

# Jean-Daniel Colladon

Geneva scholar and industrialist



# L. SAUTTER, LEMONNIER & C<sup>E</sup>

26, avenue de Suffren (Champ-de-Mars), PARIS

## COMPRESSEURS D'AIR SYSTEME COLLADON

BREVETES S. G. D. G.

Paris, 1<sup>er</sup> Novembre 1875.

L'emploi de l'air comprimé, soit comme transmetteur de force, soit comme agent principal ou auxiliaire de diverses industries, tend à se généraliser de plus en plus. Pour ne citer que quelques exemples, dans les mines et les carrières, dans le fonçement des puits et des piles de ponts, dans le creusement des tunnels, dans la production artificielle de la glace, dans la sucrerie, la raffinerie et plusieurs industries chimiques et métallurgiques, on se sert ou l'on pourrait se servir utilement de l'air comprimé.

Dans l'application aux mines qui paraît être jusqu'à présent la plus importante de toutes, on est souvent retenu par l'élévation de la dépense qu'on croit nécessaire pour un essai machinant de la perforation mécanique, moins à cause du prix relativement peu élevé des perforateurs proprement dits, qu'à cause des frais d'achat et d'installation des compresseurs d'air et de leurs moteurs.

Nous avons cherché à lever cette objection en construisant des compresseurs d'air portatifs et économiques, donnant une quantité d'air suffisante pour la mise en action d'au moins deux perforateurs. Ces compresseurs sont à double effet ou à simple effet.

COMPRESSEURS A DOUBLE EFFET (Tarif N° 1)

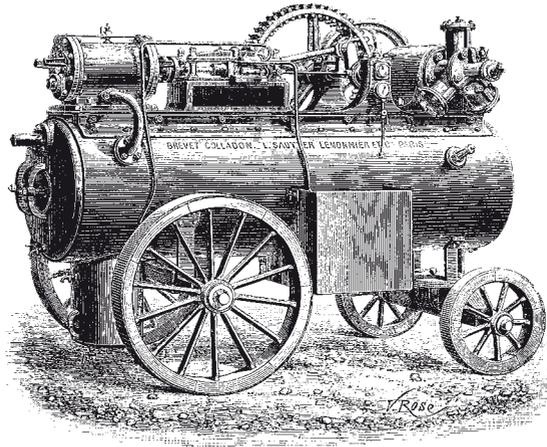


FIG. 1.

Colladon patented his air compression system in France in 1871. The Parisian company Sautter, Lemonnier & Co. manufactured mobile Colladon compressors (powered by steam), under licence.

Sautter and Lemonnier Catalogue, Colladon Archives, Paris 1875

Bibliothèque de Genève

Cover: Portrait of Jean-Daniel Colladon

Souvenirs et mémoires, Genève, 1893

Library of the Musée d'histoire des sciences de Genève

## Jean-Daniel Colladon

Jean-Daniel Colladon (1802-1893) is a significant figure in science and industry in 19th century Geneva. He was both a scholar and an engineer and his research and inventions resulted in numerous practical applications.

This booklet briefly describes the scientific and industrial career of Colladon illustrated by objects, manuscripts, drawings and other documents held by the History of Science Museum.

“ ... I was born under a lucky star, and during my life I was able to witness many political revolutions and make numerous inventions and discoveries. I measured the speed of sound in water and I showed that water has prodigious elasticity; I studied the electricity produced by friction machines and the Leiden jar, and electricity in the atmosphere; I was the first to show that light can follow a curved line in a flow of water and that, under certain conditions, water vapour can stop fires. I was the first to demonstrate that the paddles of a steamship must move on the wheel while it is in motion; I showed that wheels can be used to measure the efficiency of marine steam engines up to several thousand horsepower; in particular, I demonstrated that compressed air exerts a force only half as strong as previously thought and that it is better used for tunnelling through mountains. I was the first to observe the circular marks produced by lightning and I gave an explanation of hail, etc., etc ...  
I received many awards, prizes, medals and honours from the Institute and other scholarly bodies for these various inventions ... ”

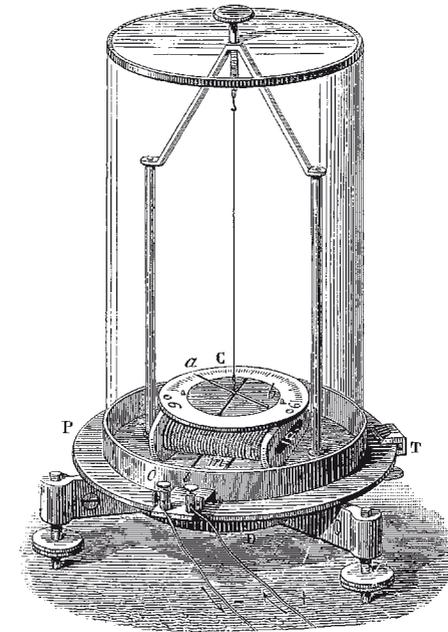
Jean-Daniel Colladon, Souvenirs et mémoires, Genève, 1893

**During his stay in Paris, Colladon carried out a number of fundamental experiments on electromagnetism**

After studying law in Geneva, Colladon went to Paris in 1825 with his friend, the future mathematician Charles Sturm (1803-1855). He went to study mathematics and physics and to work on his dissertation on the compressibility of liquids. The two friends met François Arago (1786-1853) and André-Marie Ampère (1775-1836), who had made major discoveries on the interactions between electricity and magnetism. Colladon carried out various experiments on electromagnetism with Ampère in the laboratories of the College de France.

While he was working in Paris, Colladon made a new very sensitive galvanometer which was designed to detect the electric current produced by electrostatic friction machines.

Colladon used the galvanometer to test the performance of anti-hail devices. These were long poles equipped with metal spikes placed in fields to protect crops from lightning. He discovered that they were less effective than deciduous trees of the same height. In order to study atmospheric electricity Colladon connected his galvanometer to the guide wires of kites which were then flown at heights of several hundred metres. He observed that heavy rain whether or not accompanied by lightning “poured torrents of electricity, generally positive, from the atmosphere to the ground ...”



*The galvanometer*

*This instrument was invented in the 19th century and was one of the first to measure the strength of electric current. Current is sent through two wires to terminals on the outside of the instrument then through a copper wire encased in silk and wound many times around a bobbin placed under a suspended magnetised needle. The bobbin, traversed by the electric current, produces a magnetic field which makes the needle move. The instrument is enclosed within a glass cloche to protect it from drafts and oxidation.*

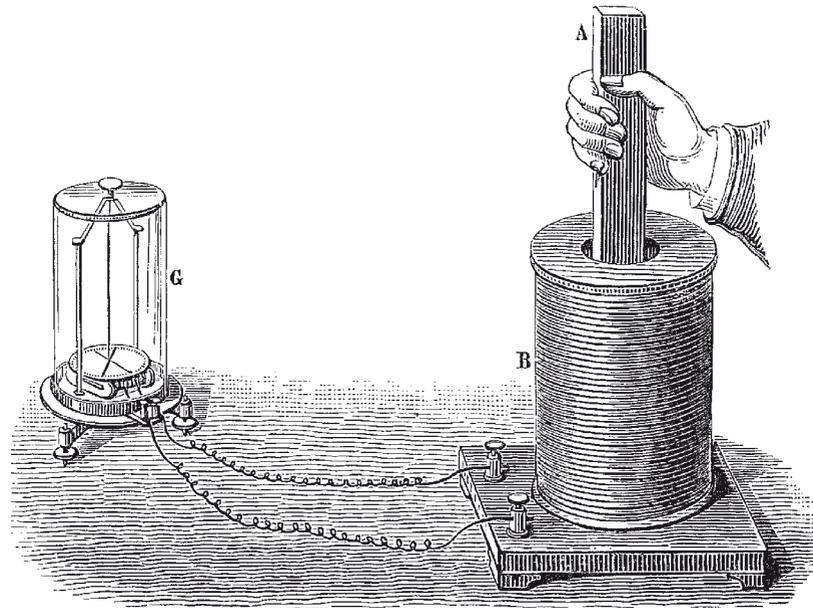
*Ganot, traité de physique, Paris, 1884  
Library of the Musée d'histoire des sciences de Genève*

**Colladon narrowly misses a major discovery: induction**

In *Souvenirs et Mémoires* Colladon admits that, in 1825, he nearly made a very big discovery in the field of electricity: that of induction. It was eventually demonstrated by the English scientist Michael Faraday (1791-1867) in 1831. Colladon was seeking to prove that a magnet presented to a coil of conducting wire can induce an electric current in the wire. In order to ensure that the magnet did not interfere with the galvanometer he placed the latter in a different room. After presenting the magnet to the wire coil,

he moved to the other room to observe the galvanometer and saw that the needle had not moved. The young scientist had not realised that induction is transitory and occurs only when the magnet passes in front of the wire. He would have observed this had he left the galvanometer in sight.

The discovery of induction was to open the way to many discoveries and practical inventions in the second half of the 19th century which still underlies much of our modern technology: generators, dynamos, power stations, etc.



*Magnetic induction*

*A strongly magnetised steel bar (A) is introduced into a coil of copper wire (B) the two ends of which are attached to a galvanometer (G). As soon as the bar is introduced, the needle on the galvanometer moves indicating the presence of an electrical current.*

*Ganot, traité de physique, Paris, 1884*

*Library of the Musée d'histoire des sciences de Genève*

## The speed of sound in water

**To ensure accurate measurements Colladon had to employ his considerable experimental skills.**

One thousand, four hundred and thirty-five metres per second (1435 m/sec). This is the speed of sound measured in the waters of Lake Geneva by Colladon in 1826 during one of his best-known experiments. This figure appears in the dissertation on the compressibility of the main liquids that Colladon and his colleague Charles Sturm presented to the Academy of Sciences in Paris in 1827. The work was awarded the Grand Prix of the Academy. Several years before, the French physicist Pierre-Simon Laplace (1749-1827) had devised a formula to calculate the speed of light in a liquid according to its density and compressibility. For water, the theoretical speed was 1437 m/sec which was thus brilliantly confirmed in the field by Colladon.

In *Souvenirs et Mémoires* Colladon revealed how he developed his experimental protocol. His first attempts to measure sound in the waters of Lake Geneva were in 1825. To produce the sound he vigorously struck a partially submerged anvil with a hammer. At the same time he let off a rocket to alert a second person, who was responsible for timing the speed of the sound on the other side of the lake, that the sound had been made. During one of his first attempts, Colladon injured his right hand when a rocket caught fire.

Colladon improved his experimental design in 1826. The anvil was replaced by a submerged bell weighing 65 kg which was struck with a long, elbowed hammer from a boat. In a second boat, Colladon plunged his head in the water to listen for the sound of the bell and signal to a second observer armed with a chronometer when he heard it. Colladon was searching for a more practical method of listening to sound in water. For example, he tried a metal watering can. By placing his ear at the spout he noticed that he could hear the sound perfectly and that it was even amplified. He therefore designed a tin ear trumpet which was held vertically in the water by lead weights. He was very pleased with this device: "this instrument increases

the sensation of sound so strongly that a strike on a bell fourteen thousand metres away seems as intense as the same sound at two hundred metres heard by simply putting one's head into the water" he wrote.

Colladon carried out several series of tests on Lake Geneva between Rolle and Thonon, a distance of some 14 km. His father, stationed on a boat anchored near the shore at Rolle, hit the submerged bell. A flash of gunpowder, produced by a device linked to the hammer, alerted Colladon the younger in a second boat that the hammer had been struck. With his head pressed against the mouth of the ear trumpet, he set off his chronometer and stopped it when he heard the sound of the bell.

Fifteen years later Colladon carried out a new test on the transmission of sound through water in order to confirm his previous observations. He borrowed the new 500 kg bronze bell made for the church at Lancy and made a larger ear trumpet. He put all this on two boats one stationed at Montreux the other about 50 km away near Nyon (see map p. 7). The experiment was conclusive: the sound of the bell was perfectly reproduced in the ear trumpet. Colladon was sure that his large device would be able to detect a sound emitted at double the distance "at 100 km and perhaps more". He dreamed of a new telegraphic method for communications between England and France under the English Channel. Unfortunately, he learned that the English were already planning telegraph communication by cable under the Channel.



Map of Lake Geneva showing the sites of Colladon's experiments to demonstrate the speed of sound in water.

Colladon et Sturm, *Mémoire sur la compression des liquides*, Genève, 1841  
Library of the Musée d'histoire des sciences de Genève

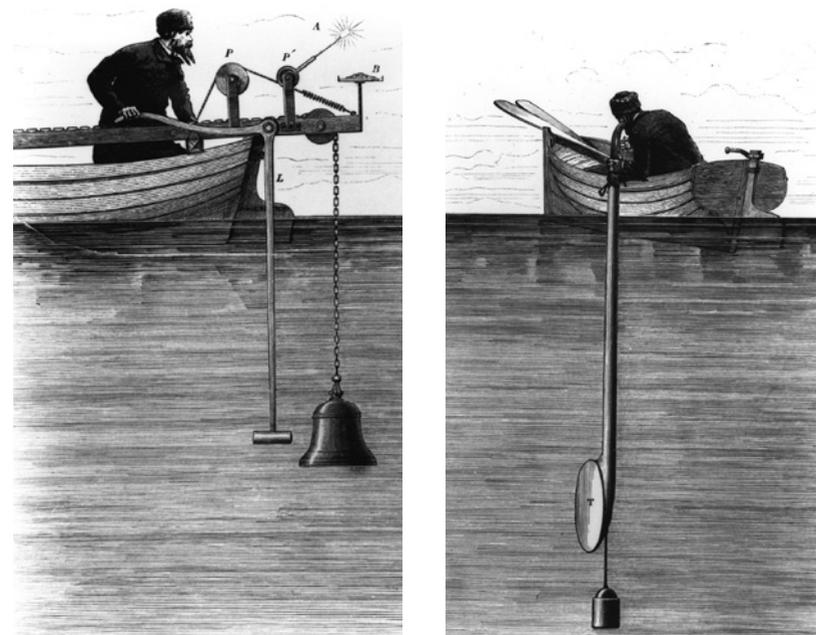
### Anticipating sonar

Sonar, developed during the First World War for use in ships and submarines, works by sending out sounds and detecting their echo in order to locate objects under water or to measure their depth. The sounds are emitted and captured by hydrophones which transform them into electrical signals. Colladon did not invent sonar but he is perhaps one of the first to envisage it. He wrote that, other than an underwater cable, his experiments could result in another application "... to use the echo from the bed of deep oceans to measure depths ...". From this perspective, Colladon's hearing cone could be viewed as the precursor of modern hydrophones.

### Compression of liquids

In 1825, the theme for the Paris Academy of Sciences' Grand Prix was the measurement of the compressibility of the most common liquids. Colladon decided to enter the competition and quickly wrote a preliminary paper on water, alcohol, mercury and ethyl ether. He went to Paris with his friend Sturm to study the mathematics. The two Genevois met the French physicist Arago who was also a member of the Grand Prix jury. Arago promised Colladon that he would delay the Grand Prix award for one year on the condition that he finish his paper and extend its scope to other liquids, as well as adding a section on the measurement of the speed of sound in water. Colladon could not refuse. He returned to Geneva to continue his experiments on the Lake while Sturm, who had become his partner, continued the tests on the compressibility of liquids.

The work was eventually delivered in three parts: a detailed description of the experimental design, measurements of the heat released by different liquids under heavy and rapid pressure and, finally, measurements of the speed of sound in water.



*Experimental design to measure the speed of sound in water*

*Figure 1: the emitting boat*

The submerged bell is held in place by a chain. The hammer which strikes the bell is fixed at the end of a lever  $L$  which pivots around a fixed axis and ends in a handle. A small rope attached to the handle runs through a return pulley  $P$  and is attached to another smaller pulley  $P1$ . When the handle is lowered to strike the bell, pulley  $P1$  is turned by the rope. At the end of the beam which extends beyond the bows of the boat, a horizontal board  $D$  is fixed on which the powder is poured. During the experiment, a firelighter ( $A$ ) is lit and attached to pulley  $P1$ . When the bell is struck, the firelighter is lowered onto the powder which ignites, thereby providing a light signal to the reception boat.

*Figure 2: the receiving boat*

The sound of the bell can be heard underwater through a long cylindrical tube made of tin, curved at its upper end and culminating in a small aperture to which the ear is applied. In the lower part, the tube is curved and flared. Its mouth  $T$  is closed by a tin sheet. The tube is maintained in its vertical position by a weight attached to its lower end.

Colladon, *Souvenirs et mémoires*, Genève, 1893  
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1824-1841

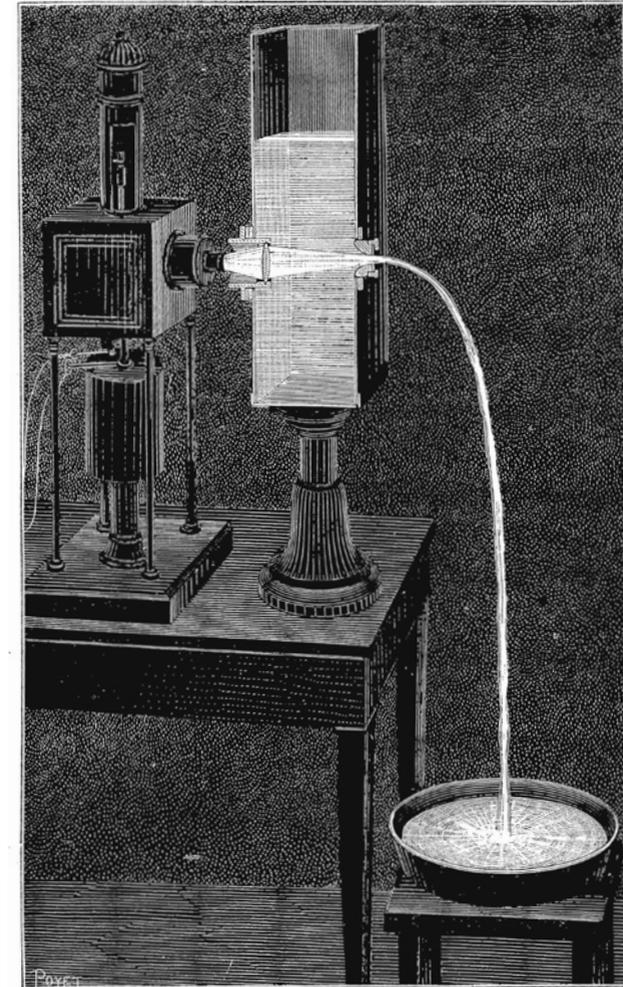
## Optics, light and fountains

**During his career, Colladon developed two instruments related to optics: a light meter and an illuminated water spout**

When he was just 22 years old, Colladon began his career as an inventor by making a light meter for a competition to develop an instrument to measure the intensity of light organised by the Science and Technology Society of Lille. Colladon won first prize. His light meter consisted of an optical tube connected to two other sliding tubes separated from the first by transparent papers. A candle is placed in one of the tubes and serves as the light reference; the second is focused on the object whose light intensity is to be measured. Unfortunately, we have lost all trace of this instrument.

Still in the field of optics, Colladon is the inventor of another famous device: illuminated water jets. In order to show the different shapes of jets of water from different apertures, around 1841 he built a large tank 7 m high with an opening to which spouts of different diameters could be attached. On the opposite side, he attached a convex lens to concentrate a light beam which lit the base of the jet of water. The light rays cross the lens and the water in the tank towards the opening from which the liquid escapes. The result is startling: "the light circulates in this transparent tube as if in a canal, and follows all the bends" wrote Colladon. With this apparatus, Colladon was able to show that the path of trapped light is not necessarily straight as was thought until then, but could also be curved.

The first experiments were carried out using sunlight. Later models of "Colladon's fountains", notably the one used by August de la Rive (1801-1873) in his physics lectures at the Geneva Academy, worked with an electric arc lamp. Colladon's invention interested artists too. Colladon advised the Paris Opera on the installation of luminous fountains for the ballet "Elias et Mysis" in 1853. Giant Colladon fountains lit by electricity were attractions at the Glasgow and Paris international exhibitions in 1888 and 1889.



Expérience de la fontaine Colladon.

### *The illuminated fountain*

*An arc lamp operated from a battery produces a very intense white light. The light beam is guided into the container through a convex lens fitted into its wall. Having crossed the lens and the liquid, the light rays converge on the opening where the liquid flows out. The light is trapped by the jet of liquid and follows it for the whole of its length. The light rays are exclusively reflected by the internal walls of the water jet. The physics principal of total internal reflection is at the basis of fibre optics.*

*La Nature, 1884*

*Library of the Musée d'histoire des sciences de Genève*

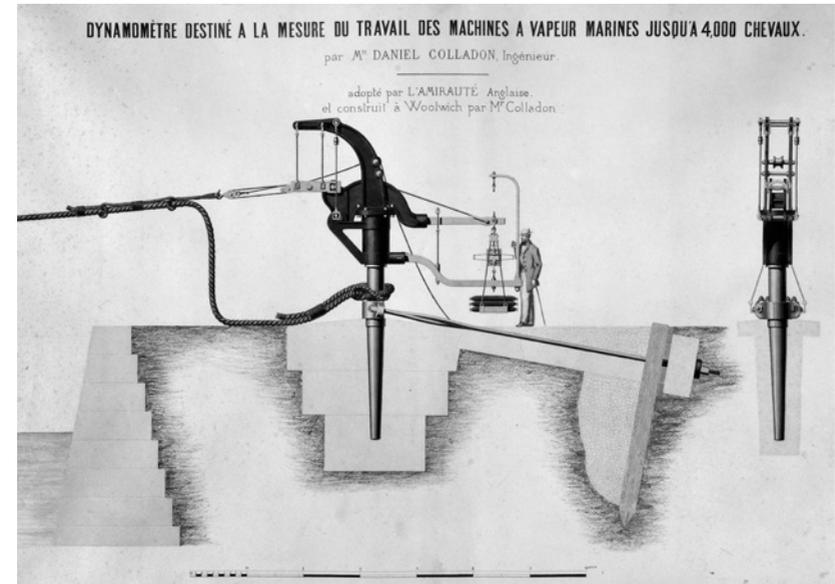
## 1827-1836 Steamboats

**During his years in Paris, Colladon became interested in steamboats. He designed an instrument to measure engine power while the boat was in dock.**

In Paris, Colladon's attention was drawn to a rapidly developing new type of transport: steamboats. From 1827, he began to study different types of mobile wheel paddles. He made a miniature boat 2 m long equipped with paddle wheels driven by an axial piston engine and a spring motor engine. He carried out many tests on a canal near Paris changing the number, shape and pitch of paddles. He developed a driving wheel equipped with mobile paddles arranged around a horizontal axis. These enter and leave the water by their blade edges and are only perpendicular in relation to forward movement when they are immersed. The boat therefore "moves faster and further" than if it were equipped with fixed paddles. Colladon was convinced that his invention would result in "a more agreeable and smoother ride in boats and more efficient use of power".

As Colladon had borrowed money for his experiments, he entered his invention for the Montyon award of the Paris Academy of Sciences in the hope of winning the first prize and paying off his debts. Unfortunately, he only received a very small consolation prize. He did have the satisfaction though of seeing his invention installed on several sea-going boats and boats on the Seine. Between 1830 and 1840, he was called to many boatyards in France and Switzerland to modify paddle wheels or improve the performance of steam engines. After 1831, he gave courses on steam engines at the new Central School which he had helped to create several years earlier.

In order to measure the efficiency and coal consumption of steamboat engines, Colladon developed a new device which could be used when the boats were moored at the quayside. Held at a fixed point by a horizontal cable, the engines were operated at cruising speed but with only a small area of the paddles under water. The tension on the cable was measured with a dynamometer. In 1842, Colladon patented the device in Paris and



*Dynamometer used to measure the power of nautical steam engines*

*The equipment is installed at the quayside. A vertical shaft is firmly fixed into the ground with concrete. A cylindrical barrel turns on the upper part of the shaft. The barrel supports a kind of large quadrant scale. The vertical arm bears the traction of the cable which is holding the boat. For balance, a counterweight and a dynamometer are used to measure the tension in the horizontal cable.*

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*The Aigle paddle steamer  
Between 1840 and 1841,  
Colladon carried out dynamo-  
metric experiments on two Lake  
Geneva steamboats, the Léman  
and the Aigle.*

*Library of the Musée d'histoire des  
sciences de Genève*

then offered it to the French government. In spite of a favourable reception from the French Academy, the minister of marine affairs procrastinated. Finally, Colladon contacted the British Admiralty who financed the installation of one of the devices at the Woolwich Arsenal in 1844.

1844-1862

## Town gas arrives in Geneva

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### The beginning of a new science: thermodynamics

While Colladon was carrying out practical tests of the performance of steam engines in boats, Sadi Carnot (1796-1832), a French engineer, published in 1824, almost unnoticed, a monograph which was to become a crucial text in the history of science and technology: *Réflexions sur la puissance motrice du feu et sur les machines propres à développer cette puissance*. In his text, Carnot laid out the theoretical base for a new scientific discipline which inspired builders of steam and heat engines: thermodynamics. He described how the ideal heat engine should operate. Had Colladon read Carnot's *Réflexions*? It is unlikely as the document was published without fanfare and it was only after about 1850 that the scientific community woke up to its importance.

### Colladon was one of the main actors in the installation and development of town gas in Geneva.

On the evening of 25 December 1844, the people of Geneva received a glittering Christmas present. Two hundred and seventy nine gas jets were ignited simultaneously along the main streets of the city. Following the example of other towns and capital cities in Europe, Geneva finally had an efficient, technologically advanced, public lighting system. This was the end of the lamplighters and the advent of a network of gas lamps giving constant and uniform light. The gas was produced by distilling coal in a type of retort called a *cornue*. It was then stored in gas holders.

In addition to his work as Professor of Mechanics at the Academy, Colladon played an important role in the provision of town gas in Geneva. One of his former pupils from Paris who had become an expert in gas, was responsible for the construction of the new works at the Coulouvrenière which included 8 furnaces of 4 retorts each, 2 gas holders of 1500 m<sup>3</sup> each, a coal storage shed and a lime scrubber. From 1844 to 1862, Colladon was the consulting engineer for the new *Société genevoise pour l'éclairage au gaz*, a private company managing public lighting in the city of Geneva. He was Chair of the Board of the company until 1893. After 1846, he was involved in the expansion of the gasworks which was already unable to meet demand. He constructed 24 new retorts and improved gas production especially the purification systems. Thanks to Colladon, the *Société genevoise pour l'éclairage au gaz* was the first in Europe to use fire-clay retorts (in place of iron) which were less vulnerable to distortions which damaged the furnaces. He equipped several high points in the town with jet regulators in order to better control the height of the flame in the lamps. Finally, he participated in the construction of a 2000 m<sup>3</sup> gas holder. A host of activities which Colladon looked back upon with satisfaction. "... Our services have constantly improved and we are able to light the streets of Geneva at cost price or even below, to sell gas to private individuals at nearly the same price as that of Paris, Lyon or Marseille, etc., and to make a larger profit

than any made by French gas. Geneva gas is famous for its purity and for its lighting capacity -...." he wrote in *Souvenirs*. He did, however, forget to mention that gas in Geneva was one-third more expensive than in France!

Colladon's company, renamed *Compagnie d'éclairage et de chauffage par le gaz*, built works in several towns in Switzerland (Bienne, Aigle, Morges, Nyon, Vevey) as well as in Naples, Italy.

To further underline Colladon's intense involvement with the gas industry, the family of his wife, Stéphanie-Andrienne Ador, held large numbers of shares in many European gas companies.

*Gas lamp on the lakeside in Geneva, about 1860*



*Centre d'iconographie genevoise, Bibliothèque de Genève*

### **Production of town gas**

Production of town gas for street lighting and for heating is a complex process and involves a number of different technologies. The coal is heated in a fire-clay or iron retort. After preliminary purification of the gases given off they are gathered into a condenser composed of a series of vertical tubes where tar and ammoniac salts are removed. The gas then crosses a large cylinder filled with coke where solid particles are removed. It goes through final chemical purification through lime (later replaced by iron oxide or calcium chloride) to remove certain toxic components such as carbonic acid, hydrogen sulphide or ammonium sulphide. Finally, the purified gas is stored in a gas holder, a large basin of water with a cover suspended over it.

From the end of the 19th century, town gas was gradually replaced by natural gas (essentially methane) which has a higher calorific value and is less dangerous to health. Town gas contains carbon monoxide which caused many deaths through asphyxiation.



*Gas lamps on the Quai de Mont-Blanc around 1860  
Centre d'iconographie genevoise, Bibliothèque de Genève*

### Key dates for town gas in Geneva

- 1843: Bern, first Swiss town to have gas light
- 1844: Inauguration of Coulouvrenière gasworks on 25 December 1844
- 1845: 302 public gas jets, 408 private ones
- 1858: Gas network extended to Carouge, Eaux-Vives and Plainpalais
- 1859: Lyon-Geneva railway opened; coal brought from St-Etienne coal basin
- 1870: Miners' strike in France. Coal from the Saarland, Germany
- 1878: First electric lighting, Universal Exhibition, Paris
- 1896: Gas networks taken into municipal control
- 1909: Most of the large outlying communes connected to gas
- 1909: Explosion at the Coulouvrenière gasworks: 13 dead, 12 wounded
- 1914: Inauguration of new gasworks at Châtelaine
- 1915: Coulouvrenière plant closed
- 1964: Start up of a cracked gas plant (from high gravity petrol) to meet increasing demand
- 1965: Gas production in Geneva: 65% from coal distillation and 35% from cracked gas
- 1966: Coal distillation abandoned in favour of cracked gas
- 1973: World oil crisis
- 1974: Natural gas arrives in Geneva
- 1975: Beginning of conversion to natural gas
- 1977: End of the conversion work

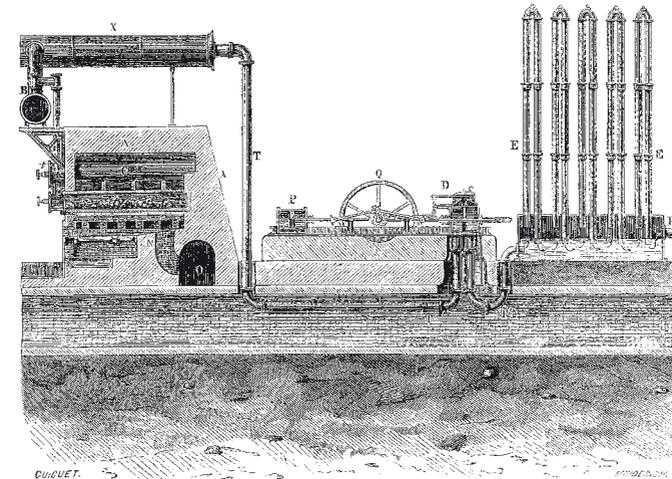


Fig. 78. — Vue générale des appareils pour la préparation du gaz.

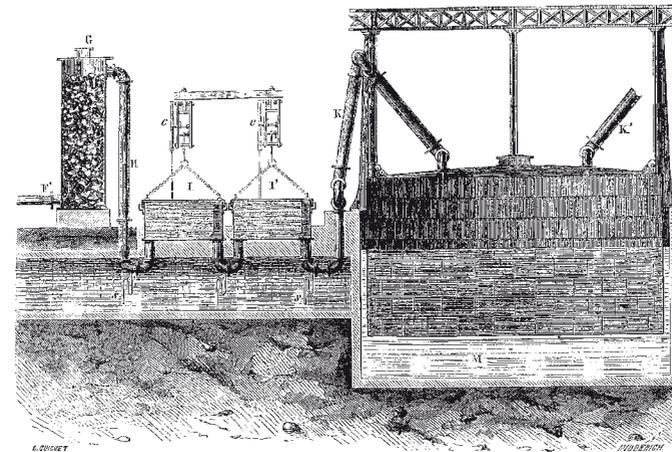


Fig. 79. — Vue générale des appareils pour la préparation du gaz (suite).

### Operation of a town gasworks

A and C: furnace and coal distillation retorts

PQD: steam engine driving the pump which sends distilled gas into the condenser

E: condenser; G: coke column; I: scrubbers; L: gas holder

Figuier, *les merveilles de la science*, Paris 1870

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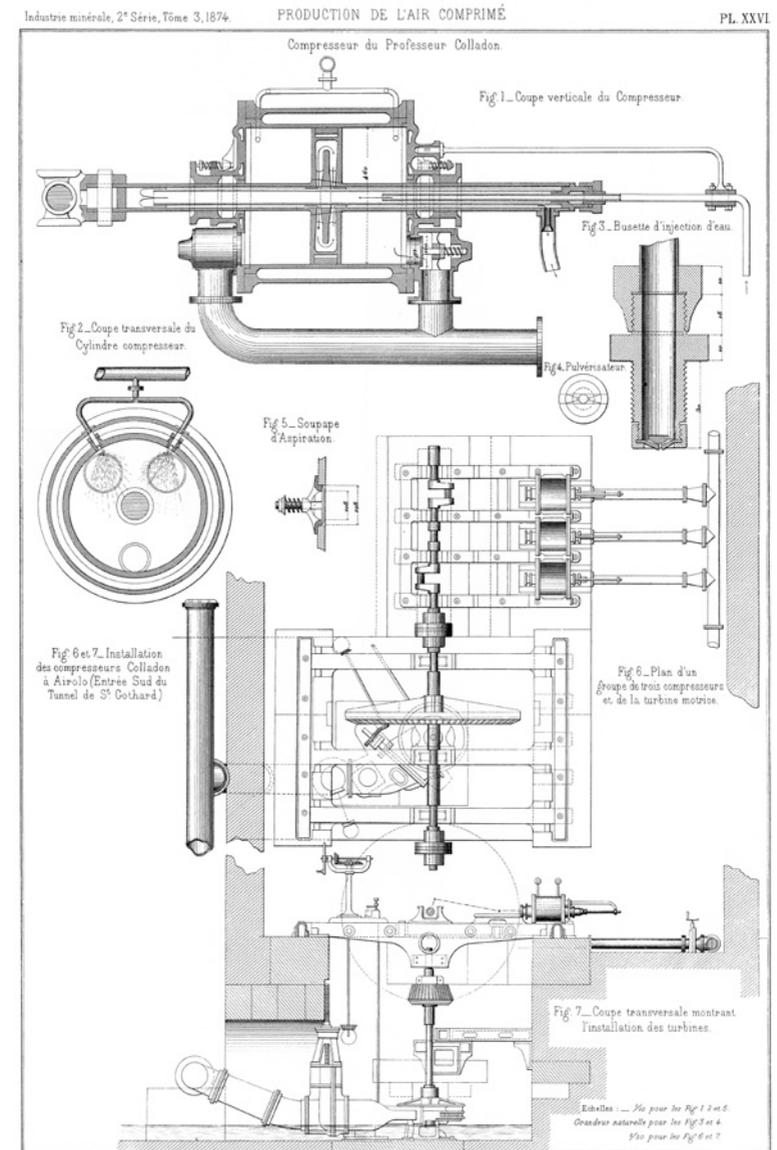
## Compressed air for excavating tunnels

### Colladon designed a new method of distributing energy by compressed air which was used for excavating the Gotthard tunnel

After he was appointed engineer at the new *Société genevoise pour l'éclairage au gaz*, Colladon embarked on several experiments on the distribution of gas over a distance. He observed that the loss of pressure was less than expected. He replaced the gas with air in order to test a new distribution method using compressed air. As luck would have it, Colladon learned that the government was planning to build a rail tunnel at Mont-Cenis to link Piedmont to the Savoy and that the technical method (the wire rope transmission) proposed was not up to date. He thought that if compressed air were used it could both drive the borers and ventilate the tunnel.

Colladon spent a year as Commissioner for the Federal government at the London Universal Exhibition in 1851 but then returned to his experiments with compressed air. Using a compression pump, he managed to start a traction engine parked 500 m away and connected to the compressed air reservoir through metal pipes. Colladon deposited a paper and a patent request with the Sardinian government for "a new method to facilitate the excavation of tunnels using compressed air". The patent is accompanied by a description which includes a number of technical details. The compressed air, delivered through pumps cooled by injected water and driven by turbines, supplies the drill pieces "similar to a steam hammer but where the hammer is replaced by a blade and rotates".

In spite of a favourable response from the Academy of Sciences in Turin, the Sardinian government took a long time to consider the patent request. Even worse, three Savoyard engineers, including Germain Sommeiller (1815-1871) who was to become one of the key players in the excavation of the Mont-Cenis tunnel, took out a patent for another compressed air tunnelling system using compressor hammers. In 1857, Sommeiller and his team replaced the hammers with hydraulic pumps of the same type as those described in Colladon's submission.



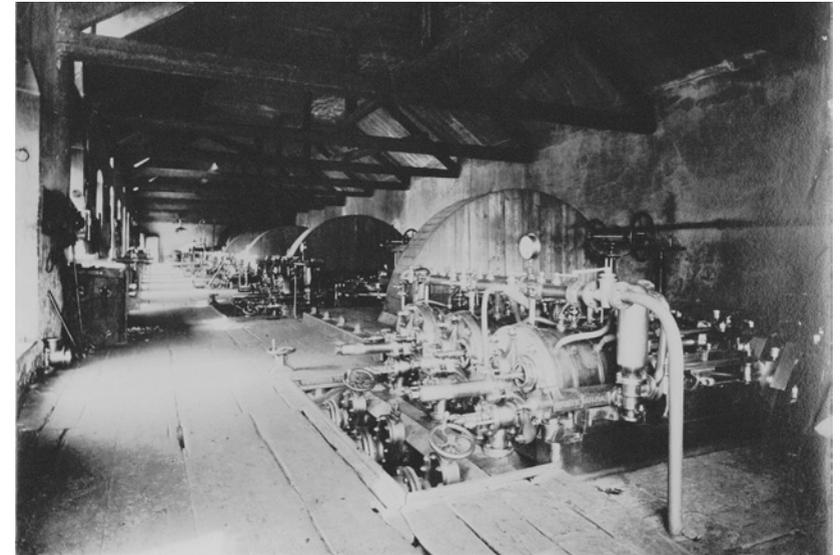
Method of producing compressed air for the Saint-Gothard tunnel

Industrie minière 1874, Colladon Archives  
Bibliothèque de Genève

Colladon made up for his defeat on the Mont-Cenis project a few years later when he was one of the major actors in the excavation of the Gothard tunnel. He was the consulting engineer in charge of boring for the company established by Louis Favre (1826-1879). His patented air compression system was used during the whole excavation between 1872 and 1881. On either side of the tunnel entrance, four turbines powered groups of pumps supplying compressed air which was stored in metal cylinders acting as reservoirs. From there, the air was sent into the tubes to the excavation face where it both drove the blades and renewed the air. The pistons and their stems were cooled in the inside of the cylinder by water sprays in order to avoid over-heating of the pumps.

In 1885, Colladon was awarded the Fournayron Prize by the Academy of Sciences in Paris for his compressed air production method. The citation also recognised his contribution to the Mont-Cenis construction: "Mr Colladon is the first to have proposed, in 1852, the use of compressed air instead of cables to convey power into the tunnels, and it was his ideas which lay behind the Modane and Bardonnèche compressors ....".

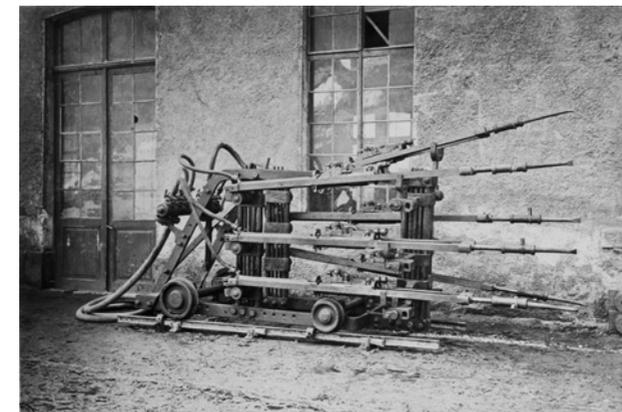
Colladon was involved in another tunnel project: an undersea rail tunnel between France and England. From 1874, he had been a member of a French committee (composed mainly of the Northern Railways Company and the Rothschild family) responsible for the preliminary work. His compressors equipped the preparatory excavations. Two galleries each nearly 2 km in length were excavated on the English and French sides when the British government suddenly decided to cancel the project in 1882.



*Air compression hall during the Gothard excavation, around 1880*

*A group of three parallel compressors driven by a 3-crank drive shaft. The drive shaft is driven by a turbine. The compressed air supplies the drilling machine and ventilates the galleries under construction.*

*Library of the Musée d'histoire des sciences de Genève*



*Compressed air drilling machine*

*The machine used during the excavation of the Gothard, driven by Colladon compressors.*

*Library of the Musée d'histoire des sciences de Genève*

## Hydraulic machines and floating wheels

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### Health in the tunnels

During construction of the first Gotthard railway tunnel between 1872 and 1882, 200 workers died and there were many injuries. Most of the workers were Italians. The main cause of death was inexperienced use of dynamite (nitroglycerine) which caused rock slides and the collapse of built structures. The deplorable hygiene at the worksite meant that illness was an indirect cause of death. Gases and dust in the polluted air gave rise to silicosis, a lung illness, while intense heat and high humidity in the tunnels caused many fatal cases of anaemia related to infestation by a tropical parasite.

Colladon felt that health could be improved by greater use of compressed air. In a paper which was published at the end of the construction, he suggested spraying with pressurised cold water to cool the air, clear the dust and clean the tunnel walls. Why was this not done at the Gotthard? Because, according to Colladon, of the lack of hydraulic power available to drive the turbines in winter (and therefore the compressors) on the south side of the tunnel. Experience had taught Colladon that "money is the key to most projects but for the underground battle between the genius of Man and the obstacles thrown up by the hardness of rock, the earth's heat or excessive infiltration, it is not money but the production of power which is the vital condition for rapid and economical excavation, and for hygienic conditions in very long, closed, tunnels".

### Colladon invents a floating water wheel to drive pumps

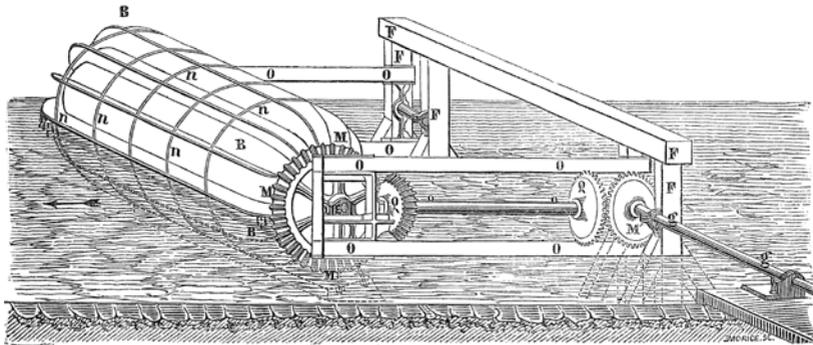
In the 19th century, paddle wheels of boats were not very different from waterwheels of mills or factories along rivers or streams. Colladon was already an expert in steamboats so it was natural for him to turn to "hydraulic motors" the term used at the time to describe wheels which supplied energy using the power of water. He carried out experiments to determine the true power of mill wheels and of water pumping stations. In 1835, he designed a new hydraulic machine (a water wheel coupled to pumps) to supply drinking water to the town of Challons-sur-Saône in France. In Geneva, he promoted a project to install a new hydraulic machine downstream of the Ile near Place Bel-Air, to replace the aged Abeille machine which had supplied the town with drinking water until then. The project, which was to have been entrusted to a private company, was not carried out. The town authorities chose to build a more powerful machine upstream from the Ile on the site of the present Pont de la Machine.

Colladon is himself the inventor of an intriguing hydraulic machine: a floating wheel. This was a hollow metal floating cylinder with blades, attached to a pontoon. It was equipped with several gear wheels to distribute power (using drive shafts) to a machine or to pumps installed on the river bank. The machine rose and fell with the water levels because it floated and was thus always operational. Its installation was also less costly than suspended wheels, the most often used on large rivers which required strong scaffolding and complex hoisting systems to lower or raise them. Finally, floating wheels could be positioned perpendicularly or parallel to the current according to the width and depth of the stream.

In 1865, a floating Colladon wheel was installed on the Rhone at Onex, a little way upstream from the watermill at Evaux. It was built by a private investor to provide energy for the new hydraulic machine which supplied the villages of Onex, Lancy, Bernex and Confignon with water. The wheel was 7 m long and 3 m wide. It was equipped with narrow paddles set in a herringbone pattern. The wheel was fixed to the end of two movable

## Hail, lightening and waterspouts

arms anchored to the centre of a frame of metal beams. A winch on the metal structure could raise the wheel. Three pairs of cylindrical gears and crankshafts distributed the energy produced by the rotating wheel to a group of pumps housed in a brick building. The pumps did not return the water to the Rhone but into a nearby stream and was filtered before being channelled 70 m higher to a reservoir on the Plateau des Bossons. Inaugurated in 1866, Colladon's wheel only operated for a short time. It was dismantled in 1887 following the start-up of the Bâtiment des Forces Motrices at the Coulouvrenière which henceforth supplied drinking water for practically the whole canton.



Plan of floating paddle wheel

*B* is the floating wheel made of a hollow wooden or cast-iron cylinder on which flat paddles are fixed

*F*: structure on piles

*O*: securing rods designed to anchor the floating wheel without preventing its movement according to changes in water level

*M, Q, M', Q'*: toothed conical wheels transmitted the power to a factory.

Colladon, *Nouveaux moteurs à eau*, Paris, 1857

Library of the Musée d'histoire des sciences de Genève

### In addition to his engineering projects, Colladon was intrigued by weather phenomena

Having studied and observed hailstorms for a long time, Colladon put forward a new theory on their formation. "... Rainfall during thunder storms and columns of hail produce a vertical wind by virtue of their own fall which channels cloud to the ground and therefore creates a deep depression which must be present in the cloud itself at the points where the rain or hail is generated, and produces at these points a continuous aspiration or suction of air during the length of the storm ....". The aspiration brings a constant flow of highly charged dry, cold air from the highest levels which contains supercooled ice needles or drops. The influx of air from areas surrounding the cloud maintains the electrical charge in the cloud which explains why storms of hail or rain last for some time, often for several hours.

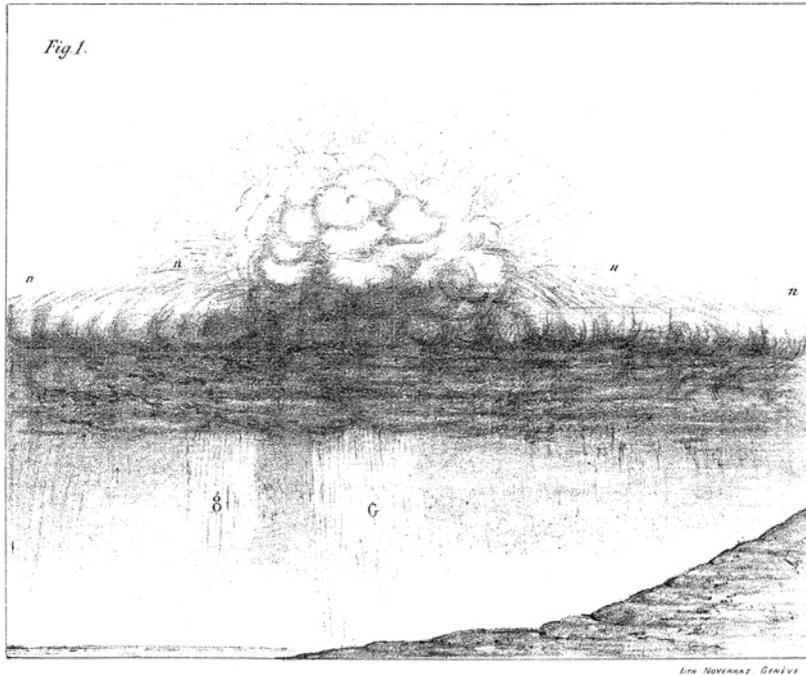
#### The formation of hail, a complex process

Unfortunately for Colladon, his theory on how hail is produced was proved wrong. Hailstones are indeed formed within very humid storm clouds (cumulonimbus) with strong upward drafts. At a certain height, the water drops within the drafts begin to freeze resulting in hailstones. These grow in size by attracting water which freezes on their surface. The hailstones continue to mount within the cloud (up to several kilometres high) until they become too heavy. They then begin to fall although still growing in size as water droplets attach to them on their way down.

GRÊLE DU 5 JUIN 1877.

Archives des Sciences phys et nat. 1879 t. II

Pl. I.



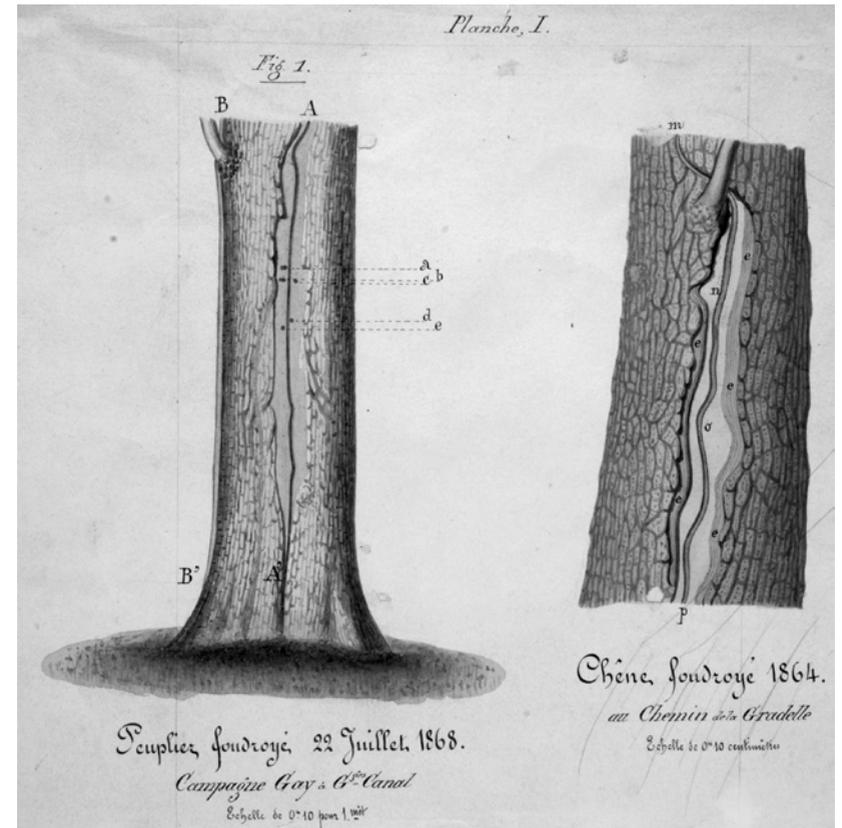
Apparence des nuages à Grêle et des nimbus supérieurs, vus de Genève pendant que l'orage traversait le lac entre Yvoire et Morges.

A hailstorm in Geneva

Two columns of hail G and g are seen under the nimbus which is overhung by cumulus. At the summit of the nimbus, strong nearly horizontal air currents can be seen. They are approaching and converging on the cumulus from where the columns of hail are released. Steeply angled shreds of cloud n, n, n indicate the presence of strong air currents.

Colladon, Contributions à l'étude de la grêle, Genève, 1879  
Library of the Musée d'histoire des sciences de Genève

Colladon was also interested in lightning particularly its effect on trees. He concluded that poplars attract more lightning than acacias, elm or oak which made them excellent lightning conductors. On the other hand, while poplars are excellent conductors in their higher parts that is not the case in their lower sections. He therefore recommended that people who had poplar trees close to their houses attach a metal strip to them with its end buried in damp earth to avoid lightning jumping to the building.



Trees struck by lightning

Observation of the effect of lightning: fissures, scars and circular marks

Colladon, Mémoire sur les effets de la foudre, Genève, 1872  
Library of the Musée d'histoire des sciences de Genève

## Important events in Colladon's career

During the last years of his long career Colladon still found time to write a paper on the formation of waterspouts. He noted the presence of rotating updrafts which contributed to their formation. In order to prove his theory, Colladon produced an apparatus – a rotating agitator in a container of water mixed with sawdust – which reproduced experimentally the formation of waterspouts. The elderly scholar felt that this apparatus deserved to be present in all good technological or physics laboratories. It was commercialised for several years by the *Société genevoise d'instruments de physique* (SIP).

*Appareil de petite dimension pour des démonstrations de cours.*

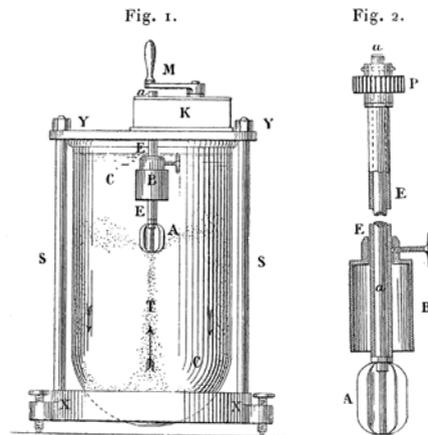


Fig. 1. — Vue générale de l'appareil.

- A, agitateur à palettes et à mouvement rotatif.
- aa, son axe de rotation.
- B, capuchon glissant le long de aa et pouvant recouvrir partiellement l'agitateur A.
- CG, cloche en verre pouvant avoir 0<sup>m</sup>,25 à 0<sup>m</sup>,30 de diamètre, sur 0<sup>m</sup>,45 à 0<sup>m</sup>,50 environ de hauteur.
- X, Y, plateaux en bois servant de supports.
- S, S, tiges en fer qui relient ces deux plateaux.
- K, caisse en tôle contenant une roue dentée et un pignon P quatre fois plus petit en diamètre.
- EE, tube servant à maintenir l'axe a du pignon P et de l'agitateur.

Fig. 2. — Les pièces de l'agitateur.

*Instrument for producing a waterspout*

*Design of the apparatus to simulate the formation of waterspouts*

*Colladon, Sur les tourbillons ascendants dans l'air et dans les liquides, Paris, 1887*

*Library of the Musée d'histoire des sciences de Genève*

- 1802: Born in Geneva.
- 1822-1824: Studies law at the Geneva Academy and qualifies as a lawyer. Also follows Pictet's courses in experimental physics. Wins first prize from the Lille Société des sciences et des arts for a photometer he invents.
- 1826: At the Collège de France in Paris experiments with a new galvanometer designed to measure current produced by electrostatic friction machines.  
Measures the speed of sound in water.
- 1827: Grand Prix of the Paris Academy of Sciences for dissertation on the compression of liquids and measurement of the speed of sound in water.
- 1828: Experiments on fixed and mobile blades on paddle wheels.
- 1835: Construction of a steamship on the River Saône.
- 1841: Second series of experiments on measurement of the speed of sound in water, Lake Geneva.
- 1841: Works on the reflection of light in water jets.
- 1844: Develops a dynamometer to measure the effective power of steam engines for boats.
- 1850-1854: Colladon appointed Commissioner of the Swiss booth at the Great Exhibition, London.
- 1852: New system of tunnelling using compressed air.
- 1856: Description of floating waterwheel.
- 1871: Paper on the effect of lightning on trees.
- 1872-1876: Final design of air compressors for Gotthard tunnel.
- 1885: Awarded Fourneyron prize of the Paris Academy of Sciences for work on compressed air in tunnel construction.
- 1886: Works on the origins of electric currents in storm clouds and the formation of hailstones.
- 1887: Notes on vortices and waterspouts.
- 1893: Death of Colladon.

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