How Cool Is That?
Evaporation of Liquids

Introduction

It's a hot and sunny summer day, and you step out of the pool, cool and refreshed. Soon, however, your teeth start chattering and your lips turn blue. Water evaporating from your skin draws heat from your body, leaving you feeling cold. The "cooling effect of evaporation" is nature's most important way of cooling not only our bodies but also the Earth! How cool is evaporation?

Concepts

- Evaporation
- Kinetic-molecular theory
- Polar vs. nonpolar compounds
- Hydrogen bonding

Background

Vaporization is the process by which a substance changes from a liquid to a gas or vapor. When vaporization occurs gradually from the surface of a liquid, it is called *evaporation.* Evaporation is an endothermic process—energy is required for molecules to leave the liquid phase and enter the gas phase. The most common way to provide energy for the vaporization of a liquid is by heating it. Water evaporating from the Earth's oceans, for example, absorbs heat energy from the sun and helps to moderate the temperature around large bodies of water. When the heat energy for vaporization comes from the surroundings rather than from external heating, the temperature of the surroundings will decrease when a liquid evaporates. This is the origin of the cooling effect of evaporation. Water evaporating from the surface of the skin by perspiration, for example, cools the body.

Evaporation and the cooling effect of evaporation may be explained using the *kinetic-molecular theory*. According to this model, molecules in the liquid state are in constant motion, and interactions among neighboring molecules influence the motion of the molecules and the properties of the liquid. The temperature of a substance is proportional to the *average kinetic energy,* and thus the average speed, of the molecules. Evaporation occurs when fast-moving molecules near the surface of a liquid have enough energy to break free of their interactions with neighboring molecules and "escape" into the gas phase. Molecules with the highest kinetic energy evaporate and become gas molecules. The average kinetic energy, and thus the temperature, of the remaining molecules decreases—a liquid cools as it evaporates. This phenomenon is known as "evaporative cooling." The rate of evaporation of a liquid increases at higher temperatures, because more molecules have enough energy to break free of the liquid's surface.

The rate of evaporation of a liquid depends on the nature of the liquid and the type of attractive forces between molecules. Strong intermolecular attractions hold the molecules in a liquid more tightly. Liquids with weak intermolecular attractive forces have low heats of vaporization and are volatile—they evaporate easily. Liquids with strong intermolecular attractive forces evaporate more slowly, because a greater amount of energy is needed to overcome the attractive forces between the molecules.

Nonpolar compounds generally have very weak attractive forces, called London dispersion forces, between molecules. The strength of London dispersion forces increases in a regular manner as the size of the molecules increase. Dipole interactions occur when polar molecules are attracted to one another. Because dipole interactions are stronger than dispersion forces, polar compounds generally have higher heats of vaporization and evaporate more slowly than nonpolar compounds (assuming that the molecules have similar molar masses). Hydrogen bonding represents a special case of dipole interactions, in which F–H, O–H and N–H groups in molecules associate very strongly with electronegative atoms in adjacent molecules. Hydrogen bonds are the strongest type of intermolecular attractive forces. Hydrogen bonding in water, for example, leads to a high degree of association among water molecules in the liquid and solid state. As a result, water is a very unusual liquid in many ways. It has an unusually high heat of vaporization and a very high boiling point compared to other compounds that are about the same size or have similar structures. Evaporation of water acts as a "heat sink" for energy from the sun. A significant portion of the sun's energy that reaches Earth is spent evaporating water from the oceans, lakes, and rivers rather than warming the Earth.

Experiment Overview

The purpose of this experiment is to measure the temperature changes that occur when different liquids evaporate and to compare their rates of evaporation. The experiment will be carried out using a computer interface with temperature probes or sensors that have been soaked in various liquids. The temperature will be recorded versus time as the liquids evaporate. Liquids will be compared pair-wise (e.g., polar versus nonpolar, presence or absence of hydrogen bonding, etc.) and the results will be analyzed in terms of the strength of attractive forces.

Pre-Lab Questions

Complete the following table summarizing the properties of the liquids to be studied.

Compound	Structural Formula	Molar Mass	Polar vs. Nonpolar	Hydrogen Bonding Ability
Acetone				
Ethyl Alcohol				
Heptane				
Hexane				
Isopropyl Alcohol				
Methyl Alcohol				