Count Rumford Discovers Thermal Convection

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WHEN dining, I had often observed that some particular dishes retain their heat much longer than others, and that apple pies and apples and almonds mixed (a dish in great repute in England) remain hot a surprising length of time.

Much struck with this extraordinary quality of retaining heat which apples appeared to possess, it frequently occurred to my recollection, and I never burnt my mouth with them or saw others meet with the same misfortune without endeavoring but in vain to find out some way of accounting in a satisfactory manner for this surprising phenomenon.

About four years ago, a similar accident awakened my attention and excited my curiosity still more. Being engaged in an experiment which I could not leave, in a room heated by an iron stove, my dinner which consisted of a bowl of thick rice soup was brought into the room, and as I happened to be too much engaged at the time to eat it, in order that it might not grow cold I ordered it to be set down on the top of the stove. About an hour afterwards, as near as I can remember, beginning to grow hungry and seeing my dinner standing on the stove, I went up to it and took a spoonful of the soup, which I found almost cold and quite thick. Going, by accident, deeper with the spoon the second time, this second spoonful burnt my mouth. This accident recalled very forcibly to my mind the recollection of the hot apples and almonds, with which I had so often burnt my mouth a dozen years before in England. Even this, though it surprised me very much, was not sufficient to open my eyes and to remove my prejudices respecting the conducting power of water.[1]

In this chatty style, Count Rumford began to describe in 1797 his discovery of the thermal current in fluids. His first observations of convection currents were accidental, as he watched the behavior of the contents of the bore of a large thermometer he was using in an experiment:

I saw the whole mass of the liquid in the tube in a most rapid motion running swiftly in two opposite directions, up and down at the same time. The bulb of the thermometer, which is of copper, had been made two years before I found leisure to begin my experiments, and having been left unfilled without being closed with a stopple, some fine particles of dust had found their way into it and these particles which were intimately mixed with the spirits of wine, on their being illuminated by the sun's beam, became perfectly visible . . . and by their motions discovered the violent motions by which the spirit of wine in the tube of the thermometer was agitated. . . . On examining the motion of the spirits of wine with a lens, I found that the ascending current occupied the axis of the tube and that it descended by the sides of the tube. On inclining the tube a little, the rising current moved out of the axis and occupied the side of the tube which was uppermost, while the descending currents occupied the whole of the lower side of it.

The Count recognized that he had made a discovery of the first magnitude, and he correctly assigned the thermal motions to the changes in density of the fluid as a result of heating. The hot liquid, being lighter, tended to rise and the heavier liquid, which was cold, fell, and thus the currents could be separated into a continuous motion. To dramatize the experimental observations of these currents, he designed equipment which was easily constructed and could show the currents in a simple fashion.

Looking through the tables of specific gravity, he noticed that amber had almost the same density as that of water. Therefore, he reasoned, if he mixed ground-up amber with a solution of salt water, whose density was carefully adjusted so that the amber would be suspended in the liquid, he would have a device to demonstrate this effect. On heating of the bulb of the instrument, either by a candle or by one's hand, the currents set up could easily be seen in the motion of the amber particles. Not only was the Count's scientific reputation greatly enhanced by his discovery of thermal currents, but the apparatus he invented to show it became standard for many years afterward as a classroom demonstration of the convection effect.

Another piece of equipment which Rumford designed and about which he became very enthusiastic was used in a similar demonstration in which the suspended amber particles were held between two glass panes separated by about an inch of liquid. The panes were mounted directly in the mullions of a window, so that the outside pane was cold, at least in winter, and the inside was warm from the heat of the room. The suspended particles were then in perpetual motion and became a center of attraction for visitors to observe. Rumford found this device tremendously exciting:

I discovered horizontal currents running in opposite directions, one above the other, or regular winds which, springing up in the different regions of this artificial atmosphere, prevailed for a long time with the utmost regularity, while small particles of the amber collecting themselves together, formed clouds of the most fascinating forms, which being carried by the winds, rendered the scene perfectly fascinating! It would be impossible to describe the avidity with which I gazed on these enchanting appearances. In the state of enthusiasm in which I then was, it really seemed to me that Nature had, for a moment, drawn back the veil with which she hides from mortal eyes, her most secret and most interesting operations, and that I now saw the machinery at work by which winds and storms are raised in the atmosphere! Nothing seemed to be wanting to complete this bewitching scene and to give it the air of perfect enchantment, but that lightning in miniature should burst from these little clouds and that they were frequently so thickened up and had so much the appearance of preparing for a storm, that had that event actually taken place, it could hardly have increased my wonder and ecstasy.

For all the Count's enthusiasm about this piece of apparatus, we know that it only lasted three weeks, for he mentions in a footnote that "an end was put to the experiment by an accident, the box being broken by the carelessness of a servant, shutting the window shutter."

The immediate scientific result which Rumford set out to investigate was whether the transmission of heat in fluids was solely by means of convection currents in which heated fluid was moved bodily from one place to another or whether there was, in addition, a conduction of heat similar to that known to be operating in solids. He devised an elaborate series of experiments to determine the conductivity of liquids in which the thermal motion was interrupted, either by the changes in viscosity of the liquid or by mechanical means such as fibers in filters of various sorts. To carry out these investigations, he designed what he calls his "cylindrical passage thermometer." The thermometer bulb was mounted in a brass tube in such a way that it did not touch the outer wall of the brass tube. Material to be studied was packed between the thermometer tube and the outer wall. His method of using the device was to surround the thermometer bulb with the material to be tested and then place the whole instrument in ice water until the thermometer fell to 32°F. He then removed the instrument from the ice water and plunged it into boiling water and measured the length of time that it took the thermometer to pass from 40°F. to 60°F. This became a standard temperature differential by which he could rate various substances to be measured.

> Having still fresh in my memory, the accidents I had so often met with in eating hot apple pies, I was very impatient when I had completed this instrument to see if apples which, as I well knew, are composed almost entirely of water, really possess a greater power of retaining heat than that liquid when it is pure or unmixed with other bodies.

As he suspected, he found almost immediately that the passage of heat through stewed apples took much longer than the passage of heat through water, as measured by his instrument. The Count then measured the amount of fibrous material in stewed apples as compared with the amount of water, and substituted for the apple fibers an equivalent amount of eiderdown. He discovered that the passage of heat through his cylindrical passage thermometer gave the same time reading in either case. He then decreased the amount of eiderdown and showed that the amount of heat which was transmitted through the fluid in a given time increased as the ratio of eiderdown to water decreased. He reasoned that if he could decrease the internal motions of the water to zero, the conductivity of the liquid would also be zero, and he therefore stated this extrapolation as a conclusion of his experiments.

It was not until 1834 that the well-known William Prout, writing in one of the *Bridgewater Treatises*, suggested:[2]

> There is at present no single term in our language employed to denote this mode of propagation of heat; but we venture to propose for that purpose the term *convection* (*convectio*, a carrying or converging), which not only expresses the leading facts, but also accords very well with the two other terms [conduction and radiation].

Even after this name was suggested, it took twenty years for *convection* to find its way to the universal acceptance which the term now enjoys.

References

1. Rumford, "Of the Propagation of Heat in Fluids," in *Complete Works* (Boston: American Academy of Arts and Sciences, 1870); Vol. I, p. 239.
2. *Bridgewater Treatises* (W. Pickering, London); Vol. 8, p. 65. Volume 8, which was published in 1834, was written by Prout.