Journal of Physics and Technology, Volume1 (2017), Number 2, pp.65-69 ISSN 2535-0536

# Trapping Radiant Cold Via Mirrors

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**Abstract.** A modern experimental setup with an educational purpose is proposed, recreating Marc-Auguste Pictet's classical experiment from the end of the XVIII century. Thermodynamic and geometrical optics phenomena are demonstrated via a system of spherical mirrors, a heat source and an infrared detector. The personal standpoints of certain esteemed scientists (members of the Geneva scientific community in the period 1770-1820) on the matter are examined. The experiment offers, not only the opportunity for a visual demonstration of physical phenomena, but also for a thorough discussion on contemporary views, in contrast with older and disproved ones, on fundamental issues in the field of physics. The article is of interest to people with affinity to history of physics.

**Keywords**: *Pictet's experiment, Radiant energy, Spherical mirrors, Educational purpose, History of physics.*

## 1 INTRODUCTION

In the process of teaching natural sciences such as physics, a number of difficulties arise when explaining unintuitive phenomena to students. It is widely accepted that experimentation and demonstrations ease the understanding process and are cherished by teachers and students alike. Current education should be contemporized to match the exponential growth of information and technology, but one should not misjudge or understate lessons of the past. Delving into the history of physics is not only interesting, but also allows one to follow the perceptional progress, regarding fundamental issues, and extract ideas of how to enrich and enliven the studying process. Based on these assumptions, the authors have recreated a modern version, including experimental set-up, of Pictet's obscure experiment, concerning calorific and frigorific rays. Suited for educational purposes, it is able give insight into radiant energy to nowadays students. At the end of the XVIII$^{th}$ century, this controversial demonstration led to questions concerning the nature of heat and the plausible existence of a physical quantity such as cold. Consequently, many scientists went on to explain the phenomena, producing influential work, thus shaping a new branch of physics – thermodynamics. Pictet's experiment is a milestone in XVIII$^{th}$ century physics and should be included in modern education. The aim of this paper is to familiarize the reader with the historic importance of the experiment and to introduce the authors' adaptation, specifically created for educational applications.

## 2 HISTORICAL OVERVIEW

It is evident that great interest in the nature of radiant energy, the laws which govern it and its applicability dates back to ancient times, a famous example being Archimedes' story - the victory over the enemy fleet. Evidence, regarding experiments on radiant heat, shows up scattered in English, Italian, German and French publications in the period XVI-XVIII century. One finds the same demonstrations, repeated independently, by experimenters separated from one another in time (Evans & Popp, 1985), (Cornell, 1936). Serious work on radiant heat was underway in the 1770's and by 1780 two important experimental results had been obtained. Radiant heat had been distinguished from convection and conduction phenomena. More importantly, radiant heat had been clearly separated from visible light, although it followed the same physical laws of propagation. Notable authors, for their clear and specific experimental work, and for their influence on the Swiss school, were J.H. Lambert and C.H. Scheele (Evans & Popp, 1985). The Swedish chemist Scheele himself introduced the term "Strahlende Hitze" – radiant heat. The primary distinguishment of radiant heat from convection and conduction, as well as visible light, was empirical, whilst the theoretical explanations of those phenomena were unclear and often overlapping. Thus the natural question that arose was: What is radiant heat?

In the midst of XVIII century the nature of heat was a lively discussed topic. According to Pier Prevost writing in 1818, the opinion of physicists on the nature of light and heat divided them into three camps: "les emissionaires, les undulateurs, et les indifferens" (Evans & Popp, 1985), (Prévost, 1818). Simply put, the questions was whether heat phenomena were a result of emissions of a material substance, or were they due to undulations. The emissionist's view, a materialistic one by nature, prevailed at that age. Basically stated, it described heat phenomena as a transfer of a material substance known as fire, aka caloric. It was believed to be very light and had discrete structure. On the other hand, the zealots of undulations, described the transfer of heat as waves, propagating through an all-pervading subtle fluid. It was known by the names fire, igneous fluid, also caloric. The vocabulary overlap in the two camps somewhat blurs the distinction between them. One might ask, what were their perceptions of cold? Was cold the absence of heat or was it a sole entity, a separate physical quantity?

In the beginning of the XVIII$^{th}$ century some thermometric scales, including the centigrade scale of Celsius, were inverted. Thus, the zero was the highest temperature on the scale and lower temperatures were indicated by ever increasing numbers, the lowest being a hundred in the case of Celsius. Even the British Royal society thermometer's scale was inverted. The reasons for the inverted scales are not clear. In the opinion of Hasok Chang, a famous physics historian, it is possible that some researchers measured the degrees of coldness instead of heat. Following this logic, one might call the inverted thermometers – frigometers (Chang, 2002). According to the esteemed scientist, Thomas Young, from a metaphysical point of view, heat being the absence of cold is equally acceptable as cold being the absence of heat. Despite the prevailing opinion in this century that cold is an absence of heat, there is a lack of definite metaphysical commitment it is not a real entity. A single experiment raised the spirits of XVIII$^{th}$ century scientists, producing a new invigorated search for the nature of heat and the plausible existence of frigorific rays. This experiment remains in the history under the name of Pictet.

## 3 PICTET'S EXPERIMENT

Marc-Auguste Pictet (1752-1825), (Fig.1) was a Genevean nobleman, lawyer, esteemed natural philosopher with interests in geodesy, astronomy, meteorology. He was the editor and co-founder of two respected journals: the Journal de Genève and the Bibliothèque brittanique. Throughout most of his life, he was an active figure in the local public affairs, playing a role in all critical points in Genevan history (Evans & Popp, 1985).

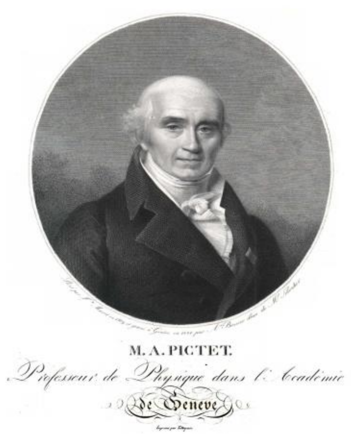


**Fig 1.** Marc August Pictet, aged 57, engraving by A.Bouiver in 1821

Despite his many interests, his most original and meaningful research was a long series of experiments on heat, described in his "Essai sur le feu", published in 1790. A translated version by W. Belcombe in English is available, published in 1791. One can download it for free, as it is found in a digitalized version by Google, under the name of "Essays on fire".

Pictet's experiment (Pictet, 1791), conducted around 1780 consists of the following: two metallic concave mirrors facing each other, each of radius 9 inches, made of polished tin, separated from each other by over 10 feet. Having placed a sensitive thermometer at the focus of one of the mirrors, Pictet introduced a hot object at the other focus (Fig 2.)

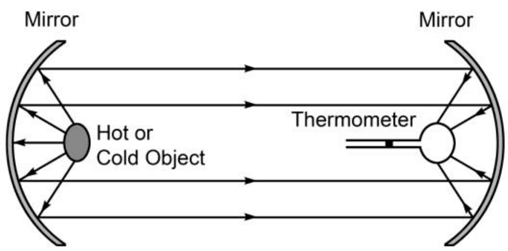


**Fig 2.** Pictet's experiment

In the case of a hot iron bullet (not glowing), the temperature rose with 10,5 degrees Fahrenheit after 6 minutes. A lighted wax taper and a flask of boiling water had similar effects, though raised the temperature less. The effect was instant, even when he separated the mirrors at a distance of 69 feet (Chang, 2002). This version of the experiment is well-known and is used as a demonstration at some educational facilities. What is obscure and more of an interest is the continuation of the experiment, which sometimes dazzles physicists even today, having seen it for the first time.

By the influence of L. Bertrand, a famous mathematician and a student of the immortal Euler, Pictet repeated the experiment, this time with placing a cold object at the focus of the mirror and a sensitive air thermometer at the focus of the other one. It turned out that a matrass full of snow, made the temperature reading descend several degrees, the effect starting instantly. The temperature remounted as soon as the matrass was removed.

The news of this experiment being spread around the scientific community of Geneva, Britain, France became a stimulus for experimentation and ponder upon the nature of heat. It also invigorated a new search for frigorific rays, for cold, being an entity on its own right. In response of the experiment, Pierre Prevost, a colleague of Pictet's, produced one of the most influential works of that era, a treatise titled "Memoire sur l'equilibre du feu'' (Prevost, 1791), describing the transfer of heat as a two-way transfer of particles (discrete fluid), forming a dynamic equilibrium. The experiment also had a profound influence on Count Rumford, a famous experimenter and zealous defender of the frigorific rays. The count was a long life opponent of the emissionist's school and saw a worthy opponent in the face of Pierre Prevost. Rumford's series of experiments, tried to prove that cold exists and made Pierre Prevost adapt his theory to account for the new results. In his late years (Prevost being 67), received a letter from non-other than the famous Fourier. The letter said: "I regard the experiments of M. Pictet as fundamental, because they have directed the view of physicists on an order of phenomena that one had scarcely perceived. The use that he made of the air thermometer, the formal experiment on the reflection of cold, and the theory that you have given on this subject have created this new branch of physics (Prevost, 1832).

Thus, Pictet's experiment remains in the history of physics, as influential and fundamental, having inspired other scientists and helped establish the foundations of a new branch of physics – thermodynamics.

## 4 MODERN REPRESENTATION

Despite of the historic importance of Pictet's experiment, there is, but a small number of modern and popular representations of the experiment (https://www.youtube.com/watch?v=mW4T0ZaiGno), (Evans & Popp, 1985). Our approach is to simplify the experimental set-up and make it more user-friendly, flexible affordable and easier for construction.

The main parts of the experiment are two identical spherical or parabolic mirrors, aligned to the optical axis (Fig 3.). It is important to accurately determine the focal points (and focal distance respectively) of each of the mirrors, in order to conduct the experiment successfully. To achieve that, and to align the mirrors, we're using a standard H – shaped aluminum rail to maintain the axial symmetry and to support the stands. The stands are crafted from basic aluminum pipes with close diameters that allow them to fit tightly into one another and to provide vertical and axisymmetric degrees of freedom (Fig. 3).

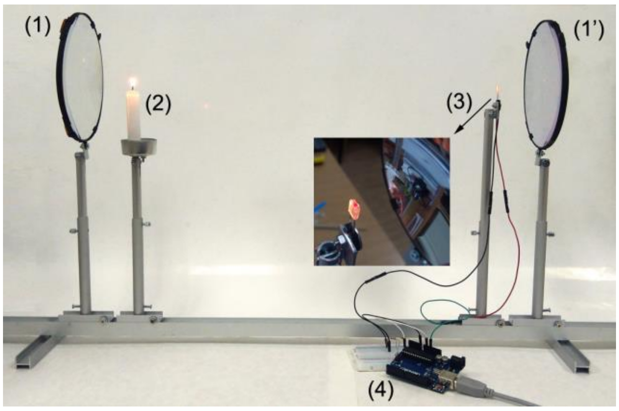


**Fig 3.** Experimental setup

As the original Pictet's experiment, a hot object is placed - the flame of a burning candle (2), into the focal point of the mirror (1). A parallel beam of luminous rays is formed and propagates to the opposite mirror as a result. Instead of a thermometer, we're using a simple infrared detector (3) LTR-301. The detector is positioned into the focal point of the second mirror (1'). The infrared spectral intensity change is registered by the detector connected to an Arduino UNO-R3 development board (4), (as shown on Fig. 4).

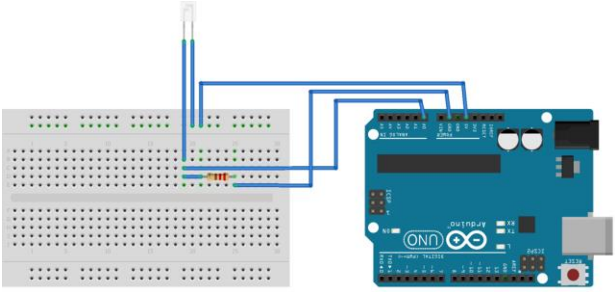

**Fig 4.** Arduino detection system

Thus the analog signal is digitized and sent to a computer for monitoring in real time. The values of the normalized signal are displayed by the "Serial monitor" option, integrated in Arduino IDE. The amplitude change, of the signal received, is shown (Fig. 5), the small ripples are induced by the ambient fluorescent light.

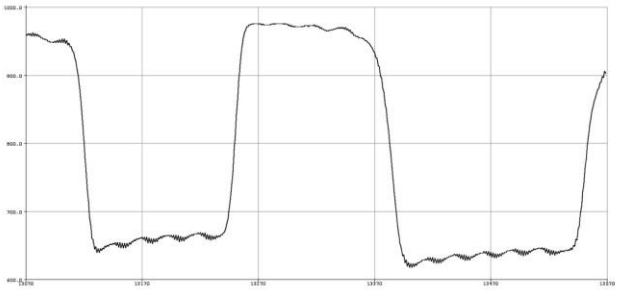

**Fig 5.** Real time data acquisition

As part of the detection system, the Arduino makes the experiment more flexible in terms of program code writing, software requirements and hardware implementations.

## 5 RESULTS AND DISCUSSION

After the optical alignment of the experimental set-up, the experiment begins with calibration of the signal with the ambient light. Lighting up the candle causes significant increase of the signal amplitude, so additional software calibration may needed. This demonstration shows that the radiant heat propagation, between the mirrors, obeys the optical laws.

The next step is to replace the candle with a transparent block of solid ice with an appropriate size (the cold object should be comparable with the candle flame in size). It is useful to operate the ice with a handle, to assure easy placing and then removal of the block. The transparency of the ice is an attractive evidence for the students that it does not simply interrupt the optical path, but it absorbs the invisible infrared radiation. The result of these operations is shown (Fig. 6).

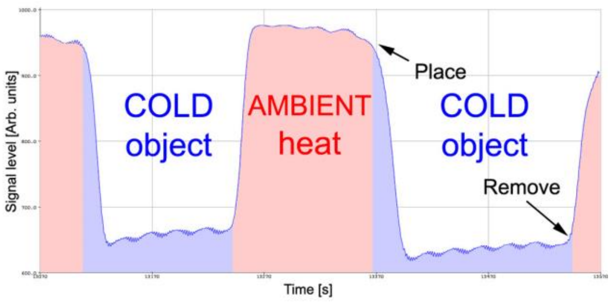


**Fig 6.** Analysis of the signal

When the cold object (ice block) is placed in the mirror focal point, the signal level significantly drops. Removing the cold object causes the signal to go back to normal ambient level. In addition to that demonstration, when a thin sheet of white paper is placed instead of the ice, a noticeable, but smaller signal change is detected.

(The block of ice absorbs a part of the incoming infrared radiation from the room. Meanwhile it emits less radiation than a hot object or one that is in equilibrium with the room. This causes a decrease in the intensity reading of the detector. If there was a thermometer instead, it would indicate a lower temperature.)

We conducted a poll among 7$^{th}$ and 9$^{th}$ grade students. The results were in immense contrast. Over 90% of the 7$^{th}$ graders, who face the subject physics for the first time, say they like it, while after only two years of education none of the 9$^{th}$ graders likes it. What is common between the two groups is that they both want more experiments in class with modern technology.

The experiment we present demonstrates thermodynamics, geometrical optics phenomena, and also electronical applications. The goal is to have the students understand them easier. They may be involved into assembling the setup and conducting the experiment as this can develop their interest in science. The results can provoke a thorough discussion in class. It is suitable for causing reflections and drawing conclusions.

During the demonstration of the experiment we received positive feedback. The audience was intrigued and impressed, which convinces us that the reaction in every class in front of which the experiment is presented, will be positive.

## ACKNOWLEDGEMENTS

This project was developed with the help and support of SciTeam http://phys.uni-sofia.bg/~zoggy/sciteam and the Department of Condensed Matter Physics at Sofia University “St. Kliment Ohridski”.

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