The Physics Instrument Collection at the University of Rennes 1, France

Dominique Bernard†, William Tobin††, Alain Canard† and Jean-Paul Taché†

The "Faculté des Sciences de Rennes": An Old University in Brittany

Rennes 1 is a multi-site and multi-disciplinary university in the west of France (not far from the famous Mont Saint Michel!) with 27,000 students and 2,500 teachers, researchers and other staff.

The Faculté des Sciences de Rennes was founded in 1840 and was located in the Présidial (provincial courthouse) in the center of the city until 1855. Its first dean was Félix Dujardin, a professor of zoology and botany. Parts of the Faculté's collections originated from confiscations during the French revolution (for example, de Robien's 'cabinet de curiosité'). The collections were augmented by purchases (the Rennes city council allocated 20,000 francs (~$4,000) for the physical sciences 'cabinet', which was managed by a physics professor named Morren). A museum was also opened.

The Faculté des Sciences moved three times: in 1855 (to the Palais universitaire), in 1896 (Place Pasteur), and in 1965 (Campus de Beaulieu). The collections and museum followed. The museum was closed during the Second World War and never re-opened.

Today, a substantial heritage exists which includes items in paleontology, archaeology, zoology, botany, physics and chemistry, and also historic books. Some of the holdings are summarized on the University's web site: http://cst.univ-rennes1.fr/themes/lieuxCulture/ The geology and zoology collections are open to the public.

Physics Instrument Collection

For the most part, the physics instrument collection dates from 1840 onwards; however, it contains some older items such as a Gregorian telescope made by James Short in 1740. Following the last removals in 1965, the collection was dispersed across numerous sites and part has been lost.

In 2004, following the discovery of certain Curie instruments (see below), we decided to regroup the physics collection. About 800 objects or instruments dating from 1840 to 1930 were discovered, identified and photographed from all subdisciplines of physics: acoustic, optics, mechanics, electricity, magnetism, etc. We now present some of them.

1. Acoustical Apparatus

About one hundred objects were discovered made by Albert Marloye (1795-1874) or Rudolph Koenig (1832-1901) and identified with the help of Paolo Brenni.[1,2]

The Marloye instruments were bought by Professor Morren. We have found Marloye's bills dating from September 1841 for a differential sonometer, organ pipes, a Chladni plate and a large wind-chest (unfortunately lost).

The Koenig instruments were collected by Professor Émile Gripon in *c.*1868.[3] Most were devised by Heinrich Helmholtz. They comprise:

- Several boxes of tuning forks, including a very rare large tuning fork (750 mm tines, see Fig. 1) with adjustable frequency (16 to 24 Hz) like at Harvard and Cornell Universities, and the Science Museum in London. We also found electromagnetic tuning forks and kaleidophones.
- A Helmholtz double siren.
- A manometric flame harmonic analyser, rotating mirrors and resonators for examining the timbre of sounds, and a Quincke and Koenig apparatus for the interference of sound waves.
- Kundt tubes for measuring the speed of sound, and a Koenig trombone.
- Organ pipes and a wind-chest, and sounding cylinders.

Further acoustical items in the collection are a Cagniard de la Tour siren (maker: Bianchi, 1840) and a large megaphone (Pixii, 1841, cost: 15 F (francs)).

Most of these instruments are used during visits, lectures, and public shows at science festivals. One of our students, Nathalie Rozé, devised excellent experiments using them.[4] We also discovered a Marey recording cylinder (horizontal kynograph) made by Charles Verdin in 1875 (cost: 200 F) similar to those presented by David Pantalony at the University of Toronto (web site: http://www.psych.utoronto.ca/museum/horizontal.htm). Its presence along with an electromagnetic tuning fork with mercury interrupter suggests experiments in psychology around this time. Probably this apparatus comes from the experimental psychology laboratory established in Rennes in 1896 by Professor Benjamin Bourdon.[5]

2. Optical Apparatus

When the Faculté was starting up, Professor Dujardin bought a very large quantity of optical apparatus, as indicated by a hefty bill for 3,375 F from *Soleil, Opticien, Rue de l'Odéon,* dated September 1841. Some of these instruments have been lost (like a Newton bench and a Gambey heliostat). Using one of Brenni's books[6], and various old catalogues, we have been able to identify several interesting pieces such as:

Fig. 1 *Very large tuning fork by Rudolph Koenig with adjustable frequency (16 to 24 Hz).*

- An Arago polarization apparatus (cost: 100 F) and a telescope (280 F).
- A terrestrial telescope and a diasporam-

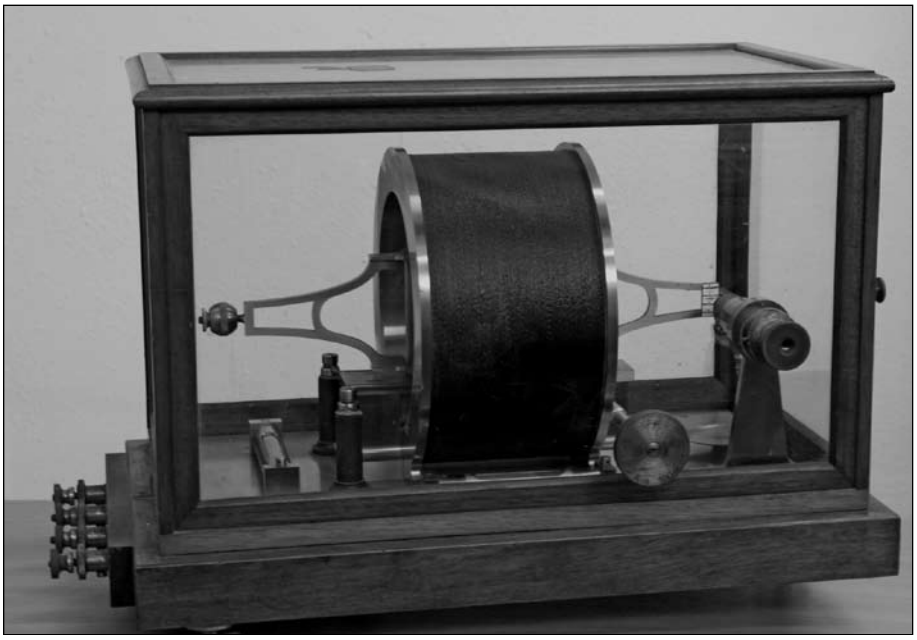

Fig. 2 *Pellat dynamometer by J. Carpentier (1886).*

eter made by A.-M. Rochon (a physicist from Brest in Brittany!).

- Biot polarization mirrors (180 F).
- A Silbermann reflection and refraction apparatus.
- Numerous prisms (liquid-filled, conical, polyprisms), a Fresnel press, Fresnel's double rhomb, etc.

A significant part of the optical collection comprises apparatus ordered from the Duboscq and Pellin company by Professor Gripon in the period 1873-1880. About thirty objects have been found:

- A Babinet goniometer (1873, 200 F).
- A Thollon spectroscope (1880, 550 F) and a horizontal spectroscope.
- A Duboscq-Pellin kaleidoscope (1875) and a Wollaston camera lucida.
- Various slide projectors including a vertically-projecting one. Associated slides (or 'chromatropes') date from 1860 and include atomic and stellar spectra.
- A Cornu photometer.
- A Fizeau and Foucault apparatus to measure wavelength.
- A saccharimeter, and Senarmont and Norremberg polariscopes.
- Apparatus for Brewster's fringes, Newton's rings and other interference demonstrations (Herschel, Fresnel).
- Numerous small items: diaphragms, mirrors, prisms, lenses, crystals (quartz, mica, polarization samples, etc.).

Among the remaining optical apparatus, we have been very pleased to find a Brunner goniometer. We know of only three other such pieces: two at the Lycée Louis le Grand and Musée des Arts et Métiers (similar to ours), and one at the École Polytechnique in Paris. We have also found a Foucault prism. It is a polarizing prism rather similar to the Nicol prism except that it is stubbier and the Canada-balsam cement has been replaced by an air gap.

3. Apparatus for Electrostatics, Electricity and Electromagnetism

In electrostatics, the Faculté des Sciences de Rennes does not possess any unusual apparatus. We find classic items: a Wimshurst machine, an electric egg, a de la Rive tube, electroscopes, a Franklin or Mascart flask, Leiden jars, Biot hemispheres, a Benjamin Franklin picture experiment, etc.

In electricity, we have many standard instruments like ammeters (maker: Carpentier), galvanometers (D'Arsonval, Thomson, Bourbouze), voltmeters (Carpentier, Deprez), resistors and capacitors, Wheatstone bridges (Carpentier, Breguet), standard resistances, etc. There are also some rarer or more interesting items:

- Elihu Thomson's ring experiment (maker: Ducretet); Roget, Jamin and Bertin apparatus, an Ampère table.
- An Abraham balance (also known as a plate electrometer) made by Bourbouze and Torchebeuf. It was used to measure potential difference.
- An 'Electrodynamomètre absolu de Pellat' made by J. Carpentier in 1886 (Fig. 2) for making absolute measurements of current.[7] Very good measurements have been obtained with it by one of our students, Ronan Guillaume, in 2006.[8] We know of only two other such pieces, in the Conservatoire National des Arts et Métiers (CNAM) in Paris and at Lille University.
- Thermo-electric batteries by Clamond (1885) and Melloni.
- A bismuth magnetic-field sensor (Hartmann-Braun), and a selenium cell for optical communication.
- Switches and keys, including a Morse telegraph key.

In electromagnetism, we have noted numerous Ruhmkorff coils (makers: Ducretet, Carpentier), two magneto-electric machines, as designed by Siemens (maker: Ducretet-Lejeune, 1850) and Gramme (1890), a telephone magneto, and a Ducretet transformer.

Recently, we have been happy to discover

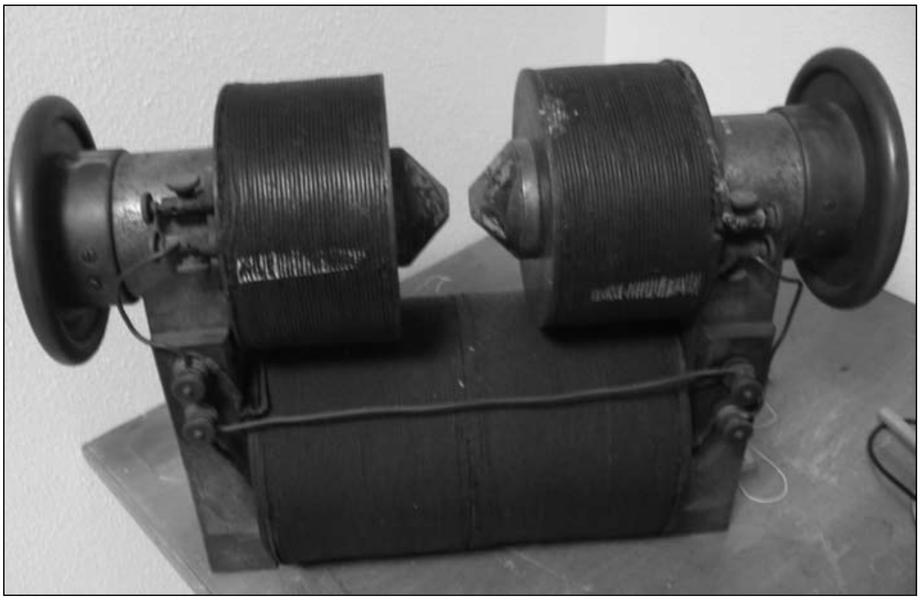

Fig. 3 *Pierre Weiss's first electromagnet (Rennes, 1898).*

the first electromagnets built by the French physicist Pierre Weiss in Rennes in 1898. Weiss is very well known for his studies on magnetism ('Curie-Weiss law' and 'Weiss domains'). He was a teacher in the Faculté des Sciences de Rennes from 1895 to 1899. He obtained his doctorate in 1896[9] before going to Strasbourg University. In Rennes, he investigated magnetism in several materials, including pyrothine and iron, and built 'a new laboratory electromagnet'[10] (Fig. 3). This prototype was marketed widely by Ruhmkorff and J. Carpentier around 1900. We have an example; another can be seen at the Fondazione Scienza e Tecnica in Florence.

Our collection includes a few geomagnetism instruments: a Chaselon inclinometer and declinometer (makers: Brunner Brothers) and a Mascart apparatus (maker: Ruhmkorff).

4. Mechanics, Fluids, and Miscellaneous Apparatus

For the period 1840-1900, numerous objects were discovered relating to the domains of mechanics, fluids, heat, etc. Most are classic items frequently found in French school or university collections.

- In ***mechanics***, items include numerous balances, the figure of the earth, mechanical motions (Bourdon, 1841), a compensated pendulum, an apparatus with seven ivory balls (maker: Pixii, 1841), a reversible Kater's pendulum (maker: Ducretet), crane models and wooden machines, a water hammer, and a demonstration model of James Watt's steam engine (maker: Eugene Bourdon, 1841, cost: 1385 F).
- In ***fluids and pneumatics***, the collection includes several instruments sold in 1841 by Lecomte and Bianchi, including an Archimedes' screw (cost: 50 F) and Hero's fountain (75 F).
- In ***heat and pressure***, items include a Saussure hygrometer and baroscope (maker: Lecomte and Bianchi), Regnault's and Alluard's condensation hygrometers, a Leslie differential thermometer, Cadran and Wedgwood pyrometers, an Ingenhousz apparatus (maker: Pixii), a Fortin barometer, a Leslie cube, parabolic heat reflectors, and a Clement and Desormes apparatus. Also remarkable is a copy of Lavoisier's calorimeter, the original of which is preserved in the Musée des Arts et Métiers.
- Concerning ***measurements***, we find a spherometer by Lecomte and Bianchi (1841), a dividing engine (maker: Duboscq), a cathetometer by Perreaux, and an original meter standard made by A. Collot. Another rare item is a Jules Violle actinometer (for obtaining the solar constant and the temperature of the sun) probably made by Ducretet (two other examples exist at the Conservatoire des Arts et Métiers and at Nebraska University).

Fig. 4 *Curie quartz piezoelectric balance (serial number 2).*

5. Instruments from Jacques, Pierre and Marie Curie

In our collection, we have found three instruments conceived by Jacques, Pierre and Marie Curie which were used to discover and measure radioactivity in radium and polonium. They are: a quartz balance (piezoelectric standard source), a gold-leaf electroscope, and a quadrant electrometer.

Quartz Balance

The first important discovery made by Pierre Curie (1859-1906) was the piezoelectric effect, in collaboration with his elder brother, Jacques. The Curie brothers found that when pressure is applied to a quartz crystal, it generates electric charge. As early as 1885 the Curie brothers and Bourbouze built an instrument to provide a standard source of charge which made use of this property and employed a quartz piezoelectric crystal. In 1890, the Société centrale des produits chimiques commercialized a model. The principal component of the instrument is a rectangular quartz slab. To pick up electricity, it is silver-plated on both faces and two tin strips are attached. One strip is connected to ground and the other to an electrometer. The upper end of the quartz is attached to a supporting arm. A tray is suspended from its lower end, in which weights are placed in order to exert force on the quartz and so produce charge. The device is variously known as a 'quartz piezoélectrique' or 'balance à quartz' (quartz balance).

We have discovered a quartz balance in the Rennes collections (Fig. 4). Engraved on the cylinder is *Quartz Piézoélectrique / Société Centrale de Produits Chimiques N°2 / rue des écoles, 44 et 42 / Paris.* Similar instruments can be seen in Paris at the Curie Museum, the École Supérieure de Physique et Chimie Industrielle de Paris, and the Conservatoire National des Arts et Métiers. Our quartz balance was well described in Jacques Curie's thesis.[11] The low serial number (N°2) indicates that it is one of the first built.

Gold-leaf Electroscope and Microscope

In 1900 Pierre Curie presented a gold-leaf electroscope to the French Physics Society for the expeditious study of radioactive substances.[12] Radiation intensities were measured via the speed of the discharging gold leaf. Such electroscopes are very rare, with examples in Paris at only the Curie Museum and the Conservatoire des Arts et Métiers. We found such an electroscope in our collections (Fig. 5). It is a compound of a gold-leaf electroscope with a microscope and brass cylinder. The radioactive substance is placed on one of two condenser plates

Fig. 5 *Pierre Curie's gold-leaf electroscope.*

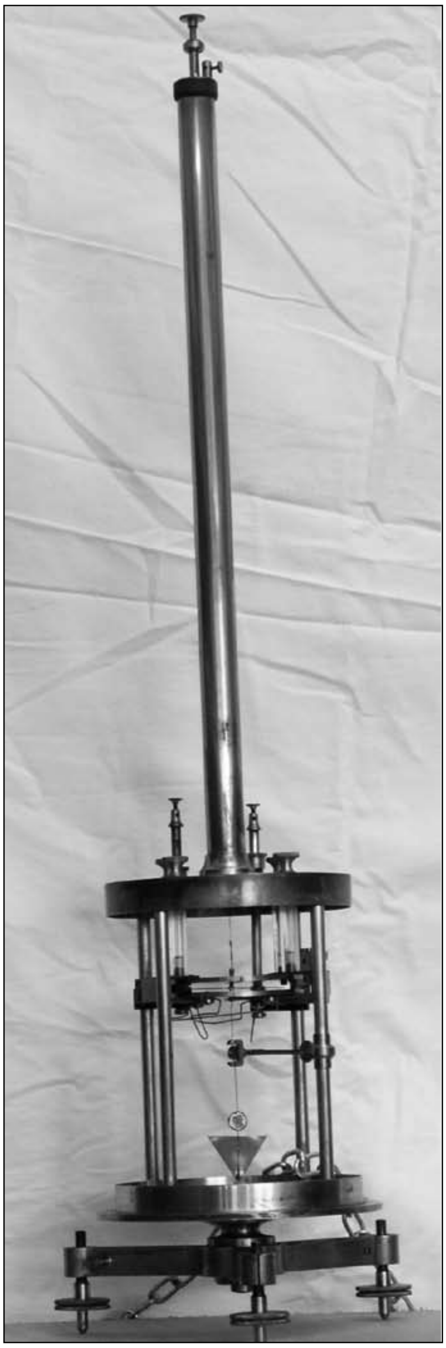

Fig. 6 *Curie quadrant electrometer (serial number 30).*

Fig. 7 *The complete Curie apparatus in Rennes.*

within the cylinder. The Rennes apparatus is marked *Electroscope de M. P Curie / Sté Centrale Matériel Scientifique / 44 rue des Ecoles, Paris.*

Four Quadrant Electrometer

The primary function of an electrometer is to measure an electrical potential or charge. By measuring the change in the charge over time, current can also be determined. The basic quadrant electrometer was developed in the 1860s by William Thomson (later Lord Kelvin). In 1885, the Curie brothers, Pierre and Jacques, devised an aperiodic electrometer[13], that is to say, an apparatus which, because of an air damper, sets directly to its final reading without any oscillations.

The quadrant electrometer takes its name from the fact that it uses a flat cylinder sliced through two perpendicular planes to form four quadrants. Inside the cylinder there is a thin metal needle attached to a small mirror with a conducting wire which, for the Curies' electrometer, is made of quartz.The mirror reflects a light spot onto a scale. All the parts are enclosed in a metal container.

The Rennes quadrant electrometer (Fig. 6) is inscribed *La société centrale de produits chimiques / 42-44 rue des écoles, Paris / N° 30.*

Radioactivity Measurements

At the beginning of 1898, Pierre and Marie Curie made the first quantitative measurement of the radioactive intensity of substances. The 'Curie method' comprised an ionization chamber, a quadrant electrometer and a current balance.This experiment is well described by Loïc Barbo, Denis Beaudoin and Michel Lagues[14], and can now be seen at the Espace des Sciences de Paris (ESPCI) or at the Curie Museum, with apparatus made by Bernard Pigelet. The Curies' measurements were probably repeated soon afterwards in Rennes. Professor Leon Joubin, in his book *La faculté des Sciences de Rennes*[15] published in May 1900, indicates the existence of a Curie electrometer and quartz balance. We have also found a Moulin absolute capacitor and a transparent divided scale made by J. Carpentier which are necessary to complete the experiment. It was probably the physicist-teacher Émile Gripon who performed these measurements. Today, the complete set of apparatus is regularly shown to the public (Fig. 7). We hope to be able to perform the whole experiment soon.

Other Curie Apparatus

Several other instruments devised by the Curie brothers have been discovered: a Curie-Cheneveau magnetic balance (*N° 34 / Société Centrale de Produits Chimiques*), probably a Blondlot-Curie electrometer, and very recently a precision aperiodic balance.

6. Foucault Gyroscope and Induction-Current Apparatus

Two apparently-unrelated Foucault instruments in the Rennes collection show a visual similarity that reflects a historical link.

Gyroscope

The French physicist Léon Foucault (1819-1868) is best remembered for his 1851 pendulum experiment.[16]The slow, clockwise veering of the swing plane reflected the anticlockwise rotation of the Earth beneath, and finally provided the first *dynamical* proof of the terrestrial rotation.The following year, 1852, Foucault devised a further experiment for demonstrating the Earth's rotation. He called it the *gyroscope,* from

Greek words meaning ‘to look at the rotation’.

The University of Rennes holds a Foucault gyroscope set in its physics collection (Fig. 8). The set was acquired *c.*1875, probably at a cost of 1500 francs. The maker is the firm of Dumoulin-Froment, successor to the Froment firm that made Foucault’s original gyroscope in 1852. Foucault gyroscopes are exceedingly rare, perhaps because they were very expensive (1500-2500 F). The original 1852 gyroscope was bequeathed to the Collège de France and has been lost. We know of only 3½ other sets besides the Rennes one: Paris, Musée des Arts et Métiers (1867); Coimbra, Physics Museum (1878); London, Science Museum (1883); and Washington, Smithsonian Institution (prior to 1877, one box missing). If you know of other Foucault gyroscopes, please let us know!

Fig. 8 *Foucault gyroscope set.*

A gyroscope set came with two rotors. One is missing from the Rennes set. The other has broken suspension pins, so we have not yet been able to set the gyroscope going. However various accessories have survived for demonstrating other properties of rotary motion.

Induction-Current Apparatus

Another University of Rennes Foucault instrument is his induction-current apparatus for demonstrating the conversion of mechanical energy into heat, made by Heinrich Daniel Ruhmkorff (1803-77) (Fig. 9). The experimenter turns the crank to spin the copper disc between the poles of the electromagnet. Induction currents heat up the disc.

Foucault induction-current machines are relatively common, perhaps because of their lower price (350-400 F). Generally similar machines exist in Bologna, Museo di Fisica; Florence, Fondazione Scienza e Tecnica; Paris, École polytechnique, Lycée Louis le Grand, and Musée des Arts et Métiers; Pavia, Museo di storia dell’Università; Pisa, Fondazione Galeleo Galilei; Washington, Smithsonian Institution. We suspect many more Foucault induction-current machines have survived. If you know of any, please let us know.

Induction-current machines of this style can be found illustrated in instrument-makers’ catalogues as late as *c.*1910. However, the form of the poles in the Rennes apparatus is unusual. Only the machine at the Lycée Louis le Grand in Paris is similar. All other examples bar one have semi-circular poles, presumably to increase magnetic coupling and hence the heating effect. This leads us to suspect that the Rennes and Lycée-Louis-le-Grand machines are of early date.

Operating Current for the Induction-Current Machines

The Rennes electromagnet has a resistance of ~1.0Ω between the terminals. For the Louis-le-Grand instrument, a more reliable measurement of 0.30Ω was made between breaks in the insulation at the ends of the windings, suggesting poor contacts at the terminals after 150 years. Contemporary texts indicate the use of 2-6 Bunsen cells (e.m.f. ~1.9V). We are unsure what internal resistance typical Bunsen cells would have had: two 1890s values discovered on the web are 0.1Ω and 0.9Ω. Corresponding currents range from 1½ to several amps. To obtain hand-obvious heating with the Rennes instrument we needed to use a current of 3-5A. However, the disc speed was probably lower than the intended value because the gear teeth are damaged, and to avoid further damage we were unwilling to crank hard. Foucault talks of 150-200 r.p.s. for his verification with the gyroscope torus, but slower speeds may have been intended with the generally coarser Ruhmkorff device. A contemporary textbook claims temperatures of 95ºC could be obtained.

An Historical Link

The obvious similarities between the gyroscope and induction-current machines reflect an historical link. The idea of the conservation of energy was gaining ground in the 1850s. In Ruhmkorff’s workshop one day, Foucault witnessed the dramatically-rapid deceleration of a metal block dropped into the field of a powerful electromagnet. “What happens to this motion that dies into nothing?”, Foucault asked. “According to the new doctrines,” he judged, it “should reappear as heat.” “Having to hand all the items necessary for a prompt verification,” Foucault went on to test the new doctrine.

One of the *necessary items* was his gyroscope torus seated on its cranking mechanism. Foucault set the poles of an electromagnet across the torus. As he continued to

Fig. 9 *Foucault induction-current apparatus.*

crank, the torus got hotter – from

"16ºC to 20, 25, 30 and 34º", and then hot enough to perceive with his hand. "If the experiment seems worth of interest," he wrote, "it will be easy to reproduce with increased effect.… one will be able to produce high temperatures, and put before the eyes of the public gathered in lecture rooms a curious example of the conversion of work into heat." There was nothing radically new in Foucault's demonstration, but it was influential in spreading the concept of the conservation of energy in France.

Although Foucault says he used his gyroscope torus and crank in his verification, it was only when we saw that the copper disc was mounted in exactly the same way as the torus (in a ring, locked to the gears with four sliders) that we appreciated the accuracy of his description. The Rennes instrument, made by Ruhmkorff, embodies closely what Foucault actually did.This illustrates, yet again, the importance of hands-on experience as well as theoretical description for full understanding of physics and its history! Very recently, experiments with induction-current apparatus were realized, in collaboration with Bertrand Wolff and Alain Faisant. Video movies are visible on the AMPERE site: http://www.ampere.cnrs.fr/parcourspedagogique/zoom/video/aragofoucault/video/index.php

A Note on the Instrument Makers

We have seen that inspiration for Foucault's induction-current demonstration came in the Paris workshop of H.D. Ruhmkorff, who is labelled as the maker of at least the Rennes, Pisa and Musée-des-Arts-et-Métiers machines. Though the apparatus was listed in the catalogues of many other contemporary makers (Chevalier 1861, Ducretet 1870, Hachette 1872, Secretan 1874), 'rebadging' was common. We suspect Ruhmkorff as the maker of all examples from that time even though the Louis-le-Grand and École-polytechnique machines, for example, are unmarked.

We have no information about the Coimbra gyroscope set, but all the others are by Dumoulin-Froment. It is regrettable that no trade catalogues are known for Ruhmkorff, Froment or Dumoulin-Froment.

Conclusion

The scientific heritage of the University of Rennes 1 is particularly rich. To save, protect and display its historic instruments, and allow their use for research, the University of Rennes 1 has plans to develop projects in several directions:

- Preservation and development of the University's scientific heritage: various collections (zoology, archaeology, physics, chemistry, etc.) and historical archives.
- Exploration, reflection, curiosity, dialogue with the public, and discussion regarding the challenges of research.
- A research and education forum for students, teachers, researchers and scientific associations, with experiments, exhibitions and publications.

In addition, work on the University's 20th-century heritage has begun in association with the Conservatoire National des Arts et Métiers in Paris (D. Thoulouze and C. Cuenca, visit: http://patstec.fr).

Acknowledgements

The authors would particularly like to thank Nathalie Rozé, Jérémy Thouin and Ronan Guillaume for their collaboration in presentations at festivals and school exhibitions, and for their masters reports. Thanks also to Paméla Huron, who set up the web site for the Scientific Culture Commission (http://cst.univ-rennes1.fr/) and to Bernard Le Garff for photographs. Visitors to our collections are numerous and very interesting for us. Special thanks go to Paolo Brenni for his constant help and frequent and fruitful advice. Denis Beaudoin[17], Bernard Pigelet[18] and Renaud Huynh (Curie Museum) provided precious information on the Curies' instruments.

Notes and References

1. Paolo Brenni, 'Le triomphe de l'acoustique expérimentale: Marloye et Koenig', *La Revue du Musée des Arts et Métiers,* **12** (September 1995), p. 29.

2. Anna Giatti and Mara Miniatti, *Acoustics and its Instruments, The collection of the Instituto Tecnico Toscano* (Florence: Fondazione Scienza e Tecnica, 2001).

3. Émile Gripon, *Traité élémentaire de physique appliquée* (Paris: Librairie classique Eugène Belin, 1870).

4. Nathalie Rozé, *Les instruments d'acoustique de Rudolph Koenig*, Rennes, 2005-2006, Masters report, Université de Rennes 1.

5. On the activity of Benjamin Bourdon, see the University of Rennes 2 web site: http://www.uhb.fr/sc_humaines/crpcc/lpe/musee/cylindres.html

6. Paolo Brenni, *Gli strumenti du fisica dell'Instituto Tecnico Toscano–Ottica* (Florence: Istituto e Museo di Storia della Scienza, 1995).

7. Jules Carpentier, Ingénieur-constructeur, *Catalogue d'instruments* (Paris, 1900).

8. Ronan Guillaume, *Galvanomètres et instruments électriques*, Rennes, 2006, Masters report, Université de Rennes 1.

9. Pierre Weiss, *Recherche sur l'aimantation de la magnétite cristallisée et de quelques alliages de fer et d'antimoine*, Thèse de doctorat, Paris, 1896, Georges Carré éditeur.

10. Pierre Weiss, 'Un nouvel électro-aimant de laboratoire donnant un champ de 30000 unités', *L'éclairage électrique,* **15**, no. 25 (1898), p. 481.

11. Jacques Curie, 'Recherches sur le pouvoir inducteur spécifique et la conductibilité des corps cristallises', **17** (1889. ser. 6) *Annales de Chimie et de Physique*, p. 385. Available at http://gallica.bnf.fr/ark:/12148/bpt6k34887n

12. Pierre Curie, 'Electroscope pour l'étude rapide des corps radioactifs', *Oeuvres de Pierre Curie*, (Paris: Gauthier-Villars imprimeur 1908), p. 591.

Available at http://gallica.bnf.fr/ark:/12148/bpt6k2282p

13. Pierre Curie, 'Electromètres à quadrants apériodiques', *Oeuvres de Pierre Curie* (Paris: Gauthier-Villars imprimeur, 1908), p. 564. Available at http://gallica.bnf.fr/ark:/12148/bpt6k2282p

14. Loïc Barbo, Denis Beaudoin and Michel Laguës, *L'expérience retrouvée* (Paris: Belin, 2005)

15. L. Joubin, *La Faculté des Sciences de Rennes* (Rennes: Fr. Simon, 1900).

16. On Léon Foucault see: William Tobin, *The Life and Science of Léon Foucault. The Man who Proved the Earth Rotates* (Cambridge University Press, 2003); also http://pagesperso-orange.fr/tobin/foucault.html

17. Denis Beaudoin has published an excellent book, *Charles Beaudoin, une histoire d'instruments scientifiques* (Paris: EDP Sciences, 2005) where we found copious information about the Curies' instruments.

18. Bernard Pigelet has replicated the Curie experiments for ESPCI (located in the École Supérieure de Chimie de Paris) and the Curie Museum.

Authors' addresses:
† Scientific and Technical Cultural Commission
Université de Rennes 1
Campus de Beaulieu, Bat. 6
Avenue Général Leclerc
35042 RENNES Cedex, France
e-mail: Dominique.Bernard@univ-rennes1.fr
http://cst.univ-rennes1.fr/

††6 rue Saint Louis, 56000 VANNES, France
e-mail: william.tobin@wanadoo.fr
http://pagesperso-orange.fr/tobin/