THE DISCOVERY OF THE BROWNIAN MOTION

Peter W. van der Pas.

It sometimes happens that a concept which is discovered by an investigator, working in one scientific field, appears to be more fruitful in quite another field, into which it is consequently absorbed completely. An interesting example is osmosis, which was first described, very accurately, by the physicist NOLLET (1752), was further studied by the plant physiologists DUTROCHET (1837), PFEFFER (1877) and DE VRIES (1883) and finally became one of the corner stones of physical chemistry through the work of the chemist VAN 'T HOFF (1887).

Brownian motion is another example. The botanist ROBERT BROWN (1827) is credited with its discovery. His observation lay dormant for some 30 years, until the time the physicists started to become interested. They offered many explanations for the Brownian motion before the true explanation was first suggested by DELSAUX (1877), which explanation was later established with certainty through the experimental work of PERRIN (1909) and the theoretical work of EINSTEIN (1905).

It appeared that the Brownian motion was a visual demonstration of the actual existence of molecules. The number of AVOGADRO, the number of molecules in a liter of gas under standard conditions, could be determined from observations of the Brownian motion and the results compared reasonably well with the estimates of this number, made from experiments on quite different phenomena which were also explained by the actual existence of molecules.

ROBERT BROWN announced his discovery in a long paper (1), 22 pages in the edition of the Ray Society: *A brief account of microscopical observations, made in the months of June, July and August (1827), on the particles, contained in the pollen of plants and on the general existence of active molecules in organic and inorganic matter.* In this paper, he describes how he found small particles in vivid motion, originating from pollen grains of plants, how he extended his research to pollen grains, obtained from herbarium material (some of which quite old) and finally, how he investigated material, such as lava, obsidian, meteorites

(1) R. BROWN (1), vol. I, pp. 465-486, 1866.

etc. He observed the motion in small particles, obtained from all these materials.

BROWN's discovery therefore consists of : 1) observing the vivid motion of small particles which are suspended in water and 2) recognizing the fact that this motion is exhibited not only by particles which are obtained from living, organic matter, but also by particles, obtained from dead, inorganic material.

The cause of this motion, the fact that the small particles are in continuous collision with the molecules of the liquid in which they are suspended, and the fact that the impulses, given to the particles this way are not in balance at any time, and the fact that the resulting impulse causes the particle to move, was not known to BROWN; this was discovered only many years later.

BROWN called these particles *molecules*, or sometime *active molecules* and he stated that these molecules were either spherical or built up from spheres if they were observed to have another shape, and that they were approximately of the same size; their diameter varying between 1.26 and 1.6 microns. These statements are not true. BROWN was led to them because he worked with an imperfect lens at the border line of its magnifying power.

In his paper BROWN mentions the names of some investigators who might have anticipated his discovery. Indeed, since microscopical observations had been made already for more than 150 years, one might have expected that motion would have been observed long before. The names of the possible precursors, mentioned by BROWN are : LEEUWENHOEK, GRAY, NEEDHAM, BUFFON, SPALLANZANI, GLEICHEN, WRISBERG, O.F. MÜLLER, DRUMMOND and BYWATER. He does not give a reference to the location in the books of these scientists where the statements, which he had in mind may be found; he does not even mention the titles of the books he has consulted. However, a study of likely places in the works of these scientists (2) has shown that it is not probable that any of these investigators qualifies as the discoverer of the Brownian motion. Some of them indeed observed the irregular motion, but none made the crucial experiment of obtaining very small particles from dead, inorganic material and checking whether these also exhibited the motion. Those of them who did observe the motion were under the impression that they were dealing with small, living organisms.

(2) P.W. VAN DER PAS, (1968).

However, BROWN overlooked one precursor, JAN INGEN-HOUSZ. We cannot blame BROWN too much for this oversight; the communication of INGHEN-HOUSZ occurs at two places only, places where one would not expect to find this information, while the discovery is formulated in only a few sentences.

In July 1784, INGEN-HOUSZ contribured to the *Journal de Physique* a paper (3) on the origin and the nature of the «green matter» of PRIESTLEY. A german translation of this paper was included in the second volume of the second edition of a collection of papers by INGEN-HOUSZ (4), published in 1784. Preceding this paper, a small contribution : *Remarks on the use of the magnifying glass* (5) is found. Most of the papers in this collection were originally written in the french language; there exists a french edition of this collection also, of which the first volume was published in 1785 and the second one in 1789. In the second volume of this french edition, an augmented version of the paper on PRIESTLEY's «green matter» is found (6), preceded by the *Remarks on the use of the microscope* (7). It was this version of the paper wich had been used for the german translation; the french original was published five years after the german translation because of the tardiness of the publisher. This small communication on the use of the miscroscope and its german translation are the only places where INGEN-HOUSZ announces his discovery .A translation of the french original of this communication is presented at the end of this paper. It is only in this french version that INGEN-HOUSZ links the little paper with his essay of the «green matter» of PRIESTLEY. We may therefore assume that this discovery was made while working on the problem of the identification of the «green matter», about 1783-84.

INGEN-HOUSZ actually wrote this small paper to discuss his method of covering liquid microscopical objects with a thin film of glass, to avoid premature vaporization.

The idea of covering microscopical objects was not new. Cover plates may well have been used since the time, microscopes which were equipped with a stage, became available. In 1742, BAKER recommended to inclose objects which are flat and transparent, between «Muscovy talcs» or

(3) J. INGEN-HOUSZ (1), 1784.
(4) J. INGEN-HOUSZ (2), vol. 11, 127-236, 1784.
(5) J. INGEN-HOUSZ (2), vol. II, pp. 122-126, 1784.
(6) J. INGEN-HOUSZ (3), vol. II, pp. 6-136, 1789.
(7) J. INGEN-HOUSZ (3), vol. II. pp. 1-5 1789.

«isinglass» (8). Both these substances are mica. It is obvious that mica was used because it can be split very easily into thin lamina and is quite transparent. Muscovy talc, which is not actually a talcum, came from the region of Archangel; it was valued more especially for use in microscopic work because it was available in large pieces. It was also called, and more appropriately, Muscovy glass or *glacies Mariae* (9). The lamina were cut into disks, which were placed in the round holes of ivory sliders and fastened between elastic brass rings. For living objects, such as fleas, BAKER recommended to encage them between plates of mica but, warns BAKER, in this case, the plates should not be pressed together too firmly. GEORGE ADAMS gave much the same advice in 1746 (10).

From the way these authors express themselves in the discussion of the observation of animalcules in water and growing crystals, one may deduce that these objects were always viewed without cover plates.

A century later, mica was still mentioned by HARTING (11) as a possible material for preparing cover plates, especially for preparations which were to be preserved, since glass cover plates were at the time very expensive. But according to HARTING, glass cover plates were most frequently used at that time. The thick ones (2/3 to 3 mm), used for small magnifications, could be made by the microscopist himself; thinner ones (1/5 mm) were commercially available.

In his paper, INGEN-HOUSZ discussed the fact that small droplets of water or alcohol, in which one wants to observe the «insects» (infusoria), evaporate rapidly. In addition, he cited the curved surface of the droplets, or the wedge shape they assume in the solar microscope, as sources of colored borders in the image. In order to avoid these inconveniences, he recommended covering microscopical objects in the liquid state with disks of mica or, even better, with the thin glass films which are produced in glass blowing operations and which are discarded in the shop. This was the first time that this procedure was recommended. In 1848, HARTING still mentioned the glass film, first suggested by INGEN-HOUSZ, however without mentioning his name. Two years later, HARTING wrote that the mica plates, and also the glass films, were no more desirable since very thin glass sheets of large size, from which one could cut the plates himself, were available from England (12). It seems that

(8) H. BAKER, pp. 56-64, 1742.
(9) J.C. VALMONT DE BOMARE, vol. V, pp. 420-422, 1775.
(10) G. ADAMS, pp. 29-32, 1747.
(11) P. HARTING, vol. II, pp. 122-124, 1848.
(12) P. HARTING, vol. III, pp. 447-449, 1850.

HARTING did not know that INGEN-HOUSZ was the first to recommend the glass films, otherwise he would certainly have given the credit to him.

While discussing the problems due to evaporation of a liquid under the microscope, INGEN-HOUSZ mentions his observation of the Brownian motion :

> As long as the droplet lasts, the entire liquid and consequently everything which is contained in it is kept in continuous motion by the evaporation, and this motion can give the impression that *some of the corpuscules are living, even if they have not the slightest life in them.* To see clearly how one can deceive one's mind on this point if one is not careful, one only has to place a drop of alcohol in the focal point of a microscope and introduce a little finely ground charcoal therein, and one will see these corpuscules in a confused, continuous and violent motion, *as if* they were animalcules which move rapidly around.

Here the two elements of the Brownian motion, the rapid random motion of the corpuscules and the fact that the motion is also shown by non-living material are presented by INGEN-HOUSZ in only two sentences, which are buried in the presentation of quite another subject. Clearly, INGEN-HOUSZ did not realize the importance of this observation, if he had done so, he would have elaborated on the subject and perhaps even conjectured about the cause of the phenomenon. BROWN considered his discovery of sufficient importance to devote a long paper to a description of all his experiments and to the conclusions he drew from the phenomena at various stages of his investigation. After his first observations on the particles which emerged from the pollen grains, after bursting due to their immersion in water, he thought that he had observed the *organic molecules* of BUFFON; after his experiments with inorganic particles, he did not know what to think of them any more. BROWN arrived at the fact that inanimate particles do exhibit the motion only after a long series of experiments and in reality only by accident. If he had not tried herbarium material, he would never have investigated inorganic matter and would have firmly believed that he had discovered the source of life. It is only in a short additional paper (13), published two years after his observations, that he positively affirms that inanimate particles also show the motion. INGEN-HOUSZ, on the contrary, apparently did not perform a long series of experiments. From the

(13) R. BROWN (2), 1829.

casual way in which he presents his remark, one has the impression that he describes a control test, made after suspecting that the motion does not always indicate life. It is interesting to note that he recommended to use alcohol in this control test which used powdered charcoal as an object. Due to the higher molecular weight, the motion is much more vivid in this medium. That particles show a more vivid motion in alcohol had already been described by GLEICHEN (14) in 1764; INGEN-HOUSZ probably knew this book. Altough he does not say so, INGEN-HOUSZ may have chosen alcohol as a medium for still another reason, the expectation that living organisms would not survive long in this medium.

It will be clear that INGEN-HOUSZ has an earlier claim to the discovery of the Brownian motion than ROBERT BROWN himself. The reason that the name of INGEN-HOUSZ is not associated with this phenomenon is not the fact that he did not realise its importance; ROBERT BROWN did not realise that either. The reason is that JAN INGEN-HOUSZ was too modest. In BROWN's paper, there is a dramatic built-up as he describes his successive observations one by one and discusses his current interpretations. The remark of INGHEN-HOUSZ is only casual; it might easily be overlooked by some-one who was reading his book, especially since INGEN-HOUSZ said not only once, but twice, that the remarks in his little paper were of no importance to those who are familiar with the use of the microscope. But in those few sentences he shows a much deeper intuitive insight in the phenomenon than BROWN did in his 22 page long article. It is now too late to introduce the term «Ingen-housz motion» into the scientific literature to replace the term «Brownian motion». However, INGEN-HOUSZ is certainly entitled to a foot note in future text books, pointing out his priority.

(14) W.F. VON GLEICHEN, pp. 30-31 (first series), 1764.

REMARKS ON THE USE OF THE MICROSCOPE.

By Jan Ingen-housz.

N.B. I have thought it appropriate te precede the following paper with these considerations which, although of no importance for those have frequently used the microscope, will at least be a guide to others.

I have often troubled my head about the problem to find a method to avoid the too rapid evaporation of a drop of water, or any other liquid, in which I wanted to observe the insects, and I know that other observers are plagued with the same problem. Even if one wishes to observe the shape and size of some of these corpuscules for even the short time during which such a droplet lasts in the focal point of a microscope, one must agree that, as long as the droplet lasts, the entire liquid and consequently everything which is contained in it, is kept in continuous motion by the evaporation, and that this motion can give the impression that some of these corpuscules are living, even if they have not the slightest life in them.

To see clearly how one can deceive one's mind on this point, if one is not careful; one has only to place a drop of alcohol in the focal point of a microscope and introduce a little finely ground charcoal therein, and one will see these corpuscules in a confused, continuous and violent motion as if they were animalcules which move rapidly around.

If the droplet is rather large ,it has a convex surface which refracts the light more or less; if it is very small, it lasts hardly long enough to enable observing its contents at one's leisure.

These difficulties are even greater if one uses the solar microscope, because in this case, the object is placed in a brilliant cone of light which increases the temperature and accelerates the evaporation. In addition, since the plate on which the droplet is placed vertically in the solar microscope, the droplet assumes an uneven shape, it becomes prism-shaped, which adds to the refraction and produces colors in the image. If the liquid is placed in a tube, the refraction becomes worse and the body of the liquid is too thick and too unequal; the rays of light assume the prismatic colors while passing through the tube.

These difficulties can be avoided largely if the droplet is placed between two flat, polished glass plates, such as are used for the manufacture of mirrors. In order to distribute the droplet evenly between the plates, I glue pieces of thin paper at the edges of one of the glass plates.

This way, all difficulties would be overcome, if it were possible to find glass which is polished on both sides, and in addition is sufficiently thin. However, not being able to find glass of the desired kind, I have helped myself very well with the following, simple method.

Having placed the drop of liquid which I want to examine, on a glass object carrier, I cover it with a very thin sheet of talc (i.e. mica) The round plates, between which it is customary to place dry objects in the slides of almost all microscopes, have served me very well, although I like them a little larger. But the very thin films of glass, which litter the floors of all glass blowing shops are even better than those sheets of talc; I use those to cover the droplets which I want to examine. These films flatten the droplet, makes it thinner and of an even thickness. Under these films, the vaporisation is so slow that a droplet which would evaporate in a few minutes, hardly vaporizes in the course of hours. Hence, by this means one can observe at one's leisure, the smallest objects for a sufficiently long time to follow the changes or metamorphoses which occur in them.

These glass films serve equally well in the solar microscope as in the ordinary microscope, wheter a simple microscope, such as the aquatic microscope according to Mr. ELLIS or whatever other kind, or the compound microscope.

Most of the infusoria and other small insects swim as freely in this flattened droplet as in an uncovered one. However, there are cases in which a sheet of talc or a glass film hamper the movement of the animalcules, therefore the droplet should always be examined before it is compressed ,in order to decide whether the particles which one believes to be living, have a motion which proves this or not.

This, idea, simple as it may seem, has been so useful to me, especially during the difficult research on the green matter, that I thought it appropriate to discuss it in a special article, in order to draw the attention of the reader to it. If it were presented as a passing remark, it might be overlooked among the subjects which occupy the reader's mind. Finally,, this article is only intended for those who are not yet sufficiently experienced in the use of the microscope to think of such an easy and simple method themselves.

Bibliography.

G. ADAMS, **Micrographia illustrata or the knowledge of the microscope explained.** London. Sold for the author, 1747.

H. BAKER, **The microscope made easy.** London, R. Dodsley, 1742.

R. BROWN (1), **The miscellaneous botanical works, containing the geographico-botanical and the structural and physiological memoirs.** London, The Ray Society, 1866.

R. BROWN (2), **Additional remarks on active molecules.** Phil. Mag., N.S. **6,** 161-166, 1829.

P. HARTING, **Het microscoop, deszelfs gebruik, geschiedenis en tegenwoordige toestand.** Utrecht, van Paddenburg & Co., 1848-1858. Four volumes.

J. INGEN-HOUSZ (1), **Rémarques sur l'origine et la nature de la matière verte de M. Priestley, sur la production de l'air déphlogistiqué par le moyen de cette matière et sur la changement de l'eau en air déphlogistiqué.** Journal de Physique, **25,** 3-12, 1784.

J. INGEN-HOUSZ (2), **Nouvelles expériences et observations sur divers objets de physique.** Paris, Th. Barrois, 2 vol. s, 1785, 1789.

J. INGEN-HOUSZ (3), **Vermischte Schriften physisch-medicinischen Inhalts.** Vienna, C.F. Wappler, 1785.

P.W. VAN DER PAS, **The discovery of the Brownian motion.** Paper, read at the XII International Congress of the History of Science, 26 August, 1968.

J.C. VALMONT DE BOMARE, **Dictionnaire raisonné universel d'Histoire naturelle,** Paris, Brunet, 1775.

Summary.

A relatively unknown paper of JAN INGEN-HOUSZ, in which he accurately descrbies the Brownian motion, 43 years before the paper of ROBERT BROWN, is descussed. A translation of this paper is added.

Zusammenfassung.

Ein fast unbekannter Aufsatz des JAN INGEN-HOUSZ, in dem die Brownsche Bewegung genau beschrieben worden ist, ist besprochen. Es stellt sich heraus dass INGEN-HOUSZ die Brownsche Beweging 43 Jahre früher als BROWN kannte. Eine Uebersetzung in englischer Sprache ist beigefügt.

1324 Gates Place,
South Pasadena,
California.