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A Review of Fabry and Perot discoveries

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1. Introduction

It is a great pleasure for us, daily Fabry-Perot interferometer (hereafter referred to as FP) users, to pay homage to the genius inventors of the FP. Each day we are still bewildered by the power of this instrument which mainly consists of two pieces of half-silvered glass. Even if equations of physics are perfectly able to describe multiple-beam interferences (hereafter referred to as MBI), something magic remains in our mind.

We will tackle this paper from a historical point of view. As any discovery, the invention of the FP did not occur just by chance from nowhere. As pointed out by Connes (1986) the invention of the multiple-beam interferometer may be understood as having proceeded from the fortunate convergence of two independent developments : *(i)* During 2 centuries, MBI has been observed and even computed but its specific and pregnant feature, the fringe sharpening, was not understood before Fabry's thesis. *(ii)* A long production of mirrors, leading to the semi-transparent silver film.

Between the first observations and descriptions of MBI and the final discovery of the FP, two centuries were needed. It is clear that the MBI cannot be understood before the development of wave theory (Huygens and Fresnel) and the discovery of monochromatic radiations: solar absorption lines by Fraunhofer (1814) and Sodium emission lines by Fizeau (1864).

Over almost one century, thousand of papers dealing theory, practice and application of FP appeared throughout the world as well in physics astronomy, metrology, geophysics, chemistry or biology. Vaughan (1989) and some others (see references) already published excellent works about theory, research and development of the FP. The core of this review consists of a bibliography of the original publications of Fabry, Perot and some others. At the picture of their multidisciplinary work, their papers have been classified into the several great fields of FP early applications. It is impressive to realize so how they were pioneered such a multitude of applications. In particular, both scientific careers of Perot and Fabry have strongly contributed to narrow the gap between physics and astronomy to give sense to astrophysics at the beginning of the century.

2. The Discovery of the Fabry-Perot Interferometer

A very accurate and exhaustive history of multiple-beam interference up to FP discovery has been reviewed (in English) by Connes (1986).

2.1. First observations and descriptions of MBI: Hooke, Newton and Herschel

About MBI, as well as about gravity theory, Robert Hooke (1635-1703) has undertaken preliminary works before Newton's ones. Hooke described the first soap-bubble observations and produced colour scale (but no well defined fringes) by observing light between 2 pieces of glass stiffly rubbed. Isaac Newton (1643-1727) described the famous Newton's rings given by an air film limiting two spherical surfaces or a spherical and a plane surface. He studied the variation of ring diameter versus increasing incidence. He observed sharp fringes near the total reflection limit (it was MBI). Using a prism, Netwon discovered achromatization "... see the Rings distinct and without any other colour than black and white (Sic)" To explain these fringes Newton introduced for rays some periodic disposition "... the progress of the Rays returns at equal intervals ... these ... Fits of easy reflexion ... and those ... Fits of easy transmission ... (sic)" William Herschel (1738-1822) also observed MBI and achromatic fringes produced by a thin air film. Using two "perfect" flat glass and eye observing pretty close to the surface, Herschel saw fringes localized at infinity. Furthermore he drew the multiple reflections between the two parallel surfaces but could not explain fringes: Herschel totally ignored Young's work and even the periodic feature introduced by Newton.

2.2. Computations on multiple-beam interference: Young, Fresnel, Poisson, Airy and Fabry

Thomas Young (1773-1829) was the first one to explain the principle of interference fringes and thus established the wave character of the light. Some years after Augustin Fresnel (1788-1827) elaborated the wave-theory, with transversal vibrations and demonstrated interference, diffraction and polarization phenomena. At that time interference fringes were obtained for small path difference, and only in 1846 Fizeau and Foucault demonstrated the perfect regularity of the light waves on a long optical path (7000 waves). Using his formulae for "reflection and refraction coefficients", Fresnel computed the extremum intensity but curiously for only two waves. Simeon-Denis Poisson (1781-1840) discovered that an infinite set of reflections must be involved, but he computed only the extremum intensities. George Airy (1801-1892) provided the full expression for reflected and transmitted light intensity by a plate of glass (1830): the famous Airy formula. Unfortunately, Airy never drew any conclusion about the shape of the function he gave the mathematical expression. So, Airy discovered the expression of the MBI but did not realize the link between the sharpness of the function and the factor of reflection of the plate, gateway to understand the FP. This acuity of the resonance with the reflectivity, "the Airy *Finesse*" was only understood by Charles Fabry in his thesis (1892).

2.3. Towards conclusive experiments on multiple-beam interferometer: from Fizeau to Boulouch

Leon Foucault (1819-1868) realized first half-silvered plates. Armand Fizeau (1819-1896), using his two-beam interferometer, which consisted of a thick variable air layer, illuminated by Na D_1 and D_2 emission lines, observed sinusoidal fringes. Periodically, for some thicknesses corresponding to the discordances,

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fringes vanished (visibility minima) and reappeared at the next coincidences. In 1893, in a (too) short paper, Raymond Boulouch (1861-1937) got the genius idea to use Foucault's half-silvered plates to reproduce Fizeau's experiment (but here in MBI conditions and observing transmitted light). Boulouch claimed that, "in case of perpendicular lightening, when increasing the reflectivity of the plates by a thin silver layer ... then at the discordances, Na D_1 and D_2 lines produces two systems of sharp rings (splitting of the lines)". This is the physical content of the FP. Nevertheless, it seems that Boulouch did not realize the practical significance of his capital discovery. As a proof, he did not draw any practical consequence and the last part of the paper is much less interesting. Boulouch used the Airy function but did not explicit its fringes sharpening while Fabry had already described them in his thesis (1892). Moreover, he gave neither experimental description nor measurements. It seems that Boulouch got the conviction that his work was completed.

2.4. The interferometer : Fabry and Perot

In 1894, Alfred Perot and Charles Fabry were in Marseille Faculty of Science, at the optical laboratory headed by Jules Macé de Lépinay (1852-1904), the best place in France to learn about interferences. The discovery, partly by chance, came from an electricity problem. Spark discharges were produced between metallic surfaces separated by a very small space ($\leq 1\mu$m). In order to measure the distance between the metallic plates, Fabry got the feeling to use lightly silvered glass plates following the method published by Boulouch a year ago. In collaboration with Perot, Fabry clearly understood the relation between fringes sharpening (the contrast ratio), and the high reflective power of silvered plates. The first application was the construction of an absolute electrometer which allowed fast thickness measurement by the method of superimposed fringes (1897). Perot, who was very skilful mechanically, built the electrometer while Fabry attempted the optical part. Being well experienced in dealing with fringes from silvered film, Fabry and Perot further developped a lot of applications to lengths measurement of gauges used in accurate mechanical work, to the study of fine spectral lines, to the determination of standard etalon (meter, kg) and spectroscopic standard (wavelength), to solar and astronomical studies, and so on ... Fabry said about Perot and himself : "Our turn of mind were complementary". Fabry reported that Perot was a genius experimenter who read not much and hated writing, he was a very secret man, but his real (and almost feverish) activity was in the laboratory where he always got and realized new experimental ideas. Fabry was, on the contrary, a teacher, a writer and a traveller. Its fame is probably more important due to his international reputation.

So, one can conclude that the discovery of the FP by Fabry and Perot proceeded from two processes. First, they built interferometers and carefully, methodically and extensively studied the fringes produced by half-silvered plates. The *finesse* of the fringes and channelled spectra were referring to Airy function. The resolving power of the interferometer was computed and improved. The localization of the fringes at infinity was demonstrated. The adjustment of plane-parallelism was described. The coincidence and fringes superimposition techniques were invented and developped. The solid glass etalon was introduced. Scanning FP systems were introduced. The phase effects at the reflection were understood ... Second, from the very beginning and later in collaboration with Henri Buisson (1873-1944), Fabry and Perot performed metrological, physical, astrophysical and geophysical studies. These scientific works definitely proved their mastery of the instrument.

It is amazing to notice that one year after Fabry and Perot discovery, the same phenomenon was discovered and understood with Hertzian waves in Heinrich Hertz (1857-1894)'s laboratory.

3. Review of the publications of Fabry, Perot and Buisson

Fabry and Perot produced theoretical studies, developped analysis methods for optical interferences, spectroscopy and photometry. Their fields of application were physics, astrophysics and even geophysics. Except for laser development, it is difficult to point to anything that had not been, at least envisaged by Fabry and Perot.

In this section we will try to provide a bibliography, as complete as possible, of the Fabry, Perot and Buisson original publications. We divided their work into 5 themes (metrology, laboratory spectroscopy, laboratory and astronomical photometry, astrophysics and geophysics). Each theme is again separated divisions appear. Within a division, a chronological order has been adopted. Keywords have been given to introduce each division. As it is absolutely impossible, in a few pages, to describe and comment the entirety of their huge and multidisciplinary work, free comments have been given, on subjectively chosen topics, at the end of each theme. A last paragraph refers to Fabry teaching books and conferences.

We have used hereafter the following code for the authors :

Fabry is referred to as F,	Bosler as Br,	Kaiser as K,
Perot as P,	Boulouch as Bl,	Laporte as L,
Buisson as B,	Bourget as Bg,	Lindstedt as Li,
and others collaborators:	Collinet as C,	Macé de Lépinay as M,
Ames as A,	Deslandres as D,	Paschen as P,
Benoît as Bt,	Jausseran as J,	Rouard as R.

We have used hereafter the following code for the Journals :
Astrophysical Journal is referred to as ApJ,
Comptes Rendus de l'Académie des Sciences de Paris as CRAS,
Journal de Physique (théorique et expérimentale) as J Phys,
Revue d'optique as R Opt,
Annales de Chimie Physique as Ann Ch Ph,
Bureau International des Poids et Mesures as BIPM,
Gerlands Beitrage zur Geophysik as GBG,
Congrès International sur l'Ozone, Paris as CIO,
Bulletin des Recherches et Inventions as BRI.
Annale der Physik as AdP,

As a proof of their huge work, P was involved in 90 papers, F in 135 and B in 76. A total of 218 papers has been published including 23 in ApJ.

3.1. Metrology

The discovery of the FP was related to length measurements (thin and thick air layers). These high accuracy measurements were furthermore applied to better definiting of standard units (metre, kg, ohm) and matching of units together. Electrometers were also developped to measure weak potentials.

3.1.1. Interference phenomena

Keywords: *Theory of visibility and orientation of interference fringes; grazing incidence; mirages with interference; thin plates; Hertzian resonators; dielectric constant; electromagnetic oscillations; $\lambda/4$ phase shift in Newton's rings (Gouy phenomena).*

MP 1889 CRAS 108, 1043	F 1890 CRAS 111, 788	P 1892 CRAS 114, 1528
MP 1889 J Phys 9, 376	MF 1891 J Phys 10, 5	P 1892 CRAS 115, 38
F 1890 CRAS 110, 455	P 1891 Ann Marseille 8, 67	F 1892 J Phys 1, 313
MF 1890 CRAS 110, 895	P 1891 J Phys 10, 149	F 1892 CRAS 115, 1063
MF 1890 CRAS 110, 997	P 1892 CRAS 114, 165	F 1895 CRAS 120, 314
F 1890 CRAS 111, 600	MP 1892 Ann Ch Ph 27, 94	F 1900 CRAS 130, 238

3.1.2. The invention of the FP : Multiple-beam interference and half-silvered plates

Keywords: *Fringes sharpening and acuity of the corresponding resonance; superposition fringes; phase effect at reflection; method of coincidences; channelled spectra; grating and FP cross-dispersion; scanning interferometer by elastic water pressure*

Bl 1893 J Phys 2, 316	FP 1898 CRAS 126, 1561	B 1903 J Phys 2, 881
FP 1896 CRAS 123, 802	FP 1899 Ann Ch Ph 16, 115	F 1905 CRAS 140, 848
PF 1896 CRAS 123, 990	PF 1899 Bull Astron 16, 5	P 1906 CRAS 142, 566
FP 1897 Ann Ch Ph 12, 459	FP 1901 Ann Ch Ph 22, 564	FB 1908 J Phys 7, 417
FP 1898 CRAS 126, 34	FP 1901 ApJ 13, 265	BF 1909 CRAS 148, 828
FP 1898 CRAS 126, 331	MB 1903 CRAS 137, 312	P 1909 CRAS 149, 725

3.1.3. Thickness measurements and standard meter

Keywords: *-Thin, very thin, thick - air layer - relative, absolute measurements; étalons de longueur à bouts; glass thickness measurement indepently of index; 1 meter = 1,553,163.99 Cd* 6438Å.

FP 1898 CRAS 126, 1779	PF 1901 Ann Ch Ph 24, 119	PF 1904 CRAS 138, 676
PF 1899 Ann Ch Ph 16, 289	MB 1902 CRAS 135, 283	B 1906 CRAS 142, 881
PF 1899 ApJ 9, 87	MB 1903 CRAS 137, 1038	BtFP 1907 CRAS 144,1082
PF 1901 Ann Ch Ph 16, 289	MB 1904 Ann Ch Ph 2, 78	BtFP 1913 BIPM 15,3

3.1.4. Mass of a cubic decimeter of water, air and glass indexes

Keywords: *Ordinary and extraordinary indexes in quartz; air viscosity; cubic decimeter of water.*

M 1887 Ann Ch Ph 10,166	MFP 1897 Ann Ch Ph 2, 102	B 1905 J Phys 4, 669
M 1892 J Phys 3, 23	FP 1898 Ann Ch Ph 13, 275	P 1907 CRAS 145, 1157
M 1895 CRAS 120, 770	FMP 1899 CRAS 128, 1317	MBtB 1910 BIPM
M 1895 Ann Ch Ph 5, 210	FMP 1899 CRAS 129, 709	B 1919 J Phys 9, 25
M 1896 CRAS 122, 595	M 1902 CRAS 134, 898	F 1931 CRAS 193, 99

3.1.5. Equivalence between electric and length units, electrometers

Keywords: *Interferential electrostatic voltmeter; absolute interferential electrometer for very small voltage measurements; comparative measurements of gravity force* *and electromotive force with FPI; international Volt, Latimer-Clark battery; international Ampere unit, mercury specific mass*

PF 1897 CRAS 124, 180	PF 1898 J Phys 7, 317	PF 1898 J Phys 7, 650
FP 1897 CRAS 124, 281	PF 1898 Ann Marseille 8, 205	P 1925 CRAS 180, 130
PF 1898 J Phys 7,1	PF 1898 Ann Ch Ph 13, 404	F 1927 CRAS 185, 684

ABOUT A VALUE OF THE MASS OF A CUBIC DECIMETER OF WATER

The decimal metric system was born from the mind of universality of the French revolution (Borda, Lagrange, Laplace, Condorcet and Monge). Nevertheless, at the begining of the century, the mass of the cubic decimeter of water was still poorly known (with a relative accuracy of 10^{-3}). PFM improved the measurements till 10^{-6}. The unit of mass has been historically chosen as the mass of a dm^3 of water at 4 C (by immersion of $1dm^3$ of quartz in a bath of water at 4 C). In order to approach the exact dimensions of a cubic decimeter of quartz, PF and PFM cartographied the thickness of 60 cm^3 of quartz using interferometric length measurements. The surface cartography reached the accuracy of 0.1μm. The mass of the dm^3 of water is measured: 0.999 979 instead of 1 kg. To day 0.999 974 kg is adopted; the modern measurements are obtained, by the same interferometric principles but with a sphere instead of a cube (high quality machine finishing of a sphere being easier). The new specific mass of water allowed PF to deduce the specific mass of mercury. As a consequence, they determined the electric unit of resistivity (the Ohm) by producing a current through a column of mercury defined as 106.3 cm long and 14.4521 g mass (section is too imprecise).

3.2. Laboratory Spectroscopy

Due to its high spectral resolution and contrast, the FP is perfectly adapted to spectrocopic measurements. Laboratory, terrestrial, solar and astronomical lines studies were always closely interconnected. The compactness of the instrument and its relative operating facilities (with respect to the Michelson interferometer for instance) allowed various fields of application. But above all, the authors got the will to link laboratory physics to astrophysics and geophysics.

3.2.1. Emission Lines

Keywords: *Th, Hg, Cd, Ni, Mn, Na, Si, H, I, Fe, Mg rare gas spectra; BaF_2 bands; Iron atlas; separation of close spectral lines (doublet and triplet); H and electric tubes; identification of unknown spectral lines.*

PF 1898 CRAS 126, 407	FP 1901 CRAS 132, 1264	F 1905 ApJ 21, 356
PF 1898 CRAS 126, 1624	F 1904 ApJ 19, 116	FB 1906 CRAS 143, 165
FP 1898 CRAS 126, 1706	F 1904 CRAS 138, 854	BF 1907 CRAS 144, 1155
FP 1900 CRAS 130, 406	PF 1904 Ann Ch Ph 27, 5	BF 1912 AdP 98, 245
PF 1900 CRAS 130, 492	PF 1904 J Phys 3, 28	B 1924 CRAS 178, 1270

3.2.2. Fine Structure

Keywords: *Hg, Cd, Th - doublet and triplet; satellite line due to impurities; pressure effect in Hg lamp; iron arc and mercury arc in vacuum.*

FP 1900 CRAS 130, 653	P 1910 CRAS 150, 1684	P 1913 CRAS 156, 132
P 1909 CRAS 148, 404	PBr 1910 CRAS 151, 216	P 1913 CRAS 156, 310
FB 1909 CRAS 148, 1240	BF 1910 CRAS 151, 223	P 1913 CRAS 156, 1679
P 1910 CRAS 150, 1515	BF 1910 J Phys 9, 929	PC 1925 CRAS 180, 2030

3.2.3. International Wavelength Units

Keywords: *Corrections to Rowland's wavelengths; international system; secondary standards.*

FP 1902 ApJ 15, 261	PF 1904 J Phys 3, 842	KFA 1911 ApJ 33, 85
PF 1902 ApJ 16, 36	FB 1908 ApJ 28, 169	BF 1913 CRAS 156, 945
FP 1904 ApJ 19, 119	BF 1908 J Phys 7, 169	FB 1913 J Phys 3, 613
PF 1904 ApJ 20, 318	KFA 1910 ApJ 32, 215	KABP 1914 ApJ 39, 93

3.2.4. Kinetics Gas Theory

Keywords: *Temperature in gas lamps; He, Ne and Kr lamps; rare gas in the atmosphere; Doppler-Fizeau line broadening.*

BF 1912 J Phys 2, 442	BF 1912 CRAS 154, 1349	BJ 1925 CRAS 180, 505
FB 1912 CRAS 154, 1224	FB 1912 CRAS 154, 1500	BJ 1926 R Opt 5, 149

3.2.5. Spark spectrum

Keywords: *Enhanced lines of Lockyer.*

FB 1908 CRAS 146, 751	FB 1910 CRAS 150, 1674

About spectroscopic standards and length of the meter

Laboratory wavelength metallic arc spectra and solar spectrum had been first determined by Fraunhofer (1787-1826). Rowland (1841-1901)'s famous spectral line measurements were based on solar spectra while later interferometric measurements by Michelson (1852-1931) were based on spectral lamp. Michelson's and Rowland's values presented a well known discrepancy of about 1/30 000 (due to an error made by Rowland in determining the basic absolute wavelength of the sodium line by means of a grating). Nevertheless, FP attempted a direct comparison between solar spectra and laboratory spectral lamps spectra, using a concave grating. The result was a complete shakemate! FP settled the problem by using MBI methods (on solar absorption lines and on laboratory sources), exhibited small systematic errors (of 0.004 nm) in Rowland's tables and explained that the random differences found between solar lines and arc spectra lines were due to the peculiarity of electric arcs. These measurements led FPBBt to a new definition of the meter, based on the red cadmium line, 20 years after the historical experience of Michelson (1894). The average relative error for these line measurements was, of 5 10^{-8}.

About the emission lines atlas

When preparing their Fe emission lines atlas BF (1908) noticed that an electric arc emits in a very restricted area and that this arc is produced by a high electric field rather than by a high temperature, as was currently thought.

About the width of spectral lines

FB (1912) evaluated gas temperature by line width measurements using the visibility of the fringes. According to kinetic gas theory, FB (1912) have shown (by cooling a spectral lamp inside a bath of liquid air) a line narrowing when the temperature decreases. Knowing the atomic mass and the lines width of monoatomic rare gases(He, Ne, Kr) they demonstrated that the temperature inside a Geissler tube is similar to external temperature. At liquid air temperature, they measured a line width of 6 10^{-3} Å.

3.3. Laboratory and astronomical photometry

Since Bouguer (1698-1758) very few progresses had been made in photometry. F made several discoveries, mainly in heterochrome photometry. He compared sources of different spectral ranges using coloured filters in order to compare their fluxes at the same mean wavelength. Luminosities of stars were also related to photometric standards: 1 mm^2 on the solar disk gives a light emission equivalent to 1800 candles, illumination produced by Vega is identical to 1 decimal-candle seen at 780 meters.

3.3.1. Fluxes

Keywords: *Monochromatic fluxes; standard fluxes; absolute flux for Hg 5460Å line is measured (0.583 10^{-5} watt/cm^2); equivalence between light flux and mechanical force is obtained (55 candles per watt); plages de Fabry; stellar photometry; heterochrome photometry.*

FP 1899 CRAS 128, 1156	FB 1906 CRAS 142, 784	BF 1911 CRAS 152, 1838
PF 1899 CRAS 128, 1221	PL 1906 CRAS 143, 743	FB 1911 CRAS 153, 93
FP 1900 J Phys 9, 369	BF 1908 CRAS 146, 1143	BF 1911 CRAS 153, 254
F 1903 CRAS 137, 743	F 1909 ApJ 30, 318	F 1922 R Opt 1, 413

3.3.2. Photographic plates and eye

Keywords: *Photographic plate; minimum radiation visually perceptible: 1 candle to 27 km.*

B 1917 ApJ 46, 296	B 1919 BRI	BF 1924 R Opt 3, 1
B 1917 J Phys 7, 68	BF 1924 J Phys 7, 97	F 1928 CRAS 186, 53

3.3.3. Microphotometer and photometer

Keywords: *Universal photometer; microphotometer for photographic plates.*

BF 1913 CRAS 156, 389	FB 1919 J Phys 9, 37	FB 1920 J P,hys 1, 25

3.4. Astrophysics

3.4.1. Doppler-Fizeau redshift and absorption solar lines

Emission and absorption line profiles were analysed in order to measure physical parameters (pressure, density, temperature). Redshifted emission lines of extended astronomical sources have been studied in order to study their internal kinematics.

Keywords: *spectra, rotation, vertical movements; feeble pressure and reversing solar layer; solar spectra vs solar radius; lines shifts and widths (Fe, Mg, Na, H, Ca, Hg); telluric lines.*

PF 1900 CRAS 131, 700	P 1908 CRAS 147, 340	P 1915 CRAS 160, 549
PF 1901 CRAS 133, 153	FB 1910 ApJ 31, 97	FB 1919 J Phys 9, 239
FP 1902 ApJ 15, 73	FB 1910 J Phys 9, 197	P 1922 CRAS 174, 215
FP 1902 Ann Ch Ph 25, 98	BF 1910 J Phys 9, 298	P 1924 CRAS 178, 380
F 1905 CRAS 140, 1136	FB 1914 CRAS 158, 1498	

3.4.2. Pressure in Solar Gaseous Layers

Keywords: *Na D1 line in solar atmosphere; polar and equatorial velocity for H lines; profile variations of solar lines with solar radius; variation of Mg and Cyanogen lines; motions of gaseous layers.*

FB 1909 CRAS 148, 688	P 1910 CRAS 151, 429	P 1912 CRAS 154, 326
BF 1909 CRAS 148, 1741	PL 1911 CRAS 152, 1367	P 1912 CRAS 154, 1684
P 1910 CRAS 151, 38	P 1911 CRAS 153, 36	

3.4.3. Verification of General Relativity

Keywords: *First laboratory verification of Doppler-Fizeau effect; Doppler-Fizeau shift when optical index rapidly varies; Doppler-Fizeau shift due to earth and solar motions; profile corrections for calibration wavelengths in vacuum. profile corrections due to pressure and motions in gaseous layers with Mg, Cyanogen and Fe lines; gravitational redshift, Einstein effect.*

P 1920 CRAS 170, 988	P 1921 CRAS 172, 578	P 1922 CRAS 174, 933
P 1920 CRAS 171, 229	BF 1921 CRAS 172, 1020	P 1922 R Opt 1, 260

3.4.4. Nightsky light and Galactic Brightness

Keywords: *Intrinsic brightness for starlit sky and for Milky Way; intrinsic brightness of the sun: 184 000 candles per cm^2 and of the moon: 0.312 candles per cm^2.*

F 1903 CRAS 137, 973	F 1905 CRAS 141, 940	P 1912 CRAS 154, 1331
F 1903 CRAS 137, 1242	F 1910 ApJ 31, 394	F 1917 ApJ 45, 269
F 1905 CRAS 141, 870	F 1910 CRAS 150, 272	F 1919 ApJ 50, 308

3.4.5. Orion Nebula

Keywords: *Focal reducer; radial velocity field, motions and turbulence; electronic temperature (15 000 K); wavelengths of nebulium lines (λ3727 and 3729); profile of Hγ line; wrong evaluation of nebulium atomic mass.*

FB 1911 CRAS 152, 995	BtFB 1914 CRAS 158, 1017	BF 1914 J Phys 4, 573
FB 1911 ApJ 33, 406	BtBF 1914 CRAS 158, 1269	BF 1914 J Phys 4, 578
BFBt 1914 ApJ 40, 241	BFBt 1914 J Phys 4, 357	

3.4.6. Occultations

Keywords: *photometric influence of planet atmospheres during star occultations.*

F 1928 CRAS 187, 627	F 1928 CRAS 187, 693	F 1928 CRAS 187, 741

ABOUT ASTRONOMICAL PHOTOMETRIC MEASUREMENTS

F measured the intrinsic brightness of the starlit sky. In order to compare fluxes emitted at different wavelengths by different sources, Fabry developed a new method well known today as *Plages de Fabry*.F linked integrated fluxes emitted by the Milky Way and the night sky to solar emission.

ABOUT THE VELOCITY FIELD OF THE ORION NEBULA

Using the equatorial of Marseille Observatory , interference rings due to [OIII] λ5007 Å, Hg λ4341 Å and Nebulium [OII] λ3727 Å were recorded on photographic plates by FB (1911). The variation of wavelength from one point to another gave circulatory movement of the gas. An indication on the temperature is given by the widths of the hydrogen lines, while the width of unknown lines gives a clue to the atomic weight of the gas which forms them.

Using (i) the 80 cm diameter Foucault's telescope of Marseille, (ii) two silvered pairs of plates spacers between 0.1 and 3 mm, (iii) absorption filters (to isolate different lines) and (iv) photographic plates, BFBg (1914) obtained fourteen 1-2 hours exposures, on $H\gamma+H\beta$, $H\gamma$, Nebulium [OII] $\lambda 3728 Å$ lines of Orion nebula.

ABOUT DOPPLER-FIZEAU EFFECT WHEN LIGHT CROSSES MEDIUM FOR WHICH THE INDEX VARIES RAPIDLY WITH TIME

P (1924) attached 12 prisms on the edge of a cream-separator! So the light crossed the prisms at different distances from its base. This produced a medium for which the index varies rapidly with time. The agreement of his measurements with the theory was better than 10^{-8}.

ABOUT GRAVITATIONAL REDSHIFT OF SOLAR LINES

Einstein's theory predicts, at optical wavelength, a relative gravitational redshift of 2 10^{-6} between solar and terrestrial lines. Its experimental verification is quite delicate due to the superimposition of 4 different effects: *(1)* Doppler-Fizeau broadening due to solar rotation, *(2)* vertical motions of absorbing particules, *(3)* pressure shift of line and *(4)* gravitational redshift. Metallic lines are not equally shifted when the pressure increases. By this way, it is possible to disentangle the pressure effect from other effects like Doppler-Fizeau which produce the same shift for all lines. P (1911,1921) deduced that the solar pressure is very low. Applying this appropriate correction, he obtained a relative gravitational redshift of 2.5 10^{-6}.

Solar iron lines redshift observed by BF (1909) was first attributed to (high) pressure effects. Nevertheless, this explanation was unsatisfactory because of various anomalies of observed shift width and shift. Under the assumptions of low solar pressure, the mean displacement for 32 solar lines was within 20% of Einstein's theory predictions (BF 1909-1921).

3.5. Geophysics

3.5.1. Ozone and UV Rays

Keywords: *double subtractive spectrograph; UV spectrum drop; atmospheric absorption in UV solar spectra; ozone absorption in Hartley's bands; Rayleigh's diffusion and haze effect; very high ozone absorption in UV (only 1/70,000 UV rays is transmitted for λ leq 292 nm); location of ozone in the outer layers of the atmosphere above 40 km; explanation of its origin; daily, seasonal and annual variations in the quantity of ozone.*

B 1908 J Phys 7, 952
BF 1911 Revue des Sciences
FB 1913 CRAS 156, 782
BF 1913 J Phys 3, 196
B 1921 J Phys 2, 197
FB 1921 ApJ 54, 297
FB 1922 CRAS 175, 156
BJ 1926 CRAS 182, 232
B 1928 CRAS 186, 1229
B 1929 CRAS 188, 647
F 1929 1er CIO Paris
B 1929 R. d'actinologie
B 1932 R. d'actinologie
B 1929 GBG 24, 18 et 30
BJR 1930 CRAS 190, 808
FB 1931 CRAS 192, 457
BJR 1932 CRAS 194, 1477
BJR 1933 R Opt 12, 70

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3.5.2. Terrestrial magnetic field and Diffusion

Keywords: *Zeeman effect; Terrestrial magnetic field and electromagnets.*

F 1907 CRAS 145, 112
DP 1914 CRAS 158, 226
DP 1914 CRAS 158, 658
DP 1914 CRAS 159, 438
P 1922 CRAS 175, 869
F 1928 CRAS 187, 61

ABOUT OZONE

Taking into account Rayleigh's diffusion FB (1921) measured the distribution of energy in the UV solar spectrum ($\lambda \leq 315nm$) compared to UV absorption produced by ozone on mercury lamp flux in laboratory. FB concluded that atmospheric absorption is equivalent to an ozone layer of about 3 mm thick. FB measured the very high UV absorbing power of ozone in laboratory: 50% for a 0.025 mm layer, i.e. 2^{120} for a 3 mm layer. As the extreme dilution (2.5 x 10^{-8}) of ozone in air at ground level was known, FB concluded to the presence of ozone at higher concentration in the outer layers of the atmosphere. Due to the curvature of the earth Bouguer's law varies (by 30% for h = 5°) with the altitude of one atmospheric layer, FB suggested this method to compute the ozone location shown to be above 40 km.

FB pointed out the azimutal, season and annual variations of the ozone layer, emphasized the quasi-total UV absorbing role of the ozone layer (only 1/70000 is transmitted). During the late period of his life, Fabry was worried with ozone studies. He even organized a colloquium held at Paris in 1929. Fabry was physicist, astronomer, metrologist and also geophysicist.

3.6. Books and lectures of Charles Fabry

1920 Les piles électriques, Ency. Sc. Aide Mémoire Ed. Gauthier-Villars, Paris
1923 Les applications des interférences lumineuses Ed. Revue d'optique, Paris
1923 La lumière monochromatique Ed. Revue d'optique, Paris
1924 Leçons de photométrie Ed. Revue d'optique (Théor. et Instrum.), Paris
1924 Histoire de la physique Ed. Plon Nourrit, Paris
1927 Introduction générale à la photométrie Ed. Revue d'optique, Paris
1928 Introduction à l'optique appliquée Ed. Revue d'optique, Paris
1928 Eléments de Thermodynamique Re-Ed. Armand Colin, Paris, 1962
1932 Cours de physique à Polytechnique Ed. Gauthier Villars, Paris
1935 Physique et astrophysique Ed. Flammarion, Paris
1938(*) Oeuvres Choisies, Jubilé Scientifique Ed. Gauthier-Villars, Paris
1949 Propagation de la chaleur Ed. Armand Colin, Paris
1950 Eléments d'électricité Ed. Armand Colin, Paris
1950 L'ozone atmosphérique Ed. du CNRS, Paris
1950 Optique - Cours Sorbonne Ed. Presses Universitaires de France
1951 Les radiations Ed. Armand Colin, Paris

(*) In this very precious book of 700 pages published by Fabry for his retirement, one can find a very complete selection of almost 50 years of publications by Fabry, Perot, Buisson and Macé de Lépinay. The list of publications re-printed in this book is not exhaustive, mainly to avoid repetition. Some papers have also been slightly improved for clarity and concision. Some notes have been added too.

4. Quick biographies

4.1. Alfred Perot (1863 - 1925)

Preamble: Should one write Perot or Pérot ?

On a birth certificate, we got from the Museum of Metz (France), Perot is written without any accent. In the same way, ministerial decree of the appointements both as *Maître de conférences* and as Professor, there is no more accent on the e of Perot. Strangely, Perot referred to himself in some publications as Pérot ! Maybe to make it more Gallic ....

1863 : Born at Metz, November 4.

1882 : Ecole Polytechnique of Paris.

1888 : His thesis being entitled " *Sur la mesure des volumes spécifiques des vapeurs saturantes, et de l'equivalent mécanique de la chaleur*" consisted of a thermodynamical work on saturated vapours. Perot got a position of *Maître de Conférences à la faculté des sciences de Marseille* where he taught and worked during 13 years. At the same epoch, Charles Fabry, younger, was a student at the same university. Macé de Lépinay was the director of the group where Perot started to work in. Perot was first working on electricity theory (Hertzian waves and properties of dielectrics) and industrial applications.

1894 : Perot became Professor of Industrial Electricity at Marseille University. His succesor as *Maître de Conférences* being Charles Fabry. The long collaboration between Perot and Fabry started at this time.

1901 : First director of the *laboratoire d'essai (Paris)*. As a director, he spent a large part of his time for administrative work.

1908 : Professor of Physics at the *Ecole Polytechnique* and Physicist at Meudon Observatory. At Meudon Observatory (Paris) he worked mainly on spectrometric and interferometric measurements of solar atmospheric absorption lines. His works on electricity were also going on in order to produce very intense magnetic field.

1914 : During (and after) the Great War, Perot was engaged in problems relating to communication (applications of three electrodes lamps, apparatus for measuring the terrestrial magnetic field).

1925 : Died in Paris November, 28. He was survived by 5 children.

4.2. Charles Fabry (1867 - 1945)

1867 : Born at Marseille, June 11, into a scientific family. Charles Fabry was a cousin of Edmond Rostand, the famous author of *Cyrano de Bergerac*.

1885 : Ecole Polytechnique (like Perot 3 years earlier).

1889 : *Agrégation de Sciences Physique*. He started his thesis in the Macé de Lépinay's laboratory in Marseille. He taught in secondary Schools (Pau, Never, Bordeaux, Marseille and Paris) from 1890 to 1893.

1892 : Thesis at La Sorbonne (Michelson was also in Paris). entitled *Théorie de la visibilité et de l'orientation des franges d'interférence.*

1894 : Maître de Conférences at Marseille University, succeeding at Alfred Perot. During the years he spent in Marseille University, Fabry realized the most important part of his scientifical work.

1904 : Professor at Marseille University (On a chair of industrial electricity).

1920 : First director of the *institut d'optique*, Paris.

1921 : Professor of Physics at La Sorbonne (until retirement in 1937).

1927 : Chair of Physics at the *Ecole Polytechnique* succeeding at Perot (who died in 1926). Fabry taught and wrote books. Member of the *Académie des Sciences*.

1945 : Died in Paris, December 11.

5. Conclusion

Hooke, Newton, Herschel, Young, Fresnel, Poisson, Airy, Fizeau, Foucault and Boulouch contributed to the emergency of the discovery of MBI, but without Fabry and Perot, it would have taken much more time to reach such a practical importance in applied physics.

Hooke and Newton first observed without understanding multiple-beam interference (MBI). Herschel described MBI close to total reflection and observed fringes located at infinity.

Poisson and Airy approached the discovery of MBI in giving its mathematical expression without realizing its physical significance.

Fizeau used the first scanning two-beam interferometer for metrology and spectroscopy. Foucault realized the first half-silvered plates and using them Boulouch produced MBI by transmission.

Fabry first clearly understood the link between the acuity of Airy function and the reflectivity of the plates. Perot and Fabry fully realized the importance of the Boulouch's discovery for further applications. Together they built interferometers and extensively experimented, developed and used them for metrology, photometry and spectroscopy. Often in collaboration with Buisson, they made important and various scientifical discoveries and/or pioneer works in physics as well as in astrophysics or geophysics.

Finally, they strongly contributed to narrow the gap between physics and astronomy in developing and applying laboratory spectroscopic methods of analysis to the sky. Conversely, some important physical problems have been set by observations of astronomical character. In modern language the interrelation between physics and astronomy gave rise to astrophysics.

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