1 / The Mafia Invents the Barometer

Textbooks mention half of him: “Other units [for pressure] in common use are the atmosphere, the millimeter of mercury, or torr, and the millibar.” Gads. It is a damnation of the highest caliber: He has been magnified from a person to a unit and lost his name. Truncated and lowercased, proof positive that he has faded into the cultural background like his invention, which hangs uselessly on the walls of seafood restaurants. Sometimes writers do let drop his entire name. The reference is invariably laconic: “Another instrument used to measure pressure is the common barometer, invented by Evangelista Torricelli (1608–1647).” Air pressure, barometer. Ah. Once in a great while, when an author turns reckless, Torricelli flickers momentarily in human form. Berte Bolle, from his history of the barometer, bravely:

> Torricelli set up his tube of more than 33 feet (10 meters) long in his house with the top protruding through the roof. He floated a small wooden dummy on the water at the top of the tube; in bad weather the height of the water column fell so much that the dummy could not be seen from the road whereas in fine weather it floated high and clear for all to see. It was soon rumoured that master Torricelli was in league with the devil and the water barometer was quickly removed!

We are convinced. But wait. In Sheldon Glashow’s account, Torricelli carries on his heretical work, darting around the quayside to the delight of onlookers. Rumors, evidently—and the Inquisition—failed to deter him: “Torricelli filled long tubes, sealed at one end, with liquids such as honey, wine and seawater, and lashed them upright to ships’ masts. He found that the height of the column depended only upon the total weight of the liquid within.”

Isaac Asimov, eschewing drama for knowledge, provides a complete tale for his readers’ edification. The immortal Galileo, Torricelli’s boss, suggested that his assistant investigate why water pumps failed to raise water more than ten meters above its natural level. Those were the days. Science was called philosophy, Aristotle held sway, and Nature abhorred a vacuum. Galileo’s position was purely Aristotelian: Pumps create a partial vacuum above the water, and the water rushes in to fill it. The vacuum sucks. Evidently, however, the vacuum's ability to suck had limits—about ten meters. Asimov relays Torricelli's thoughts:

> It occurred to Torricelli that the water was lifted, not because it was pulled up by the vacuum, but because it was pushed up by the normal pressure of air. After all, the vacuum in the pump produced a low air pressure, and the normal air outside the pump pushed harder.
>
> In 1643, to check this theory, Torricelli made use of mercury. Since mercury's density is 13.5 times that of water, air should be able to lift it only 1/13.5 times as high as water, or 30 inches. Torricelli filled a 6-foot length of glass tubing with mercury, stoppered the open end, upended it in a dish of mercury, unstoppered it, and found the mercury pouring out of the tube, but not altogether: 30 inches of mercury remained, as expected.

Admirable detail. We feel as if we are face-to-face with Torricelli. "Hand me the mercury," he says. Totally irreconcilable, then, is this remark retrieved from cyberspace: "In 1643, Torricelli proposed his experiment, which was carried out by his colleague Viviani."

Detail. Ah.

The truth is, no one is entirely sure what happened. We do know they were Italians and they were friends. Today they would form a research group. When the research group monopolizes a territory we call it a mafia. Then, as now, the senior scientist receives the credit. To understand what no one is certain about, we return to the dawn of the seventeenth century. The Counter-Reformation in Europe is under way, the Inquisition is heating up, Galileo condescendingly ignores Kepler's discovery that planetary orbits are ellipses rather than circles, Newton has yet to be born. On the ground, the outstanding philosophical question of the age boils: Is a vacuum possible?

No. The answer is obvious; let's be off to today's witch trial. That, at least, is the current universal opinion, nineteen hundred years old. Any objection will be met by a citation from the supreme authority, Aristotle. Aristotle, in his celebrated phrase, declared, "Nature abhors a vacuum." (Whatever Aristotle declared, he declared in ancient Greek, but this is how it is usually translated, and he believed it.) Aristotle adduced a number of arguments against the vacuum, both physical and logical. You must first understand that in Aristotle's world—and in the world of the sixteenth century—there are no atoms. Water is a continuous substance. Dividing water into finer and finer pieces leads only to finer and finer pieces, ad infinitum. There is no reason to suppose that the division will lead to a state composed of ultimate particles between which is nothing. No, the universe is full, a plenum. What is more, in the pre-Galilean world, there is no concept of inertia, the idea that without interference an object travels at a constant velocity. Rather, the velocity of an object depends on the *resistance* of the medium through which it travels. A void—a vacuum—provides no resistance. Therefore the velocity of an object traveling through a void should be infinite. This is clearly nonsense.

Those are physical arguments that Aristotle brought against the vacuum. His main logical argument was that the position of an object—its place—is always understood to be within the inner limits of a surrounding body. Nonphilosophers call this a container. But the void has no properties. An object within it cannot be said to be in any sort of place. Neither could an object be said to move within a void (because it has no properties to distinguish places). Therefore an object cannot have a place unless it is within some substance. A vacuum is logically impossible.

If a vacuum is logically impossible, that would mean that God could not produce one if he wished. This troubled thirteenth-century theologians. For that reason, by the seventeenth century people were willing to discuss the issue. Yet the prevailing opinion was that a vacuum was at least a physical impossibility, if not a logical one.

In the Contemporary Panopticon of Present and Past Concepts, the exhibits on vacuum and pressure are housed side by side. This way, please. From our perspective, it is difficult to see how a sensible concept of vacuum could emerge without a sensible concept of pressure. An anonymous thirteenth-century pupil of the philosopher Jean de Némore understood that pressure in a liquid increased with depth, but the publication of Némore's book in which the discussion appears was delayed for three centuries. Isaac Beeckman (1588–1637) seems to have accepted the idea of a vaccum and in 1614 wrote in his journal that air has weight and exerts pressure on bodies below, which increases with the depth of the air. Despite such isolated beacons of insight, a clear understanding of pressure was not to be had. Air is weightless.

Two years before Beeckman grasped the essentials, Galileo, in a fit of pique, expressed this universal wisdom: "Even if we then add a very large quantity of water above [the solid], we shall not on that account increase the pressure or weight of the parts surrounding the said solid." A year after Beeckman, in 1615, Galileo continued his denials: "Note that all the air in itself and above the water weighs nothing. . . . Nor let anyone be surprised that all the air weighs nothing at all, because it is like water."

Against this background Giovanni Batista Baliani (1582–1666), from Genoa, wrote to Galileo in 1630 to report the results of an experiment.

c01.qxd 07/15/03 3:23 PM Page 8

He had attempted to siphon water from a reservoir over a hill about twenty-one meters tall, and the siphon failed to perform. The siphon, in a procedure known to gasoline thieves today, was initially filled with water and laid over the hill, but when the tube was unstoppered, the water level on the reservoir side dropped back to about ten meters. Mystery? Not to Galileo. He condescended to reply to Baliani that the answer was obvious: The force of the vacuum raised the water, but the strength of the vacuum was limited to ten meters. Baliani was closer to the mark: He believed that a vacuum was possible and that water and air had weight.

He also had friends. Of the right sort. They included Raffaello Magiotti, Evangelista Torricelli, Emmanuel Maignan, Athanasius Kircher, Niccolò Zucchi, and, evidently, Gasparo Berti. This was the Roman mafia. Somewhere between 1639 and 1641—the dates have been eliminated—Berti performed an experiment at his house in Rome. The mafiosi Kircher, Magiotti, and Zucchi were there; Maignan was absent; and Torricelli's whereabouts are unknown. Four accounts exist of the experiment, three by the eyewitnesses and one by Maignan, who was informed of the proceedings by Berti a week later. The accounts differ on the details; over the interpretation of the results they came to blows.

According to Maignan, "one of the keenest minds of the seventeenth century," the experiment was set up roughly as follows. Berti clamped a long leaden tube, at least "forty palms" in height, to the outside of his house. The bottom of the tube, which ended in a barrel of water, was fitted with a valve. Over the top end of the tube was sealed a glass flask, which was also fitted with a stopcock. The experimenters closed the bottom stopcock, then from a tower window filled the entire tube, including the glass flask, through the upper valve. The upper stopcock was closed, the bottom one opened.

Tension. Suspense.

The water level falls—but not completely. The experimenters lower a sounding line into the tube to determine the height of the water. The data are in: eighteen cubits. This is the height to which Galileo claims an air pump can raise water. The water level stands for a day. The experiment is repeated with variations. The data are solid. But what is the space above the water? When the philosophers first opened the upper stopcock to lower the sounding line, they heard a loud noise as air rushed in. Air rushing in—that is Maignan's view. The fall of the water level in the tube therefore must have left a vacuum behind. Fellow mafiosi are unconvinced.

The plenists argue that air seeped in through the pores of the lead or the glass in order to fill up the space left by the falling water. Kircher, apparently, suggests putting a small bell into the glass bulb and attracting the clapper to one side with a magnet. If within the flask exists a vacuum, no sound will be heard. Maignan objects that the glass itself will conduct the sound, and no documents in the Panopticon make clear whether the experiment is ever carried out.

Today the breakthrough would have won a Nobel prize. Then, news was kept in the family. They were a congenial bunch, judging from the letters among them, reveling in the vistas of the Golden Age that opened before them. They may have also held doubts about the Inquisition. Vacuums, you know. In 1648, some years after Berti's experiment, Raffaello Magiotti, who was there, wrote a letter to Father Mersenne in Paris, mentioning that he had told Torricelli about Berti's tube and that "they" had since made many demonstrations with quicksilver. *They.*

The mercury connection. Torricelli, born on October 15, 1608, had attended the University of Rome and had become a recognized mathematician. They say he was charming. By the end of 1641 he had become Galileo's assistant, but Galileo died only three months later, to be followed by Torricelli himself in 1647. In the meantime Grand Duke Ferdinand II made Torricelli philosopher and mathematician in Florence, a joint appointment rarely encountered today. He remained in Florence, publishing until he perished, we hope in better circumstances than Galileo.

The idea for using mercury in a device similar to Berti's may have come from that archfoe of air pressure, Galileo (perhaps he had repented). In a copy of the original edition of Galileo's *Discorsi* of 1638, there appears a marginal note made in the hand of his assistant of the time, Vincenzio Viviani, "with the approval of Galileo himself." The note reads, "It is my belief that the same result will follow in other liquids, such as quicksilver, wine, oil, etc., in which the rupture will take place at a lesser or greater height than 18 braccia, according to the greater or lesser specific gravity [density] of these liquids in relation to that of water." Viviani is a great friend of Torricelli. Ah.

Events become obscure. The first full account of Torricelli's famous experiment, described by Asimov and Bolle in hyperrealistic detail, comes nineteen years after the fact. In 1663, one Calo Dati, a pupil of Torricelli, pseudonymously published letters from Torricelli to his best friend, Michelangelo Ricci, who may also have been present at Berti's experiment. These letters report the first experiments with mercury, that is, the barometer.

On June 11, 1644, Ricci wrote to Torricelli, "I live in a great desire to know the success of those experiments that you indicated to me." Torricelli penned his celebrated reply the same day:

> I have already hinted to you that some sort of philosophical experiment was being done concerning the vacuum, not simply to produce a vacuum but to make an instrument which might show the changes of the air, now heavier and coarser, now lighter and more subtle. Many have said that [the vacuum] cannot happen; others say that it happens, but with the repugnance of nature.

Torricelli goes on to espouse his own view that the vacuum is not the issue and that one can be produced. Then the immortal phrase *"Noi viviamo sommersi nel fondo d'un pelago d'aria elementare":*

> We live submerged at the bottom of an ocean of elementary air, which is known by incontestible experiments to have weight, and so much weight that the heaviest part near the surface of the earth weighs about one four-hundredth as much as water.

He goes on to say, "We have made many glass vessels . . . with necks two ells long." *We.* The tubes, closed at one end, were filled with mercury, so that no air remained at the closed end, then inverted in a basin of mercury; as Asimov describes, the mercury falls, but not completely. Torricelli clearly understands that it is not the vacuum exerting an insufficient force on the quicksilver:

> I assert . . . that the force comes from outside. On the surface of the liquid in the basin presses a height of fifty miles of air; yet what a marvel it is, if the quicksilver enters the glass [tube] . . . it rises to the point of which it is in balance with the weight of the external air that is pushing it! Water, then . . . will rise to about eighteen ells, that is to say, much higher than the quicksilver, as quicksilver is heavier than water, in order to come into equilibrium with the same cause, which pushes the one and the other.

Thus, a thoroughly modern understanding of air pressure and the invention of the barometer, which measures that pressure. A more modern understanding than modern English usage would indicate: We do not suck soda through a straw; air pressure pushes it into our mouths.

But: "We have made many glass vessels." *We.* According to Dati, who, as we know, first reported the experiment nineteen years after the fact, Torricelli did not perform it. He forecast the result to Viviani, who procured the mercury, had the apparatus built, and verified his friend's prediction. Thus an early example of a familiar division of labor, theorist and experimentalist.

What of Torricelli's dockside activities, lashing glass tubes filled with water and wine to the masts of tall ships? That appears to be a confusion with Blaise Pascal, who performed such demonstrations in 1647 to the delight of the French public—at the Rouen glass factory. Thus were forever bound together the three sensual delights, wine, water, and barometers.

Pascal, they say, wrote to his brother-in-law Florin Perier and suggested that he take a barometer up Puy-de-Dôme to test whether the weight of the air varied with altitude. Descartes also claims priority for the idea, and textual analyses indicate that the letter from Pascal to his brother-in-law may indeed have been a falsification. Whatever. On September 19, 1648, Perier did climb the mountain. The height of the mercury in the barometer fell. No longer was there any doubt: Air pressure varied with height. The vacuum was abandoned, in horror. It is true: We live submerged at the bottom of an ocean of elementary air, which is known by incontestable experiments to have weight.