8 TO 10

Seaworthy Science – The Plimsoll Line

In this applied physics lesson, students review Archimedes' Principle and apply it to the context of ship safety. Students conduct a series of experiments on water density and consider the implications for cargo load and the transportation of goods by ship in different water conditions.

CLASSROOM TIME REQUIRED

One session of 50-60 minutes

LEARNING OBJECTIVES AND OUTCOMES

Students will:

- Review and apply Archimedes' Principle
- Review the concepts of water density, volume and mass, and conduct experiments that apply these concepts
- Understand the effect of salinity and temperature on water density
- Apply the concepts to ship safety through knowledge and application of the Plimsoll Line in cargo loading

MATERIALS REQUIRED

- Photo of load lines on the side of a ship (see *Attachments* below)
- Load lines graphic (see *Attachments* below)
- Per group of 3 students:
    - Force gauge
    - Three containers that fit within each other – the smallest should attach easily to the force gauge (e.g. bread tin with string cradle attached, or holes drilled into in the corners)
    - Means to attach force gauge to smallest vessel
    - Volume gauge (approx. 250 ml / 2 ml increments)
    - Funnel to assist pouring
    - Weigh scale (or re-use force gauge) (approx. 700 g / 0.1 g precision)
    - Water sufficient to float the smallest vessel inside the middle sized one
    - 35 / 300 g salt per litre of water used (see Activity 5)
    - Means to temporarily mark the side of the container (chalk, water soluble marker)
    - Ruler or similar measuring device

- Paper towels

TECHNOLOGY RESOURCES REQUIRED

Computer and projector or Smart Board for sharing visual resources

TEACHER PREPARATION

- Ensure students are already familiar with Archimedes' Principle
- Set up computer and projector or Smart Board to show visual resources
- Gather equipment needed to conduct the experiments

CRITICAL VOCABULARY (see Glossary for definitions)

Density	Load Lines	Volume
Force	Mass	Waterline
Freeboard	Plimsoll Line	

LESSON DEVELOPMENT

Activity 1

- Using the computer and projector or Smart Board, show students the image of the Plimsoll Line (or "Load Lines") on the side of a ship.
- Lead a discussion with the students about what the image is. Questions could include:
  - Do you know what this is called?
  - Do you know what its purpose is?
  - Do you what the letters stand for and why?
- Show students the graphic of the Load Lines that includes a legend for the letter markings (see *Attachments* below). Ask students what the significance is of the different types of water, supporting them to make connections with the concept of water density and how this is affected by water temperature and salinity.
- Expand the discussion to consider the factors that are used in determining the allowable freeboard for a vessel's design. Can the students see the value of having a means to assess likely seaworthiness while still in port?
- Review Archimedes' Principle.

Activity 2: Form Hypothesis

- Put students into groups of 3 to conduct the experiment. Ask one student to record the method followed and any observations that the group makes.
- Have each group prepare for the experiment by:
  - Placing the largest container on the bench, with the middle sized container inside it.
  - Adding enough water to the middle sized container so that the water is deeper than the smallest container is tall.

- Have each group form a hypothesis by:
    - Discussing what they expect to happen when the smallest container is placed on the water and why.
    - Considering the forces that are acting. (In which directions are they acting? Can they write an equation for those forces when the object floats?)
    - Sketching a free body diagram of the forces. (The group can collaborate on the diagram, but each student should make his/her own sketch.)
- Have each group test the free body diagram by placing the smallest vessel in the water and observing what happens:
    - What do students feel when they push down? Does the need to exert a force to overcome the upthrust lead them to change their free body diagrams?

Activity 3: Find the Waterline

- Lead a class discussion to reach a consensus that the net force due to gravity and buoyancy will be zero for a floating object.
- Have each group use the force gauge to measure the balance of forces on the smallest vessel when out of the water and then as it is lowered into the water. Record it in increments until the vessel floats.
    - Ensure that the students make an accurate (repeat and average) measurement of the mass when the vessel is out of the water.
    - Ask the groups to consider where the increasing upwards force came from. (Some will realize before others that the vessel is displacing water as it lowers.)
- Have students mark the waterline on the side of the vessel with chalk or marker.
    - Does the waterline always come to the same place on the side of the vessel?

Activity 4: Displacement

- Tell students that they are now going to measure the water that overflows when the vessel is placed in a full container.
- Ask students: what should be measured in order to test the hypotheses from above?

  Students will likely suggest volume: explore why this is a reasonable proxy for weight (density) but that it is the weight that matters (Archimedes).

  Target hypothesis: the mass of water that overflows will equal the mass of the vessel (given constant gravity). If the class prefers to use volume, this may be a useful hypothesis to carry forward as it will be tested later. (Extension: measure the volume of the vessel under water.)
- Have students follow this method:
    - Fill the middle tank to its brim with tap water so that it slightly overflows. Mop up the spill with a paper towel. If the students find this difficult, adjust so they fill until a positive meniscus forms but does not overflow.
    - Place the vessel into the water so that any water that overflows is captured by the outer tank.
    - Observe and record whether the waterline is still in the same place.
    - Measure the volume and mass of overflowed water.
    - Compare the mass of the overflowed water to the mass of the vessel. (Extension: compare the accuracy achieved by different groups. What factors do they consider might be cause of inaccuracies?)

Activity 5: Effect of Salt on Displacement Volume

Note: It may be challenging for most students to make measurements that are sufficiently accurate to differentiate the displaced mass of water for this Activity. You may prefer to guide them to the alternative Activity 5 (below).

- Have students follow this method:
  - Remove the floating vessel and refill the tank.
  - Dissolve salt in the water to mimic seawater (35g / l of water).
  - Repeat the overflow experiment.
  - Mark the waterline.
    - Is it in the same place? Why? (How has adding the salt affected where it floats? What changed? Why does this change the floating point?)
  - How do the weight and volume measurements of the overflow compare to those measured previously? (Weight will be approximately equal, volume will be different by ~3.5%. Some students may now discover / observe the value of accurate measurements.)

Alternative Activity 5

- To aid students in differentiating the results of Activities 4 and 5, depending on the accuracy of measurement achieved, it may be easier to add salt in a much higher ratio: 300g / l of water. This is equivalent of the Dead Sea.

Activity 6: Recap

- Finish with a recap of the Plimsoll Line. Ensure that students understand that the scientific principles that they have just explored – and the accurate calculation of them – have had several benefits for shipping and cargo transportation, including:
  - Many sailors' lives have been saved because of improved shipping safety.
  - The maximum amount of cargo can be carried safely. This means fewer voyages are needed to carry the same amount of cargo, which saves money and reduces carbon emissions.

ASSESSMENT

- Have students write up the experiments.
- Have students write a description of the value to marine transportation of the Plimsoll Line.

EXTENSIONS

- Repeat Activity 5 using hot tap water. Density of water can be predicted using the following:

  $\rho_1 = \rho_0 / (1 + \beta (t_1 - t_0))$

  where

  ρ_1 = final density (kg/m^3)

  ρ_0 = initial density (kg/m^3)

  β = volumetric temperature expansion coefficient [0.0002 (m^3/m^3 °C) at 20°C]

  t_1 = final temperature (°C)

  t_0 = initial temperature (°C)

- Some students may notice that the various load lines are arranged to show where a ship should sit in different waters for the same load. For example, a ship loaded to F in fresh water will sit at W if it subsequently sails into winter ocean water. The standards authorities (Classification Societies) need not have taken this approach. An alternative would have been to allow a greater load on denser water (so that the same safe freeboard is ensured for each density of water). However, the standards authorities chose not to take this approach. Lead a class discussion to explore this important choice. Can the class describe alternative systems and their respective pros and cons?

Geography / Social Science related activities

- Based on their own knowledge of the location of the terminals at the Port of Prince Rupert, or with reference to Nautical Chart 3958, have students determine whether ships in Prince Rupert load in fresh or salt water. To which load line do they load?

- Have students review the regulatory framework for ship safety in Canada (as it pertains to buoyancy and stability) and identify one segment of the marine industry where vessel stability issues are a current concern. Useful online resources and information for this include:

    - **International Maritime Organization – International Convention on Load Lines**

      The first International Convention on Load Lines, adopted in 1930, was based on the principle of reserve buoyancy.

      In addition to these simple calculations, modern regulations take into account the potential hazards present in different zones and different seasons as well as other factors.

      All assigned load lines must be marked amidships on each side of the ship, together with the deck line.

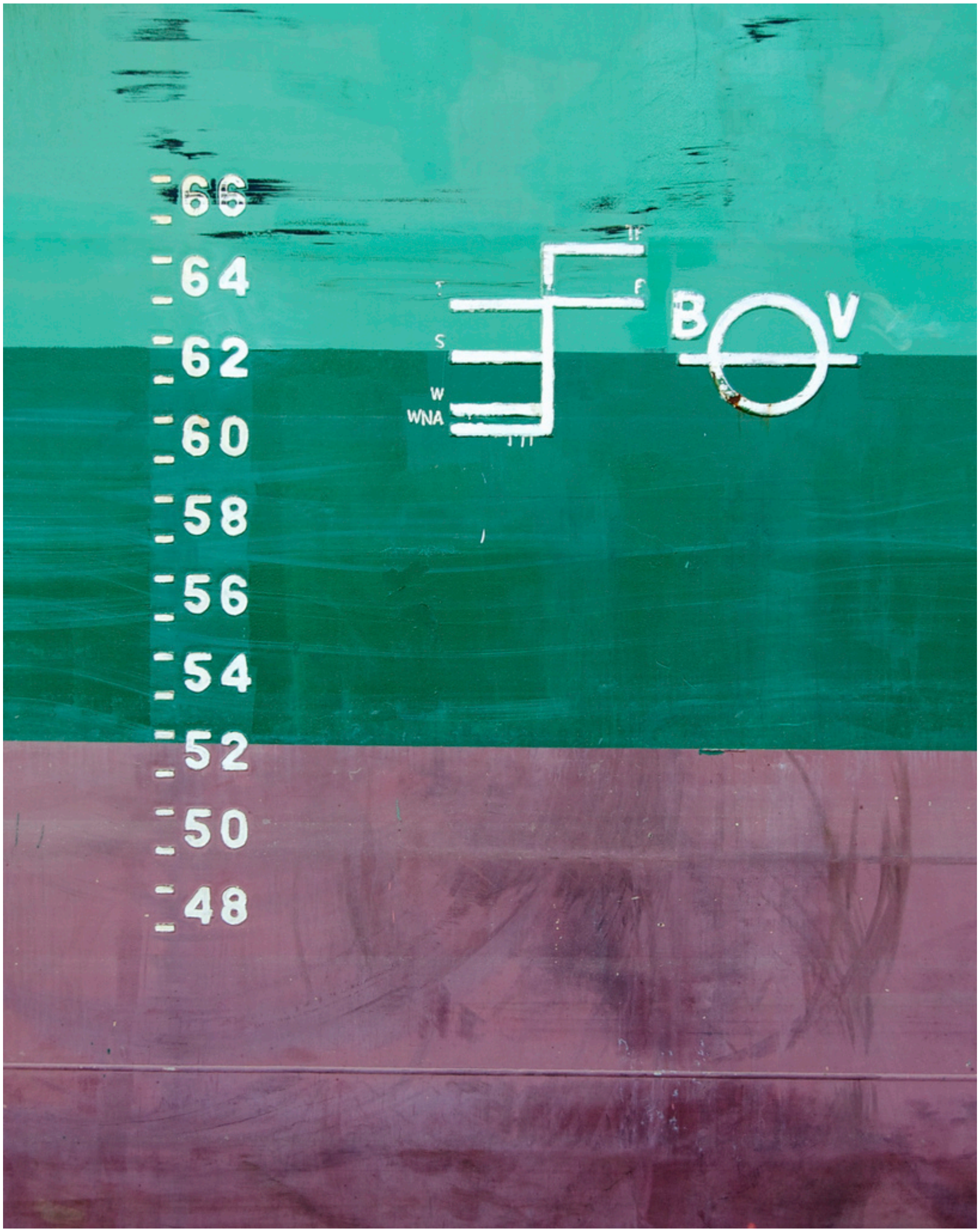
    - **Canada Shipping Act - Load Line Regulations**

      Canada has adopted the International Convention on Load lines in our domestic legislation the Canada Shipping Act.

    - **Transportation Safety Board of Canada** – The Safety Issues Investigation into Fishing Safety in Canada revealed that vessel stability issues were one of the top 10 key safety issues for the fishing fleet.

ATTACHMENTS (below)

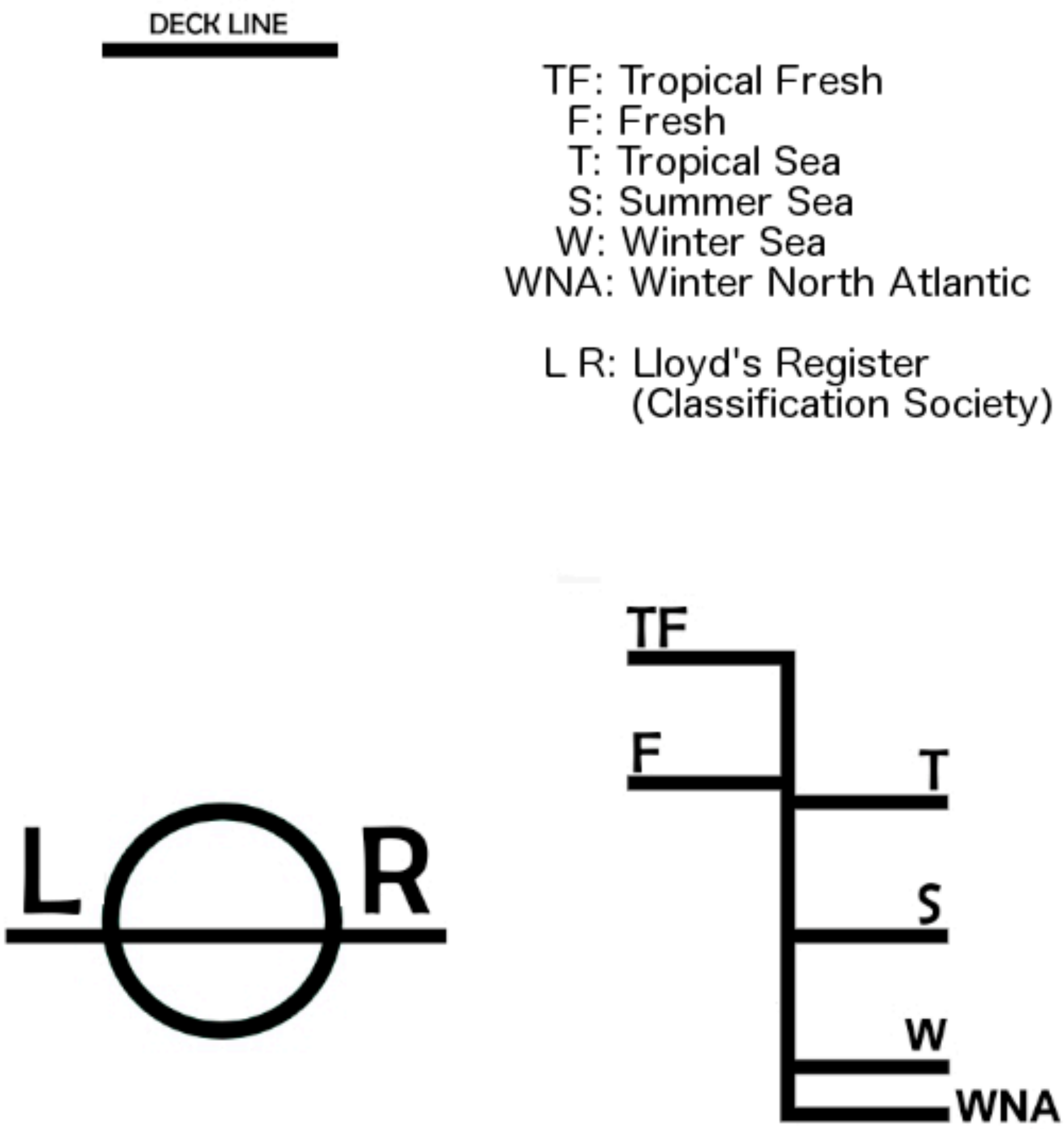
- Photo of load lines on the side of a ship
- Load Lines graphic



Load Lines, Classification Society Bureau Veritas (BV)

(Picture credit: westy48, Creative Commons)

Load Lines


DECK LINE
TF: Tropical Fresh
F: Fresh
T: Tropical Sea
S: Summer Sea
W: Winter Sea
WNA: Winter North Atlantic
L R: Lloyd's Register
(Classification Society)
L
R
TF
F
T
S
W
WNA