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Mastering picocoulombs in the 1890s: The Curies' quartz–electrometer instrumentation, and how it shaped early radioactivity history

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A B S T R A C T

This paper describes the instrumentation developed by Pierre and Jacques Curie in the 1880s to perform very precise charge and low current measurements. Using this set-up, which is nearly as precise as most present digital electronic charge measurement apparatuses, Jacques Curie established the absorption current law for insulating materials. A detailed analysis is made of the experimental path followed by Marie Curie from the choice of her research subject to her first discoveries, using the same Curie quartz–electrometer set-up. From the Curie "discovery notebooks" and a modern reconstitution of this experiment, it is possible to reconstruct what were her main experimental difficulties concerning the measurements of the picoampere leakage currents produced by the radioactive rays. We will underline that the availability for Marie Curie of a precise ready-to-use electrostatic measurement technique played an important, if not decisive, part in her career and her research. A more general issue addressed here is that laboratory techniques are not only a prerequisite of modern scientific work, but in a great part influence knowledge production.

1. Introduction

Developed by Pierre and Jacques Curie, the quartz–electrometer measurement system was, at the end of the 19th century, probably the most precise available for very weak current measurements. Combining a charge generator built around a piezoelectric quartz lamella and a quadrant electrometer, it was able to detect charges as weak as a few picocoulomb, to measure precisely currents of a few tenths of picoamperes, and allowed Jacques Curie to establish the law of absorption in insulators. It also took a pre-eminent part in Marie Curie's 1897 discovery of radium, by allowing a precise quantification of the leakage currents caused by the "uranic rays" through an ionization chamber and hence, coupled to chemical separation methods, the progressive concentration of materials with an increasing radioactivity. In the first part of the 20th century, this Curie electrostatic measurement system continued to be a worldwide reference in radioactivity measurements for its reliability and precision.

We will underline in this paper several aspects of interest to both historians of sciences and the electrostatics research community. First, electromechanical devices could have been, more than one century ago, nearly as precise as most modern digital electronic charge measurement devices. Besides, the principle of the Curie measurement system (Fig. 1), combining a piezoelectric sensor (the quartz lamella) with an electrostatic actuator (the electrometer) is at the heart of many 21st century technological devices. Second, the detailed reconstruction of the experimental problems encountered by Marie Curie in her early research work that led her to the discovery of radium shows the decisive importance of several factors, which might seem without interest at first glance, such as the problem of having a precise reference voltage or avoidance of insulator leakage. These kind of issues, often neglected in the discovery narrative because they are rather technical, are at the heart of laboratory work. Moreover, and this is maybe the most important issue that we will underline, laboratory techniques are not only a prerequisite of modern scientific work, but in a great part influence knowledge production, as has been recognized by historians of science in the last decades (see for instance [1]). In the particular case of Marie Curie, the availability for her of a precise ready-to-use electrostatic measurement technique played an important, if not decisive, part in her career and her research.

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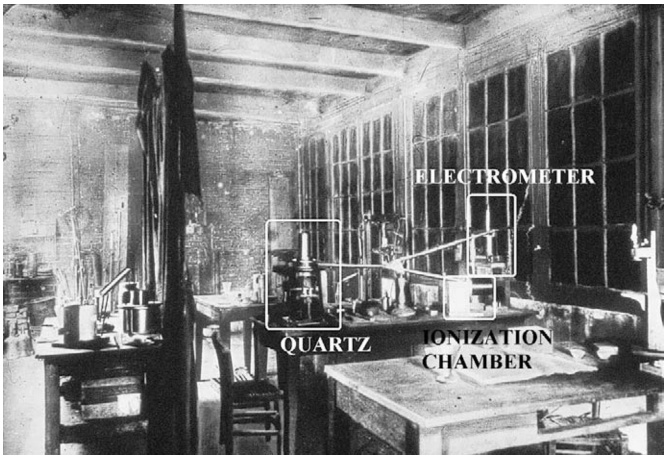

Fig. 1. The Curies' famous "discovery shed", and the radioactivity measurement set-up (photo 1903, ©ACJC).

2. The Curie quartz electrometer measurement system

2.1. From the piezoelectricity discovery to a precise electrostatic charge generator

Piezoelectricity was discovered in 1880 by a common work of the Curie brothers, initiated by Jacques, the elder, who entered the mineralogy laboratory of the Paris *Faculté des Sciences* to work on electricity induced by crystals. Pierre collaborated with him almost from the beginning and played an important role in the discovery. In the following decade, he developed a theoretical reflection on symmetry, whose importance was to be recognized only later, and accomplished his well-known important works on magnetism. Pierre also developed several measuring instruments, and especially electrometers, which we will describe below.

The discovery of piezoelectricity led the Curie brothers to build a calibrated generator of electrostatic charges (Fig. 2a [2,3]). This device is built using a thin quartz lamella, with both sides metallized, so that the charge generated when a force is applied to the lamella can be collected. The quartz crystal is cut in order to maximize the charge generation on its sides, the lamella sides being chosen perpendicular to the crystal electrical axis, and its width in the direction of its optical axis. A suspended tray allows deposition of calibrated weights, and therefore generation of charge amounts directly proportional to these, according to the relationship:

$$q = \frac{Klp}{e} \tag{1}$$

where K is quartz specific coefficient, l lamella length, e lamella thickness, p applied weight.

Each quartz charge generator is therefore characterized by its own Kl/e constant, and by its capacitance, an important parameter, since the induced charge will distribute between this capacitance and that of the outer circuit to which it is connected in parallel. Weak currents measurement can easily be achieved by using the quartz calibrated charge production to compensate the current to be measured. This compensation method requires the use of an electrometer, as described below, and allows its use with maximum sensitivity and minimum leakage currents (since the mean applied voltage to the electrometer is zero). In this case, capacitances need not be taken into account either. Lastly, let us remark that this instrument allows production of calibrated electricity amounts in a ratio from one to ten thousand, since it is possible to hang on to the lamella (without significant departure from linearity) masses varying from 0.5 g to 5 kg.

2.2. Quadrant electrometers, from Kelvin to Pierre Curie

Throughout the 19th century, the measurement problem of weak electricity amounts had received more and more elaborate technical responses, accompanying the progresses of electrostatics and electromagnetism. One of the most precise achievements of this century in that field had been the quadrant electrometer. Designed by Lord Kelvin in 1867 [4], its basic principle is the rotation of a light metal vane (called *needle*), suspended from

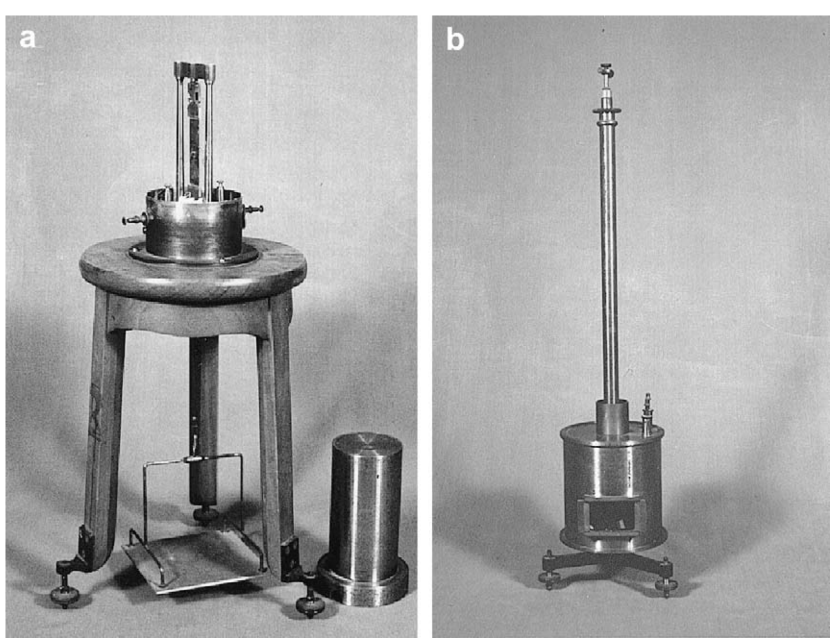

Fig. 2. Quartz generator (a) and Curie aperiodic electrometer (b) (photos S.B.–B.V.–ESPCI).