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The emergence of Melloni's Optical Bench

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Abstract – In this paper we address the emergence of one of the most common instruments in nineteenth-century physics laboratories, Melloni's optical bench, relying on the analysis of the most significant historical documents. This apparatus, devised in 1835 by Macedonio Melloni, a distinguished Italian physicist of that time, enabled the study of the properties of "radiant heat", as it was then called the thermal radiation. This apparatus is present in a large number of physics cabinets of universities and secondary schools. By this paper, we plan to foster the educational use of this device, still relevant for the study of infrared radiation, both by university and secondary school students and by teachers and scholars

1. Introduction

The so-called *Melloni's optical bench* was one of the most common instruments in nineteenth-century physics laboratories. It was invented in 1835 by Macedonio Melloni, one of the most distinguished Italian physicists of that time, with the goal of making available a reliable apparatus to study the properties of "radiant heat", as it was then called the luminous and obscure thermal radiation.

In particular, Melloni's optical bench, so named because it employed a bench with multiple accessories in the same manner as an "optical bench" is used, enabled scientists to repeat as desired Melloni's important findings on the interaction of radiant heat with liquids and solids (e.g. to reliably show that radiant heat behaves in some respects like light but, in other respects, in a completely different way) that made him a sort of father of infrared physics.

In what follows we try to unravel the origin and significance of this successful apparatus relying on the most significant primary sources, with a focus on Melloni's original papers and scientific correspondence [1].

2. A new thermometer: the "thermo-multiplier"

The origin of Melloni's optical bench lies in a research program that started at the beginning of nineteenth-century. In 1800, the British astronomer F.W. Herschel discovered, with hindsight, the

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infrared radiation in the solar spectrum [2-3]. He measured directly the temperature of various parts of the solar spectrum, with common bulb thermometers (with blackened bulb), by projecting the spectrum on a screen and placing the thermometers in various spectral regions. Herschel discovered that the temperature in the different regions of the visible spectrum increased going from purple to red. By moving the thermometer in the "invisible" area immediately beyond the red, the temperature reached a maximum and then fall to zero (above the shadow temperature) when the thermometer was moved further. According to Herschel this meant that in solar spectrum were present, besides luminous rays characterized by a certain luminosity (black dotted curve in Fig. 1), also invisible rays (gray-filled curve), of given temperature, called calorific rays.

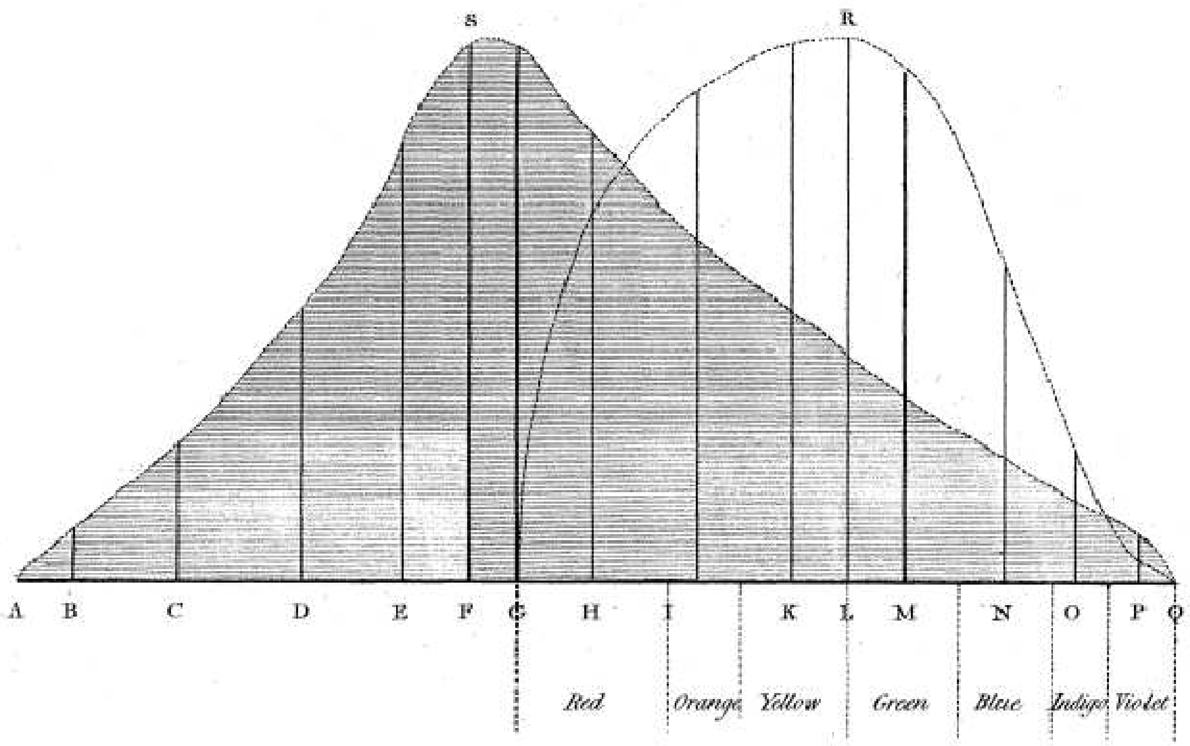

Fig. 1 – Herschel's "spectrum of heat" (gray-filled curve) and "spectrum of illumination" (black dotted curve) [3]

Though Herschel's hypothesis did not enjoy a universal acceptance, radiant heat was much experimentally studied in early 1800s, still by means of liquid thermometers. However, significant progresses occurred only when Macedonio Melloni, and a new device, the *thermo-multiplier*, entered the picture.

Melloni, who was born in Parma in 1798, after having studied Mathematics and Physics in his hometown, since 1819 continued his studies at the prestigious *École Polytechnique* of Paris, where

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he remained for four years. In 1823 he returned to Parma, where he soon became Professor of Physics at the local University and started working on experimental physics subjects. His first contacts with Leopoldo Nobili, an Italian physicist from the nearby Reggio Emilia best known for his expertise as scientific-instruments maker, date back to those years.

In 1825, Nobili had developed a very sensitive electromagnetic *galvanometer*, that is an apparatus to measure electric currents by the effect they have on magnetic needles, which became known as *astatic galvanometer* [4]. The availability of a device that made possible the accurate detection of weak electric currents, was pivotal in guiding Nobili toward the idea of using this device to measure the recently discovered thermoelectric current produced by the *Seebeck effect* (1822), i.e. the current that are established when the junctions of a circuit consisting of a suitable pair of metal conductors (e.g. bismuth and antimony) are at different temperatures [5]. Upon the basis of this effect, Nobili developed in 1829 a sort of electromagnetic thermometer, in which from a current measurement one could infer a temperature measurement [6].

By the end of 1829, Nobili's *thermo-multiplier* – as the Reggio physicist had named his sensitive thermometer – was completed [7-8]. It was formed by a box containing a thermopile made of six bismuth-antimony pairs: the odd junctions were outside of the box, while the even ones were hidden by it (Fig. 2). The edges of the pile could be connected through wires to an astatic galvanometer. If the instrument was introduced e.g. into a "cold" environment, only the odd junctions were in contact with it, the even ones being immersed into putty.

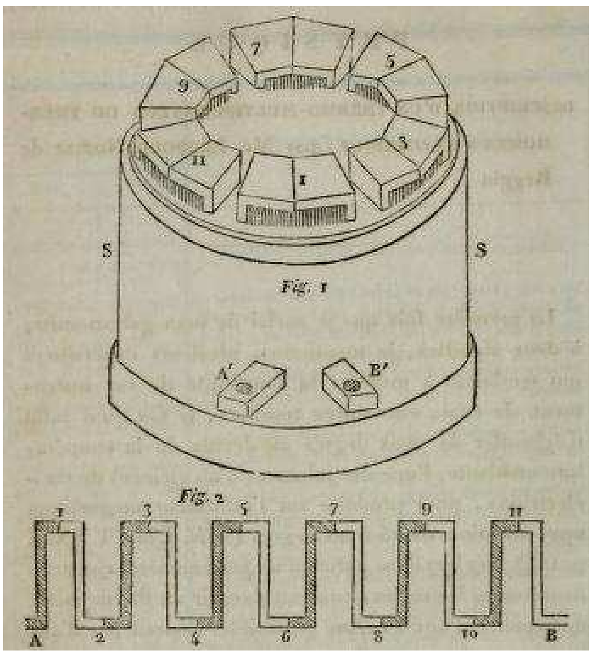

Fig. 2 – Schematics of Nobili's thermopile (1829) [6].

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Immediately, Nobili made Melloni aware of the construction of this new “thermo-electric” thermometer, and Melloni, in turn, made changes to the apparatus so that it might be best used in the study of calorific rays. In particular, Melloni increased the number of bismuth-antimony elements (up to thirty-eight elements, as can be seen in Fig. 3), changed its size and arrangement, equipped it with a cone-shaped metal opening so as to focus the beam, and placed it on a support in such a way that it might be turned in all directions (Fig. 4).

On 5 September 1831, Nobili and Melloni presented to the *Academie des Sciences* in Paris the results obtained by this new, improved, version of thermo-multiplier, by means of which they were able “to appreciate changes of temperature so small as to be undiscoverable by any other instrument”. It was indeed “so delicate an indicator of temperature, as to be sensibly affected by the natural heat of a person, placed at the distance of twenty-five or thirty feet” [9]. The new instrument removed a major difficulty affecting the common bulb thermoscopes when used to study the radiant heat, namely the absorption of radiant heat by the glass covering nearly all of them, and in a short time opened new vistas in this field of research. This instrument, in its later versions developed by Melloni himself and by others, was used up to the 1880s, when it was replaced by the more sensitive “bolometer” [10].[1]

With this new device Nobili and Melloni immediately began to study a number of phenomena concerning the radiant heat, like the passage through transparent bodies of the radiation emitted by a “iron-ball heated with red-hot coals or hot water”, the “specific heat of insects, of phosphorous, and of the lunar rays”, and the “radiating, absorbing and reflecting powers of different bodies”. These early experiments were designed as simple trials to demonstrate the superiority, as regards sensitivity and ease of use, of the thermo-multiplier with respect to the normal thermometers. Besides this, by the new apparatus Nobili and Melloni observed a peculiar behavior of calorific rays if they are made to pass through water, the transparent body *par excellence*: “the most common liquid in nature, water, totally shuts off the passage calorific rays” [11] (actually, as later discovered by Melloni himself, calorific rays can penetrate through water if the source temperature is high enough).

[1] The bolometer, or “actinic balance”, was invented in 1880 by the American astronomer and physicist Samuel Pierpont Langley. This instrument, that still required a very sensitive electromagnetic galvanometer, was based on a different thermo-electrical property, namely the dependance of the electrical resistivity by the temperature.

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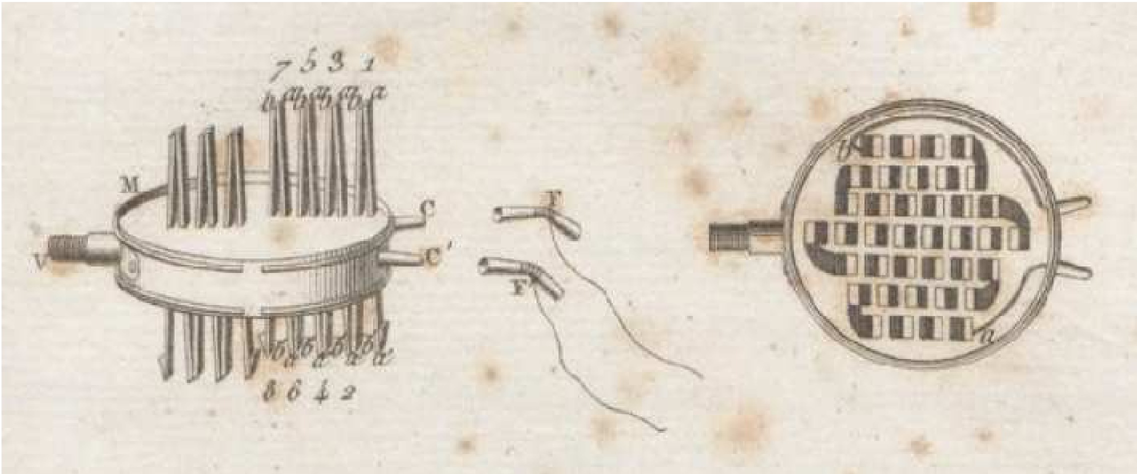

Fig. 3 – Nobili and Melloni's improved thermopile (1831) [9]

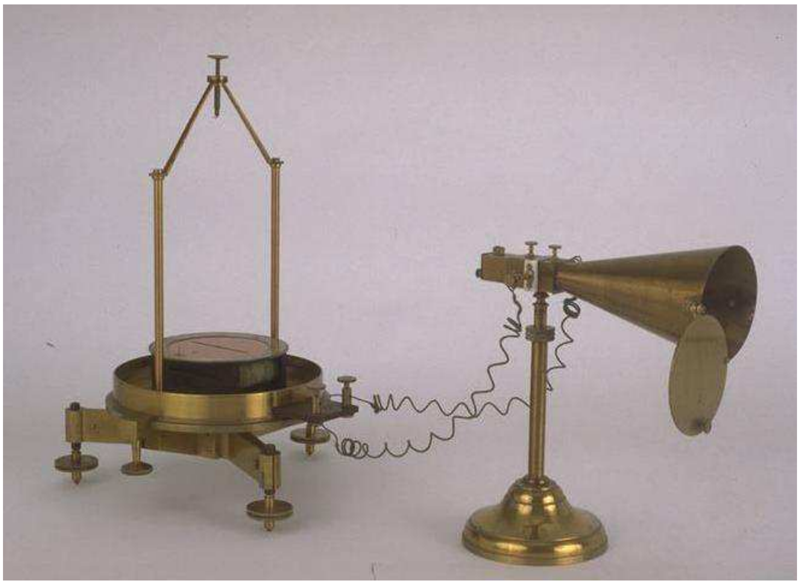

Fig. 4 – Nobili and Melloni's thermo-multiplier (Urbino Museum of Science and Technology)

3. Measuring the transmission of radiant heat through bodies

In the meantime, the collaboration between Nobili and Melloni suffered a sudden halt because of the political turmoil that rampaged through the Italian states during the *Risorgimento* struggle. On November 16, 1830, Melloni was removed from the chair of physics by Maria Luigia, duchess of Parma, for having commended the Parisian students who contributed to the expulsion of King Charles X the previous July, and left Parma. Then, in February 1831, Melloni returned in town and became member of the local revolutionary government, before being forced, the following March, to flee because of the Austrian military intervention and the following restoration of the duchy.

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Prevented from returning to his chair of Physics and his hometown, Melloni acquired the status of "*réfugié italien*" (Italian refugee) and moved in Dôle (France), Genève and Paris, keeping up alone his work on the properties of radiant heat by means of his "trusted" thermo-multiplier, that he brought with himself in exile.

On February 4, 1833, Melloni submitted an important memoir to the *Academie des Sciences* [11]. From the outset of his memoir, Melloni provides details on his approach. One crucial point studied by Melloni at the beginning of his exile period, a point which was lost by Herschel, was that the calorific rays penetrating a screen, warm it making it "to radiate anew". And this radiation, "mingling with the [calorific rays] which pass through the screen … prevents its being measured exactly" [11, p. 5]. Melloni, however, thanks to the high sensitivity of his thermo-multiplier, was able to find the most suitable "source – screen – thermo-multiplier" arrangement as to ensure that the effects seen were due exclusively to the calorific rays (i.e. by placing thermopile and source very far apart and the material to be irradiated exactly midway between them). Having succeeded in isolating the effect of calorific rays, and therefore in making possible studying these rays free from spurious effects, was the highlight of Melloni's approach. It was just by this arrangement that he demonstrated indeed the "immediate transmission" of calorific rays, as it is the case for light.

Another difficulty addressed by Melloni was to trace the amount of calorific rays back from the deviation of the galvanometer's needle; the response of the galvanometer was indeed nonlinear. Melloni successfully solved this problem as well, by measuring the deviations of needle under different arrangements of sources and thermopile and arriving at a first accurate calibration of the apparatus (called by him "table of the intensities") [11, p. 14].

At this point, after choosing a source that guaranteed a constant temperature for more than two hours (i.e. a "good lamp with a double current of air and a constant level" [11, p. 16]), and placing the lamp at such a distance from the thermopile that the needle of the galvanometer fixes itself at 30°, he began his analysis (he postponed to a second memory, that will be presented in 1834, the goal of discussing the effect of varying the source).

At first, Melloni explored the roles of surface on the transmission of calorific rays emitted by the "constant source of heat". He interposed several screens perfectly similar in all respects, except as to the state of the surface, and discovered that "the quantity of heat which passes through the medium is greater in proportion as the surface is more finely polished, as it happens in respect to light". When studying the dependence on the thickness, he discovered that the resistance of transparent screens to the transmission of radiant heat and light "differ enormously". Then, he studied the passage of calorific rays through a number of substances (each in form of 2 mm thick

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screen). To achieve this goal he tested as many as 79 different substances (13 uncoloured and 14 coloured glass, 29 liquids, and 23 crystallized bodies) (Fig. 5). These measurements produced impressive results. As he wrote:

> The results … seem to me to establish beyond the possibility of doubt a fundamental proposition in the theory of radiant heat, namely, that *the power of transmitting caloric rays is by no means proportioned to the transparency of the media* … ([11], p 26, 31).

The differences in transmission were very large, e.g. rock salt transmitted 92% of calorific rays, flint lead glass 67%, sulphur chloride 63%, common crown glass 49%, olive oil 30%, calcium sulphate 20%, nitric acid 15%, alum 12%, and water 11%.

CORPS CRISTALLISÉS. (Épaisseur commune $2^{mm},62$.)	DÉVIATIONS du GALVANOMÈTRE.	RAYONS TRANSMIS.
Verre de glace	21°,60	62
Sel gemme (diaphane)	28 ,46	92
Spath d'Islande (diaphane)	21 ,80	62
Autre espèce (diaphane)	21 ,30	61
Cristal de roche incolore (diaphane)	21 ,64	62
Cristal de roche *enfumé* (diaphane fortement coloré en brun)	20 ,25	57
Topaze incolore du Brésil (diaphane)	19 ,18	54
Carbonate de plomb (diaphane)	18 ,35	52
Agate blanche (translucide)	12 ,48	35
Baryte sulfatée (diaphane louche veiné)	11 ,72	33
Aigue marine (diaphane légèrement coloré en bleu)	10 ,16	29
Agate jaune (translucide coloré en jaune)	10 ,10	29
Borate de soude (translucide)	9 ,87	28
Tourmaline verte (diaphane coloré en vert)	9 ,54	27
Adulaire (diaphane louche veiné)	8 ,30	24
Chaux sulfatée (diaphane)	7 ,15	20
Chaux fluatée (diaphane louche veiné)	5 ,40	15
Acide citrique (diaphane)	5 ,15	15
Sardoine (translucide)	4 ,98	14
Carbonate d'ammoniaque (diaphane louche à stries.	4 ,50	13
Tartrate de potasse et de soude (diaphane)	4 ,40	12
Alun *de glace* (diaphane)	4 ,36	12
Sulfate de cuivre (diaphane fortement coloré en bleu)	0 ,00	0

Fig. 5 – Crystallized bodies' power of transmitting "caloric rays" [11]

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Since a body could be almost opaque and affords a very easy passage to calorific rays and, on the other hand, it could be diaphanous and intercepts a large part of these rays, Melloni proposed the name "*trans-calorique*" or "*diathermanes*" to indicate the bodies that are transparent to calorific rays, in analogy with the "transparent or diaphanous names" used for the bodies transparent to the light.

The February 1833 memoir was the first of a long series of communications where Melloni informed the *Academie*, in the form of letters, about the progress of his research. Though some of these communications had not been published at that time, we have found the original letters in the *Academie*'s archives. This archival material shows that Melloni informed the *Academie* – at a relentless succession of about one communication per month – about the results obtained by varying the source of calorific rays, employing new materials, focusing on colored glasses, exploring the properties of rock salt, using this material to demonstrate the refraction of calorific rays from a source of hot water, and studying the solar spectrum.

In particular, in a letter sent to the November 25, 1833 *séance* of the *Academie* (Fig. 6) – a letter never published –Melloni addressed the problem, still open, of establishing if the solar and terrestrial calorific rays are the same thing. In fact, notable differences exist, e.g. the solar rays pass through a glass screen without an appreciable decrease, while the latter ones do not. In this letter, Melloni shows that "there is not an essential difference between the nature of terrestrial calorific rays and the solar ones, but both, such as light, consist of different rays", and that "rays of the same species are not found in the same proportions".

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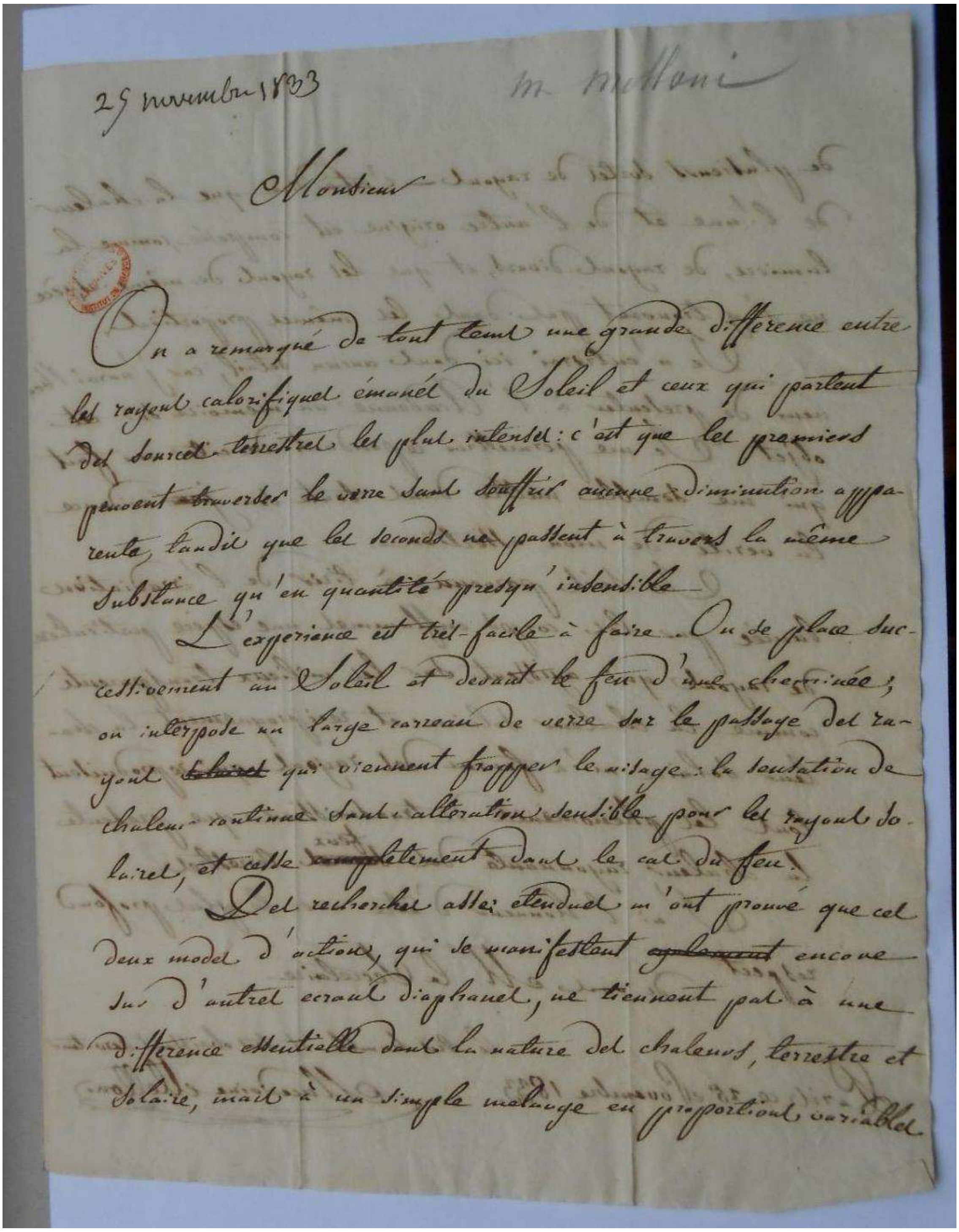

25 novembre 1833 M. Melloni

Monsieur

On a remarqué de tout temps une grande différence entre les rayons calorifiques émanés du Soleil et ceux qui partent des sources terrestres les plus intenses: c'est que les premiers peuvent traverser le verre sans souffrir aucune diminution apparente, tandis que les seconds ne passent à travers la même substance qu'en quantité presqu'insensible.

L'expérience est très facile à faire. On se place successivement au Soleil et devant le feu d'une cheminée; on interpose un large carreau de verre sur le passage des rayons ~~[illegible]~~ qui viennent frapper le visage: la sensation de chaleur continue sans altération sensible pour les rayons solaires, et cesse ~~complètement~~ dans le cas du feu.

Des recherches assez étendues m'ont prouvé que ces deux modes d'action, qui se manifestent ~~également~~ encore sur d'autres écrans diaphanes, ne tiennent pas à une différence essentielle dans la nature des chaleurs, terrestre et solaire, mais à un simple mélange en proportions variables

Fig. 6 – Melloni's unpublished November 25, 1833 letter to the *Academie* (Archives de l'Institut de France)

4. Changing the source of radiant heat

The goal of systematically studying the role of the source whence the rays emanate was addressed in the next great memoir submitted by Melloni to the *Academie* on April 21, 1834 [12]. In order to make the comparison legitimate, he decided to operate "upon rays emitted by a source having a

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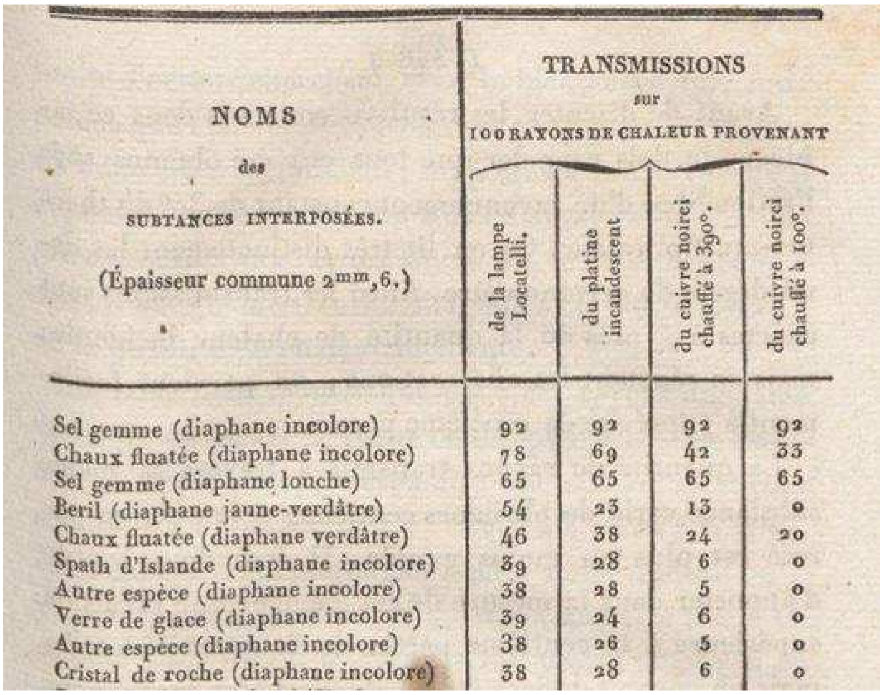
constant temperature”, a condition that was met “by means only of certain flames and boiling liquids”. Melloni made use of two luminous and two non-luminous sources. The first two were a Locatelli lamp (a common oil lamp with a reflector) and a spiral of platina wire kept in a state of incandescence by means of a lamp fed with spirit of wine. The non-luminous sources were a plate of Copper heated to 390 °C by a flame of alcohol and a Leslie cube, i.e. a vessel of thin copper, blackened on the outside and filled with boiling water. Melloni discovered that differently of the luminous rays, “the radiant heat from different sources is absorbed in greater or less proportion while it is passing through diaphanous bodies”. The only exception to this rule is represented by rock salt that, since it transmits 92% of incident calorific rays independently of the source, and “really acts in respect to radiant heat just as colourless glass and colourless diaphanous bodies in general act in respect to light” (Fig. 7).



NOMS des SUBTANCES INTERPOSÉES. (Épaisseur commune 2mm,6.)	TRANSMISSIONS sur 100 RAYONS DE CHALEUR PROVENANT			
	de la lampe Locatelli.	du platine incandescent	du cuivre noirci chauffé à 390°.	du cuivre noirci chauffé à 100°.
Sel gemme (diaphane incolore)	92	92	92	92
Chaux fluatée (diaphane incolore)	78	69	42	33
Sel gemme (diaphane louche)	65	65	65	65
Beril (diaphane jaune-verdâtre)	54	23	13	0
Chaux fluatée (diaphane verdâtre)	46	38	24	20
Spath d'Islande (diaphane incolore)	39	28	6	0
Autre espèce (diaphane incolore)	38	28	5	0
Verre de glace (diaphane incolore)	39	24	6	0
Autre espèce (diaphane incolore)	38	26	5	0
Cristal de roche (diaphane incolore)	38	28	6	0

Fig. 7 – Transmission of calorific rays from four sources through plates of different kinds [12]

By recalling the behaviour of a coloured glass when illuminated with differently coloured lights, where lights of the same tint as the glass pass abundantly while the rest are almost totally intercepted, Melloni concluded that “the radiations from different sources of heat [are not] of the same nature”:

> Thus boiling water, copper heated to 390°, incandescent platina, and the flame of oil will be to us the sources of a heat that is more or less *coloured*, that is to say, sources

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> each of which gives out a greater quantity of calorific rays of a certain quality ([12], p 51).

As the sources of heat are "coloured", so the diaphanous substances are when exposed to radiant heat:

> We feel convinced that bodies which are transparent and colourless ⋯ the rock salt excepted ⋯ possess a species of *invisible calorific tint* [upon which] will depend whether a greater or a less quantity of heat be transmitted ([12], p 53).

The transparent bodies, therefore, retain some of the calorific rays and let pass others, precisely as do the coloured substances on light. So, by appealing to a simple, but keen, analogy, Melloni could characterize, as it was for light, not only the light but also the heat with a "colour".

Furthermore, by experimenting with a prism of rock salt ("the *true glass* of radiant heat"), Melloni discovered that "*calorific rays of every kind are* …, like luminous rays, *susceptible of refraction*", and that "each species of heat possess a different refrangibility" (Fig. 8).

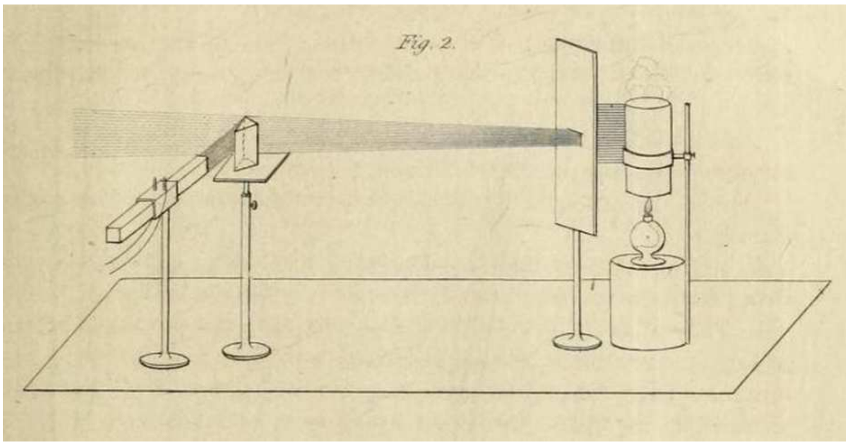

Fig. 8 – Experiment for studying the refraction of radiant heat by rock salt crystal [12]

In the final part of the memoir, Melloni turned his attention back to the thermo-multiplier by discussing some improvements made to it by a Mr. Gourjon under Melloni's guidance. Gilles-Toussaint Gourjon, portrayed by Melloni as an "able mechanic" in Paris, was instrument maker at the École Polytechnique and, by 1837, curator of the collections at the same establishment. In order to operate "on small pencils of calorific rays", he reduced the "acting surface" of the thermopile to the size of the section of a common thermometer. Then, he improved the sensitivity of the

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galvanometer and, by mounting the galvanometer in copper rather than in wood, he solved the problem of hygrometrical variations in the atmosphere.

On August 7, 1834, Melloni sent copies of his two great memoirs to one of the fathers of electromagnetism, Michael Faraday, begging him to report about them to the Royal Society of London [13, p 134]. Faraday was much impressed by Melloni’s achievements and at once recommended him for the prestigious Rumford Medal, awarded by the Royal Society for “new discoveries tending to improve the theories of fire, of heat, of light, and of colours”. Faraday’s recommendation was endorsed by the Society that, by the end of 1834, awarded the medal to the Italian physicist [13, p 144]. Winning the award had a significant impact on Melloni’s international prestige. A tangible sign of this newly acquired prestige manifested itself a few weeks later, when Melloni presented to the *Academie* a new apparatus specially crafted to study radiant heat and to repeat all the experiments he had performed in the preceding years. This apparatus, crowning years of struggle to study the properties of radiant heat, will be known by the name of Melloni’s optical bench.

5. Melloni’s optical bench: epitome of radiant heat research

The official date of birth of Melloni’s optical bench is January 12, 1835. On that date Melloni read at the *Academie* a memoir titled: “Description of an apparatus proper to repeat all the experiments on the science of radiant heat, containing the exposition of some new facts on the calorific sources and the radiations that they emit.” A few days later, the memoir was published in *L’Institut,* a French language weekly journal intended to serve as an organ to academies in France and abroad [14].

Melloni’s memoir was accompanied by the first drawing ever of Melloni’s optical bench (Fig. 9-11).

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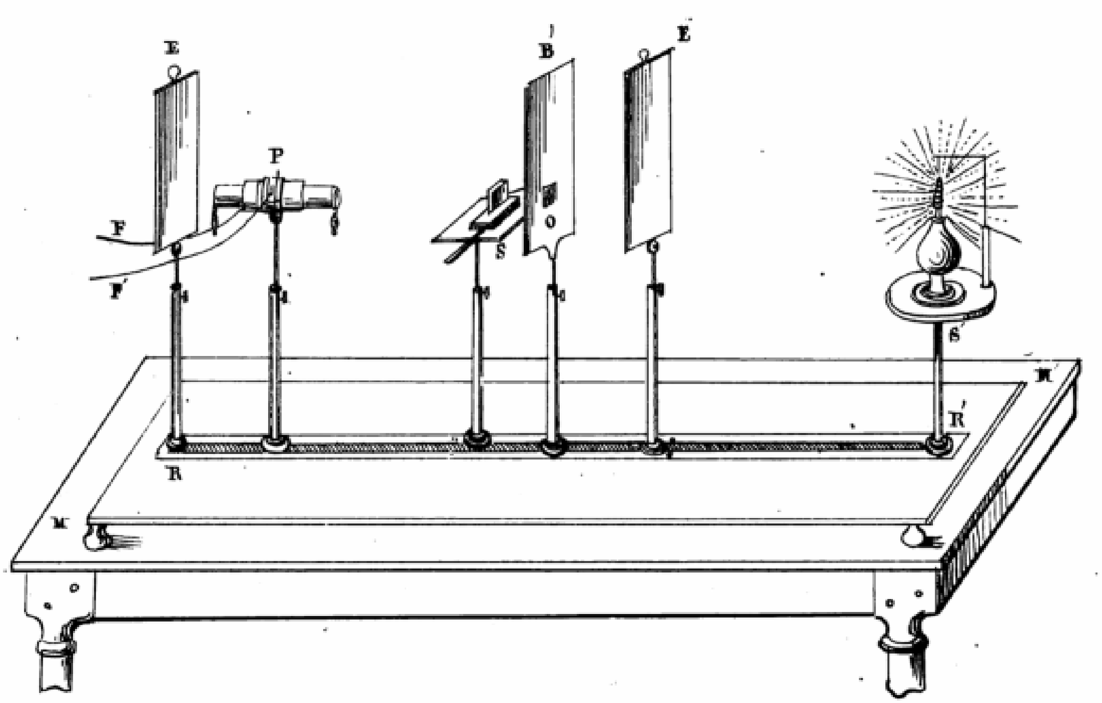

Fig. 9 – Drawing of the first Melloni's optical bench [14]

The very structure of the new apparatus epitomized all the previous research carried out by Melloni. In Fig. 9 we can see indeed, from the left to the right: the thermo-multiplier, that is the thermopile (P) and the wires connecting it to an astatic galvanometer (paragraph 2 above); the substance (S) to be studied with respect to its behaviour when exposed to radiant heat, thereby making possible the study of absorption of calorific rays by different substances (par. 3); one out of many possible sources of radiant heat (S') resting on an horizontal disk (par. 4). Furthermore, since it was found important to change the distances between thermopile, substance and source, these elements of the bench (and the screens to interrupt or to select a narrow beam of radiant heat) are placed on vertical rods sliding along a guide (RR') in the middle of a table (MM').

Both the thermo-multiplier and the rest of the apparatus were built, under Melloni's guidance, by Gourjon. As it was explained in a footnote to Melloni's memoir, "this artist is now busy in making other exactly similar apparatus for Faculté des Sciences, Ecole Normale, Collége de France, and other public institutions."

As reported by Melloni, by suitably arranging the different components of this apparatus it was possible to re-discover the main physical properties of radiant heat by repeating the experiments of previous years on immediate transmission, refraction, reflection, and emissive and absorbing power.

According to the minutes of the January 12, 1835 meeting, a committee composed of three distinguished members of the *Academie*, J.-B. Biot, F. Arago (Perpetual Secretary) and

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S.D. Poisson, was charged to examine and report about Melloni's memoir on the optical bench [15]. On February 18, following recommendations received by influential members of the *Academie*, the French Ministry of Education François Guizot granted to the Italian physicist the sum of 1200 francs "as scientific encouragement" [16]. This was just the first of a series of economic encouragements obtained by Melloni from the Ministry of Education (e.g. in 1836 Biot made a plea to Guizot for an additional funding "more for physics than for Melloni"). A few days later, on March 6, Melloni wrote to Faraday that "Biot, Poisson and Arago have examined my work and are enthusiastic about it" [13, p 146].

Perhaps due to recent fame acquired by Melloni through the Rumford Medal, the commission, unlike previous occasions, concluded its enquiry fairly quickly: on the June 22 meeting, Biot, the *Rapporteur*, finished indeed reading the committee report about Melloni's memoir. The overall assessment of the committee on Melloni's work was highly positive and Biot's conclusions were rather clear: "we will only propose that the *Academie* gives its approval on the experiences that Mr. Melloni has submitted to it and that his memoir will be printed in the [*Academie*'s] Collection of Foreign Fellows".[2] Biot's report was eventually published in 1838 in the *Memoires de l'Academie Royale des Sciences de l'Institut de France* [17].

The optical bench had provided the key to the recognition of Melloni's work showing that radiant heat, like light, propagates "instantaneously", is "coloured", can be reflected and refracted. A short time later, Melloni will also discover that radiant heat, once again as light, can be polarized and follows the inverse square law.

After the Rumford Medal and Biot's report, further honors awaited him. Within a few years he was elected member of the most prestigious scientific academies,[3] and a number of his publications were chosen to be translated and republished at the head of the *Scientific Memoirs*, a collection of the most important scientific papers published in the 1830s in non-English language journals [18]. And what about the apparatus – Melloni's optical bench – that made all this possible? At the April 12, 1841 meeting of the *Academie*, Arago presented "*l'instrument*", constructed by Heinrich Daniel Ruhmkorff, "by which M. Melloni made all his experiments on radiant heat". This successful version of Melloni's instrument, soon commercialized, was "very elegant and convenient" and

[2] Melloni's memoir, despite being recommended for publication, will never be published in the collections of the Academie.

[3] August 4, 1835: *correspondant* of the French Academie des Sciences; March 24, 1836: *Korrespondierendes Mitglied* of the Königlich-Preußische Akademie der Wissenschaften; May 30, 1839: *Foreign Member* of the Royal Society.

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“suitable for public demonstrations as well as for the most delicate researches” [19]. The optical bench with its accessories, in the hands of instruments manufacturers like the Ruhmkorff laboratories of Paris [20], will become one of the most popular devices of experimental physics. A large number of physics cabinets of universities and secondary schools had, and hopefully still have, in their historical collections of scientific instruments one sample of this apparatus, concrete testimony of one of the most significant moments of the nineteenth-century physics. The benefits of using one of the widely available samples of this historical apparatus for educational purposes were explored by us in 2014 within the framework of the National Plan for Scientific Degrees (PLS) sponsored by the Italian Ministry of Education (MIUR). A number of secondary school students took a suitably planned physics laboratory at the Department of Physics of Melloni’s hometown, Parma. In this “Melloni laboratory” the students were instructed to observe the original sample of Melloni’s bench there preserved and to read some selected excerpts of Melloni’s original papers. Later, they experimentally studied the properties of “radiant heat” by carrying out some of Melloni’s measurements with present-day instruments, e.g. a Leslie cube heated by an incandescent light bulb, and a modern thermopile producing a voltage proportional to the intensity of radiation in the infrared spectrum. In the end it was found that by this historical laboratory the students not only had learned something about the history of Melloni and heat physics, but had also learned how to make sense of the data Melloni had been collecting by his device [21].

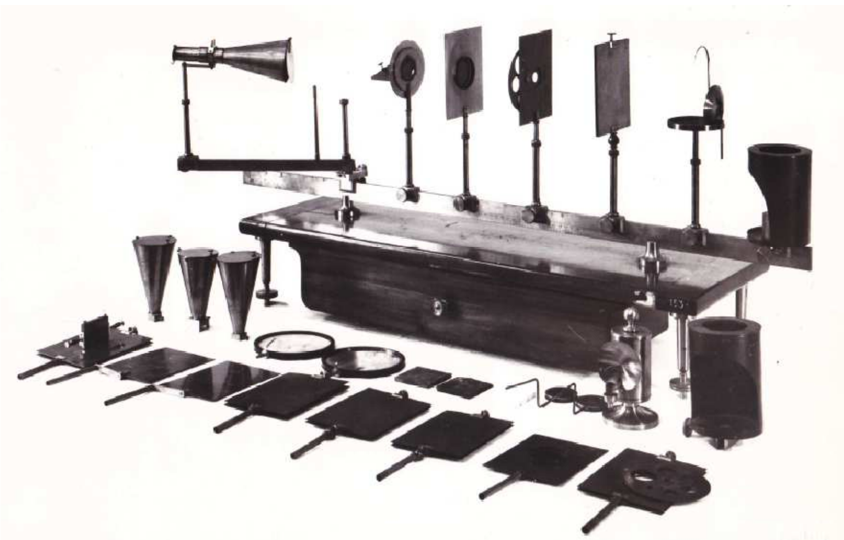

Fig. 10 – Melloni’s optical bench preserved by the Melloni Collection of the University of Naples (Dipartimento di Fisica e Scienze della Terra “Macedonio Melloni”, Parma)

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Fig. 11 – Oil painting showing Melloni with his optical bench (Dipartimento di Fisica e Scienze della Terra "Macedonio Melloni", Parma)

6. Epilogue

By 1837 onwards, Melloni was no longer a refugee, mainly though the scientific and political influence of academicians like Arago and von Humboldt. On January 16, 1837, Arago communicated to the *Academie* that he was informed by Metternich, Cancellor of the Austrian Empire, that Melloni was now free to return to his hometown. He eventually settled in Naples (1839) where he was appointed Director of the Conservatory of Arts and Crafts and Director of the

Cabinet of Meteorology. In Naples he worked on a number of topics and, in particular, as he had done with the calorific rays, he undertook a systematic study on the other end of visual spectrum, the ultraviolet spectrum (then named “chemical rays”), as a consequence of the recent discovery of daguerreotype [1].

This work, framed in the context of the wave theory of light, was instrumental in guiding him, in 1842, toward the “principle of identity”. Not only radiant heat and chemical rays behave *like* light, but they *are* forms of light, i.e. different part of a continuous spectrum, where the wavelength makes the difference. Melloni’s brilliant insight achieved a widespread consensus by the 1850s.

In his latest years, he was again involved in the political turmoil of Risorgimento. Following the 1848 uprising, when he was in favour of institutional reforms even though he played no active part in the upheavals in the Kingdom of the Two Sicilies, he was forced to abandon the Direction of the recently established Vesuvian Meteorological Observatory. Dismissed for the second time from an institutional position and sentenced again to exile, he submitted a petition to King Ferdinand II and he was eventually allowed to stay in Naples. By that point, Melloni had come full circle, once again isolated from the world. He retired indeed from public life in his house in Portici, one of the towns at the foot of Vesuvius in the bay of Naples, where he died of cholera in 1854.

And so, the brief, but significant, life of one of the major physicists of the Nineteenth Century came to an end.

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