

1 **An approach to the Venturi effect by historical instruments**

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5

6 **Abstract**

7 Student understanding of the laws that describe the flow of a fluid is often hampered by a defective
8 knowledge of basic classical mechanics (kinematics, statics, dynamics, and conservation laws) and
9 by wrong common-sense ideas about quantities related to fluids, such as velocity and pressure. A
10 pedagogical discussion about the Venturi effect, based on experiments inspired by historical
11 instruments, may be an effective way to introduce students to these laws. In this paper, we discuss
12 an approach to the understanding of the Venturi effect based on the study of historical
13 instruments and on simple experiments. In particular, after a presentation of the Venturi effect,
14 also from a historical point of view, we illustrate some interesting applications, the Venturi meter,
15 the Bunsen burner, the Venturi vacuum pump, and propose some simple experiments.

16

17 **Keywords:** Physics education, **Hydrodynamics**, Venturi effect, Bunsen burner, Venturi
18 vacuum pump

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28 **1. Introduction**

29 History of Science and Scientific Museums have a central role in enhancing the understanding of
30 scientific concepts and physical phenomena, which can be bolstered using pedagogical paths, from
31 an historical approach and including the study of working principles and the nature of scientific
32 instruments [1-4]. Research shows that, among the Physics subjects taught in schools, the laws
33 that describe the fluid flow seem to be hard to be authentically understood by students [5-7].
34 Indeed, this requires a good knowledge of basic classical mechanics and some close understanding
35 of specific concepts related to fluids, such as velocity lines (streamlines) and pressure [8].
36 Moreover, many common-sense ideas about the above-mentioned concepts (i.e. pressure vs.
37 velocity and static vs. dynamic pressure) have been identified as negatively influencing an
38 authentic understanding of the laws that describe the fluid flow [7-9]. The decrease of fluid
39 pressure where its speed increases (e.g. in the constriction of a pipe) often surprises students.
40 This may be due to their difficulty in distinguishing between pressure within the moving fluid
41 (static pressure) and the pressure of the fluid on something that interferes with its flow (dynamic
42 pressure). In our experience, many undergraduate science-degree students, and also some
43 teachers at secondary-level school, are unaware of this distinction. A pedagogical approach to
44 the laws that describe the flow of a fluid based on a discussion of the Venturi effect may be an
45 effective way to introduce students to these laws. The idea that static pressure must be
46 distinguished from dynamic pressure can arise in students' minds through experiments. The
47 educational research shows evidences of this [6,8], highlighting that the students' common-
48 sense idea that the greater the fluid velocity the greater its **static** pressure can be due to an
49 incorrect interpretation of real-life experience, as in the case of the experiment of covering a
50 hose's outlet mouth to increase the fluid velocity when exiting the hose mouth: the smaller the
51 outlet mouth the greater the force exerted by the water on the finger [5]. Since students easily
52 associate this force with the pressure of the fluid inside the hose, they conclude that the higher
53 the velocity the greater the **static** pressure of the fluid in motion must be. Moreover, the fact
54 that, according to common sense, force is easily linked to velocity rather than to acceleration
55 [9] only reinforces the uncorrected students' interpretation of the relationship between pressure
56 and velocity in a fluid. Other authors suggest that this idea may also be related to the perception
57 of liquids as compressible substances [7], so that when the water flows from a wide pipe to a
58 narrower one it is seen as compressed and thus its **static** pressure should increase.

59 In this paper, we will discuss an approach to the understanding of the Venturi effect based
60 on the study of historical instruments and on the realization of simple experiments that may help

61 to redirect student common-sense ideas about pressure and velocity in a fluid towards conceptions
62 more coherent with scientific knowledge. After a description of the Venturi effect, some simple
63 experiments will be described that illustrate very well the principles of operation of the Venturi
64 meter, the Bunsen burner, and the Venturi vacuum pump. Finally, we will show a Bunsen burner
65 and a Venturi vacuum pump of the Historical Collection of Physics Instruments at the Palermo
66 University [10].

67

68 **2. Theoretical framework**

69 It is well acknowledged that experimentation in the laboratory substantiates and contextualizes
70 scientific knowledge and understanding. The laboratory is a perfect environment to bolster
71 student authentic learning [11-16], as it allows students to think about the phenomena they want
72 to study and to discuss them in specific contexts. Furthermore, it allows students to solve real
73 problems, to isolate and study the quantities that can be considered relevant for the description
74 and/or explanation of the phenomenon, and to build models representing the relationships
75 among the quantities experimentally observed. In this way, students can develop skills and
76 attitudes, not only knowledge that is just an intermediate step in the learning process [17]. On
77 the other hand, an understanding of the social, political, and scientific contexts, in which the
78 laboratory experiments were thought and developed, may help students to see Science as a human
79 endeavour, focused on the construction of logical, rational and objective conjectures, in continuous
80 evolution and fully part of the Culture [18-20], rather than as a mere collection of rules and
81 algorithms to be memorized in order “to solve problems”. In this view, it may be valuable and
82 interesting for students to deepen the relationship between the laboratory instruments as
83 artifacts [21] and the natural phenomena they were designed to study, by referring to historical
84 scientific instruments kept in University scientific collections and museums [1-4]. Their use may
85 help students to understand the physical laws that they are based on, since their operating principles
86 are often easy to study [22,23]. Moreover, it has been shown that an exploration that starts from
87 the replica of historically and conceptually significant experiments, even presented in their original
88 historical context and thoroughly discussed in their technical and conceptual aspect, can help
89 students to enrich their understanding, grasping many relevant aspects of the nature of the scientific
90 topics studied [24].

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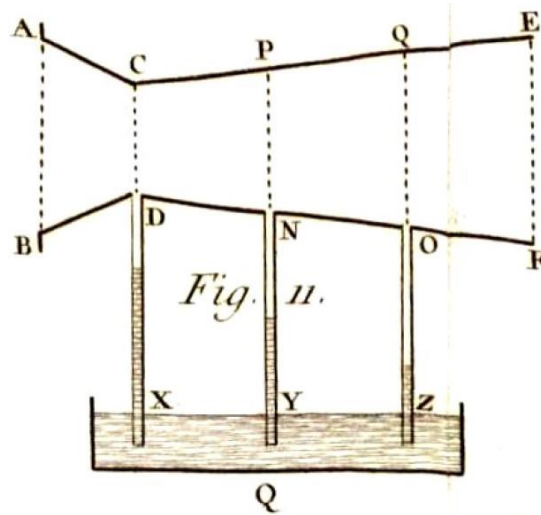
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94 **3. The Venturi effect**

95 In 1797, the Italian **hydraulic engineer** Giovanni Battista Venturi (1746-1822) reported that a
96 fluid, flowing through a constriction in a pipe, drags a second fluid along with it from a
97 secondary pipe. Figure 1 shows the **static** pressure at various points in a **horizontal** pipe of
98 changing size [25]. Because of the principle of continuity, **which expresses the conservation of**
99 **mass in a given space occupied by a fluid**, in the constriction, fluid speeds up. The result is that
100 its **static** pressure is the lowest where the fluid speed and the pipe constriction are the greatest.
101 In Fig.1, the height of the liquid in the vertical straws is related to the **static** fluid pressure at
102 various points along the pipe. The liquid in the straws is pushed up by the atmospheric pressure,
103 p_a , acting on the liquid in the bath Q and it is pushed down by the pressure, p , within the pipe,
104 thus: $p_a = \rho g z + p$, where ρ is the density of the liquid inside the straws, z **the height of the**
105 **liquid in the vertical straws**, and g the gravitational acceleration. The pressure inside the straw,
106 above the liquid, is less than the outside atmospheric pressure, which therefore pushes up the
107 liquid at the bottom of the straws. Thus, where the height of the liquid in the straws is maximum
108 the **static** pressure in the horizontal pipe is minimum, indicating that **static** pressure is least at
109 the narrowest point of the pipe. **An insight into the historical development of hydrodynamics is**
110 **given by Ref. [26]**

111



112

113 **Figure 1.** Pressure at various points in a pipe of changing size, from Venturi's original paper [24].

114

115 The Venturi effect can be explained by the Bernoulli principle, named after that Daniel
116 Bernoulli (1700-1782) published, in 1738, his book *Hydrodynamica* [27]. For a smooth steady
117 flow (laminar flow) of an incompressible ideal fluid, the Bernoulli's equation is

$$\frac{1}{2}\rho v^2 + \rho gh + p = \text{constant} \quad (1)$$

118

119 where ρ is the density of the fluid, v its speed, h its elevation, and p its internal **static** pressure.

120 It is worth noting that changes in velocity and pressure should be considered along the same

121 streamline, whereas the elevation h should be considered with respect to the fixed level.

122 Bernoulli's equation is the result of applying the conservation of energy to a flowing ideal fluid,

123 in the absence of friction. From Eq.(1), at constant h , the Venturi effect derives

$$\frac{1}{2}\rho v^2 + p = \text{constant} \quad (2)$$

124

125 an increase in v causes a decrease in p , and vice versa. In most cases, the elevation h in Eq.(1)

126 remains constant along the constriction in a pipe, or its variation can be neglected with respect

127 to the other addends. It is worth noting that pressure and velocity are described by Bernoulli's

128 equation independently of the direction of flow. In the constriction, for the continuity equation,

129 the speed of the fluid is greater than the speed of the fluid in **the rest of** the pipe and therefore

130 the **static** pressure in the constriction is smaller than elsewhere along the pipe. **Changes of the**

131 **static pressure** can be illustrated by a flow of water that contains gas bubbles. The bubble size

132 depends on the surrounding water **static** pressure. When water speeds up, pressure decreases

133 and the bubble size gets bigger. Conversely, when water slows down pressure is higher than

134 before and, consequently, air bubbles get smaller [28].

135

136 **4. Experimental demonstration of the Venturi effect and its applications**

137 Simple experiments on the Venturi effect can be carried out in the classroom to introduce

138 students to the topic and to deal with the physical laws necessary to explain what they observe.

139 These laws describe the working principles of instruments that students can easily find in real-

140 life contexts. Simple models of these instruments, such as the Venturi meter, can also be easily

141 built by students, actively engaging them in the discussion of their operating principle.

142 An experiment consists in blowing into a long tubular plastic bag (e.g. about one meter

143 long and 20 cm wide) with the mouth attached to the bag's opening. A volume of about 4 litres

144 of air (corresponding approximately to the amount contained in human lungs) will inflate the

145 bag. Conversely, if one blows with the mouth about 10 cm away from the bag's opening,

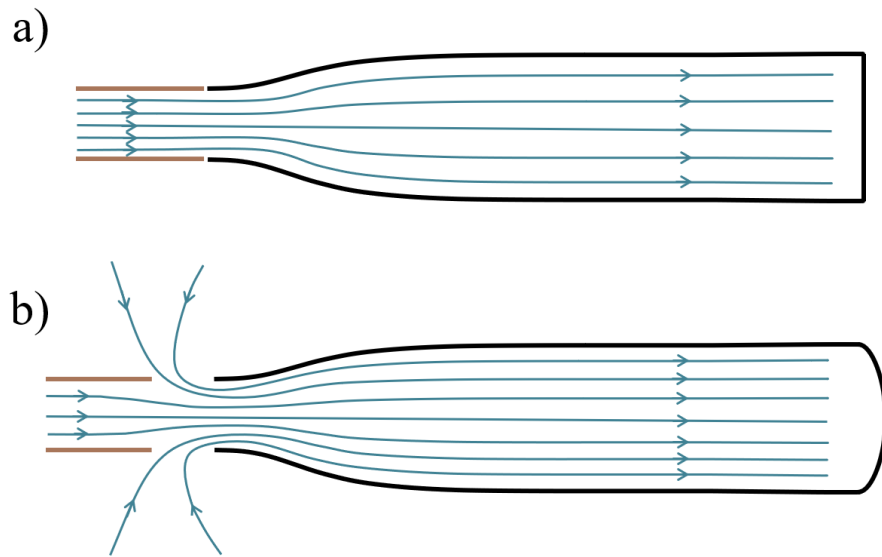
146 surprisingly much more air will go inside the bag inflating it immediately. This is so because

147 the high velocity of the air flow in the region in front of the bag's opening determines a **static-**

148 **pressure** decrease that makes air from the surroundings to go into the bag, inflating it more and

149 more quickly. For a better understanding of the airflow, in Fig.2 we show the qualitative

150 distribution of streamlines of the airflow around the mouth and the bag's opening. This effect
 151 can help the teacher to explain the operation of the so-called bladeless air multiplier fan [29].
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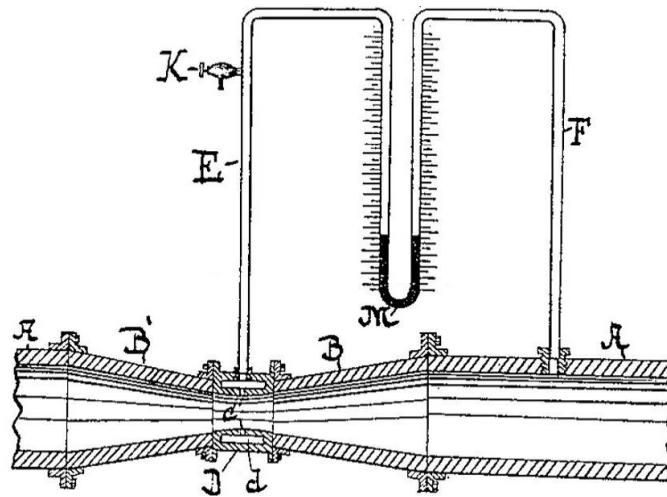


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 154 **Figure 2.** Qualitative distribution of streamlines of the airflow around the mouth and the bag's opening:
 155 a) mouth close to the bag's opening; b) mouth about 10 cm away from the bag's opening.
 156

157 The reduction of **static pressure** in fluids due to the Venturi effect is at the basis of the
 158 principle of operation of many instruments and devices widely used in real-life contexts; the
 159 most important is the Venturi meter, an apparatus for measuring the quantity of liquid flowing
 160 through a pipe, patented in 1888 by the American hydraulic engineer Clemens Herschel (1842-
 161 1930). Figure 3 shows Herschel's drawing of the Venturi meter used with a mercury pressure
 162 gauge [30], which measures the differential pressure $\Delta p = p_1 - p_2$, where p_1 and p_2 are the **static**
 163 pressures in the pipe and in the constriction, respectively. From Δp , by using Bernoulli's Eq.(1)
 164 and the continuity equation, one obtains the flow speed v_1 in the pipe

$$v_1 = \sqrt{\frac{2\Delta p}{\rho[(S_1/S_2)^2 - 1]}} \quad (3)$$

165
 166 where S_1 and S_2 are the cross-sectional areas of the pipe and of the constriction, respectively. It
 167 is worth noting that actually the Venturi meter works well at low fluid-flow velocity when the
 168 energy dissipation, due to the viscosity (internal friction) of real fluids, is negligible.



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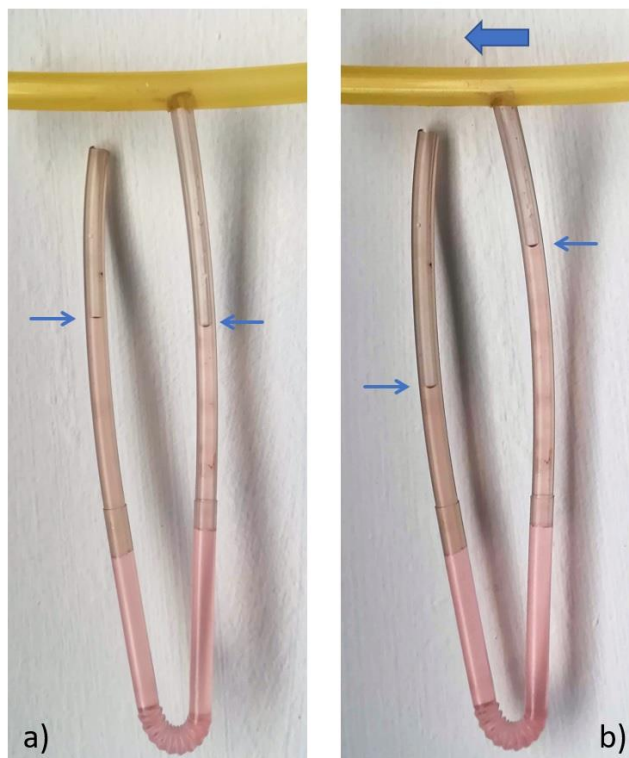
171 **Figure 3.** Herschel's drawing of the Venturi meter used with a mercury pressure gauge [30]. The figure
 172 shows the Venturi meter when no fluid flow is present in the pipe. The horizontal lines in the drawing
 173 inside the pipe are not streamlines; they are simply technical lines to represent a cylindrical section.
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174

175 For educational purposes, students may build a simple Venturi meter by using a
 176 U-shaped pipe, filled with coloured water, connected to a horizontal tube, as shown in Fig.4, in
 177 which an air flow is established. Initially, the water in the two arms of the U-shaped pipe is at
 178 the same level (indicated by the thin arrows in Fig.4a); conversely, in the presence of an air
 179 flow in the horizontal tube, the water level in the two arms are now different (indicated by the
 180 thin arrows in Fig.4b) due to the different **static** pressures at the top of the two arms: the
 181 atmospheric pressure in the open arm and the airflow **static** pressure in the other arm. By
 182 measuring this difference in level (in the case shown in the figure is about 25 mm), one can
 183 approximately determine the speed of the airflow inside the horizontal tube. This effect can also
 184 help the teacher to explain the operation of the atomizer, developed in 1887 by the American
 185 otolaryngologist Dr. Allen De Vilbiss (1841-1917) and patented in 1888 [31] as a medical
 186 device, known as a dispenser for perfumes and spray guns for paint applications [32].
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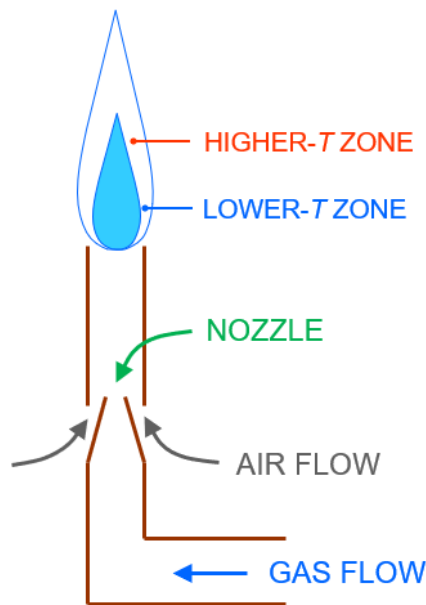
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 190 **Figure 4.** A simple Venturi meter built by using a U-shaped pipe (vertical tube), of 2 mm inner diameter
 191 and 11 cm long, connected with a horizontal tube of 4 mm inner diameter. (a) no air flow is present in
 192 the horizontal tube; (b) in the presence of an air flow in the horizontal tube, the two water levels now
 193 differ, as indicated by the thin arrows.
 194

195 **4.1. The Bunsen burner**

196 In the first edition of his *Chemical Manipulations* of 1827, Michael Faraday (1791-1867)
 197 described a gas burner consisting of a movable metallic cone placed at the top of the metallic
 198 gas outlet. By raising the cone above the top of the burner, the air supply, from outside, could
 199 be increased, producing a non-luminous flame with a blue inner cone [33]. Some years later,
 200 August Wilhelm von Hofmann (1818-1892), working at the Royal College of London, built a
 201 burner in which the air-gas mixture flowed through a cylindrical wire gauze before ignition, so
 202 preventing the danger of flashbacks [34].

203 In 1852, Robert Wilhelm Bunsen (1811-1899), Professor of Chemistry at Heidelberg
 204 University, asked that his laboratory was equipped with gas piping, both for lighting and
 205 heating. When his student Henry Roscoe (1833-1915), back from London, showed him a gauze-
 206 type burner, Bunsen noticed that it delivered a too large and unsteady low-temperature flame,
 207 owing to the excessive gas-air dilution. So, Bunsen asked to the mechanic Peter Desaga (1812-
 208 1879) to design a simple burner, without gauze, that could deliver a non-luminous soot-less
 209 flame for his spectral investigations [35]. Desaga realized a simple model (Fig.5 and Fig.6),

210 which consisted of a vertical metallic pipe (barrel), bearing a nozzle and two lateral holes at its
211 base. Gas flow could be regulated by the tap in the pipe for the gas inlet, and the air inlet could
212 be adjusted by rotating a sliding collar, at the barrel's base, thus opening or closing the holes.
213 When the gas flowed upward through the nozzle, its speed increased, while its **static** pressure
214 decreased, giving rise to an inward airflow through the lateral holes. So, before ignition, the gas
215 was mixed with air, in an adjustable ratio. This caused a complete combustion of the
216 mixture [3], with a smaller non-luminous soot-less flame, and a greater heating power
217 [3,35,36], with which a temperature of about 1400°C could be reached.



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Figure 5. Drawing of a Bunsen burner and its non-luminous flame [2].

221 The Bunsen burner, shown in Fig. 6, belongs to the Historical Collection of the Physics
222 Instruments at the University of Palermo, Italy [10]. The burner is made of cast iron (base) and
223 brass (pipe, collar and valve) and it is provided with a needle valve for gas flow adjustment. It
224 probably dates back to the end of the 19th century and was used as a laboratory tool.



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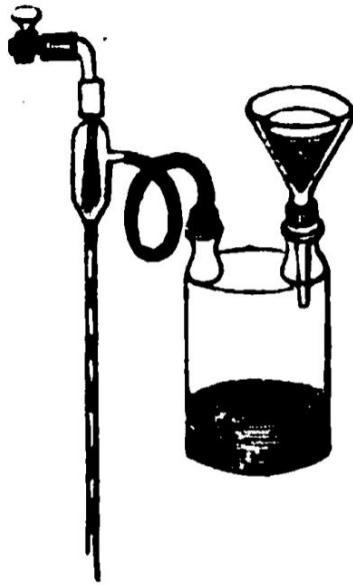
226 **Figure 6.** Bunsen burner with needle valve for gas flow adjustment (8 × 8 × 12.5 cm). (Courtesy
227 Historical Collection of Physics Instruments of the University of Palermo, Italy)
228

229 Bunsen used this colourless flame also for analytical purposes. By introducing salts of
230 different cations, it was coloured in different specific ways. Then, with Gustav Robert
231 Kirchhoff (1824-1877), Bunsen designed and built a spectroscope, by which they identified the
232 different cations from their radiation spectra [37], providing a new diagnostic tool for
233 qualitative analysis.

234

235 **4.2. The Venturi vacuum pump**

236 In the Venturi vacuum pump, a flow of water passes through the restriction of a straight pipe
237 where the fluid velocity increases and the **static** fluid pressure decreases. In 1865 the German-
238 British chemist Hermann Sprengel (1834-1906) developed a “pneumatic machine” based on
239 the ancient technology of the “trompe” (a hydraulic air compressor), developed in Italy around
240 1588 [38] to provide compressed air for large forges and mines. In the Sprengel pump, columns
241 of mercury falling downward in a pipe produced a better vacuum than that obtained with the
242 usual air pumps [39]. Sprengel suggested that also water columns should behave in a similar
243 manner. The same year, the Swiss chemist, Jules Piccard (1840-1933) developed the Venturi
244 vacuum pump (water aspirator) sketched in Fig.7 [40,41], which provided a continuous and
245 uniform pressure difference, greatly improving the speed and the efficiency of filtration of
246 solid-liquid mixtures [41].



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Figure 7. Piccard's apparatus for vacuum filtration with the Venturi vacuum pump [40].

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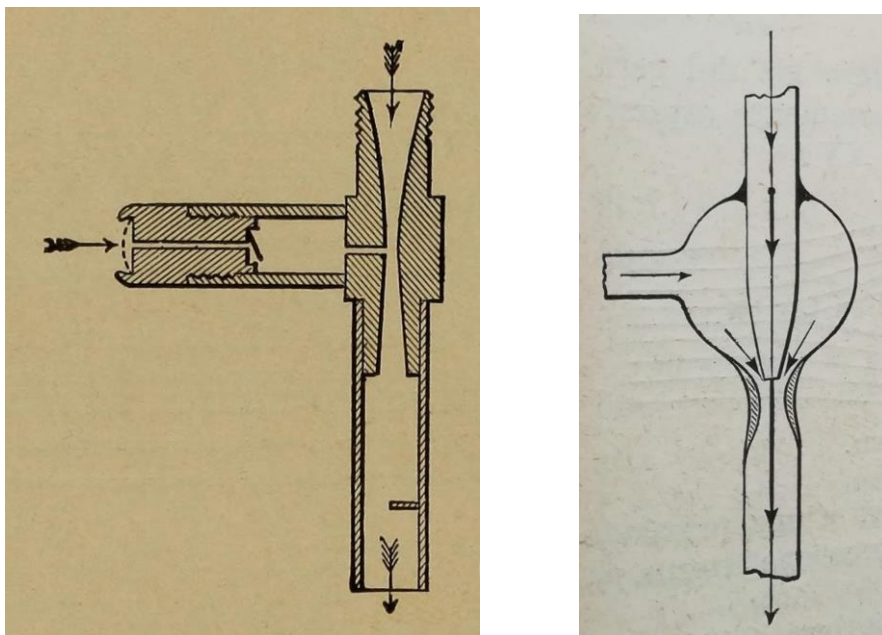
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Later, two different kinds of Venturi vacuum pump were developed. Figure 8 (left) shows a drawing of the metal pump made by Mr. E.C. Chapman, in Brooklyn, N.Y. [42]. Figure 8 (right) shows a drawing of a glass pump [43]. From the lateral hose, connected with the low-pressure chamber, one can create a relatively high vacuum, limited by the vapour pressure of the water, about 3 kPa (24 mmHg), at room temperature. These simple and cheap mini-vacuum pumps have been widely used in research laboratories.



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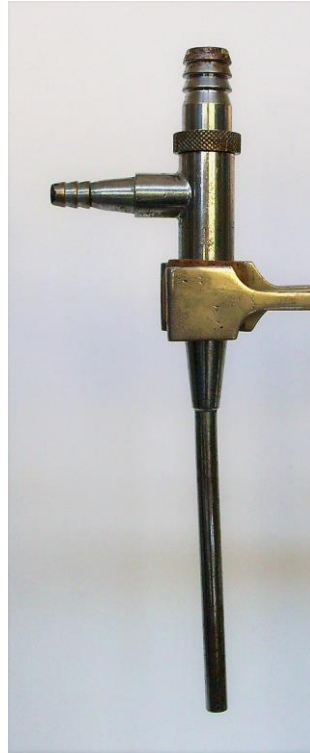
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Figure 8. A drawing of Venturi vacuum pumps: (left) a metallic pump [42]; (right) a glass pump [43]. Vertical arrows indicate the water flow, horizontal arrows indicate the air flow.

259 Figure 9 shows the Venturi vacuum pump belonging to the Historical Collection of the
260 Physics Instruments [10], which was purchased in 1936 by Emilio Segrè (1905-1989), during
261 his stay in Palermo as Director of the former “Istituto di Fisica” (today Department of Physics
262 and Chemistry - Emilio Segrè). It was probably used by Segrè and the mineralogist Carlo
263 Perrier (1886-1948) in the experiments of radiochemistry that led, in 1937, to the discovery of
264 the element Technetium [44].

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Figure 9. Venturi vacuum pump made of chrome-plated brass ($5 \times 2 \times 35$ cm), purchased by Emilio Segrè in 1936. (Courtesy Historical Collection of Physics Instruments of the University of Palermo, Italy)

272 **5. Discussion and conclusions**

273 An approach to the understanding of the Venturi effect based on the study of historical
274 instruments and by simple experiments has been discussed here. Some interesting applications
275 of the Venturi effect, the Venturi meter, the Bunsen burner, the Venturi vacuum pump, and the
276 atomizer, relevant also from a pedagogical point of view, have been presented. **The proposed
277 simple experiments on the Venturi effect can be carried out in the classroom to introduce
278 students to the study of basic laws of hydrodynamics. Simple models of these instruments, such
279 as the Venturi meter, can also be easily built by students, actively engaging them in the
280 discussion of the fluid-flow laws. It allows students to think about the phenomena they are**

281 studying, to discuss them in specific contexts, and to build models representing the relationships
282 among the quantities experimentally observed. Finally, historical instruments with
283 experimental demonstrations can be used to bolster an authentic understanding of the laws
284 describing the flow of a fluid, and to redirect some typical students' common-sense ideas about
285 pressure and velocity in a fluid towards conceptions more coherent with scientific knowledge.

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287 **References**

- 288 [1] Pantano, O. and Talas, S. (2010). Physics thematic paths: laboratorial activities and
289 historical scientific instruments. *Phys. Educ.*, **45**, 140-146
290
- 291 [2] Barbacci S., Brenni P., Giatti A. (2012). Strumenti scientifici: object reading e didattica
292 informale. In: Peruzzi A., (a cura di). Pianeta Galileo 2011. Consiglio regionale della
293 Toscana, Firenze 2012.
294
- 295 [3] Agliolo Gallitto, A., Pace, V., and Zingales, R. (2017). Multidisciplinary learning at
296 the university scientific museums: the Bunsen burner. *Museologia Scientifica*, **11**, 103-
297 107
298
- 299 [4] Mujtaba, T., Lawrence, M., Oliver, and M., Reissa, M.J. (2018). Learning and
300 engagement through natural history museums. *Studies in Science Education*, **54**(1),
301 41-67
302
- 303 [5] Martin, D.H. (1983). Misunderstanding Bernoulli. *Phys. Teach.*, **21**(1), 37-37
304
- 305 [4] Besson, U. (2004). Students' conceptions of fluids. *International Journal of Science
306 Education*, **26**, 1683-1714
307
- 308 [7] Brown, S., Beddoes, K., Montfort, D., and Baghdanov, A. (2017). Engineering
309 students' fluid mechanics misconceptions: A description and theoretical explanation.
310 *Int. J. Eng. Educ.*, **33**, 1149-1162
311
- 312 [8] Suarez, A., Kahan, A., Zavala, G., and Marti, A.C. (2017). Students' conceptual
313 difficulties in hydrodynamics. *Phys. Rev. Phys. Educ. R.*, **13**, 020132-12
314
- 315 [9] Barbosa, L.H. (2013). Development and validation of an instrument to measure
316 student learning: the Bernoulli's law test. *Revista Educación en Ingeniería*, **8**, 24-37
317
- 318 [10] Agliolo Gallitto A. (2012). *Historical Collection of Physics Instruments of the
319 University of Palermo*. [https://sites.google.com/site/aurelioagliologallitto/collezione-
320 storica](https://sites.google.com/site/aurelioagliologallitto/collezione-storica)
321
- 322 [11] Collins, A., Brown, J.S., and Newman, S.E. (1989). Cognitive apprenticeship:
323 Teaching the crafts of reading, writing, and mathematics. In Resnick L. B. (Ed.)
324 *Knowing, learning, and instruction: Essays in honor of Robert Glaser* (pp. 453-494).
325 Hillsdale, NJ: Lawrence Erlbaum Associates
326

- 327 [12] Newman, F. and Wehlage, G. (1993). Five standards of authentic instruction.
 328 *Educational Leadership*, 8-12
 329
- 330 [13] Donovan, S., Bransford, J. D., and Pellegrino, J.W. (1999). *How People Learn:*
 331 *Bridging Research and Practice*. Washington, DC: National Academy of Sciences
 332
- 333 [14] Battaglia, O.R., Fazio, C., Guastella, I., and Sperandeo-Mineo, R. M. (2010). An
 334 experiment on velocity distribution of thermionic electrons. *American Journal of*
 335 *Physics*, **78**, 1302-1308
 336
- 337 [15] Pizzolato, N., Fazio, C., and Battaglia, O. R. (2014). Open inquiry-based learning
 338 experiences: A case study in the context of energy exchange by thermal radiation.
 339 *European Journal of Physics*, **35**, 015024-16
 340
- 341 [16] Persano Adorno, D., Pizzolato, N., and Fazio, C. (2015). Elucidating the electron
 342 transport in semiconductors via Monte Carlo simulations: an inquiry-driven learning
 343 path for engineering undergraduates. *European Journal of Physics*, **36**, 055017-19
 344
- 345 [17] Scager, K., Boonstra, J., Peeters, T., Vulperhorst, J., and Wiegant, F. (2016).
 346 Collaborative Learning in Higher Education: Evoking Positive Interdependence. *CBE*
 347 *Life Sci. Educ.*, **15**, ar69, 1-9
 348
- 349 [18] Iaccarino, M. (2003). Science and culture. *EMBO Rep.*, **4**, 220-223
 350
- 351 [19] Kovác, L. (2006). Science, an essential part of culture. *EMBO Rep.*, **7**, 128-132
 352
- 353 [20] Galili, I. (2012). Cultural content knowledge – The case of physics education.
 354 *International Journal of Innovation in Science and Mathematics Education*, **20**, 1-13
 355
- 356 [21] Norman, D.A. (1991). Cognitive artifacts. In J. M. Carroll (Ed.), *Cambridge series on*
 357 *human-computer interaction*, No. 4. *Designing interaction: Psychology at the human-*
 358 *computer interface*. Cambridge University Press, Cambridge, pages. 17-38
 359
- 360 [22] Agliolo Gallitto A. and Fiordilino E. (2011). The double cone: a mechanical paradox
 361 or a geometrical constraint? *Phys. Educ.*, **46**, 682-684
 362
- 363 [23] Aglione, F., Agliolo Gallitto, A., and Fiordilino, E. (2013). 'Naughty cylinder'
 364 mechanical paradox. *Phys. Educ.*, **48**, 137-139
 365
- 366 [24] Metz, D. and Stinner, A. (2007). A Role for Historical Experiments: Capturing the
 367 Spirit of the Itinerant Lecturers of the 18th Century. *Science & Education*, **16**(6), 613-
 368 624.
 369
- 370 [25] Venturi, G.B. (1797). *Recherches expérimentales sur le principe de la communication*
 371 *latérale du mouvement dans les fluides, applique a l'explication de différents*
 372 *phénomènes*. Paris: Houel et Ducros, Théophile Barrois
 373
- 374 [26] Darrigol O. (2005). *Worlds of Flow: A History of Hydrodynamics from the Bernoullis*
 375 *to Prandtl*. Oxford: Oxford University Press
 376

- 377 [27] *Great Moments in Science and Technology: Daniel Bernoulli and Hydrodynamics*
378 (n.d.). Deutsche Welle Transtel.
379 <https://archive.org/details/DanielBernoulliHydrodynamics>
380
- 381 [28] Hewitt, P.G. (2019). Bernoulli bubbles. *Phys. Teach.*, **57**, 212
382
- 383 [29] Jafari, M., Afshin, H., Farhanieh, B., and Sojoudi, A. (2016). Numerical investigation
384 of geometric parameter effects on the aerodynamic performance of a bladeless fan.
385 *Alexandria Eng. J.*, **55**, 223-233
386
- 387 [30] Herschel, C. (1888). Apparatus for measuring the quantity of water flowing through a
388 pipe. *U. S. Letters Patent* no. 381373
389
- 390 [31] De Vilbiss A. (1888). Atomizer. *U. S. Letters Patent* no. 378357
391
- 392 [32] Marshall Cavendish (Ed.) (2003). *How it Works: Science and Technology*. Marshall
393 Cavendish Corporation, New York, vol. 16, pags. 2227-2228
394
- 395 [33] Kohn, M. (1950). Remarks on the history of laboratory burners. *J. Chem. Educ.*, **27**,
396 514-516
397
- 398 [34] Jensen, W.B. (1991). Michael Faraday and the art and science of chemical
399 manipulation. *Bull. Hist. Chem.* **11**, 65-76
400
- 401 [35] Lockemann, G. (1956). The centenary of the Bunsen burner. *J. Chem. Educ.* **33**, 20-22
402
- 403 [36] Jensen, W.B. (2005). The Origin of the Bunsen Burner. *J. Chem. Educ.*, **82**, 518-519
404
- 405 [37] Kirchhoff, G. and Bunsen, R. (1860). Chemical Analysis by Observation of Spectra,
406 *Annalen der Physik und der Chemie* (Poggendorff), **110**, 161-189
407
- 408 [38] Langborne, P.L. (1979). Hydraulic air compression: old invention – new energy
409 source. *Chartered Mechanical Engineer* **26**(10), 79-81
410
- 411 [39] Sprengel, H. (1865). Researches on the vacuum. *J. Chem. Soc.* **18**, 9-21
412
- 413 [40] Piccard, J. (1865). Eine wesentliche Beschleunigung des Filtrationsgeschäftes. *Z.*
414 *Anal. Chem.*, **4**, 45-48.
415
- 416 [41] Jensen, W.B. (2006). The Origins of the Hirsch and Büchner Vacuum Filtration
417 Funnels. *J. Chem. Educ.*, **83**, 831283
418
- 419 [42] Hiscox, G.D. (1909). *Compressed air*. New York: N. W. Henley
420
- 421 [43] Perucca, E. (1932). *Fisica Generale e Sperimentale*. Turin: UTET, vol. I
422
- 423 [44] Agliolo Gallitto, A., Chinnici, I., and Zingales, R. (2018). 1937: Palermo. *The*
424 *discovery of Technetium*. Proceedings of the XXXVIII Congress of the Italian Society
425 for the History of Physics and Astronomy, Messina 3-6 October