Hydrogen Bond Energy Drives Hurricanes

Peter Graneau

The American Chemist Gilbert Lewis suggested the name "hydrogen bond" for the chemical bond which endows water with liquid cohesion. It is a relatively weak attraction between a hydrogen atom in one H_2O molecule and an oxygen atom in a neighboring water molecule. The attraction is due to quantum mechanical interactions between the electrons and the nuclei of the two bonded atoms. As in all chemical bonds, the long-term stability of the interaction rests upon the nuclear repulsion which counterbalances the chemical attraction. Just like a compressed spring, the internuclear repulsion stores potential energy. It is the same kind of chemical energy that is being stored in fossil fuels.

For some reason the hydrogen bond energy of water does not receive as much attention in the literature as it deserves. The bond itself is discussed extensively together with the effect it has on the structure of liquid water and ice. Perhaps some chemists have been led to believe that hydrogen bonds do not store chemical energy because no energy appears to be liberated when hydrogen bonds are broken in the evaporation of water. This is an experimental fact which proves, as we now know, that the thermal rupture of the bonds in question consumes as much mechanical work as the energy that is set free by the bonds. In the mid-1990s, however, we discovered, in the laboratory, that the tensile rupture of hydrogen bonds consumed only of the order of 1% of the previously stored and later liberated bond energy.[1] This opened the door to the economic extraction of hydrogen bond energy for the generation of electricity.

Unlimited Renewable Solar Energy from Water[1] is a collection and discussion of nine peer-reviewed papers on water arc explosions. In the middle of more than twenty years of research in this field, at MIT and Oxford University, it was discovered that electric arcs pull water apart into small fog droplets. This event must liberate the energy stored in the bonds that were originally holding the droplets together. It was the first indication that hydrogen bonds can be undone by pulling them apart without heating the water and evaporating it.

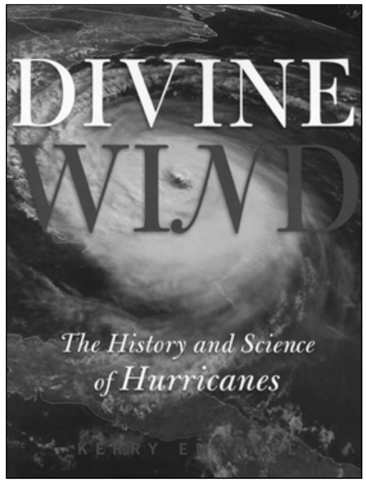
When burning gasoline, we are converting one set of chemical bonds into another set of chemical bonds, both involving carbon atoms. The second set stores less chemical energy than the first set. The difference in the stored energies is liberated as the heat of combustion and drives our automobiles. It also dumps carbon dioxide into the atmosphere. Decisive differences between the combustion of fossil fuels and the rupture of hydrogen bonds by electric arcs are that, first of all, the arc-liberated bond energy appears as kinetic energy of fog instead of as heat and, secondly, no carbon atoms are involved which would give rise to air pollution with greenhouse gas.

The question which arises immediately is: can we tear liquid water apart into fog droplets by other means than the electrodynamic tension in the electric arc column. As discussed in my previous editorial (#70),[2] the answer is "yes." Storm force winds blowing over the ocean surface will create fog, foam, and liquid spray. Friction at the air-water interface shears off droplets of liquid water. This involves the tensile rupture of hydrogen bonds. It is a much more efficient way of producing fog than the thermal processes of liquid evaporation and consequent water vapor condensation involving latent heat.

The tensile rupture of hydrogen bonds in the surface of ocean water was first discussed in the above-referenced editorial. The cover of the magazine showed the satellite image of a hurricane in the Mexican Gulf which was meant to indicate that the hurricane is powered by clean chemical energy which accelerates the fog cloud and drives the cyclonic motion. Nature accomplishes this feat of chemical energy liberation without producing an ounce of carbon dioxide. This natural phenomenon encourages us to believe that the clean production of renewable energy from water is a promising R&D objective to greatly reduce the combustion of fossil fuels.

Two aspects of hurricane behavior have been difficult to explain. One concerns the creation of dense fog at the junction between eyewall and the sea. This is the location where the highest wind speeds are measured and the storm rages at full fury. The mixture of air and fog in this region seems to be prevented from spreading into the calm eye by their large tangential momentum. The crucial division between a calm eye and the extreme conditions just outside it is clearly related to the strong unexplained updraft which causes the fog to rise upward. The second weakness of conventional hurricane physics is the absence of a clear understanding of what causes the self-intensification of cyclonic storms over water. Both with regard to updraft and self-intensification, the windshear production of fog and the associated liberation of hydrogen bond energy offers new insights.

Kerry Emanuel,[3] in his book *Divine Wind*, on the history and science of hurricanes, writes that a mature Atlantic hurricane can extract power of the order of 3×10^{12} W (watts) from the ocean. This is roughly equal to all the electric power being generated on earth. A satellite image of just such a hurricane is shown on the cover of Issue 70. The swirling storm cloud is about 400 miles in diameter and 10 miles high. The energy of the hurricane is taken to be the kinetic energy of the mixture of air, water vapor, fog droplets, rain drops, ice crystals, and snow flakes. Some of the power flowing into the 1.26×10^{6} cubic-miles of the storm volume is lost to the space environment by the dispersal of the storm cloud. Part of the power flow is likely to be invested in the intensification of the hurricane. On an adjacent 400 mile diameter patch of the ocean, the water temperature and the temperature distribution will be virtually the same as under the hurricane. What is it then that transfers tons of fog droplets from the ocean into the hurricane only when the cyclonic storm is already in existence?



Before the hydrogen bond of water was introduced in 1923, the evaporation of the liquid and the condensation of gaseous water were described with the aid of the latent heat concept. This was heat which disappeared without trace during evaporation and later reappeared from nowhere during condensation. Latent heat at first seemed to violate energy conservation in so far that the energy could not be tracked for long periods of time. The introduction of hydrogen bonds brought with it bond energy transfers during phase changes. They should be related to latent heat. No discussion of this subject has been found in the water science literature.

Normally hurricane physicists argue that thermal energy is taken from the oceanic heat bath to evaporate water molecules from a wide ocean area. This requires an energy input from the ocean of at least the latent heat per unit mass of water evaporated. This vapor is pushed into the storm center by the higher pressure surrounding the storm. The latent heat can be released again into the atmosphere when the vapor condenses. Since this occurs over a smaller volume, it is reasoned that the latent heat can be concentrated in the storm cloud. However, condensation normally takes place in calm and cool places, which does not apply to the eyewall of a hurricane.

We are therefore suggesting a more likely mechanism of energy injection into the storm. This involves the liberation of hydrogen bond energy when fog droplets are sheared off the ocean surface by the horizontal wind over the water. This model appears to be more reasonable for it contains a mechanism with positive feedback in which higher wind speed leads to more hydrogen bond ruptures, resulting in a greater energy release and further wind intensification.

How much explosion (kinetic) energy can be added to the hurricane by the tensile rupture of hydrogen bonds per unit time? This is a very difficult question to answer. An ordinary cloud in the sky contains, typically, three grams of fog per cubic-meter of the cloud volume. The fog in a hurricane cloud could be far denser. An important parameter is the size of the droplets, because it indicates how many hydrogen bonds have been broken. This number determines the amount of liberated bond energy which is being donated by the liquid ocean water to the kinetic energy of the storm cloud.

In meteorology fog droplets are said to be of 1 – 100 μm in diameter. The lower limit arises from the wave length of light. Smaller droplets may exist but, like atoms, they cannot be seen. At the 100 μm upper limit, the droplets are no longer capable of floating in air and then rain down to the ground. When all droplets are of the same diameter, d, it can easily be shown that the total surface area of the fog droplets, per gram of water, decreases as (1/d) with increasing diameter. Hence for a given quantity of water, the smallest (1 μm) fog droplets have 100 times the surface area of the largest (100 μm) droplets. Assuming that the number of broken hydrogen bonds is proportional to the droplet surface area, it follows that the smallest droplets produce 100 times as much fog kinetic energy, per unit mass, than the largest droplets.

Let us now look at the water arc experience. The tension in the volume of a water arc is known to be an increasing function of the arc current. Raising the current—and therefore the tensile stress—in the arc makes the fog explosion more powerful, even though the created fog mass appears to remain the same. From this observation it has been deduced that greater tensile stress in the surface of the ocean water, below the hurricane cloud, reduces the size of the sheared-off fog droplets and boosts the explosion strength. Hence intensification of the wind speed liberates more hydrogen bond energy, which is supplied to the storm cloud and there causes more wind speed. This amounts to positive feedback of energy and explains the self-intensification of the hurricane strength. As Roger Smith[4] wrote in a recent review of hurricane science: ". . .we still have much to learn about the basic physical processes that are responsible for the intensity of storms."

Wind shear is likely to produce fog everywhere on the ocean waves where patches of white foam become visible. The stronger the wind, the smaller the fog droplets will be, and the more hydrogen bond energy is liberated per unit ocean surface area. As revealed by water arc research, the way the chemical energy can be dissipated, concurrently with bond rupture, is by electrostatic repulsion between the atomic nuclei in the fog droplets. These repulsions cause the fog explosion.

For the sake of simplicity, consider a horizontal water surface area. Fog explosions in this surface can be resolved into horizontal and vertical components. Along the surface, the repulsions between droplets sets up compressive stress without significant horizontal droplet motion. In the vertical direction, fog droplets will be pushed upward into the atmosphere and downward into the sea. The upward fog velocity becomes part of the storm cloud and contributes kinetic energy to it.

Water arc experiments have revealed that fog droplets leave the arc column at very high velocities of 1,000 m/s (= 2,237 mph) and more. Their mass is also far greater than that of air molecules. The momentum disparity ensures that the upward flying fog droplets simply punch through the horizontal hurricane wind. This effect will be most pronounced near the eye of the hurricane where the wind speed is a maximum. Even though the fog droplets push air molecules out of the way, there will be a tendency of viscous drag pulling air along with the fog. This could be the cause of the updraft which is observed in the eyewall of the hurricane.

To obtain some idea of the order of magnitude of the fog power supplied by the ocean to the spiraling hurricane cloud we have to make a number of assumptions which could all be far off the mark. First we will speculate that the horizontal wind will continuously convert the top layer of the water into small fog droplets. The layer thickness converted in one second will be denoted by t_f. Its value is not known.

The storm force exerted on the ocean surface is not expected to be the same at all locations in the hurricane area, A_h, of radius R_h. Nevertheless, we continue to speculate that an approximate result can be obtained by assuming an average rate of fog production which prevails over a certain fraction of the hurricane area. If this average area is multiplied by the average fog production rate, we obtain the total fog mass per unit time catapulted from the ocean into the atmosphere.

Emanuel[3] estimated that a typical mature Atlantic hurricane transfers 3×10^{12} W of power from the ocean to the storm cloud. If we take the diameter of this typical hurricane to be 300 miles, then its radius R_h will be

$$R_h = 150 \text{ mi} = 241.4 \text{ km} = 2.414 \times 10^7 \text{ cm}. \qquad (1)$$

We will study this problem in cgs-units because the liberated kinetic energy of fog is given in joules per gram. The stormy hurricane area is

$$A_h = \pi R_h^2 = 1.83 \times 10^5 \text{ km}^2 = 1.83 \times 10^{15} \text{ cm}^2. \qquad (2)$$

Fog droplets will be wind-sheared off A_h in just those places where the unconstrained water surface is parallel to the horizontal wind. As discussed before,[2] this condition is met at the wave crests. If we were dealing with square waves, fog would solely be produced at the flat wave tops. Wind striking the vertical sides of the wave does not produce the necessary tensile stress in the water surface. The area occupied by breaking wave crests will be a small fraction of A_h in Equation (2). Let this small fraction be the effective hurricane area A_e to be used in calculations of the power transfer from ocean to storm cloud. A_e can be expressed as

$$A_e = x A_h, \qquad (3)$$

where x<1. In practice x will be much smaller than unity and we will speculate that it is

$$x = 1\% = 10^{-2}. \qquad (4)$$

From Equations (3) and (4) we then find that

$$A_e = x A_h = 1.83 \times 10^{13} \text{ cm}^2. \qquad (5)$$

Now we have to define a thin layer of water on A_e which will be ablated, per second, by the storm and gives rise to high velocity fog in the atmosphere. Let this layer be of thickness t_f (cm/s). If δ is the density of water (1 g/cm^3), the total fog mass, M_f, produced per second may be written

$$M_f = \delta A_e t_f = 1.83 \times 10^{13} t_f \text{ (g/s)}, \qquad (6)$$

where t_f is in centimeters ablated per second.

Finally we have to estimate the kinetic energy, E_f, per gram of fog. From water arc research[1] we know that this energy varies between 100 and 500 (J/g), depending on the size of fog droplets. Let us take

$$E_f = 100 \text{ J/g}. \qquad (7)$$

The power flowing from the ocean to the storm cloud then is

$$P_f = \delta A_e t_f E_f. \qquad (8)$$

Taking $P_f = 3 \times 10^{12}$ (W), as suggested by Emanuel,[3] we can compute the water thickness ablated per second with

$$t_f = P_f / (\delta A_e E_f) = 16.4 \times 10^{-4} \text{ cm/s}. \qquad (9)$$

The result of this speculative exercise is a 16.4 μm water ablation per second which creates fog droplets in the 1 – 100 μm diameter range. Therefore a remarkably small quantity of sheared off fog appears sufficient to make a significant contribution to the kinetic energy of the mountainous storm cloud.

Most of the sheared off fog should be found where the horizontal wind speed is greatest. This is in the central region of the hurricane. It is also the region above which the fog cloud should be very dense. The inward spiraling air of the storm is likely to sweep along and accumulate much humidity or water vapor. This saturated atmosphere will reduce ocean water evaporation near the eye of the hurricane. It is, however, at the eye where the fog density is observed to be a maximum. These facts suggest a mechanism of fog formation by wind shear rather than by evaporation and condensation.

Figure 1 is a rare photograph published on page 217 of *Divine Wind*.[3] It shows the eyewall of a strong hurricane touching the sea. The following text is the camera operator's

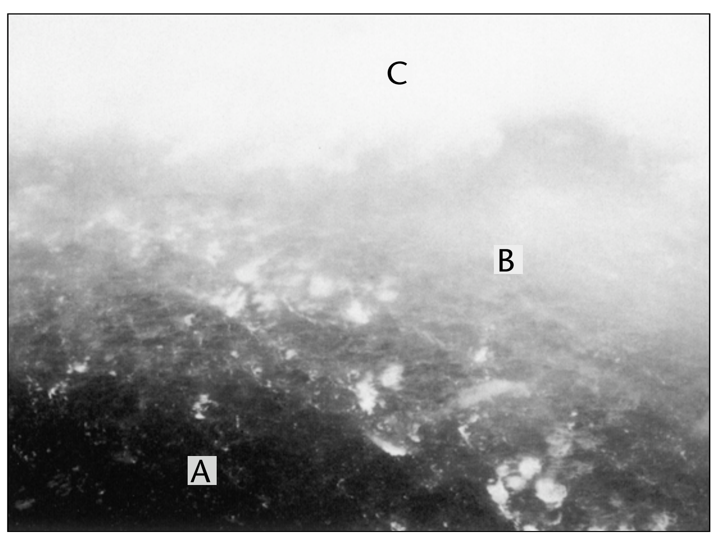


Figure 1. Photograph of eyewall at sea surface. (Courtesy of the National Oceanic and Atmospheric Administration.)

description of the photograph:

> An idea of the state of the sea under the eyewall of an intense hurricane may be gleaned from this remarkable photograph of the inner edge of the eyewall of Hurricane Gilbert of 1988, which set an all-time record for the lowest pressure observed in an Atlantic hurricane. The center of the vortex is off the lower left corner of this picture. Traveling outward from the center (starting in the lower left and proceeding upward and rightward in this picture), there is a sudden increase in wind speed, revealed by a sheet of sea spray blasted upward from the ocean. The pancake-shaped white patches are places where the wind is literally scooping water from the sea; these are large enough to contain a ship. The eyewall itself can be seen in the upper part of the picture, nearly touching the sea surface. This is a place of unmitigated violence, where bubble-filled water gradually gives way to spray- and cloud-filled air, with no definite interface which one could call the ocean surface. It is arguably the worst place in the world for a ship.

Three areas of the photograph can be distinguished. I have labeled them A, B, and C. A is the calm sea inside the eye of the hurricane. B is an extremely turbulent part of the sea surface of ill-defined depth. C is dense fog which lies on top of the wall. This has to circulate around the eye at high speed so that centrifugal forces keep the fog out of the eye.

The usually calm events of ocean water evaporation and fog condensation during cloud formation can hardly explain the violent behavior of the sea wall indicated in Figure 1. Other forces must be at work. They are likely to be the result of the storm itself and not just the molecular action of water associated with reversible phase changes between liquid and vapor.

It is gratifying to find that our previous investigation of water arc explosions should be of help in another area of research—that of hurricane science. The most interesting aspect of this interdisciplinary exercise is the vivid demonstration of massive chemical energy liberation in the storm cloud without carbon dioxide production. There is probably no way in which the hurricane energy can be tapped, in any practical sense, for electricity generation. The size of the storm, its mobility and transient character, all rule against useful exploitation.

On the other hand, there is hope that hydrogen bonds can be ruptured in flowing water with compressed air blowing over the surface. The resulting fog should be blasted vertically upward and could possibly be directed into a fog turbine, as discussed in *Infinite Energy*.[5] An advantage of this type of apparatus would be the continuous running of the turbo-generator, as opposed to the pulsed operation enforced by electric underwater arcing.

References

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