Working in Water 1
Cornerstone Electronics Technology and Robotics III
(Notes primarily from “Underwater Robotics – Science Design and Fabrication,” an excellent book for the design, fabrication, and operation of Remotely Operated Vehicles [ROVs])

- **Administration:**
  - Prayer
- **Physical Properties of Water:**
  - Water is called the "universal solvent" because it dissolves more substances than any other liquid.
  - As more impurities are absorbed into water, its chemical and physical properties change drastically.
  - **Chemical Properties:**
    - Water has the ability to dissolve salts.
      - Salt molecules break apart into ions.
      - These ions fit into spaces between the water molecules, adding mass without adding much volume to the water. Therefore, dissolved salts increase water’s density and salt water is denser than fresh water.
      - Read the story of the Aluminaut in the historical highlight on page 139 of the textbook.
      - Perform Working in Water Lab 1 – Salinity and Density of Water
      - Salinity – the concentration of salts dissolved in water
        - Expressed in parts per thousand by mass or weight (ppt or o/oo)
        - Salinity has a much higher effect on water density than does temperature.
        - Salinity of the open ocean is between 33 ppt and 37 ppt.

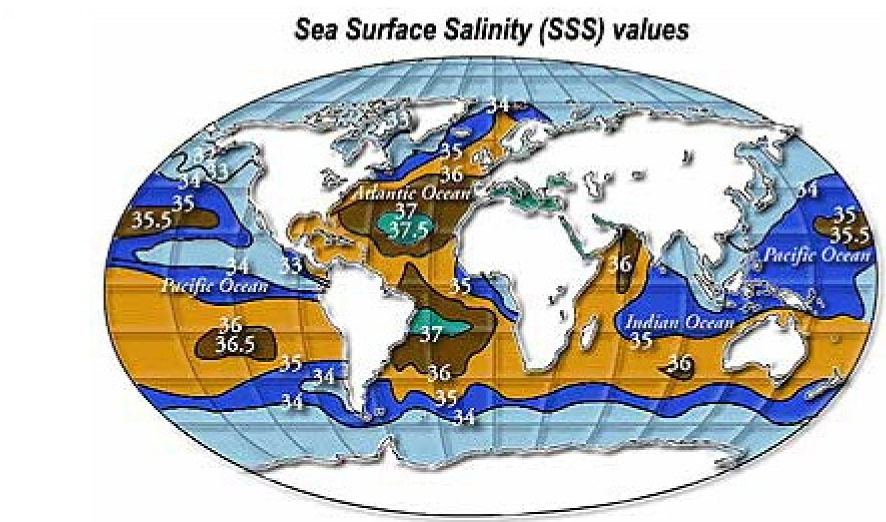


Figure 1: Sea Surface Salinity Values
From: http://science.nasa.gov/earth-science/oceanography/physical-ocean/salinity/

- Thermohaline circulation is the name for currents that occur when colder, saltier water sinks and displaces water that is warmer and less dense.   In Earth's equatorial regions, surface ocean water becomes saltier as the water, but not the salt, evaporates. However, the water is still warm enough to keep it from sinking. Water that flows towards the poles begins to cool. In a few regions, especially in the North Atlantic, cold salty water can sink to the sea floor. It travels in the deep ocean back towards the equatorial regions and rises to replace water which is moving away at the surface. This whole cycle is very important in regulating climate as it transports heat from the equatorial regions to polar regions of Earth. The full cycle can take a thousand years to complete.

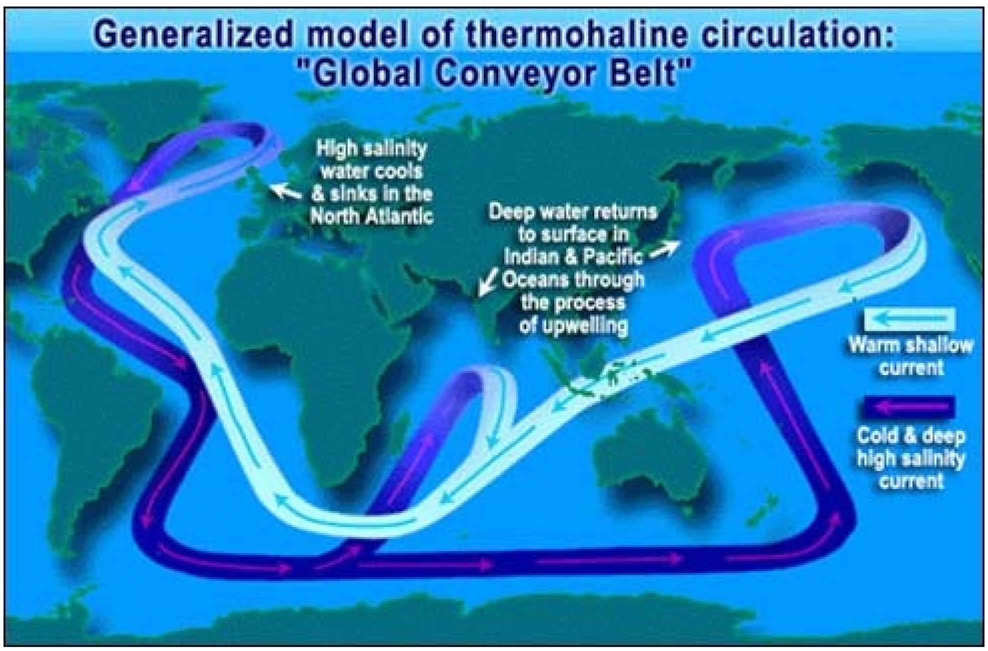


Figure 2: Thermohaline Circulation in the Oceans

From: http://science.nasa.gov/earth-science/oceanography/physical-ocean/salinity/

- o Dissolved salts in ocean water:

Component	Weight grams	ppt
Pure water	965.31	
Chlorine	19.10	19.10
Sodium	10.62	10.62
Magnesium	1.28	1.28
Sulfur	2.66	2.66
Calcium	0.40	0.40
Potassium	0.38	0.38
Minor constituents	0.24	0.24
Trace constituents	0.01	0.01
Total	1000.00	

Table 1: Dissolved salts in Ocean Water

- o Salinity of the fresh water is typically less than 1 ppt.
- o Salinity of the Dead Sea is about 300 ppt.

Figure 3: Photos from the Dead Sea

- o **Electrical Properties:**
  - ▪ **Electrical Conductivity** – The ability to conduct electrical current.
    - Water in its pure form is an insulator, but as found in its natural state, it contains dissolved salts and other matter which makes it a partial conductor.
    - Ions also increase water's electrical conductivity. Increased conductivity:
      - o Shorts out equipment that comes in contact with water
      - o Blocks radio signals
      - o Accelerates corrosion of metals
    - Seawater is a good conductor, that is, it has high electrical conductivity. Seawater has conductivity of around 54,000

microSiemens/cm (µS/cm). Regarding the unit of measure µS/cm, see http://www.eutechinst.com/techtips/tech-tips25.htm.

- As the concentration of salts in the water increases, electrical conductivity rises — the greater the salinity, the higher the conductivity.
- Most fresh drinking water will have less than 100 µS/cm. Gainesville Regional Utilities tap water conductivity measures approximately 40 µS/cm.
- Electrical conductivity of ultra-pure water is 0.055 µS/cm.
- You must take steps to protect electronics from exposure to water.
- Water's conductivity creates a serious electrocution hazard. See page 129 in the textbook for basic safety rules.
- Perform Working in Water Lab 2 – Measuring Electrical Conductivity

▪ **Corrosion** – the deterioration of a material by a chemical reaction to its environment.

- Metals corrode because they oxidize easily; the oxidation of most metals is spontaneous.
- When exposed to air, most metals develop a thin oxide coating. This coating tends to protect their internal atoms against further oxidation, as in the behavior of aluminum oxide forming on aluminum. On iron, the oxide scales off easily and exposes new metal surfaces to corrosion.
- Water accelerates corrosion rates for metals, particularly saltwater.

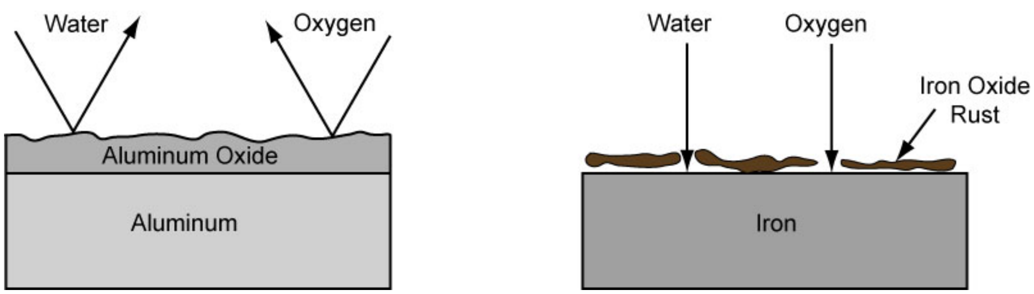


Figure 4: Oxidation of Aluminum and Iron

- Steel does not rust in dry air. Moisture and salt accelerate the electrochemical corrosion process (the rusting process).
- Corroded metal often loses its structural integrity and attractive appearance. Corrosion is generally undesirable and has a great economic impact through replacement and prevention costs.
- For the fundamentals of metallic corrosion in fresh water, see: http://www.roscoemoss.com/tech_manuals/fmcf/fmcf.pdf

- **Radio Signal Attenuation** – To reduce the amplitude of a radio signal
  - Attenuation of radio waves in water increases as the conductivity of the water increases and as the radio frequency increases.
  - Unlicensed signals from common hobby radio-controlled equipment has difficulty penetrating seawater and can only work to a depth of approximately 1.5 meters.
  - The military uses extremely low frequencies (ELF) (76 Hertz) to communicate with their submarines deep in the sea. Transmitting at these frequencies requires very long antennas. The antenna length in Republic, Michigan was approximately 52 kilometers (32 miles). Due to the technical difficulty of building an ELF transmitter, only the USA and the Russian Navy owned such systems. Two factors limit the usefulness of ELF communications channels: the low data transmission rate of a few characters per minute and the one-way nature of communications.

o **Mechanical Properties:**

- See the textbook regarding the definitions and discussion for force, weight, mass, and gravity.
- **Density** – a measure of the compactness of a substance, expressed as its mass per unit volume.
  - In underwater design, density is a very useful concept.
  - Density is defined as mass per volume:

$$d = m / v$$

Where: d = density in kg/m^3 or g/ml
m = mass in kg or g
v = volume in m^3 or ml

  - The density of water is 1 g/cm^3 or 1 g/ml or 1 kg/l or 1000 kg/m^3 or 62.4 lb/ft^3.
  - As water temperature rises, molecular agitation increases the water's volume, which in turn lowers the density.
  - As water freezes, the molecular lattice structure increases the water's volume which again lowers the density. This makes water different. Most substances are most dense in their solid (frozen) state than in their liquid state.
  - Maximum density of water is at approximately 4 degrees Celsius.
- **Specific Gravity** – the ratio of the density of a substance to the density of a reference substance. The reference substance is nearly always water for liquids or air for gases.
  - If an object's density is less than the density of the fluid it is in (in our case the fluid is water), that object will float.
  - If an object's density is more than the density of the fluid it is in, that object will sink.

- At 4 degrees C, fresh water has a density of 1 g/ml, so any substance whose density is less than 1 g/ml will float.
- Specific gravity is the ratio of the density of a substance to the density of water.

specific gravity = density of material / density of water

- A material with a specific gravity less than 1 will float in freshwater; a material with a specific gravity greater than 1 will sink.

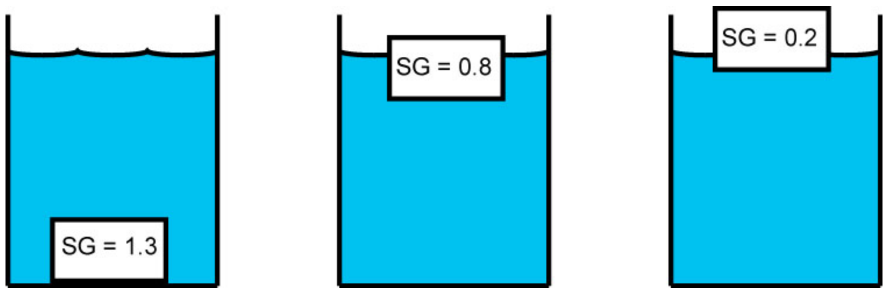


Figure 5: Specific Gravities Relative to Freshwater

- The average specific gravity of sea water is 1.025; if a material has a specific gravity less than 1.025 it will float in seawater.
- Perform Working in Water Lab 3 – Density and Sink or Float

▪ **Hydrostatic Pressure** – The pressure exerted on an object at rest which is immersed in water. This pressure is applied to the object by the weight of the water above it.
  - The deeper the object is immersed, the taller the column of water the object must support. This means the hydrostatic pressure exerted on the object increases as the depth of its immersion increases.
  - At about 10 meters below the surface, the water exerts twice the pressure (2 atmospheres) on the body as air at surface level (1 atmosphere). Standard sea-level pressure, by definition, equals 1 atmosphere.
  - As a rule, hydrostatic pressure increases 1 atmosphere for every 10 meters of additional depth.

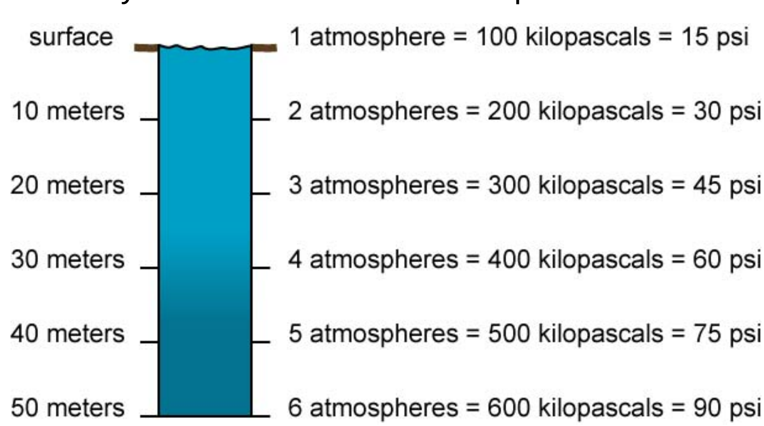


Figure 6: Approximate Hydrostatic Pressure at Increasing Depths

- When submerging a water-tight container in water, pressure differences between the inside and outside create mechanical forces that the container must withstand. For example, the container at 50 meters in Figure 7 must resist the difference between the outside pressure of 6 atm and the inside pressure of 1 atm, or a net pressure of 5 atmospheres or 75 psi.

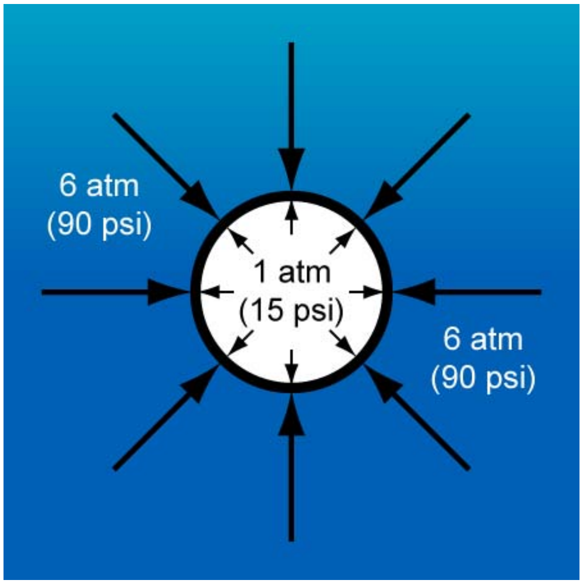


Figure 7: A Container Under Hydrostatic Pressure at 50 Meters

- The pressure in the Mariana Trench in the Pacific Ocean (the deepest part of the world's oceans) is 15,750 psi.
- Water pressure can compress foam used as floats onboard a ROV. If taken too deep, the compressed foam will not provide the buoyancy expected and the ROV may not be able to surface.
- Hydrostatic pressure also has an intrinsic ability to penetrate any gaps in waterproofing measures, leaving evidence of the leak.

Cornerstone Electronics Technology and Robotics III
Working in Water Lab 1 – Salinity and Density of Water

- **Purpose:** Observe how salt content affects the density of water.
- **Apparatus and Materials:**
    - Tap Water
    - 5 g of Table Salt
    - Food Colors in Squeeze Bottle (See: http://www.walmart.com/ip/Sauer-s-Colors-and-Egg-Food-Dye-4-pk/10536061)
    - 1 – Plastic Sandwich Bag
    - 2 – Small Water Glasses
    - 1 – Glass Vase
    - 1 – 100 ml Graduated Cylinder
    - Scissors
- **Procedure:**
    - **Perform this experiment outside**; it tends to be messy.
    - Pour tap water into the glass vase until the water is almost level with the top of the vase. Set the vase on a flat surface and let it sit undisturbed for ten minutes. This will minimize the currents caused by pouring water into the vase. The contents of the vase will be considered fresh water.
    - Pour 50 ml of tap water into each small water glass. One glass will be used for the salt water solution, and the other will be used for the fresh water solution.
    - Add 5 or 6 drops of food color into each glass.
    - Add 5 grams of common table salt into only one of the glasses to compose the salt water solution.
    - Stir both the fresh water and salt water solutions.
    - Take the plastic bag and cut **one** of the bottom corners so that a 2 – 3 mm hole is open at that corner.
    - Pour a small amount of the salt water solution into the plastic bag. Let the solution settle at the end that you did not cut.
    - Place the plastic bag against the inside rim of the vase and pour the colored solution against the glass for 2 – 3 seconds.
    - Observe where the salt water solution settles in the vase of fresh water. Record your results.
    - Now pour the colored fresh water solution into the vase in the same manner that the salt water solution was poured.
    - Observe where the fresh water solution settles in the vase of fresh water. Record your results.
- **Results:**
    - Where did the salt water solution settle in the vase of fresh water?
    - Where did the colored fresh water solution settle in the vase of fresh water?
- **Conclusions:**
    - Which solution has the higher density?

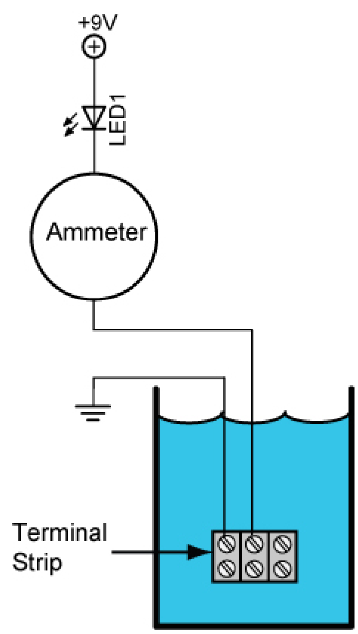
Cornerstone Electronics Technology and Robotics III
Working in Water Lab 2 – Measuring Electrical Conductivity

- **Purpose:** The student learns how to measure the electrical conductivity of water and how salt content affects the electrical conductivity of water.

- **Apparatus and Materials:**

  - Tap Water
  - Table Salt
  - 1 – 1000 ml Beaker
  - 1 – Digital Multimeter
  - 1 – Ideal #89-203 Terminal Strip
  - 1 – Breadboard with a 9 Volt Power Source
  - 1 – Red LED
  - Miscellaneous #22 Solid Wires
  - 1 – Pasco PS-2116A Conductivity Sensor See: http://store.pasco.com/pascostore/showdetl.cfm?DID=9&PartNumber=PS-2116A&Detail=1
  - 1 – Pasco PS-2100A USB Link See: http://store.pasco.com/pascostore/showdetl.cfm?DID=9&Product_ID=1536&Detail=1
  - 1 – Computer with Pasco DataStudio Lite Software See: http://www.pasco.com/support/downloads/index.cfm

- **Procedure:**
  - Fill the beaker with 1000 ml of water.
  - Wire the circuit as shown in the schematic below:



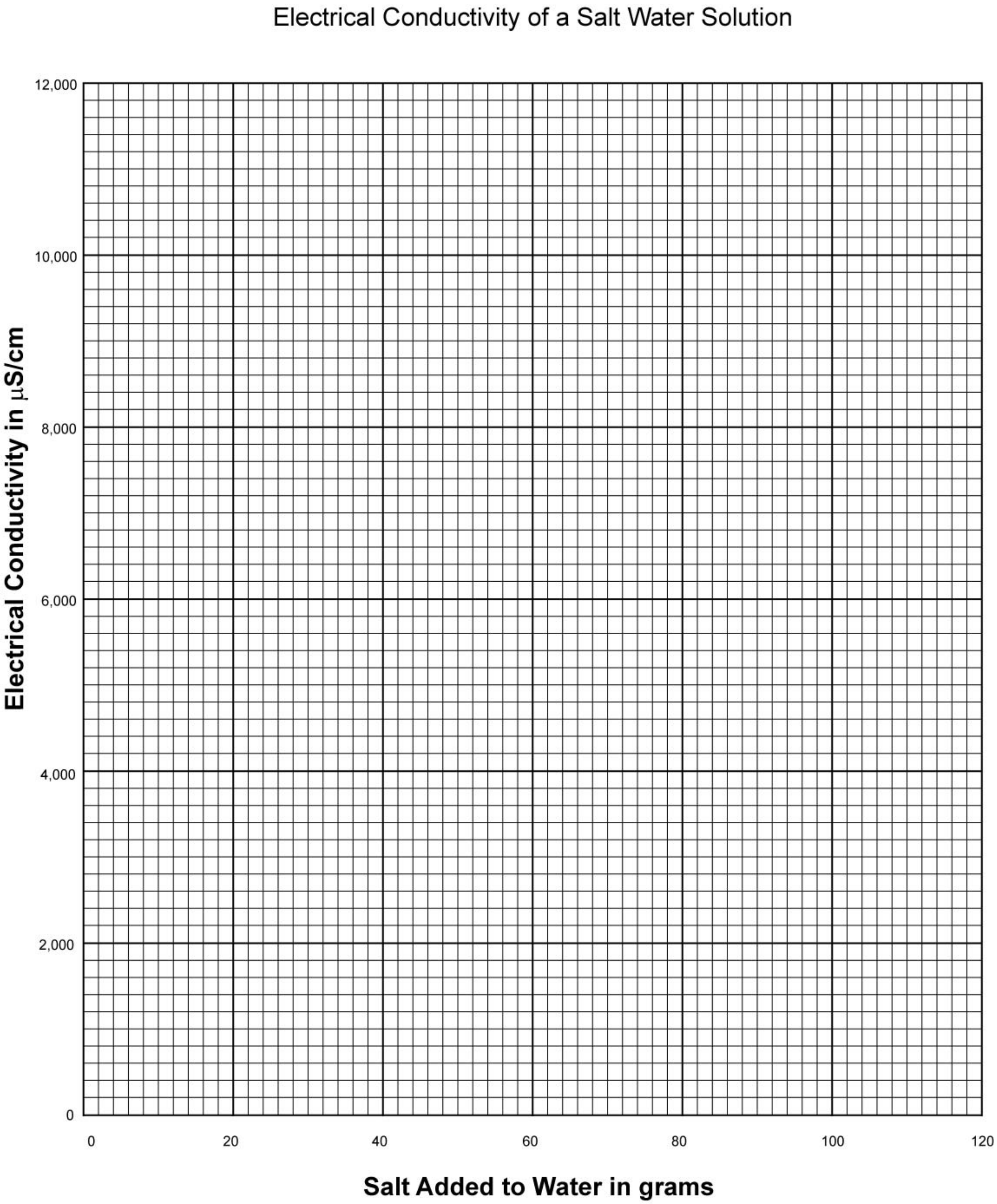
  - Set the conductivity sensor to the 0 – 100,000 µS/cm scale (the wave symbol)
  - Insert the conductivity probe into the water.

- Using the computer interface, measure the electrical conductivity of the tap water. Also measure the current on the DMM. Record your results. (You may have to reboot the computer to recognize the conductivity sensor.)
- Now add table salt to the water solution in increments of 10 grams. Stir and measure the conductivity and current after each increment. Record your results.
- Graph your results on the graph provided.

- **Results:**
  - Conductivity of tap water: _______________ µS/cm

  - Conductivity and Current of a Salt Water Solution:

Conductivity of Salt Water Solution		
Salt Added to Solution in grams	**Conductivity in µS/cm**	**Current in LED Circuit mA**
0 grams		
10 grams		
20 grams		
30 grams		
40 grams		
50 grams		
60 grams		
70 grams		
80 grams		
90 grams		
100 grams		
110 grams		



- **Conclusions:**
  - Looking at the graph above, can the electrical conductivity and the amount of salt added to the water be described as a linear relationship?

Cornerstone Electronics Technology and Robotics III
Working in Water Lab 3 – Density and Sink or Float

- **Purpose:** The student gains familiarity with density by handling objects with different densities and then calculating each density. Further, the student hypothesizes whether each object will sink or float and then tests their hypothesis.

- **Apparatus and Materials:**
  - 1 – Density Set – 10 Specimens See: http://sargentwelch.com/ten-specimen-density-set/p/IG0038029/
  - 1 – Metric Balance
  - 1 – Metric Ruler
  - 1 – Calculator

- **Procedure:**
  - Measure and record the mass and volume of each cube. 1 in^3 = 16.387 cm^3 = 16.387 ml
  - Calculate the density of each cube using the formula d = m / v.
  - Determine the specific gravity of each material.
  - Hypothesize whether the material will sink of float.
  - Test each material in water. Check your hypothesis.

- **Results:**

Density and Specific Gravity of 10 Specimens						
Material	**Mass (grams)**	**Volume (ml)**	**Density (g/ml)**	**Specific Gravity**	**Hypothesis Sink or**	**Test Results Sink or Float**
Aluminum						
Brass						
Copper						
Steel						
Oak						
Pine						
Popular						
Acrylic						
PVC						
Nylon						

- **Conclusions:**
  - Are your results consistent with the statement, “a material with a specific gravity less than 1 will float; a material with a specific gravity greater than 1 will sink?”