

Air-Water Experiments: Getting Started

The second series of experiments will deal with air and some aspects of water. The experiments related to air will range from the large scale of the circulation of the atmosphere to the quality of air that you breathe. We will simulate the flow of air with experiments in water and look at the circulation of water in an estuary and in the deep ocean basin. The experiments will introduce new ideas but also will continue the flow of ideas from the Energy unit. One of the most pressing issues of our time, global warming, involves energy, air and water. These are complex issues that can lead even the savviest scientists to disagree. The response of the planet to our machinations is not simple to predict, and there is much that goes on at the emotional and aesthetic level.

As in the first section, you will do two experiments and spend 2-3 lab periods on each. For each lab you will begin with the 'Getting Started' guide. Once you have successfully carried out these fairly explicit experiments, use the rest of the time available to make more explorations on your own. Part of the 'exploration' phase of the experiments involves writing notes in your lab-book on some of the other experiments, and where relevant, relating them to the experiments you have done. Both the 'getting started' phase and the 'later exploration' phase are important to carry out. Unlike the Energy Unit we will not be handing out a 'Background' document. Rather, at the end of each experiment description we list some applications and we hope you will research these topics on-line or in the library.

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AW1. A miniature planet: weather, heat transport, climate on a rotating planet.

The general circulation of the atmosphere is driven by heating and cooling: the Sun once again. The tropical band near the Equator receives more solar radiation than the high latitudes near the Poles. At all latitudes heat is radiating to space, and so there must be a flow of heat from low latitudes to high. The most obvious circulation of the atmosphere is the east-west winds: the 'westerlies' in middle latitudes and 'easterlies' nearer the Equator. Yet it is the north-south, up-down circulation (called the 'meridional circulation') that moves heat from hot regions to cold. The two kinds of circulation, east-west and north-south interact with one another.

1. Using a rotating platform, create a model of the atmosphere's circulation, driven (as it is driven) by temperature differences between pole and equator). A Plexiglas cylinder with a smaller glass cylinder inside it will give a 'gap', or annulus in which to put water (which simulates the air of the atmosphere). To create the solar heating contrast, put ice in the central, small cylinder and take time to center the cylinder on the table. Observe the fluid motions with dye and small particles, sketching and estimating some velocities. How does it compare with and without rotation.

2. The flow will have features which model atmospheric jet streams, convection, westerly and easterly wind. Measure temperature field with electronic thermometer, with and without rotation of the 'Earth'. Sketch and describe streamlines in the fluid ('streamlines' are curves drawn parallel with the velocity of the fluid).

3. What happens if there are mountains at the base of the fluid?

Applications: This experiment has the same basic elements as the circulation of the atmosphere: it is a heat engine, fueled by the heat flow from the warm 'tropics' to the cold 'polar region'. Without the effect of the rotation of the experiment, the response would be a simple Hadley cell, rising fluid in the tropics moving toward the pole, cooling and sinking and moving back to the tropics. As described in lectures, the spin (rotation) of the 'planet' is concentrated in fluid moving toward the pole, which then rotates round the pole faster than the underlying rotation; these are the 'westerlies' or eastward blowing winds. Conversely fluid moving outward (toward the warm region) spins less rapidly than the Earth: these are the easterly or 'trade' winds. These strong flows can break apart into weather systems, rotating cells of flow. The systems that rotate in the same sense as the experiment (counterclockwise in the northern hemisphere) are called cyclonic and have low pressure at their centers. High-pressure systems rotate anti-cyclonically. In the actual atmosphere, air rushes into the low-pressure centers along the ground, and rises upward at its center. This rising air expands, cools and the moisture in it condenses into cloud and rain (winter in Seattle, or in a small rainstorm). A high pressure center forces air outward at the ground, so that air must descend in the center: this dries it out, and skies are clear (summer in Seattle, or over the deserts). The experiment has 'jet-streams' which are rapid, thin currents concentrating the westerly and easterly flow. The jet streams exchange heat very efficiently, and snake their way round the eddies (highs and lows).

This experiment has implications for climate change, variability, greenhouse, patterns (modes) of climate variability, global warming.

AW2. Violent Storms: hurricanes and tornadoes.

Tornadoes are particularly strong vortices (vortexes) that form when conditions are just right (more than 90% of tornadoes on Earth apparently are in the US Midwest). Wind speeds can exceed 200 M.P.H. and they can lift pickup trucks and cows high in the air. They occur when clusters of cumulus clouds become intense, which involves upward air movement that can be very strong, drawing air in toward their center. Here we simulate this inward movement by withdrawing fluid at the bottom rather than the top.

1. Make tornadoes in a Plexiglas cylinder with a hole in the bottom (sitting in a lab sink); do this by filling the cylinder with water and letting it drain. You can introduce a small amount of rotation with your hand or let it develop naturally – be patient. Use dye to see the pattern of flow. Try the experiment with the tank as is which has a fairly wide region of outflow and with a the inverted dish that has a pinhole exit.
2. Using colored dye and particles study and record the motion of the fluid more carefully, its rate of spin at different distances from the axis, and its (more subtle) movement from the water source at the rim to the outlet at the center.
3. “Desymmetrize” the experiment: that is, make it not so symmetrical, for example by putting a clay ‘mountain’ on the bottom, or moving the outlet away from the exact center, and see if the tornado still can form.
4. Hurricanes are much larger storms energized by the warm, tropical ocean. Whereas the tornado cannot directly feel the Earth’s rotation, the hurricane does. Build a simulation using a rotating platform. You could heat it from below (with a heating pad) or, what is quite similar, simply use warm water and let cool from above. Explore the relation of the size and intensity of the ‘hurricanes’ and the rotation speed of the ‘planet’

Applications: cyclones (hurricanes) in Bangladesh; why is that lowland country so vulnerable? Possible change in hurricanes due to global warming, geography of tornados, why are most in the central US?

AW3. Atmospheric inversions over a city and smog particles

Much of the pollutants in air are produced near the ground by cars, factories, etc. They can be trapped by layers of atmosphere which have different density, known as ‘stable density stratification’. The situation can be made much worse by mountain ranges that block the winds, and by strong summer sunshine that can create density stratification and worsen the chemistry of the pollutants. We can make a model of the situation with stratified gas, but using a mixture of carbon dioxide (from dry ice) and air. Condensed water droplets make the cold CO₂ visible for

some time. The carbon dioxide has no chemical role here; it just comes along with the cold ice. If the sun heats up the lower atmosphere, it may convect upward but bump into the stratification. It can produce an 'inversion' or very big density change at the top of the convecting layer.

1. Create a stratified gas in a Plexiglas rectangular container, with a small beaker of dry ice. Measure some temperatures or make a full temperature profile (the density will depend both on temperature and amount of CO₂, which unfortunately we can't measure).
2. Observe waves in the stratified 'atmosphere'.
3. Introduce some candle smoke near the bottom, as a pollutant. Observe how it develops. Use a slide projector to make a sheet of light to illuminate the gas. A laser beam may tell more: in ideal circumstances it can actually tell the size of the particles it hits.
4. Put a small, weak heat source at the base of the fluid (heating pad or a resistor connected to a d.c. power supply), to simulate the morning sun; what happens to the pollution and density stratification? Could you measure the concentration of smoke pollutant using a light beam and radiometer?
5. Working in the tall Plexiglas tank, view smoke particles, chalk dust and water mist droplets with a laser or light-sheet from a slide-projector, and look at their settling, removal by electrostatic fields, and removal by 'rain'. How quickly do they settle?

Applications: air quality of LA, Denver, Seattle. What added factors make pollutant levels worse? Add chemical reaction, estimate photochemical effects (making smog). See A3 too. Look on the web for information about particle sizes in air pollutants (lately, diesel fumes in Seattle and blowing dust in eastern Washington). Look at the daily air cycle in a city like Los Angeles, where there is confinement by mountains and hot sun.

AW4. Ocean Estuaries and Tides

Estuaries are formed where rivers spill into the sea. They are often regions of great biological productivity, with biological food chain active from microscopic plankton to large sea creatures and birds. At one end the ocean provides salty, dense water rich with nutrients; at the other, the river water is very buoyant and floats out over the salt water. The tides totally change the circulation: these mix up the river water and lead to an 'overturning circulation' (seaward at the top, landward at the bottom). The strength of this circulation far exceeds the simple river inflow, and it is important in ventilating the estuary with oxygen and nutrients. In this experiment we want to explore the overturning circulation, its dependence on tides and river flow and other mixing. There may be ridges on the seafloor that are involved, and layering of the density is important to examine.

The estuary model comprises a large tank (the ocean) connected horizontally to a smaller tank (the estuary). The tank is filled with a 3 weight % salt (sodium chloride) solution (seawater) and

a motor drives a water filled bottle up and down in the main tank to generate tides. A fresh-water drip and bubbler simulate river inflow and mixing in the estuary.

1. Use the power supply to systematically vary the period of the tide (the time it takes the bottle to go up and down) and for each setting allow a couple of minutes for the model to come to steady state. Measure the tidal amplitude in millimeters at the far end of the estuary and plot them on a graph of amplitude versus period. What do you see?
2. Now turn on the river (dropper) and trace water flow with dye. You can use a slide projector to see the patterns of salinity and the salinity probe or the salinometer to measure variations in salinity.
3. Now turn on the bubbler to increase the amount of mixing within the estuary. How does this affect the flow in the estuary?
4. Put in a wedge/bump (sill) in the bottom about 2/3 toward the ocean from the river and use the dye to look at the flow and mixing over it. How has the circulation changed?
5. Add a second sill and repeat.

Applications: Estuaries such as Puget Sound, San Francisco Bay Chesapeake Bay. Flushing pollution and sewage out to sea.

AW5. Circulation of the Global Ocean and Climate Change

At a much larger scale than an ocean estuary, we find some similar events: the entire global ocean has a circulation that involves sinking at high latitude, and rising elsewhere. This kind of circulation, sometimes known as a 'conveyor belt' brings nutrients to the sea surface where in the sunlight they make for very active growth. Phytoplankton, the 'grass of the seas', grow there and lead to a whole spectrum of animal life. A fundamental property is the 'layering' of the ocean, with dense (cold or salty) waters at the bottom and buoyant (warm or fresh) waters at the top. It is very difficult to move vertically against this density difference. In the experiment we want to observe the form of the ocean circulation when at the surface the water is made dense or less dense by cooling and heating or by 'rainfall' and evaporation.

1. One of the simplest ways to begin is to use a small amount of crushed ice to cool the surface and observe the circulation that follows, using colored dyes, ink, or small particles in the water. The rates of circulation can be observed, as well as internal wave motions, where regions of different density move in a 'silent surf.'
2. Put saline water (made by dissolving 10 g of salt per 100 g of water) in a beaker. Its density will be close to 10% greater than fresh water. Instead of crushed ice, use a pipette to place a few drops of this water on the surface of the experiment near one end, and used dyes to trace the circulation that develops. This is a similar circulation, showing that evaporation at the sea surface or rainfall (which change the surface salinity) can drive deep-ocean circulation.

3. Note the vertical motion of the fluid, comparing the sinking regions with the regions of rising water (this is an appropriate model of the global ocean circulation, and its form largely controls where the biological communities in the world's oceans can be active).
4. You may want to examine the competing effects of heat and salt on the ocean circulation. Of great importance is the observation that the oceans are cooled at one end of the 'tank'; look at the difference in circulation when the crushed ice is uniformly distributed along the surface, compared with placing it all near one end.

AW6. Rain, clouds and snow: Ice crystal growth, freezing of water, cloud chamber

The temperature of the atmosphere decreases rapidly with height above ground. On a partially clear day we see clear air up to an altitude, known as the condensation level, where the bottoms of clouds are found. This level is usually quite definite. When air flows over mountains, it has to rise and when it reaches the condensation level cloud (water droplets) appears: then when it flows down the other side the cloud disappears (the air flows *through* the cloud). Higher up, water vapor forms ice crystals there rather than rain drops. Above -40°C temperature there has to be a dust particle or other nucleus for the ice to form on.

1. Using a cold chamber (tall foam plastic box) cooled by dry ice, capture ice crystals on a soap film and watch them grow; measure temperature at various depths in the box. Use a piece of copper wire formed into a loop, with a dilute dish-washing soap solution to make a bubble film you can lower into the box. There are relatively few ice crystals because only one particle in 10^8 (100 million) is the right shape and size. Note the eventual freezing of the soap film itself. On a thin layer of water observe freezing using polarized light.
2. Place a metal sheet over all but one corner of the chamber and measure how the temperature varies with depth using one of the thermostats we used to monitor our solar ovens.
3. Place a moist paper towel under a metal sheet over the top of the ice chamber and look at ice crystals growing on the end of a needle left in the cold region. Where do the crystal form and what are the temperatures.
4. With assistance set up the cloud chamber, and observe the condensation of water vapor in air that is cooled at the bottom (to -60°C) by dry ice. Alcohol vapor may also be used and has some advantages. A remarkable side-effect of this experiment is the appearance of streaks...contrails of cloud. These are the tracks of atomic particles (*individual atomic nuclei and electrons*). Measure the temperature profile if it is possible, with a small thermostat. NOTE: if you use an electric field to 'clear the air', do it only with supervision.

Applications: where are ice crystals found and what is their importance to clouds and weather, and to the chemical balances high in the atmosphere? Where are freezing levels geographically and by season? Interact with the evaporation and water vapor experiment (AW8).

AW7. Winds in the lower atmosphere.

The lowest few hundred meters of the atmosphere are known as the ‘atmospheric boundary layer’. Here the winds change from their high speed (farther up) to nearly zero at the ground. In doing so they become turbulent - unsteady, full of whirling eddies. Both the variation of wind-speed as you go up or down, and the turbulence have strong effect on the movement and dilution of atmospheric pollutants.

1. Using the water flume as a model of the lower atmosphere, we can look at the flow near lower boundary. Turn on the power to the propellers, and watch the flow develop. Use dye and eyedroppers to visualize the flow, particularly near the bottom.
2. Try to install a model ‘smoke-stack’ which can continuously inject dye (‘smoke’) into the flow. Track the dye (modeling smoke) down wind, for slow and fast flows.
3. Explore the effect of a hill or ridge on the flow: how does the average velocity change, and how will the mixing of a pollutant source change? What is the effect of the mean velocity of the water (as determined by the power setting of the propellers and measured with the velocity probe)?

Applications: effect of winds on pollutants in the lower atmosphere: the air we breathe; the role of mountains (and at smaller scale, buildings) in changing wind patterns and the ‘ventilation’ of the air near the ground.

AW8. Evaporation, water vapor

Heat moves around the atmosphere in two forms: as hot air and as moist (humid) air. If you have been in the Great Plains or the east coast in summer, you know what high humidity feels like. At night the sun goes down but it doesn’t cool off. You lie awake because sweat does not cool you. By contrast, try sail boarding on a high-mountain lake in Colorado in summer, where the humidity is very low. Don’t wear a tee-shirt! It can take you close to hypothermia when it gets wet. We want to look at how much water can be held in gaseous form by air of a given temperature.

The tendency for water to evaporate is described by its ‘vapor pressure’, which is the pressure the water molecules produce when they are a gas rather than liquid. Air can hold only about 5 to 10 grams of water per kilogram of air, and the amount is often described by its ‘relative humidity’, the amount of water vapor in air as a percent of the full air pressure (water vapor + oxygen + nitrogen...). This amount changes greatly with the temperature of the air (warm air holds more moisture). How could we observe and measure some of these effects?

1. Using a mist sprayer and piece of liquid-crystal ‘thermometer’ sheet, look qualitatively at the cooling effect of a water mist. What is the energy cycle at work?

2. Measure the room temperature and then, using a thermometer with a moist cloth wrapped round its bulb, twirl it in the air on a string so as to ventilate the cloth (or arrange an electric fan). Measure the change in temperature as evaporation occurs, cooling the thermometer. Using printed tables, convert this into the humidity value (a chart showing this is on the bulletin board).
3. Boil some water and capture the steam, measuring the temperatures throughout the whole system. Beware: the word 'scald' is frightening, and it describes what happens when steam (hot water vapor) condenses on a cool surface. Use a metal plate and monitor its temperature.
4. With help set up the experiment to look at the boiling of water in a partial and nearly full vacuum. How does the boiling point depend on pressure.

Applications: vapor pressure of a water surface; cumulus clouds taking up water vapor, condensing to visible droplets where heat is released (making the air more buoyant, so that it rises violently); heat engine in a single cloud and the global heat engine, latent/sensible heat flux. Interact with the ice crystal and cloud chamber experiment (AW6).