Working in Water 2
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 Continued:**
  - **Mechanical Properties Continued:**
    - **Buoyancy –** the phenomenon (investigated by Archimedes) that an object less dense than a fluid will float in the fluid. This takes into account both upward buoyancy force of a fluid on an object that is wholly or partly submerged in it and the weight of the object.
      - Buoyant force: The buoyant force is the difference between the larger force produced from the higher pressure pushing up under the object and the smaller force produced from the lower pressure pushing down over the object.

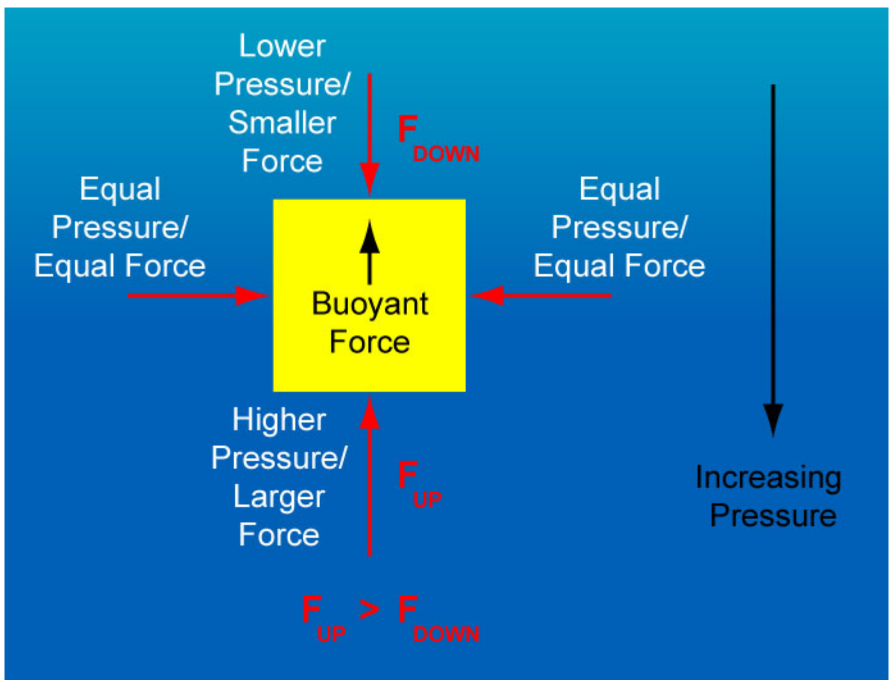
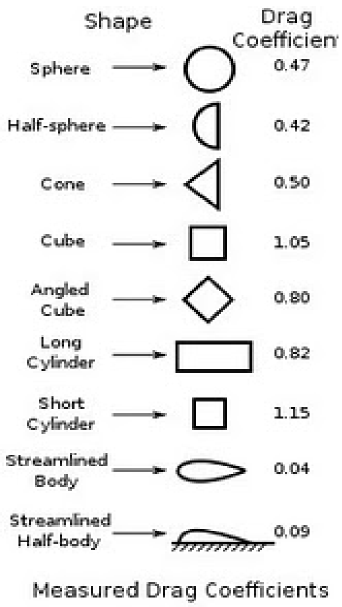


Figure 8: Buoyancy Force and Weight Acting on an Object

- Neutral buoyancy occurs when the buoyancy force is equal to the weight of the object in water. In this condition, a ROV will hover in the water and its depth can be controlled solely by the vertical thrusters.
- Perform Working in Water Lab 4 – Neutral Buoyancy.

- **Drag** – the forces that oppose the relative motion of an object through a fluid.
    - Drag opposes the motion of the object, and in a powered vehicle it is overcome by thrust.
    - Water is about 800 times denser than air so drag has a major impact on ROV movement underwater.



Equation for the force of drag in a fluid is:

$$F_D = 1/2\ pv^2 C_d A$$

Where:

F_d = the force of drag,
p = the density of the fluid
v = the speed of the object relative to the fluid,
A = s the reference area,
C_d = the drag coefficient (a dimensionless parameter, e.g. 0.25 to 0.45 for a car)

From: http://www.swimmingscience.net/2010/03/active-drag.html

- o **Acoustical Properties:**
    - **Acoustics –** the study of sound
    - **Hydroacoustics –** the study of sound in water
    - **Sonar** (acronym for **SO**und **NA**vigation and **R**anging) – A system using transmitted and reflected underwater sound waves to detect and locate submerged objects or measure the distance to the floor of a body of water.

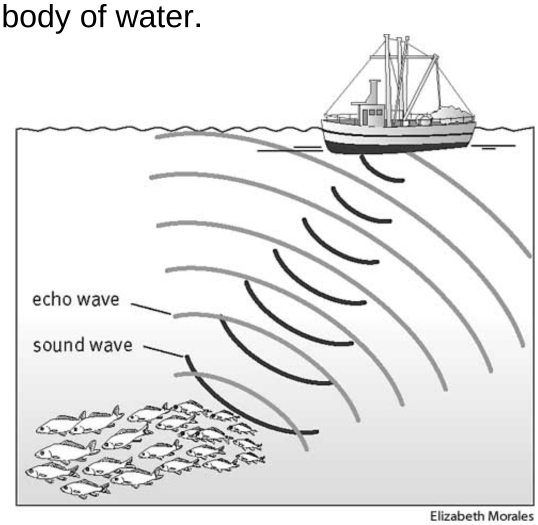


Figure 9: Basic Operation of Active Sonar
From: http://www.thefreedictionary.com/sonar

- In the simplest terms, an electrical impulse from a transmitter is converted into a sound wave by the transducer and sent into the water. When this wave strikes an object, it rebounds. This echo strikes the transducer, which converts it back into an electric signal, which is amplified by the receiver and sent to the display.
- Sonic velocity in water:
    - Sound velocity is dependent upon temperature, salinity, and pressure.
    - The speed of sound in sea water increases with increasing temperature, salinity, and pressure.
    - For our purposes, we will assign a value of 1500 m/s for the speed of sound in sea water.
- Simplified calculation for depth of an object:

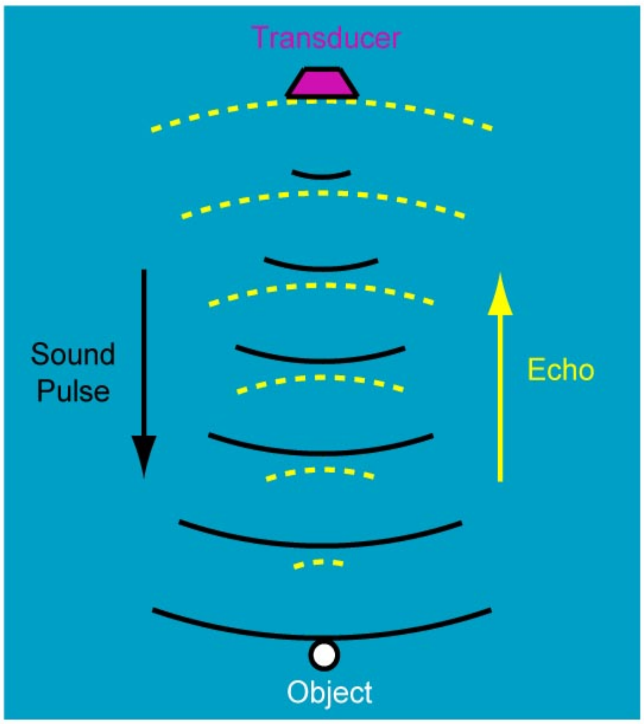


Figure 10: Sonar Sound Pulse and Echo

If 1 second passes from the time the pulse is sent into the water and the time the echo is received, then the distance to the object can be calculated.

The distance for the sound pulse to travel from the transducer to the object and back is 1 sec x 1500m/s or 1500m.

The distance to the object is ½ the distance the sound traveled or 750 m.

D = V x T/2, Where:

D = Depth
V = Mean Velocity of sound in a water column
T = Time for round trip pulse

- Applications:
    - Sound-based images of terrain, sunken ships, submarines, schools of fish
    - Submarine and ROV navigation
    - Underwater security
    - Communication to an underwater vehicle

- **Optical Properties:**
  - **Absorption** – The process in which energy of light radiation is transferred to a medium through which it is passing. Thus, the electromagnetic energy is transformed to other forms of energy for example, to heat.
    - Coastal waters are much less clear than waters offshore. Very little light penetrates more than a few meters into these waters. Sea water in the middle of the ocean is very clear—clearer than distilled water. The water is so clear that 10% of the light transmitted below the sea surface reaches a depth of 90m.
    - Different colors are absorbed at different rates. See Figure 11.

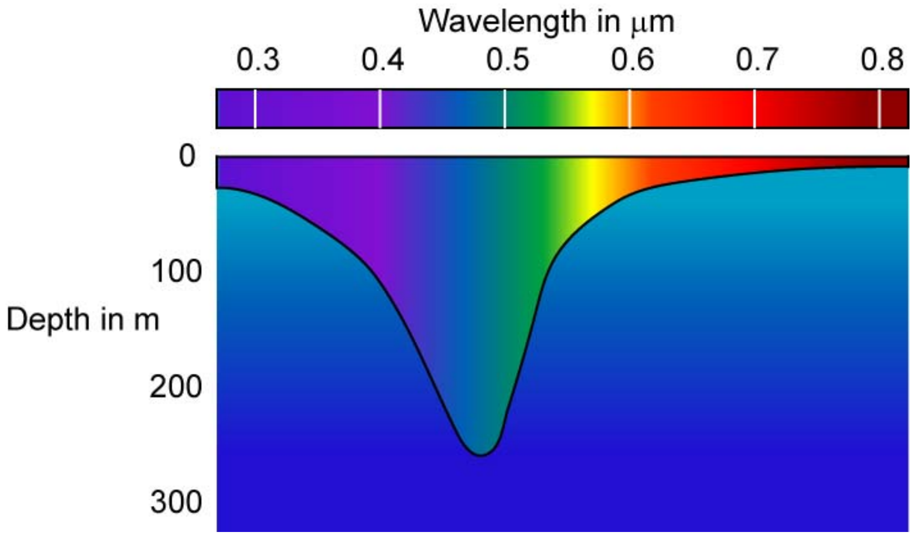


Figure 11: Light Penetration through Clear Ocean Water (by wavelength)
See: http://disc.sci.gsfc.nasa.gov/oceancolor/additional/science-focus/ocean-color/oceanblue.shtml

    - Due to this color loss underwater, underwater photography requires a means of compensation to restore the colors and contrast lost from absorption. The ideal way to accomplish this is by using artificial light.
    - Loss of illumination from onboard ROV lights by absorption can be compensated for by using more powerful lighting.
  - **Turbidity** – cloudiness or opacity in the appearance of a liquid caused by suspended solids, particles, and pollutants.
    - Turbidity measurement provides an indication of the clarity of water and water quality.
    - Causes light to be scattered and absorbed by particles and molecules rather than transmitted in straight lines through a water sample.
    - ROV pilots must be careful not to kick up sediment when working near silty lake or ocean bottoms.

- **Scattering** – light bounces off water molecules and suspended solids.
  - Further degrades light transmission through water.
  - Backscatter is the reflection of ROV onboard lighting back to the direction from which it came. Separating the camera and the source of illumination helps reduce backscattering.
  - Unlike light loss from absorption, more powerful onboard ROV lights may further reduce visibility just as car high beams worsen visibility in fog.

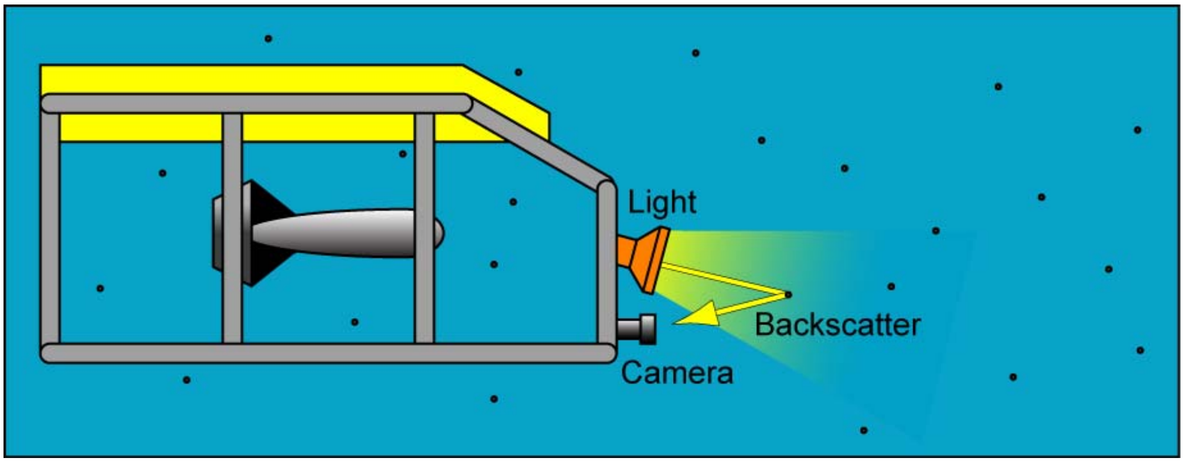


Figure 12: Backscatter Due to Suspended Particles

- **Refraction** – the deflection from a straight path undergone by a light ray in passing obliquely from one medium (as air) into another (as water).
  - When light travels through air it travels at 186,000 miles per second. As the light enters water the light slows down by 46,000 miles per second. This change in speed causes the direction of the light ray to change.

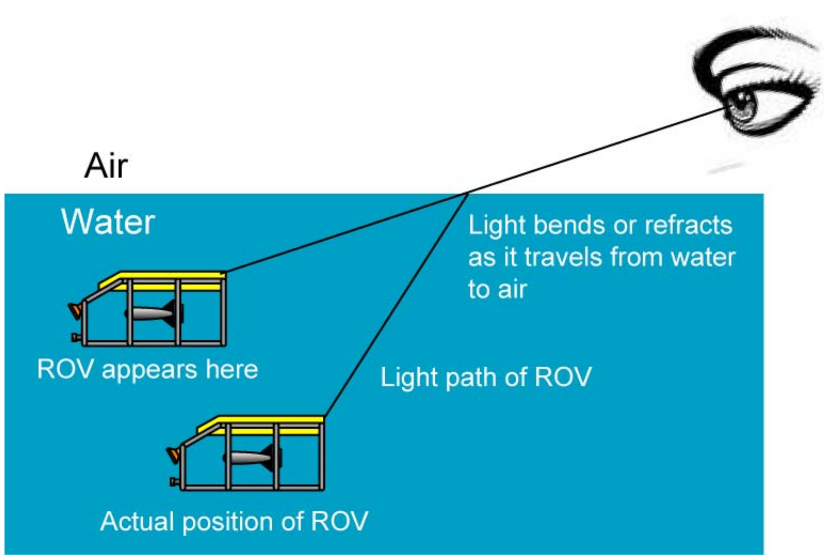


Figure 13: Refraction at the Surface of Water

        - Underwater objects look closer than they actually are when viewed by someone through a flat port. Objects are also larger when viewed through an underwater camera due to the air/water interface between the camera and waterproofing glass or plastic.
        - Perform Working in Water Lab 5 – Absorption and Refraction Effects on Underwater Cameras.
- **Thermal Properties:**
    - **Heat Capacity** – The amount of heat required to raise the temperature of a mass one degree Celsius. It is a measure of how well the substance stores heat.
        - Thus, materials with large heat capacities, like water, hold heat well – their temperature won't raise much for a given amount of heat – whereas materials with small heat capacities, like copper, don't hold heat well – their temperature will rise significantly when heat is added.
        - The specific heat is the amount of heat required to change a unit mass of a substance by one degree in temperature.

Substance	Specific Heat (cal/gram C)
Dry Air	0.240
Aluminum	0.215
Copper	0.092
Glass	0.200
Gold	0.030
Granite	0.190
Quartz Sand	0.190
Water, Pure	1.000
Wood	0.410

Table 2: Specific Heats of Several Substances

    - **Thermal Conductivity** – the property of a material's ability to conduct heat.
        - Heat transfer across materials of high thermal conductivity occurs at a faster rate than across materials of low thermal conductivity.
        - The thermal conductivity of air is 0.024 watts per meter Kelvin (W/(m·K)), whereas water at 20 degrees Celsius is 0.6 W/(m·K).
        - ROV components will quickly stabilize to the water temperature when submerged.
    - Most ROVs operate in a temperature range of 0 – 30 degrees Celsius.

- **Water Column:** A hypothetical cylinder of water from the surface to the bottom of a stream, lake, or ocean within which the physical, chemical, and biological properties or features can be measured.
    - Many water properties such as pH, turbidity, temperature, salinity, nutrient content, and total dissolved solids change with depth.
    - Water property variations can occur gradually or they may change more rapidly within a thin layer. See Figure 14.

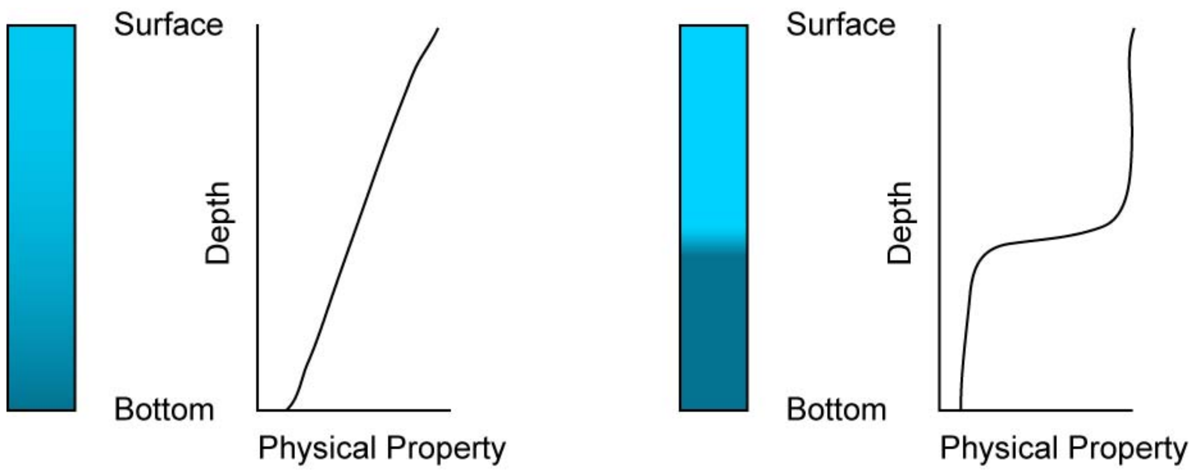


Figure 14: Temperature Variations in a Water Column

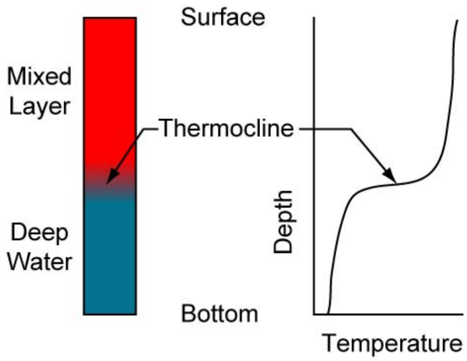


Figure 15: Thermocline – a Layer of Water with a Rapid Temperature Change

- Temperature in a water column:
    - Vertical temperature distribution in a water column is almost always decreasing temperature with increasing depth because colder water is denser than warmer water and it sinks below the warmer water.
    - The warmer surface layer of water is referred to as the mixed layer. Wind and convective mixing blend this layer to form a nearly isothermal (constant temperature) layer.
    - Thermocline – a layer of water in which temperature changes rapidly with depth.
    - A thermocline can form a barrier that traps sound and light energy, hindering the proper operation of sonar for a ROV pilot.
    - In the ocean, the deep water temperature decreases gradually with depth. The equatorial deep water temperatures are within a few degrees of the polar deep water temperatures.
    - For sample data from NANOOS, see: http://www.nanoos.org/nvs/nvs.php?section=NVS-Assets-Cruises-PRISM

- Salinity in a water column:
  - Salinity (along with temperature) affects the density and thus stability of the water column. Saltier water is denser and thus tends to sink below fresher water.
  - Salinity data is collected with the CTD. CTD stands for Conductivity, Temperature, and Depth recorder. It is an electronic instrument that continuously records the salinity (by measuring conductivity), temperature, and depth (by measuring pressure) as the instrument is lowered on a hydrowire from a ship. The CTD continually records salinity from the surface to depth, and gives a profile of salinity and how it changes throughout the water column.
  - Halocline – a layer of water in which salinity changes rapidly with depth.

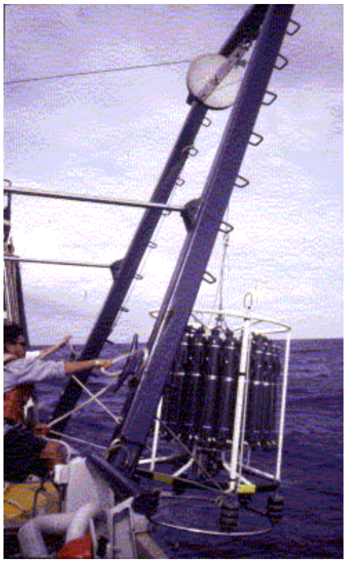


Figure 16: Deploying a CTD

From: http://www.coexploration.org/bbsr/classroombats/html/ocean_properties.html

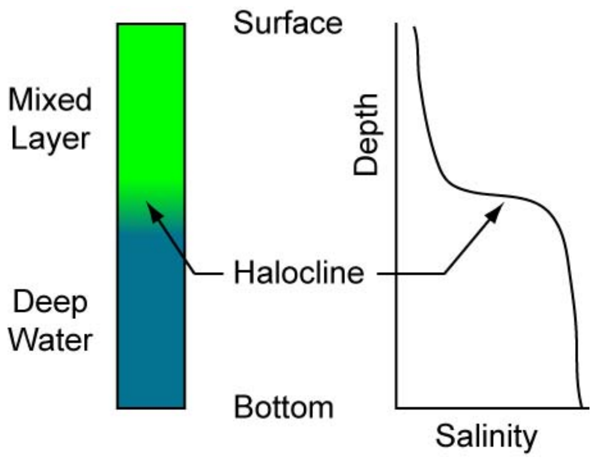


Figure 18: Halocline – a Layer of Water with a Rapid Change in Salinity

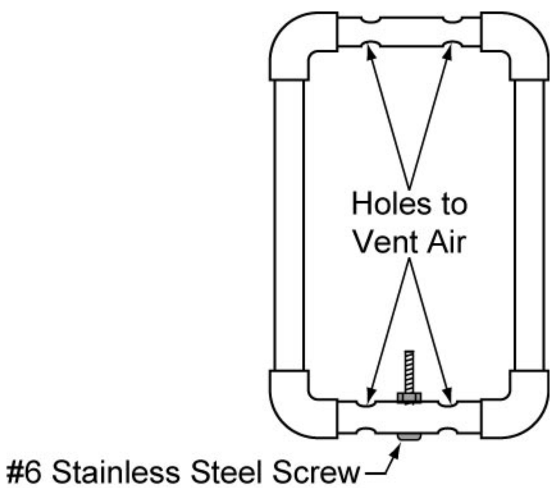
  - A halocline forms a barrier that traps sound and light energy, just as a thermocline does.
  - For sample data, see: http://www.nanoos.org/nvs/nvs.php?section=NVS-Assets-Cruises-PRISM

Figure 17: The bottles are all open when the instrument is deployed, and they are closed at various depths on the way up.

From: http://seaplexscience.com/2009/08/03/oceanographic-equipment/

Cornerstone Electronics Technology and Robotics III
Working in Water Lab 4 – Neutral Buoyancy

- **Purpose:** The student learns how difficult it is to achieve neutral buoyancy for an object immersed in water.
- **Apparatus and Materials:**
    - 2 – 15 cm Pieces of ½" PVC
    - 2 – 30 cm Pieces of ½" PVC
    - 4 – ½" PVC Elbows
    - 1 – 10 mm Piece of Floatation Foam
    - 1 – Basin or Pool at least 1 meter deep
    - 1 – #6 x 32 x 2" Stainless Steel Screw
    - 1 – #6 SS Nut
    - 10 or more #6 SS Washers
    - 2 – 7" or 11" Zip Ties
- **Procedure:**
    - Construct a rectangular frame with the ½" PVC pieces and fittings.
    - Drill ¼" vent holes through the ½" PVC pieces to let air escape when submerged.
    - Drill a mounting hole into the short section on PVC and attach a #6 x 2" stainless steel screw with a #6 SS nut as shown below.



PVC Frame with Holes and Screw Placement

    - Attach the floatation foam to the top of the frame with the zip ties.
    - When submerging the frame, be sure to shake the frame to evacuate as mush air as possible through the vent holes.
    - By cutting the foam and/or adding washers onto the #6 screw, make the frame neutrally buoyant in the basin of water.
    - Position the frame halfway down into the 1 meter basin.
    - Allow 2 minutes to pass and then observe if the frame has surfaced or sunk to the bottom.
- **Results:**
    - Did you achieve neutral buoyancy?

- **Conclusions:**
    - How easy is it to make a small object neutrally buoyant?

Cornerstone Electronics Technology and Robotics III
Working in Water Lab 5 – Absorption and Refraction Effects on Underwater Cameras

- **Purpose:** The student observes firsthand color loss in water and how refraction affects the images from underwater video cameras.

- **Apparatus and Materials:**
    - 1 – Underwater Video Camera 1
    - 1 – Underwater Video Camera 2
    - 1 – Underwater Video Camera 3
    - 1 – Laminated Color Grid

- **Procedure:**
    - Submerge the cameras to the bottom of the pool.
    - Observe color changes in the laminated grid. Record your observations.
    - Observe and record any pattern changes.

- **Results:**
    - What color differences did you observe when viewed through the video camera?
    - Sketch the pattern of the rectangular grid as viewed through the video camera.

- **Conclusions:**
    - Do objects appear larger when viewed through an underwater camera?
    - Was there any color loss at the depth tested? Which color(s) was most affected?