Eighteenth Century Theories of Evaporation and Rain

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During the first half of the eighteenth century, theories of evaporation and rain based upon a hydrostatic concept were dominant. These hydrostatic theories were characterized by the common idea that very small amounts of water are greatly increased in volume by heat. These discrete particles of water vapor are thus of less specific weight than the surrounding air and are therefore buoyed up by the weight of the air. An early example of this type of theory is that of Edmund Halley (1656-1742). Halley reasoned that if an atom of water were to be expanded to 10 times its former diameter by heat, it would then be specifically 1000 times lighter than before. Since liquid water is 800 times as heavy as air, the expanded atom of water would be buoyed up hydrostatically in air and would rise until it reached a level at which the air had the same specific weight as the expanded water atom.[1] Wilhelm Homberg (1652-1715) explained this expansion of water atoms as the result of particles of fire attaching themselves to the particles of water and forming a conglomerate lighter than air.[2] William Derham (1657-1735) agreed that evaporation was a hydrostatic process but insisted, "Water Vapour is nothing other than small Bubbles, or Vesiculae detached from water by Solar or Subterraneous Heat, or Both." Derham considered the visible bubbles formed in boiling water to be an extreme example of this process.[3]

These theories explained the formation of clouds and rain as the reverse of the process of evaporation. This created a minor conceptual difficulty. If the fire matter forms a union with, or is encapsulated by, water to form a body lighter than air, what is the mechanism by which the fire matter is released, causing precipitation? Bernard Nieuwentijt (1654-1718), a Dutch mathematician, offered a solution to this problem. He had come to this conclusion by reasoning from experimental evidence. Having subjected a cup of very hot water to the partial vacuum of an air pump, Nieuwentijt observed that the water boiled while water of the same temperature in a cup outside the air pump did not. He also observed that after having boiled under low pressure for a period of time, the water was sensibly cooler than than which had been left outside the air pump. From this evidence Nieuwentijt inferred that air pressure prevents the escape of fire matter attached to water particles while the reduced pressure in the higher levels of the atmosphere permits it.[4]

John Theophilus Desaguliers (1683-1744) argued that the existence of fire matter had never been demonstrated. Particles of matter do not actually expand upon being heated but the repulsive force of the particles is increased by heating. A given amount of heat increases the repulsive force of a water particle more than the same amount of heat increases the repulsive force of an air particle. "For the same Heat which rarefies Air only ⅓, will rarefy Water very near 14000 times, changing it into Steam or Vapour as it boils it: And in Winter that small degree of Heat, which in respect to our Bodies appears cold, will raise a Steam or Vapour from Water at the same time it condenses Air."[5]

In all of the foregoing hydrostatic theories of evaporation, water vapor is visualized as particles moving up through air like bubbles rising through water. The matter of dust and smoke, for example, was known to have specific weights hundreds of times that of air. During the eighteenth century the suspension of such particles in air was explained to be the result of their having very large surface areas in comparison to their weights. As a result, air resistance is able to greatly slow their fall. In order to have a buoyant force only equal to the downward tendency of a dust-mote, a particle of water vapor would be required to have a specific weight hundreds of times less than air. Some scientists considered this physical model unsatisfactory and began to evolve theories of evaporation and rain that were founded upon an entirely different conceptual framework.

An early example of this new type of theory appears in an unsigned item in the *Histoire de l'Académie Royale des Sciences* for the year 1742. The author gave his interpretation of the reasoning of Jean Bouillet (1690-1777). Water is known to absorb some of the air which touches its surface even though the air is much lighter than the water. Conversely, air rolling along the surface of water picks up some of the water, even though the water is much heavier than the air.[6]

In 1751, Charles Le Roy (1726-1779) presented a paper to the *l'Académie Royale des Sciences* entitled "Mémoire sur l'élévation & la suspension de l'eau dans l'air & sur la Rosée." Le Roy stated flatly that air dissolves water in the same manner as water dissolves most salts. He used the term *dissolution* in the same way it was used by *les Chimistes*. Just as hot water can dissolve more salt than cold water, hot air can dissolve more water than cold air. There is a limit to the amount of either salt or water that can be dissolved in a solvent at any given temperature. If a solution is saturated and the temperature of the solution is reduced, precipitation occurs. Thus, Le Roy substituted for the physical model of the hydrostatic theories a chemical model in which the mechanism of evaporation was "l'union intime des dernieres molécules des deux corps."[7]

Benjamin Franklin (1706-1790) was elected to the Royal Society of London in 1756. On June 3d of that year a paper written by Franklin and entitled "Physical and Meteorological Observations, Conjectures, and Suppositions" was read to the Society. Franklin stated that, although particles of air are mutually repulsive, those of air and water attract one another. "Hence water will dissolve in air, as salt in water."[8] With ". . . every particle of air assuming one or more particles of water; when too much [water] is added, it precipitates in rain."[9] The active agent of precipitation is the tendency of water to cohere. Warm air will hold more than cold air because, ". . . its particles being by heat repelled to a greater distance from each other, there by more easily keep the particles of water, that are annexed to them, from running into cohesions."[10] Franklin rejected the supposition that evaporation was analogous to boiling. In boiling heat reverses water's normal tendency to attract and cohere. Steam from boiling water does not mix with air; on the contrary, it expels air from the space it had occupied.

The solution theory of evaporation assumed that moisture-laden air is heavier than dry air, just as a solution of salt in water has a greater specific weight than that of water alone. Franklin insisted that a particle of air loaded with adhering water, although heavier than a dry air particle, could be supported and held aloft by the interaction of several particles of dry air in a system of mutual repulsion. He explained that heavy, loaded particles in descent would repel air particles in their way, forcing them nearer to other particles, which in turn, repel them back into the path of the descending particles. The repulsive force of the particles immediately below the descending ones would be augmented by that of their neighbors until it was sufficient to hold the loaded particles suspended.[11]

Thus, during the mid-eighteenth century, there were two distinctly different types of theories of evaporation and rain. The hydrostatic theories were based upon the concept of the matter of water and air having volume, weight, and impenetrability. Of these characteristics, only volume is mutable. Heat is the agent of change in volume. This conceptual model is physical, analogous to bubbles rising through water. The solution theories of evaporation and rain were based upon the concept that the matter of air is self-repulsive, the matter of water is cohesive, and that water and air have an affinity for one another. Heat is an agent only inasmuch as it increases air's repulsion for itself. This conceptual model is chemical, analogous to salt dissolving in water and to precipitates forming in supersaturated solutions.

The choice of later eighteenth century scientists between these two types of theories was probably based upon their commitment to a particular conceptual scheme. Some scientists could not subscribe to a conceptual framework which seemed to deny the well established hydrostatic and hydrolic theories of the day. On the other hand, many scientists found the concepts of saturation and precipitation so satisfying that they would not accept any theory that did not include them.

Notes and Literature Cited

[1]E[dmund] Halley, "A Estimate of the Quantity of Vapour raised out of the Sea by the warmth of the Sun; derived from an Experiment shown before the Royal Society, at one of their late Meetings," *Phil. Trans. Roy. Soc. London* No. 189 (Sept & Oct 1687), pp. [366]-[370].

[2]"Vapours" in John Harris, *Lexicon technicum, or a Universal English Dictionary of Arts and Sciences, Explaining Not only the Terms of Art, but the Arts Themselves* (London: Printed for Dan. Brown, *et al.*, 1704), pp. 7F[1*r*]-[7F1*v*].

[3]W[illiam] Derham, *Physico-Theology: or, a Demonstration of the Being and Attributes of God from His works of Creation, Being the Substance of XVI Sermons Preached in St. Mary le Bow-Church, London, at the Hon^ble Mr. Boyle's Lectures, in the years 1711 and 1712, With large Notes, and many curious Observations Never Before Published* (London: W. Innys, 1713), pp. 20-21; 48-49.

[4]Bernard Nieuwentijt, *The Religious Philosopher: or, the Right Use of Contemplating the Works of the Creator. I. In the wonderful Structure of Animal Bodies, and in particular Man, II. In the no less wonderful and wise Formation of the Elements and their various Effects upon Animal and Vegetable Bodies, And III. In the most amazing Structure of the Heavens, with all its Furniture. Designed for the Conviction of Atheists and Infidels. Throughout which, all the late Discoveries in Anatomy, Philosophy, and Astronomy, together with the various Experiments made use of to illustrate the same, are most copiously handled by that learned Mathematician Dr. Nieuwentijt. To which is prefix'd a Letter to the Translator by the Reverend J. T. Desaguliers.* Translated by John Chamberlain (3d ed.; 2 vols.; London: J. Senex, E. Taylor, W. and J. Innys, and J. Osborne, 1724), vol. 1, pp. 241-263.

[5]John Theophilus Desaguliers, "An Attempt to Solve the Phaenomenon of the Rise of Vapours, Formation of Clouds and Descent of Rain," *Phil. Trans. Roy. Soc. London* XXXVI (1729), 6-22.

[6]"Sur l'évaporation des liquides," *Histoire de l'Académie Royale des Sciences. Année M.DCCXLII. Avec les mémoires de mathématique & de physique, pour la meme année. Tirés des registres de cette Académie* (Paris: dé l'Imprimeris Royale, 1745), pp. 18-21.

[7]Charles Le Roy, "Mémoire sur l'élévation & la suspension de l'eau dans l'air, & sur la Rosée," *Histoire de l'Académie Royale des Sciences. Année M.DCCLI. Avec les mémoires de mathématique & de physique, pour la meme année. Tirés des registres de cette Académie* (Paris: de l'Imprimerie Royale, 1755), pp. 481-519.

[8]Benjamin Franklin, "Physical and Meteorological Observations, Conjectures, and Suppositions," *Phil. Trans. Roy. Soc.* London LV (1765), 182-192.

[9]*Ibid.*, p. 182 [10]*Ibid.*, p. 183. [11]*Ibid.*, p. 185.