Vol. 41 (2010) *ACTA PHYSICA POLONICA B* No 2

PHYSICS 1909: A PORTRAIT OF THE FIELD HUNDRED YEARS AGO*

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(Received January 11, 2010)

Many physicists believe that after the discoveries of Max Planck (1900) and Albert Einstein (1905) physics was quickly transformed into a modern one based on relativistic and quantum principles. The study of the physics community and the physics papers published hundred years ago, in 1909, shows however, that only very few physicists took interest in the novelties while the bulk of physics remained classical and much oriented towards practical applications. Details are given on the physics topics, the strength of physics in various countries, the most important periodicals and prominent physicists of that time.

PACS numbers: 01.65.+g

1. Introduction

The world hundred years ago was quite different from the present. The largest country on earth, the British Empire "over which the sun never set", comprised the United Kingdom, Ireland, Australia, New Zealand, Canada, India, Bangladesh, Pakistan, Burma, and large part of Africa. Central and Eastern Europe was filled by the three large empires, Austro-Hungary, Germany and Russia. The Russian Empire extended quite far west into Europe and included Finland, Estonia, Latvia, Lithuania, and large parts of present Poland, Slovakia and Romania. Poland, the Czech Republic, Slovakia, Croatia, Bosnia and Slovenia did not exist as independent states. The population of the world was about 1.6 billion of which one-fourth lived in the British Empire. Even in the largest cities, such as London, New York or Paris, the streets were still quite empty. Automobiles were few and horse driven vehicles were still in use. In fashion it was still the time of girdles and top-hats.

* Invited lecture at the XXXI Mazurian Lakes Conference on Physics, Piaski, Poland, August 30–September 5, 2009.

It should be no surprise that physics hundred years ago was also quite different from the one we know now.

2. Statistics

Statistical information about the state of physics hundred years ago can be obtained from the leading abstract journals such as *Science Abstracts* and *Beiblätter zu den Annalen der Physik. Science Abstracts 1909* [1] listed papers published between, say, October 1908, and November 1909. The delay in abstracting papers in that journal was quite small and usually did not exceed two months. Thus 71.2 % of the papers listed in *Science Abstracts 1909* were from 1909, 28.2% — from 1908, and only 0.6 % — from 1907. The *Beiblätter zu den Annalen der Physik* [2] was considerably more delayed than *Science Abstracts 1909* as shown in Table I.

TABLE I

Percentage of papers listed in the two abstract journals.

Year of publication	*Science Abstracts 1909*	*Beiblätter 1909*
1907	0.6	3.7
1908	28.2	62.1
1909	71.2	34.2

Science Abstracts 1909 listed altogether 2159 papers. The *Beiblätter 1909* listed 3107 papers; moreover, it did not include papers published in the *Annalen der Physik* because it was an appendix to that journal. The three volumes of the *Annalen der Physik* published in 1909 (vols. 28, 29 and 30) contained altogether 143 papers. The situation in 1908 was similar. Thus, the *Beiblätter* and its mother journal accounted for about 50% more items than those included in the *Science Abstracts 1909*.

The papers in the *Science Abstracts* have been classified into six sections: General physics, Electricity and magnetism, Heat, Sound, Light, and Chemical physics and electrochemistry (see Table II). Then, to facilitate reference to any desired subject, the Index was divided into a number of subsections (see Fig. 1).

The *Beiblätter* classified papers into eleven sections (see Table III). Cosmic physics in the *Beiblätter* included astrophysics, geophysics, meteorology, earth magnetism, and atmospheric electricity, *i.e.* the subjects placed in the section General physics in the *Science Abstracts.* The section Constitution and structure of matter of the *Beiblätter* included subjects such as mass, density, atomic weight, molecular weight, chemical elements, compounds, affinity, equilibrium, reactions, solutions, absorption and adsorption, alloys, colloids, crystals, and liquid crystals, and corresponded to the section Chemical physics in the *Science Abstracts.*

TABLE II

Classification of papers in the *Science Abstracts 1909.*

Subject	Number of papers	Percentage
General physics	548	25,4
Electricity and magnetism	531	24,6
Chemical physics	49	23,0
Light	443	20,5
Heat	112	5,2
Sound	28	1,3
Total	2159	

SUBJECT INDEX.

SECTION A.—PHYSICS.

To facilitate reference to any desired subject, the Index is divided into the following sections arranged alphabetically. If any of these are absent this may be taken as an indication that no Abstracts dealing with those particular subjects have been included in this volume.

The numbers refer to Abstracts, those in italics referring to References.

An asterisk indicates remarks in a discussion.

In General Physics:—Apparatus and Instruments (physical, excluding electrical, descriptive); Astronomy; Diffusion; Dynamics; Elasticity; Gravity; Measurements and Use of Instruments; Meteorology, &c.; Miscellaneous; Molecular Physics, Matter and Ether; Surface Tension; Terrestrial Physics; Theories; Viscosity.

In Light:—Absorption; Dispersion; Interference; Measurements and Use of Instruments; Miscellaneous; Phosphorescence and Fluorescence; Photography; Photometry; Polarisation; Radio-activity; Rays and Radiation; Reflection of Light; Refraction of Light; Spectra; Vision; Zeeman-Effect and Radiation in a Magnetic Field.

In Heat:—Absorption; Conductivity; Critical Points and Constants; Dilatation; Freezing-, Melting-, and Boiling-Points; Gases and Vapours; Measurements and Use of Instruments; Miscellaneous; Specific Heat and Latent Heat; Temperature; Temperatures (high and low); Thermodynamics; Thermometry, Pyrometry, and Calorimetry; Vapour Pressure.

In Sound:—All Abstracts referring to this subject have been indexed under *Sound*.

In Electricity and Magnetism:—Absorption; Alternate Current Research; Apparatus and Instruments (descriptive); Capacity (electrostatic); Conductivity and Resistivity; Dielectrics; Discharge in Gases and in Vacuo; Electromagnetic Theory; Inductance (self and mutual); Magnetism; Measurements and Use of Instruments; Electro-Physiology, Electro-Therapeutics, and Radiotherapy; Miscellaneous; Oscillations and Waves; Polarisation (electric waves); Polarisation (electrolytic); Static and Atmospheric Electricity; Terrestrial Magnetism and Electricity; Thermo-Electricity and Thermo-Magnetism.

In Chemical Physics:—Absorption; Alloys; Batteries (primary); Batteries (secondary); Chemical Equilibrium; Dissociation and Ionisation; Electric Furnace Processes; Electrolysis; Electrolytic Analysis; Metallography and Properties of Metals; Miscellaneous; Osmosis; Solution and Solubility.

Fig. 1. The index page of the *Science Abstracts, Section A: Physics*, 1909.

TABLE III

Classification of papers in the 1909 volume of the *Beiblätter zu den Annalen der Physik.*

Subject	Number of papers	Percentage
Electricity and magnetism	836	27.8
Optics	537	17.9
Constitution and structure of matter	395	13.1
Cosmic physics	326	10.8
Heat	268	8.9
Mechanics	237	7.9
Radioactivity	181	6.0
General	103	3.4
Historical and biographical	43	1.4
Acoustics	42	1.4
Measurement	39	1.3
Total	3007	

In the following we shall present some statistical data based on the *Science Abstracts alone.* Out of the total 2159 papers listed there 1679 can be classified as experimental (78%), 366 as theoretical, and 114 as reviews. Thus, one can see a clear dominance of experiment in physics of that time. Table IV includes twenty journals with the largest number of papers listed in the *Science Abstracts 1909.*

A numerical estimate of the strength of the physics community in various countries may be obtained from the number of published papers and the number of its authors. Unfortunately, the *Adressbuch der lebenden Physiker 1909* [3] turned out to be of little help in identifying the affiliation of the authors. Only 479 out of 1595 authors of papers in the *Science Abstracts 1909* were listed in that directory. We may note in passing that Albert Einstein, still a patent office employee, was listed there under his home address, Aegertenstrasse 53 in Bern. Only in the fall of 1909 he accepted an extraordinary professorship at the University of Zürich.

In preparing the statistics presented in Tables V and VI the system adopted in the present bibliometric analyses was used, that is, the actual affiliation of the authors and not their nationality was taken into account. Thus, the American physicist William Duane who worked in 1909 in Paris was taken as a French, the Swiss Walter Ritz working in Göttingen was taken as a German, Peter Debije (Debye) contributed to the share of Germany, James Jeans — to that of the USA, and so on.

TABLE IV

Twenty leading journals in the 1909 volume of *Science Abstracts.*

Journal	Papers
Comptes Rendus ... Academie des sciences, Paris	276
Physikalische Zeitschrift	140
The Philosophical Magazine & Journal of Science	131
Annalen der Physik	123
Nature	80
Proceedings of the Royal Society of London	79
Zeitschrift für Elektrochemie und angw. physikalische Chemie	77
Atti della R. Accademia dei Lincei, Roma	59
The Astrophysical Journal	59
Berichte der Deutschen Physikalischen Gessellschaft	54
The Physical Review	51
Jurnal Russkago Fisiko-Chimičeskago Obščestva	45
Monthly Notices of the Royal Astronomical Society	45
Journal of the American Chemical Society	41
Il Nuovo Cimento	40
Sitzungberichte der K. Akademie der Wissenschaften, Wien	36
Zeitschrift für Physikalische Chemie	34
Meteorologische Zeitschrift	32
Verlag van ... K. Akademie van Wetenschappen, Amsterdam	31
Journal of the Chemical Society	30

TABLE V

Distribution of papers among countries according to *Science Abstracts 1909*.

Country	Number of papers	Percentage	Country	Number of papers	Percentage
Germany	500	23.07	Sweden	26	1.20
British Empire*	494	22.80	Belgium	10	0.46
USA	382	17.63	Denmark	7	0.32
France	331	15.27	Norway	6	0.28
Italy	129	5.96	Greece	4	0.18
Russia	78	3.59	Romania	4	0.18
Austro-Hungary	71	3.27	Spain	4	0.18
Netherlands	49	2.26	China	2	0.09
Switzerland	39	1.80	Portugal	2	0.09
Japan	29	1.34	Bulgaria	1	0.05

* included Ireland, Australia, Canada, India, New Zealand, and South Africa

TABLE VI

Afilliation of authors of papers listed in *Science Abstracts 1909*.

Country	Number of authors	Country	Number of authors
Germany	394	Sweden	20
British Empire*	357	Belgium	6
USA	296	Denmark	4
France	217	Greece	3
Italy	92	Norway	3
Russia	65	Romania	3
Austro-Hungary	52	Bulgaria	1
Netherlands	30	China	1
Switzerland	30	Portugal	1
Japan	20	Spain	1

* included Ireland, Australia, Canada, India, New Zealand, and South Africa

Germany was at that time the leading country in physics. It had the largest number of active physicists and physics institutes in the universities and polytechnics. It also had the first specialized physics research institute in the world, the Physikalisch-Technische Reichsanstalt founded in 1878 in Berlin. The best known physicists in Germany at that time were Max Abraham, Wilhelm Hallwachs, Johann Wilhelm Hittorf, Friedrich Kohlrausch, Philipp Lenard, Otto Lummer, Walther Nernst, Max Planck, Ernst Pringsheim, Carl Pulfrich, Wilhelm Conrad Röntgen, Heinrich Rubens, Johannes Stark, Emil Warburg, and Wilhelm Wien.

Well known physicists in other countries were: in the United Kingdom: William Crookes, James Dewar, Joseph Larmor, Oliver Lodge, John Poynting, Ernest Rutherford, George Stokes, Frederick Soddy, William Strutt (Lord Rayleigh), and Joseph John Thomson; in France: Emil Amagat, Marcel Brillouin, Maria Curie, Gabriel Lippmann, Jean Perrin, and Henri Poincaré; in the United States: Josiah Gibbs, Albert Michelson, and Robert Wood; in the Netherlands: Heike Kamerlingh-Onnes, Hendrik Lorentz, Johannes Van der Waals, and Pieter Zeeman; in Austro-Hungary: Roland Eötvös, Ernst Lecher, Stefan Meyer, Karol Olszewski (a Pole), and Marian Smoluchowski (another Pole). One should also name Boris Golitzyn, Piotr Lebiediev, and Nikolai Umov in Russia, and Johannes Rydberg in Sweden.

The most prolific authors according to *Science Abstracts 1909* were Johannes Stark (Germany) and Robert W. Wood (USA), who published 10 papers each. Next in this classification came Charles Féry (France) with 9 papers, and Edward Emerson Barnard (USA), Jean Becquerel (France), and Alexandre Dufour (France) with 8 papers. Henri Deslandres (France), Heike

Kamerlingh Onnes (Netherlands), Arthur Scott King (USA), Augusto Righi (Italy), and Ernest Rutherford (UK) published 7 papers each. Otto Hahn, William Ramsay, Frederick Soddy, and Joseph John Thomson were among ten authors who published 6 papers in 1909.

From the *Science Abstracts* and *Addressbuch* we learn the names of women active in the physical sciences at that time. Most of them were from the United States: Laura Brant, Annie Jump Cannon, Augusta Mabel Chase, Willamina Fleming, Fanny Cook Gates, Julia Peachy Harrison, Mary Elisabeth Holmes, Elisabeth Rebecca Laird, Henrietta Swan Leavitt, Louise S. McDowell, Lena Vaughan, and Sarah Frances Whiting. There were also Maria Curie, Mme H. Baudeuf, and Mlle Lucie Blanquies in France, Hertha Ayrton, Julia Bell, Miss D.D. Butcher, Mrs. M. Cuthbertson, Miss M. Gazdar, Ruth Pirret, Margaret White, and Miss F.G. Wick in the UK, Cäcilia Böhm-Wendt, and Maria Sadzewicz (Polish woman) in Austria, another Austrian, Lise Meitner working in Germany, Evangelina Bottero-Pagano in Italy, Ellen Gleditsch in Norway (working then in Maria Curie's lab in Paris), Tatiana Afanasjeva-Ehrenfest in Russia, and Eve Ramstedt in Sweden. Women constituted about 1% of all researchers in physical sciences hundred years ago.

3. A biased selection of "Physics 1909" ideas and results

It is clear from Tables II and III that most papers published hundred years ago belonged to classical physics. The "new physics" was still marginal. Articles dealing with quantum physics or relativity were few in numbers and hidden in other topics, mainly under "general physics".

We have to remember that at that time the system of units was not yet fully established. Delegates from 24 countries met in conference at Burlington House from Oct. 12 to Oct. 22, 1908 to fix a universal system of electrical standards acceptable to all. France and the United States were in favour of the volt, but 19 countries were in favour of the ampere. After long debate the international ampere was defined as depositing silver at the rate of 0.00111800 grams per second.

3.1. Electromagnetic theory of matter

It is difficult to follow the arguments of physicists of hundred years ago without explaining the now forgotten electromagnetic theory of matter. In 1900 Wilhelm Wien published a paper "On the Possibility of an Electromagnetic Foundation of Mechanics" [4], in which he postulated that all mass was of electromagnetic origin. It is usually treated as the beginning of research toward the electromagnetic world picture.

Max Abraham from Göttingen became one of the chief propagators of a program of replacing the laws of Newtonian mechanics by the laws of Maxwell's electrodynamics, which were to be recognized as fundamental laws of physics. The mass of the electron, believed to be of electromagnetic origin, was predicted to increase with its velocity through the ether. Hendrik Lorentz in 1899 had already speculated on a possible change of electron's mass with its velocity. Abraham assumed that electron's charge was distributed uniformly over the surface of a rigid sphere and derived a formula for the change of its mass [5, 6]. The first results of measurements of the e/m ratio of beta rays from radium chloride performed by Walter Kaufmann confirmed Abraham's prediction [7, 8]. It was acclaimed as a triumph of the electromagnetic world picture. For example, Carl Barus in the talk on the progress of physics in the nineteenth century during the Congress of Arts and Science held in St. Louis in conjunction with the Universal Exposition in September 1904 concluded that [9]: "It is now confidently affirmed that the mass of the electron is wholly of the nature of electromagnetic inertia, and hence, as Abraham (1902), utilizing Kaufmann's data (1902) on the increase of electromagnetic mass with the velocity of the corpuscle, has shown, the Lagrangian equations of motion may be recast in an electromagnetic form."

However, the rigid electron model of Abraham met with criticism. Hermann Minkowski remarked jokingly that introducing a rigid electron into the Maxwell theory is like going to a concert with cotton in one's ears. Two other models of the electron were proposed soon. Hendrik Lorentz assumed [10] that the charge of the electron was distributed uniformly over the surface of a sphere, which underwent deformation in motion through the ether. Alfred Bucherer in 1904 [11] and independently Paul Langevin [12] preferred electron's charge to be distributed uniformly over the surface of a sphere which was deformed in motion through the ether, such that its volume remained constant.

The differences in the mass-velocity relations in the three models of the electron are seen when we compare the first terms of the expansion of m/m_0 as function of $\beta = v/c$. We have

$$m/m_0 \approx 1 + \tfrac{2}{5}\beta^2 + \tfrac{9}{35}\beta^4 + \dots \text{ Abraham's model,}$$
$$m/m_0 \approx 1 + \tfrac{1}{2}\beta^2 + \tfrac{3}{8}\beta^4 + \dots \text{ Lorentz's model,}$$
$$m/m_0 \approx 1 + \tfrac{1}{3}\beta^2 + \tfrac{2}{9}\beta^4 + \dots \text{ Bucherer, Langevin.}$$

In his paper on electrodynamics of moving bodies [13] Einstein also derived a formula for the change of the electron's mass with its velocity. It was formally identical to Lorentz's formula. It was just a coincidence because Lorentz's and Einstein's were two different theories. Einstein's theory did not depend in any way on the existence of electrons. Nevertheless, until about 1910 Einstein's results in the relativity paper [13] were considered to be a generalization of Lorentz's theory of the electron [10], hence the name "Lorentz–Einstein theory". Not only the mass-velocity formula but certain other results in the Einstein's paper were mathematically, but not physically, equivalent to Lorentz's.

It was not easy to discriminate between the three models of the electron. The experiments by Kaufmann and later by others involved measurements of the charge to mass (e/m) ratio of beta rays from their deflection in parallel electric and magnetic fields. However, the velocity of the electrons was not precisely known and also, at that time, the electron's charge e was known with rather large error. In reality, then, the rather uncertain procedure of deriving $m(\beta)$ values involved fitting the observed deflections to the calculations based on the theory. An excellent review of various experiments on the mass-velocity relation is given in [14].

Thus, Paul Langevin in his talk on the physics of electrons at the St. Louis Congress in 1904 discussed the three models of the electron and concluded that [15]: "The experimental points ... given by Kaufmann ... correspond equally well with the three theoretical curves."

On the other hand, Kaufmann continued his measurements [16–18] and insisted that the results agree with the prediction of the Abraham's model. "The results ... speak against the correctness of Lorentz's, and also consequently of Einstein's, fundamental hypothesis. If one considers this hypothesis as thereby refuted, then the attempt to base the whole of physics, including electrodynamics and optics, upon the principle of relative motion is also a failure... A decision between the theories of Abraham and of Bucherer is meanwhile impossible and appears not attainable by observations of the type described above." [19] Einstein remained unmoved by these remarks. He reanalysed Kaufmann's data and was convinced that they were not in contradiction with the mass-velocity relation resulting from the relativity theory.

Later experiments confirmed Einstein's conviction. In 1907 Adolf Bestelmeyer announced [20] that his results could not discriminate between the three models. In 1908 Bucherer abandoned his own model and decided that his new data agree a little better with the Lorentz–Einstein formula than with Abraham's [21]. Finally, the precise experiments of Günther Neumann in 1914 definitely proved that the Lorentz–Einstein formula provided the best fit to the data [22]. This conclusion was confirmed by Charles E. Guye and Charles Lavanchy [23]. At that time many physicists already knew that in spite of the same mathematical form of the mass-velocity relation, the theories of Lorentz and Einstein were quite different in their physics content and meaning. A more detailed account of this subject may be found in [24].

But that was still in the future. It is worth remembering that Hermann Minkowski, who introduced the four-dimensional world in his famous lecture on space and time [25], attempted to show that Lorentz's hypothesis of the contraction of bodies in motion is wholly equivalent to the new concept of space and time proposed by Einstein. It is clear from his concluding words: "The validity without exception of the world-postulate, I like to think, is the true nucleus of the electromagnetic image of the world, which, discovered by Lorentz, and further revealed by Einstein, now lies open in the full light of day." Minkowski's paper seemed to carry a message that Einstein's contribution just developed and clarified Lorentz's view of the world.

Thus, in 1909 the electromagnetic theory of matter was accepted by a large majority of physicists. We find another evidence for that attitude in the address by Ernest Rutherford, the President of the Mathematical and Physical Section at the 79th annual meeting of the British Association for the Advancement of Science held at Winnipeg (Canada) in August, 1909. According to Rutherford: "Experiment has shown that the apparent mass of the electron varies with its speed, and, by comparison of theory with experiment, it has been concluded that the mass of the electron is entirely electrical in origin and that there is no necessity to assume a material nucleus on which the electrical charge is distributed" [26].

3.2. The ether

In 1909 the ether reigned supreme in physics. Albert Einstein's 1905 paper on special relativity [13] was still little known and his proposal to abandon the ether appealed only to a very few physicists. The best evidence of that attitude may be found in the address of J.J. Thomson, the President of the British Association for the Advancement of Science, at its 79th annual meeting held at Winnipeg in August, 1909 [27]. The greater part of Thomson's lecture was spent just on discussing the properties of the ether. Einstein's name was not even mentioned.

"The ether is not a fantastic creation of the speculative philosopher; it is as essential to us as the air we breathe" — affirmed Thomson.

"Is the ether dense or rare? Has it a structure? Is it at rest or in motion? are some of the questions which force themselves upon us ... We can calculate the density of the ether attached to the corpuscle; doing so, we find it amounts to the prodigious value of about 5×10^{10}, or about 2,000 million times that of lead ... whether the density is as great as this in other places depends upon whether the ether is compressible or not ... We may, in fact, regard matter as possessing a bird-cage kind of structure in which the volume of the ether disturbed by the wires when the structure is moved is infinitesimal in comparison with the volume enclosed by them. If we do this, no difficulty arises from the great density of the ether; all we have to do is to increase the distance between the wires in proportion as we increase the density of the ether ...".

3.3. Floating magnets and atomic models

Atomic models in which existence of charged corpuscles within the atom had been assumed encountered a serious obstacle. The corpuscles had to move along closed orbits, *i.e.* undergo acceleration. However, it followed from classical electrodynamics that an accelerated electric charge radiates energy. Thus, the atoms built up from corpuscles in motion had to lose energy and could not be stable. Thomson found an ingenious solution to this problem [28]. He calculated that the intensity of radiation by electric charges moving as a ring was reduced — because of destructive interference — by many orders of magnitude; hence, atoms could be quasi-stable. For example, radiation from a ring of six electronic charges rotating with a speed $v = 0.01\ c$ is reduced by a factor 1.6×10^{-17}.

Thomson remembered an amazing experiment with floating magnets, performed in 1878 by an American self-taught physicist Alfred Marshall Mayer [29]. Mayer used large magnetized sewing needles which were pushed through thin corks and made to float in a bowl filled with water. The needles having their poles all pointing in the same direction repelled each other. The attractive force was produced by a cylindrical magnet placed above the bowl in a vertical position so that its lower pole, of opposite polarity to that of the upper poles of the floating magnets, was at a distance of several centimeters above the surface of water. The floating magnets arranged themselves in equilibrium under their mutual repulsions and a central attraction caused by the pole of a large magnet and formed various configurations depending of their number.

"A study of the forms taken by these magnets seems to me to be suggestive in relation to the periodic law. Mayer showed that when the number of floating magnets did not exceed 5 they arranged themselves at the corners of a regular polygon — 5 at the corners of a pentagon, 4 at the corners of a square, and so on. When the number exceeds 5, however, this law no longer holds: thus 6 magnets do not arrange themselves at the corners of a hexagon, but divide into two systems, consisting of 1 in the middle surrounded by 5 at the corners of a pentagon. For 8 we have two in the inside and 6 outside; this arrangement in two systems, an inner and an outer, lasts up to 18 magnets. After this we have three systems: an inner, a middle, and an outer; for a still larger number of magnets we have four systems, and so on." [30].

Louis Derr from the Massachusetts Institute of Technology published a systematic study of the configurations of Mayer's floating magnets [31]. Instead of magnetized needles floating on water he used magnetized quarter-inch steel balls which floated on clean mercury. This modification of Mayer's method has been suggested by Robert Wood. Derr produced photographs of all stable configurations of 1 to 52 balls (see Fig. 2). Similar studies have been made by other physicists [32, 33].

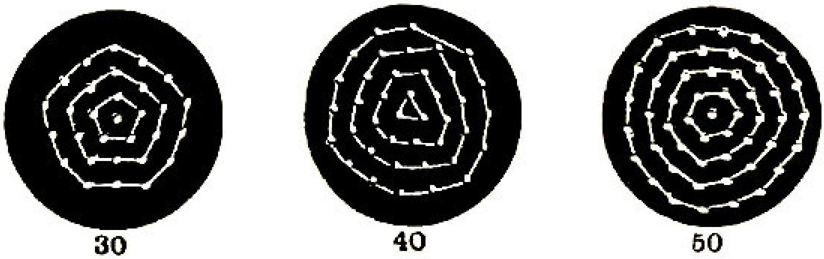

Fig. 2. Configurations of 30, 40 and 50 iron balls observed by L. Derr (adapted from Ref. [31]).

We shall see in Section 3.7 that Thomson's ideas were also helpful in explanation of radioactive transformations.

3.4. Spectra

Since the discovery of spectral analysis by Robert Bunsen and Gustav Kirchhoff in 1859 a lot of effort was spent for cataloguing the spectral lines and attempts to find regularities in their distribution. Originally it was thought that emission or absorption of lines was connected with the frequencies of vibrations in the atoms. The Irish physicist Johnstone Stoney suggested the use of wavenumber $1/\lambda \sim \nu$ instead of the wavelength λ because it would facilitate search for harmonic frequencies given by $\nu_k = k\nu_0$. Stoney found out, for example, that the three hydrogen lines having wavelengths $\lambda_1 = 6563.93\times10^{-7}$, $\lambda_2 = 4862.11\times10^{-7}$ and $\lambda_3 = 4102.37\times10^{-7}$ mm could represent the 20th, 27th and 32nd harmonics of the fundamental vibration $\lambda_0 = 0.13127714$ mm. However, this line of search did not bring progress.

In October 1908 the Swiss physicist Walter Ritz, who worked at that time in Göttingen, announced his discovery that one can determine from experimental values measured on a particular atom, a series of numbers T_n called spectral terms, such that every wavenumber corresponding to a spectral line of this atom is equal to the difference of two spectral terms $1/\lambda_{mn} = T_n - T_m$. This idea of Ritz, called the "Combination principle" [34], carried a germ of the present understanding of the energy of the transition between energy levels: $h\nu_{mn} = E_n - E_m$. It was used and quoted by Niels Bohr in his 1913 paper on the constitution of atoms.

3.5. Measuring the charge of the electron

In 1909 Felix Ehrenhaft from Vienna described a method of measuring the "atomic charge of electricity" by observing minute particles of silver, zinc, *etc.* when suspended in air in an electric field. The magnitude of the particles was determined by the rate at which they fell under the action of gravity under the assumption that Stokes' formula held in this case. Their speed in an electric field was used to determine their charge [35]. Ehrenhaft found $e = 4.6 \times 10^{-10}$ electrostatic units, in good agreement with the value found by Rutherford from his measuremnts on alpha particles. Later, however, Ehrenhaft changed his mind about the existence of the elementary charge and propagated the idea of "subelectrons".

In the same year Robert Millikan independently developed his oil drop method to measure elementary electric charge [36]: "The first determination which was made upon the charges carried by individual droplets was carried out in the spring of 1909. A report of it was placed upon the program of the British Association meeting at Winnipeg in August, 1909, as an additional paper, was printed in abstract in the *Physical Review* for December, 1909, and in full in the *Philosophical Magazine* for February, 1910, under the title 'A New Modification of the Cloud Method of Determining the Elementary Electrical Charge and the Most Probable Value of That Charge'".

3.6. Momentum of an energy quantum

As mentioned earlier, Einstein's paper on electrodynamics of moving bodies [13] had been largely ignored for several years after its publication in 1905. Even fewer physicists took seriously his idea of energy quantum expressed in another paper of 1905 [37]. An exception to this unconcern was Johannes Stark, who in 1909 became a professor in the Technische Hochschule in Aachen. Einstein and Stark corresponded on physics matters and then met for the first time in Salzburg during the 81st Assembly of German Natural Scientists and Physicians in September 1909. Stark was deeply influenced by Einstein's views on the nature of radiation. He published several papers in which he exploited the light quantum hypothesis. In one of those [38] Stark very explicitly concluded that a quantum of light emitted by an electron has to possess the total [radiant] momentum of absolute value $h\nu/c$, where h is Planck's quantum of action and ν the frequency. The idea of the momentum of a light quantum was implicit in Einstein's papers but Stark was the first physicist to state it explicitly and write its formula.

It is ironic that Stark, who was one of the few supporters of Einstein in the first decade of the XXth century, later became his fierce enemy.

3.7. Radioactivity

Science Abstracts 1909 listed altogether 153 papers on radioactivity of which 95% were experimental. Only 121 of them were included in the section Light; the remaining were attributed to Chemical physics (15), Electricity and magnetism (14), Heat (2), and General physics (1). Almost a half of the papers (49%) were written by the researchers from the British Empire; France contributed 20%, and Germany 9%, the share of other countries was small.

The unquestioned leader of the study of radioactivity in 1909 was Ernest Rutherford. A year earlier he received the Nobel Prize in Chemistry for 1908. His achievements were indeed impressive. Let us mention some of his results. Already in his first paper on radioactivity in 1899 he identified two kinds of uranium radiation which were named α and β radiation. Then, in 1903, together with Frederick Soddy, he presented the theory of radioactive transformations. In the experiment performed with Thomas Royds he proved that the α particle is a twice ionized helium atom.

Rutherford initiated study of the scattering of α particles in matter. In 1908 his collaborator Hans Geiger obtained a qualitative proof of the existence of that effect [39]. In this very simple experiment the newly found scintillation method was employed. In 1903 William Crookes and independently Julius Elster and Hans Geitel discovered that α particles falling on a luminescent zinc sulphide screen produced faint flashes of light which could be seen and counted under a magnifying glass by an observer whose eyes were adapted to darkness. In Geiger's experiment a narrow beam of α particles from radium emanation fell on a zinc sulphide screen and produced scintillations in a small area corresponding to the transverse size of the beam. When the particles had to traverse thin gold foils before hitting the screen the scintillations were observed in a wider area.

Then came the famous experiment performed by Geiger with the help of Ernest Marsden [40]. They found out, again with the scintillation method, that the scattering occurred at large angles, even greater than 90°. Rutherford declared that it was the most surprising result he had known, and he coined a graphic phrase which, again, he often used [41]: "It was as though you had fired a fifteen-inch shell at a piece of tissue paper and it had bounced back and hit you". His nuclear atom model proposed in 1911 provided explanation of these striking experimental results.

The phenomena of radioactivity seemed to fit the ideas of J.J. Thomson on the structure of atoms. We learn the story from a book on the radioactive substances [42] written by Walter Makower, another collaborator of Rutherford in Manchester:

"According to the scheme proposed by J.J. Thomson, negative corpuscles are supposed to be in rapid rotation in orbits within the sphere of positive electricity. Under these circumstances the corpuscles form themselves into concentric rings, and it can be shown that there are only quite definite configurations of the corpuscles within the atom which are stable. Thus it can be shown that with less than five corpuscles within the atom these corpuscles would arrange themselves in a single ring. On adding a sixth, a discontinuity of arrangement would occur, and the stable system would now consist of a ring of five corpuscles with one at the centre.

On further increasing the number of corpuscles the two-ring system would persist until there were fifteen corpuscles within the atom, when a three-ring system would be formed, and so on for greater numbers. This, then, is in general principle the conception of the constitution of the atoms which we are considering, and in support of this view J.J. Thomson has shown that many of the facts of chemistry can be explained by considering the atoms of the various elements as made up of such systems containing different numbers of corpuscles ...

It can be shown that if the velocity of rotation is increased above a certain critical value, other configurations may suddenly become stable. Suppose, then, that we have a system of corpuscles rotating with velocities above this critical value, certain configurations will be stable which could not exist if the velocity were reduced below the critical velocity. Now it can be demonstrated that such a system will continually radiate out energy, though possibly at a very slow rate, and this energy will be derived from the energy of rotation of the corpuscles. The velocity of the corpuscles will thus be slowly reduced, and must inevitably reach the critical value below which they are no longer in stable equilibrium.

A complete rearrangement of the corpuscles in the atom will suddenly occur, and during the violent disturbance which must thereby be caused, certain portions of the atom may break free which manifest themselves as radiations from the atom. This is what may be conceived to be taking place with the radioactive elements. If such explosions of the atoms occur frequently we have a strongly radioactive element. If they occur less frequently, or not at all, we have a feebly radioactive or non-radioactive substance, as the case may be ...

It is remarkable that a theory of matter which has been devised to explain the physical and chemical behaviour of atoms in general should be capable of interpreting the recently discovered property of radio-activity possessed to an appreciable extent by certain forms of matter only."

Indeed, as late as August 1912 Rutherford still considered "... the instability of the central nucleus and the instability of the electronic distribution. The former type of instability leads to the expulsion of an α particle, the latter to the appearance of β and γ rays ..." [43].

3.8. Magnetic rays

Between 1904 and 1906 Paul Villard, the discoverer of gamma rays, presented the results of his study of the cathode rays in electric and magnetic fields. He first thought that he had discovered a new phenomenon, and even coined the name "magneto-cathode rays" for the alleged electrically neutral radiation. Being unable to prove that it was indeed a new effect he lost interest in this matter.

Villard's idea was taken over by Augusto Righi, a distinguished Italian physicist, well known for his earlier research on electromagnetic waves. Righi claimed the existence of a new type of rays which he named the "magnetic rays". He was convinced that "magnetic rays" were streams of "planetary doublets", that is, neutral systems of electrons bound weakly to a positive ion and originating either from the gas or from the metal of the cathode. Such complexes might exist because of the stabilizing effect of magnetic fields. Righi claimed that magnetic rays could explain features of electrical conduction in gases that the only presence of electrons and ions could not. Magnetic rays have been Righi's major scientific interest for a decade and he published altogether 43 papers on this subjest (7 of these in 1909). Some other Italian physicists joined him in this research and, beginning from 1909, Righi was even recommended by his colleagues for a Nobel Prize in physics for his "discovery". There was, however, little interest of "magnetic rays" among the physicists in other countries where Righi's ideas were soon criticized. A detailed story of Righi's "magnetic rays" may be found in [44].

3.9. New elements

One has to remember that hundred years ago the structure of the periodic system of elements was still unknown. For example, the system proposed in 1907 by Antonius van den Broek [45] had 120 places and the heaviest element, uranium, was assumed to be the last, having atomic number 120 and atomic mass 240. The proposed system included a lot of empty "cells" for yet undiscovered elements.

In November 1908 Masataka Ogawa from the Imperial University in Tokyo announced discovery of two new elements closely allied to Molybdenum [46]. The author proposed the name "Nipponium" to one of them, and modestly left the naming of the second one to others. Another announcement of a new element, "Ionium" was made by Bertram Boltwood from Yale [47].

The proper constitution of the periodic system was found later, in 1913, thanks to the studies by Henry Moseley, Frederick Soddy, Antonius van den Broek, and Niels Bohr.

4. Concluding remarks

We have seen that some physics ideas popular in 1909 seem truly bizarre when perceived with the present perspective. It is a proof of the often forgotten fact that physics does not develop in a logical and straightforward way but always encounters many wrong turns and blind alleys.

It is curious that the physics textbooks of that time were almost entirely filled with classical physics. The concepts of modern physics were seldom reported. For example, the word "atom" was not mentioned at all in *Properties of Mattter*, vol. 1 of the textbook of physics by H. Poynting and J.J. Thomson published in 1909 [48]. The sixth edition of volume 5 of that textbook, *Heat*, published in 1920, included just a few sentences about the atomic hypothesis [49]. Planck's radiation formula was mentioned but described only as a modification of Wien's formula. The word "quantum" did not appear at all!

It is also curious to note that among several distinctions and honours of J.J. Thomson which were listed in the title page of the latter textbook (honorary doctorates from Princeton, Victoria, Glasgow, and Cracow and memberships of learned societies) there was no mention of the Nobel Prize for Physics which he received in 1906. Apparently, as late as 1920, Nobel Prizes were still not held in esteem.

History of physics carries an important message that we should treat successes of physics with modesty. How could we be sure that our present understanding of the physical world survives the test of time? How will our present theories be looked upon by a historian of physics in the year 2109?

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