltered and situated close to the earth's surface; the other less humid and exposed to the changes of the atmosphere. The former then will be more disposed than the latter for the precipitation of vapour, and the dew ought to show itself first on the side turned towards the soil; it may even exist only on this surface, if the air has but little moisture, or is agitated by wind. Hence the experiment of a plate covered with waxed cloth, which being placed on the grass was found sometimes to be moistened only on its lower surface, by no means proves that the dew is exhaled from the ground like those clouds of vapour which are seen to arise from a vessel full of hot water."

Melloni, in two letters to Arago, describes some experiments with thin tin plates in which the surface looking towards the ground is covered with dew while the upper portions remain dry.

While Melloni insists on the influence of radiation in the formation of dew, whereby bodies become colder than the air and so condense its vapour, he claims to have first pointed out the great influence exerted by the reaction of the air on the radiating body; and he defines dew, not as an immediate effect of the cooling produced by nocturnal radiation, but as a consequence of a series of actions and reactions between the cold due to the radiation of plants &c. and the cold transmitted to the surrounding air. The grass becomes slightly cooled below the temperature of the air, but it soon imparts to it a portion of the cold thus acquired; and as the difference in temperature between the radiating body and the air is independent of the absolute temperature at the time, grass surrounded by the colder air becomes lower in temperature and imparts a fresh amount of cold to the air, which in its turn reacts on the grass and gives to it a still lower temperature, and so on. In the mean time the air acquires a kind of vertical circulatory movement, the upper portions condensed by cold descending and those at the surface ascending. As this gradual cooling goes on, the surface air gradually becomes saturated with moisture and the slight amount of cold produced by the direct action of radiation is sufficient to condense the vapour contained in the air.

If in the above statement we read a thin metal tray instead of grass, the process and its result remain the same.

If we now turn from the grass meadow to grander natural objects, abundant proof will be found that dew is condensed from the air and does not rise out of the ground. The

interior of Persia is characterized by the absence of dew. In this region there are no rivers of any magnitude, and no rain falls from May to the end of November. But on approaching the Persian Gulf nocturnal dews are heavy and the coverings of beds on the house roofs become saturated with wet. In the African desert of Sahara, the traveller Denham suffered from the dryness of the air until within a certain distance of Lake Tchad, where, though there was no appearance of water at any part of the horizon, the dews were so abundant as to wet the clothes of people outside the tent. When Dr. J. D. Hooker was in East Nepal he noticed that the sun in many places did not reach the bottom of the valleys until 10 A.M., and was off again by 3 P.M., while the radiation towards a clear sky was so powerful that dew frequently formed in the shade throughout the day. Such, too, was the clearness of the sky that at night our traveller found the upper blanket of his bed coated with moisture from the rapid abstraction of heat by the tarpaulin of his tent, which had become frozen by its own radiation.

In equatorial regions, where the nights are long, dews are so abundant that Humboldt compares their effects to those of rain, and they become more and more abundant in approaching the equator; whereas in the great assemblage of islands known as Polynesia, the dew is feeble or absent, in consequence of the trade and other warm winds from the sea preserving a nearly uniform temperature.

There is such a vast consensus of scientific opinion in favour of the received theory of dew, that any attempt to set it aside in favour of another must be supported by the strongest experimental evidence. And yet some of Mr. Aitken's proofs seem to bear testimony to the received theory rather than to the one now advocated. For example, when Mr. Aitken exposes a turf six inches square to the air in a scale-pan and finds it to have lost weight, he does not touch the question whether the vapour that forms dew is not already in the air before it is condensed and deposited. He only proves that a moist soil is constantly giving off vapour under a clear sky. Snow and ice behave in like manner: 100 grains of light snow have been known to lose 60 grains in weight during one night when the temperature was below 25° ; and Patrick Wilson, exposing various objects on a balanced board (named by him a "snow-scale"), noticed that as they cooled down by radiation, they became covered with hoarfrost and increased in weight, and the vapour which supplied the rime was derived from the air, seeing that the scale-board was elevated 24 feet above the ground.

When Mr. Aitken places his shallow trays of thin metal "over the ground to be tested," are we to understand that the edges of the trays are in contact with the ground? If so, the results are not in harmony with another set of observations, in which two slates or two iron weights are placed one on the ground and the other elevated a few inches above it. That on the ground, "and in heat communication with it," is said to have remained dry, while the elevated one was bedewed all over. Surely this result is in favour of the received theory.

Perhaps the most startling portion of the new theory is that which relates to plants, whose very existence would seem in many cases to depend on the formation of dew. If the moisture on plants were "the excretion of liquid" by the plants themselves, and not dew, for what purpose are plants endowed with such high radiating powers, in some cases superior to that of lampblack? Taking this at 100, Melloni, by his careful method, found the radiating power of different herbs with flexible leaves to be 103, the leaves of the elm and poplar to be 101, that of vegetable mould 92.

Enough, however, has been said on this subject; but we cannot conclude without offering an apology to the readers of the 'Philosophical Magazine' for the very elementary details of this article.

LXVIII.—*On the Efflux of Air as modified by the Form of the Discharging Orifice.* By HENRY WILDE, Esq.*

IN my former paper on the Efflux of Air, the hydraulic coefficient $\cdot 62$, as commonly applied to the discharge of elastic fluids through an orifice in a thin plate, was taken as the value of the contraction of such orifice, and from this coefficient the highest velocities shown in the several tables were deduced. A review of the results of my experiments by Prof. Osborne Reynolds † led me to doubt the value of this coefficient, and to make further experiments with the object of determining the maximum rate of discharge from an orifice of the best form.

Five disks of brass had each a hole drilled through its centre two hundredths of an inch in diameter. Equality in the size of the holes was accurately determined by means of a standard cylindrical gauge. These disks I shall designate A, B, C, D, E.

* Communicated by the Author, having been read at a Meeting of the Manchester Literary and Philosophical Society, March 23rd, 1886.

† Proceedings Manchester Lit. and Phil. Society, vol. xxv. p. 55; Phil. Mag. March 1886, p. 185.