On the role of women scientists before 1945: a case study

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Abstract

Viewing the contributions of women scientists to the Philosophical Magazine between 1798 and 1945 it is found that contrary to the belief that the number of publications by women in science ought to increase continuously, there obviously was a most favorable time in the mid-twenties after which the publication rate decreased noticeably.

Judging from the affiliations quoted, so called "red brick" universities seem to have been very often forerunners of emancipation in science. The titles of the various papers suggest that nearly all fields of research in that period of time were covered also by female researchers. The number of publications in mathematics and theoretical physics is impressive.

In particular, it is found that a single person, namely Dorothy Wrinch, dominated by far women's participation in science in England and some parts of the English speaking world .

1 Introduction

One particular aspect of the history of science clearly is to give also reference to the role of women scientists played in the last 100 to 150 years, an epoche that saw two world wars with millions of dead, genocides, revolutions, the end of old empires, and a complete change of the geopolitical situation not only in Europe, but also in Africa and in Asia. By the end of the 19th century, science was already split up in many, only weakly interacting fields, discussed in an ever since growing number of journals: science no longer was simply "experimental philosophy". In particular, physics experienced in less than half a century the most dramatic changes in its history. And these changes happened very fast indeed. In only 13 years Bohr' atomic model (1913) was replaced by Schrödinger's wave mechanics (1926); the generalization of the theory of relativity occurred even faster (Einstein 1906, 1916). The discovery of radioactivity and the disintegration of atoms caused by bombardment with particles terminated traditional concepts for atoms as indivisible entities.

Since a somewhat comprehensive view of female participation in science obviously seems to be impossible in a single article, as a case study one particular journal, namely the Philosophical Magazine, was considered to serve as "data base" for female participation in science. The Philosophical Magazine, in which not only most of Faraday's, Maxwell's or Rutherford's papers were published, was founded already in 1798 and reflects besides physics progress in mathematics such as for example Hamilton's theory of quaternions as well as in physical chemistry (thermodynamics). The archives of this journal that still is very active in physics and nowadays in materials science are easily accessible[1] electronically.

The attempt to trace publications by women scientists in the Archives of the Philosophical Magazine, however, suffers a bit from the fact that sometimes the gender has to be guessed from the Christian name(s) given. Luckily, in most cases a "Miss" is put in front of a name to indicate a female author. Surely, a few contributions were overlooked because of missing information. Fortunately, in the context of the usual style of presentation in this journal the corresponding "statistical error" is very small indeed.

The earliest publication found is from 1881; investigated is the period from the very first edition of the Philosophical Magazine in 1798 to 1945, since the end of the Second World War can be regarded as a sufficiently significant mark in the history of Europe and the Americas and therefore also in the history of science.

As perhaps with the exception of Dorothy Wrinch[2], Kathleen Yardley (née Lonsdale)[3], Tatyana (Ehrenfest-)Afanasjewa[4], Katharine Burr Blodgett[5] and Ellen Gleditsch[6] no further biographical notes seem to be available and those compiled in "wikipedia" need not to be repeated, the main emphasis will be put on the affiliations quoted as a kind of socio-historical indicator and of course on the scientific topics that were dealt with. It will turn out that certain papers would indeed deserve to be quoted and acknowledged even today, although virtually nothing is known about the author. In the following particular emphasis will be put on mathematics and theoretical physics, since women very often were regarded by (male) contemporaries as being "not capable to contribute" to these fields of research.

2 Number of publications & affiliations:

To make it very short: the number of relevant papers found is not overwhelming, see Fig. 1. In the time from 1915 to 1945 on the average less than 4 publications a year by women scientists appeared. Since usually between 200 and 250 papers per year were published in the Philosphical Magazine, their share was typically less than 3%. Even in the "best" year, 1927, only 4.4% were reached.

The dashed line in Fig. 1, a Lorentzian fit to the data reflecting the years 1915 - 1945, has to be viewed with care. It shows that up to the end of the Second World War perhaps the most favorable time for women scientists was in

[1] The Philosophical Magazine, www.tandf.co.uk/journals/tphm
[2] Dorothy Maud Wrinch, 1894 – 1976, http://en.wikipedia.org/wiki/Dorothy_Wrinch
[3] Kathleen Lonsdale, 1903 -1971, http://en.wikipedia.org/wiki/Kathleen_Lonsdale
[4] Tatyana Afanasyeva, 1876 - 1964, http://en.wikipedia.org/wiki/Tatyana_Afanasyeva
[5] Katharine Blodgett, 1898 – 1979, http://en.wikipedia.org/wiki/Katharine_Blodgett
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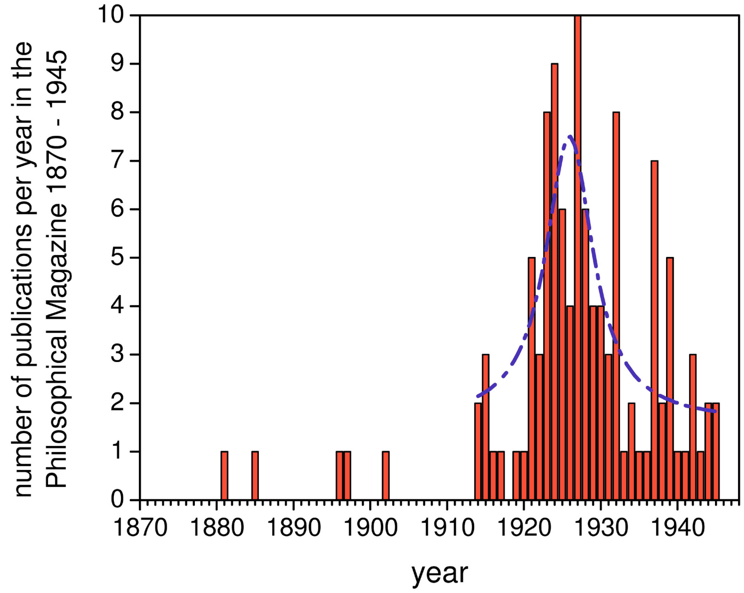

Figure 1: Number of publications of female scientists in the Philosophical Magazine between 1870 and 1945 (from 1798 to 1870 there are none). The dashed line refers to a Lorentzian fit of the data 1915 - 1945..

the mid-twenties of the 20th century, i.e., appears to be contrary to the belief that the number of their publications should increase continuously with time.

Inspecting now in the compilation of affiliations below quoted in the titles of the papers, it turns out that in the UK in particular "red brick" universities such as those of Aberdeen, Bristol, or Manchester, and the University College London were forerunners of women's participation in science, while Oxford and Cambridge joined in rather late. One has to remark, however, that in quite a few cases no affiliation is given and that occasionally women had to use their private address as affiliation. In the thirties also universities in parts of the British Empire such as Melbourne or Pretoria were quoted as affiliations. A special case seems to be McGill University, at least according to a paper from 1902, listing, however, Rutherford as the first author.

Table 1: Affiliations

Bell Telephone Laboratories: Gray (1939)

Cambridge University: Megaw (1932); Girton College: Wrinch (1921, 1922,1923. 1924, 1930, 1932)

Council for Scientific and Industrial Research, Ottawa: Weinberg (1924)

General Electric Co., Schenactady: Blodgett (1927), Hughes (1943)

German University, Prague: Blüh (1938)

John Hopkins University: Wrinch (1940)
Kansas State College: Fletcher (1937)
Leiden University: Ehrenfest-Afanassjewa (1926)
London School of Medicine for Women: Waller (1934)
McGill University, Montreal: Brooks (1902)
MIT: Walton (1881)
Oxford University: Wrinch (1938, 1939), Lonsdale (1945); Lady Margaret Hall: Wrinch (1924, 1925,1929,1932); Somerville College: Wrinch (1941); St. Hilda's College: Wrinch (1927)
National Physical Laboratory (UK): Everett (1923), Skan (1931)
Queen's University, Belfast: Chambers (1928), Hirst (1928), Carmichael (1929)
Royal Holloway College, Englefield Green: Davies (1920, 1921, 1922, 1923, 1924, 1928)
University College, London: Marshall (1896,1897), Wrinch (1919, 1921, 1922, 1923, 1924), Stratton (1924)
University College, Swansea: Jones (1927)
University College, Cardiff: Jones (1924), Viney (1931,1932,1933), Morris (1937)
University of Sydney: Makinson (1944)
University of Aberdeen: Hitchins (1915)
University of Bristol: Hobbs (1916), Dent (1927, 1929)
University of Edinburgh: White (1917)
University of Glasgow: Moir (1914), Dunlop (1921), Smith (1927)
University of Liverpool: Richards (1927)
University of Manchester: Szmidt (1915), Jones (1931)
University of Melbourne: Nelson (1930)
University of Oslo: Gleditsch (1932)
University of Pretoria: Voss (1935)
University of Toronto: Kearney (1924), Quinlan (1932)
Uppsala University: von Bahr (1914)
Wellesley College, Mass.: Nelson (1930)
private address: Jolowicz (1925), Everett (1927)
no affiliation: Marks (1825), Swain (1915), Yardley (1925), Reid (1925), Allen (1927), Trevelyan (1927), Butterworth (1928), Lonsdale (1928), White (1932), Moore (1936), Cattermole (1939, 1942), Megaw (1939), McKerrow (1944)

3 Scientific topics

Table 2 gives an overall view of the topics dealt with up to 1945. Quite obviously studies in experimental physics were of particular interest, but also problems in pure mathematics and theoretical physics seem to have been attractive.

Table 2: Overall view of topics dealt with

Field	#
pure mathematics	19
experimental physics	63
theoretical physics	24
chemistry	5
philosophy	3

It should be noted that in order to facilitate a view of the various contributions of women scientists to the Philosophical Magazine in detail, also the titles of the papers are cited in the list of references[7].

3.1 Pure mathematics

Like many other famous mathematicians (Euler, Gauss, Kummer, Riemann, etc.) Dorothy Wrinch, for example, was fascinated by the wealth of solutions of Euler's hypergeometrical differential equation[8] and Bessel's differential equation[9] and the relations of the solutions between these two. Already in 1921, she reported on an asymptotic formula [16] for the hypergeometrical function[10] and, later on, discussed properties and implications of this function [17, 48, 66]. In particular, Bessel functions[11], but also certain variations of the hypergeometrical function turned out to be of quite some importance for the theoretical description of certain physical phenomena occurring in cylindrical objects.[28, 41, 42] To use her own words [27]:

> *While Tables of the Bessel Functions of both kinds, $J_n(x)$ and $Y_n(x)$, are now fairly complete, much work remains to be done in regard to the corresponding tables for the so-called "Functions of Imaginary Argument" $I_n(x)$ and $K_n(x)$, which are of considerable importance in physics.* [27]

And exactly for these purposes [27, 33] she produced tables of Bessel functions. For her, discovering mathematical details was never just an intellectual challenge, but:

> *The solution of the problems of Electrostatics, Hydro-. dynamics, and related branches of Mathematical Physics associated with a specific surface S depends, in the first place, on the discovery of curvilinear coordinates (ξ, η, ζ) such that the surface S belongs to one of the three families ξ =constant, η =constant, or ζ =constant. Next,*

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[7] The names are quoted exactly as given in the journal. Only in the case of Dorothy Wrinch ocassionally her name ocurs as D. M. Wrinch.

[8] Euler's hypergeometrical differential equation is given by

$$x(1-x)\frac{d^2y}{dx^2} + (c-(a+b+1)x)\,\frac{dy}{dx} - aby = 0 \quad , \quad a,b,c \in \mathbb{Z} \; .$$

[9] Bessel's differential equations is usally written as

$$x^2\frac{d^2y}{dx^2} + x\frac{dy}{dx} + (x^2-\alpha^2)y = 0 \quad , \quad \alpha \in \mathbb{C} \; .$$

[10] The hypergeometric function is defined by the following series

$$|z|<1: \; {}_2F_1(a,b,c;z) = \sum_{n=0}^{\infty} \frac{(a)_n(b)_n}{(c)_n}\frac{z^n}{n!} \quad , \quad (x)_n = \begin{cases} 1 & , \; n=0 \\ x(x+1)\ldots(x+n-1) & , \; n>0 \end{cases}$$
$$a,b,c \in \mathbb{Z} \quad , \quad z \in \mathbb{C}$$

[11] Bessel functions are sometimes also called cylindrical functions, since they are part of the solutions of the Laplace equation in cylindrical coordinates.

it is necessary to obtain a suitable solution of Laplace's equation

$$\frac{\partial^2 V}{\partial x^2} + \frac{\partial^2 V}{\partial y^2} + \frac{\partial^2 V}{\partial z^2} = 0$$

in the form

$$V = f(\xi, \eta, \zeta)$$

and finally to apply the condition which has to be satisfied on the surface S given by (say) $\xi = \xi_0$. [44], see also [52].

Since it is not possible to quote from all her mathematics related papers, only two more lines of formal research shall be mentioned, namely her work on serial relations [69, 70] and about 10 years later her investigations concerning discrete vector maps, [101, 103] which seem to head for a point-wise (coordinate-free) description of differential geometry. Between 1919 and 1939 she published 21 pure mathematics papers or papers related to mathematical physics in the Philosophical Magazine. Mathematics, however, was not her only interest, as will be pointed out later.

Another mathematical physicist, Rosa Morris, originally from Cardiff, wrote in only one year 4 major papers [91, 92, 94, 95] on two-dimensional potential theory in the context of hydro-dynamics. Her book, *Mathematical Methods in Physics*, which she wrote together with John Chrisholm, [115] seems to have become a standard textbook in this field.

3.2 Experimental physics

At the beginning of the 20th century the most prominent topics in experimental physics were radioactivity and X-rays. It is therefore not surprising at all that before 1920 most papers [5, 10, 11, 13] of female physicists were devoted to these two fields. Later, in the twenties, Ann Catherine Davies, for example, carried out investigations with respect to ionization properties of hydrogen and helium [15, 20, 22, 25, 50]. Her paper on the thermionic activity of thoriated tungsten [63] is one of the very few that quotes two female scientists as authors. Magnetism and magnetic properties continued in the 20th century as area of interest [8, 51, 93]; structural analysis by means of X-rays [43, 53, 54, 78, 113, 114] became a general tool of characterization. Altogether, it can be said that in the years 1915 - 1945 in most areas of experimental investigations female researchers – although still few in number – produced remarkable results and very well-written publications.

Quite clearly, experimental studies usually seem to outdate much faster than theoretical ones, although even those can occasionally become obsolete as the example of the tables of Bessel functions show. Nowadays it would take much longer to find the corresponding entry in these tables than to compute them numerically using appropriate recursion relations.

What remains of most publications related to experimental physics is very often the careful language used, the presentation itself, and sometimes – as shown in Fig. 2 – the pride by which the sophistication of a certain experimental setup is explained.

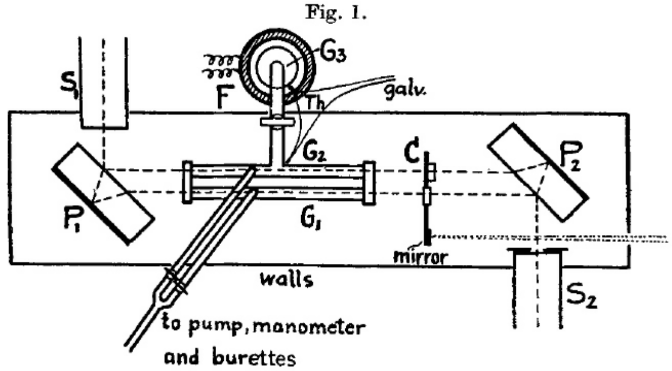

Figure 2: Measurements of thermal diffusion in gas mixtures. *In the Jamin interferometer which was used the chief features are (fig. 1) the two glass plates* P_1 *and* P_2*, silvered at the back, the slit-tube* S_1 *with a lamp, the telescope* S_2*, the Jamin compensator* C*, and the gas-tubes* G_1 *and* G_3*, which are closed with plane parallel glass plates. In fig. 1 is shown ... the way which light takes through the two glass tubes. The tube* G_2 *communicates by a wider tube with stopcock with the vessel* G_3*, which may be heated by an electric furnace* F *or cooled by a cooling mixture.* From Grete Blüh et al., [97].

3.3 Theoretical physics

Although there is quite some overlap between mathematical and theoretical physics, this distinction is still useful to classify (traditional) fields of research. Irene Viney, a theoretician like Rosa Morris from the University College in Cardiff, for instance published three quite remarkable articles [75, 81, 84] between 1931 and 1932, which seem to be completely forgotten. In particular the very first one [75] (Magnetism and electrodynamics), because of the very clear wording used and the didactical skills displayed, could still serve as a theoretically minded introduction to magnetism in any modern lecture course. For example, right at the beginning, she carefully defines all the quantities occurring throughout her paper.

> *The Magnetic Force* H *is defined generally as the magnetic force intensity per unit of magnetism, or, if a small element of magnetism* $d\mu$ *be placed at a point, then* $Hd\mu$ *is the force acting on it.*
>
> *The Potential Function* Φ *is defined so that* $\Phi d\mu$ *is the work done by the magnetic forces on a small element of magnetic charge* $d\mu$ *when carried from that point to infinity, where, by convention, the value of* Φ *is zero.*
>
> *The Magnetization* I *is defined as the magnetization per unit volume of the field; it is derived by an averaging process as the vectorial sum of the moments of all the bipolar particles, which go to make up the volume element* $d\nu$*, so that* Idv *is the resultant moment of the element,* I *being the intensity of magnetization.*

> *The Magnetic Induction B is defined so that $B_n df$ represents tile magnetic displacement across the area df, B_n, denoting the component of B, normal to df. This is the analogue of the electric displacement D, but by convention it is defined so as to include an extra 4π factor, such that*
>
> $$B = H + 4\pi I.$$
>
> *The Magnetic Density μ is defined as the amount of magnetism or magnetic charge per unit volume at each point in the field.*

It is worthwhile to quote also the main conclusion in her summary, namely a view that is totally accepted nowadays:

> *The only consistent formulation of the dynamical relations of the magnetic field is by using B, and not H, as the magnetic force vector.* [75]

Jessie Cattermole's papers [100, 107, 109] obviously share the same fate of being essentially forgotten. As an example for the cautious wording used, the introduction (usually the most difficult part of a paper) of her 1939 paper [100] is quoted below:

> *In macrophysical theory (Einstein's special theory of relativity) the motion of a particle conforms to the equation*
>
> $$p_x^2 + p_y^2 + p_z^2 + m^2c^2 + +m_0^2c^2 = 0$$
>
> *in which p_x, p_y and p_z are its components of momentum referred to rectangular axes of coordinates, m and m_0 are its mass and rest mass respectively, and c is the velocity of light in free space. This equation is, of course, valid in any field of force if we may be permitted to ignore the refinements of Einstein's general theory of relativity. The problem of a particle (e.g., electron) of microphysical dimensions is approached by regarding each term in (1) as an operator directed to some function, ψ, which we may regard as, in some sense, describing the particle. Thus instead of (1) we have the statement*
>
> $$\left(p_x^2 + p_y^2 + p_z^2 + m^2c^2 + +m_0^2c^2\right)\psi = 0$$
>
> *The individual operators are*
>
> $$p_x = \frac{h}{2\pi i}\frac{\partial}{\partial x} \quad , \quad p_y = \frac{h}{2\pi i}\frac{\partial}{\partial y} \quad , \quad p_z = \frac{h}{2\pi i}\frac{\partial}{\partial z}$$
>
> *and therefore*
>
> $$\nabla^2\psi - \frac{1}{c^2}\frac{\partial\psi}{\partial t^2} - \frac{4\pi^2 m_0^2 c^2}{h^2}\psi = 0$$

The article starts out with something that looks completely straightforward, but – as is well-known – in fact is not. After paying tribute to Dirac's theory of the electron, she and her coauthor try to proof that the quadratic operator in their second equation can be derived from linear operators in terms of a 5-dimensional continuum. In the end they don't really succeed in doing so, since the problem with the positron could not be solved satisfactorily. It was a brave attempt, proving perhaps that papers not always have to produce a positive result: sometimes those with a negative message are even more interesting. Her other two papers [108, 109] deal with relativistic approaches in the context of electromagnetism making use again of a 5-dimensional continuum. About Jessie Cattermole virtually nothing is known, since in none of her papers an affiliation is quoted.

3.4 Chemistry, Biology

Either because of the publication policy of the Philosophical Magazine or because other journals were considered more appropriate, in those years chemistry-related publications of women scientists [36, 39, 51, 59, 72, 87, 88] dealt mostly with physicochemical problems such as fluorescence [36] and magnetic rotation [51] in solutions or aspects of viscosity [59, 87, 88].

While still in Oxford, 1938, Dorothy Wrinch "discovered" a completely new field of research, namely biophysics, perhaps better termed biomathematics [98, 99]. Although at the beginning a bit belittled (mostly because of her rudimentary knowledge of chemistry), in the end she became one of the founders of a scientific field that still seems to be one of the scientific frontiers. Already 1940, after having moved to the United States, she reported on a theory of protein structures [105, 106], being thus one of the very first to apply mathematical tools in biology.

From Fig. 3 one easily can imagine that at a time when no X-ray scattering data were yet available to construct models for possible protein structures was indeed fascinating.

3.5 Philosophy of Science, Theory of Knowledge

Probably inspired by her article on probabilities [14], definitely, however, influenced by Bertrand Russell[12], Dorothy Wrinch published, together with Harold Jeffreys, a very long essay [19] in the early twenties on the theory of knowledge that was augmented in 1923 by a kind of "continuation" [24]. At that time this topic had already been discussed intensively by Henri Poincaré[13], Ernst Mach[14] and of course by Bertrand Russell.

> *It is a universal belief among physicists that when a sufficient number of inferences from a quantitative law have been verified, the probability of the correctness of the next inference from it may be made to approach indefinitely near to unity.*[24]

She and her collaborator used for example arguments related to the theory of measurements to show that this belief is not obvious at all.

> *Any observed measure is liable to differ slightly from the measure of the same quantity calculated by inference from the laws established*

[12] Bertrand Rusell, 1872 – 1970, http://en.wikipedia.org/wiki/Bertrand_Russell
[13] Henri Poincaré, 1854 - 1912, http://en.wikipedia.org/wiki/Henri Poincaré
[14] Ernst Mach, 1838 - 1916, http://en.wikipedia.org/wiki/Ernst_Mach

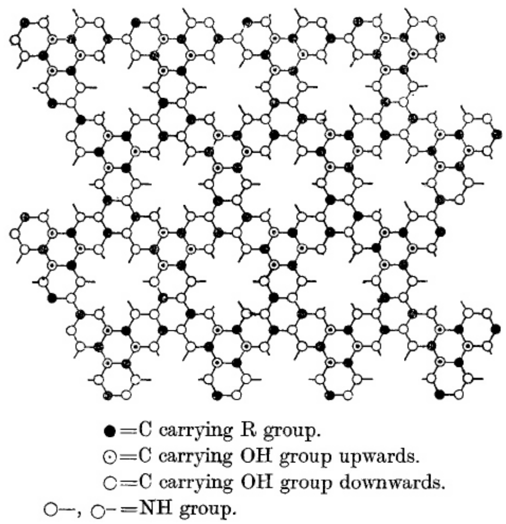

Figure 3: *To demonstrate that the idea of a cage structure for proteins is independent of any special class of fabric .... , and as a further suggestion as to a form which the characteristic protein fabric may take, a new class, having the composition appropriate for proteins, is now suggested for consideration* [105]*.* (R*: "imino acid residue"*).

> *. .... If any measured quantity l_r is found to lie between n_r and n_r+1 units, and another measure l_s is to be inferred from a number of such measures, we obtain the maximum limit by supposing each measure l_r, to have the value n_r or n_r+1 units, whichever gives the greater calculated value of the measure l_s to be inferred.*[24]

In particular the always present pre-knowledge (a conjecture in the mathematical sense, an "expectation" or "suspicion", psychological factors) they tried to incorporate to a theory of knowledge by means of probability theory:

> *Now it appears certain that no probability is ever determined from experience alone. It is always influenced to some extent by the knowledge we had before the experience. In the notation of our previous paper*[15]*, let $P(p:q)$ denote tho probability of the proposition p, given the data q. We had the general proposition*
>
> $$P(p.q:h) = P(p:q.h) = P(q:p.h)P(p:h)$$
>
> *Here let p be the general law under consideration, q the propositions found true by experiment, and the knowledge we had before the experiment. If q are implied by p and h together–in other words, if the observations satisfy the law–we have*
>
> $$P(q:p.h) = 1$$

[15] In their notation $P(p:q)$ corresponds to a proposition p on the data q. "*...we have $P(q:q)=1$, and $P(not-q:q)=O$. $P(p:q)$ may be read "the probability of p given q."*"[14]

Hence

$$P(p : q.h) = \frac{P(p : h)}{P(q : h)}$$

Thus the verification of a consequence of a hypothesis divides its probability by the prior probability of that consequence. ...

Hence at least one of the following alternatives must be true :–

(1) The general law, however often verified, can never have a probability finitely, different from zero.

(2) As the number of verifications of tile law increases, the probability that the next verification will be successful approaches arbitrarily near to certainty.[19]

This essay entitled by "On certain fundamental principles of scientific inquiry" has not lost any validity: it still can be recommended to anyone interested in the postulates or formal structure of science. The fact that she dealt with this subject is not surprising at all, since she had studied symbolic logic with Bertrand Russell. When Russell was in prison for his anti-war activities Wrinch acted as his unpaid research assistant and personal secretary. When Russell went to China he left her with the task of arranging the publication of Wittgenstein's *Tractatus* in England.

4 Summary and conclusion

Trying to summarize the first epoch of women's participation in science, covering essentially the period from the French revolution up to the end of the Second World War, it seems to be clear that Dorothy Wrinch was indeed by far the most outstanding personality. Her contributions to the Philosophical Magazine account for more than one third of all papers published there by women scientists. The range of topics dealt with by all of them is not at all different from that covered by male researchers of their time.

Contrary to the belief that the number of women in science increases more or less continuously, it turned out there was a most favorable time for participation in the mid-twenties, after which the publication rate drops. As this finding is entirely based on publications in the Philosophical Magazine, it should probably not be generalized. It does, however, give a somewhat characteristic view of science in England in this period of time and thus in some parts of the English speaking world. In particular, because of the large statistical weight of Dorothy Wrinch's contributions any social context related to Fig. 1 is at best only speculative and was therefore not attempted. Altogether, however, one does get the impression that up to 1945 female physicists or mathematicians most likely were viewed by their male colleagues as "unavoidable curiosa".

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