Canal & River Trust STEM

Gauging Rod

Gauging Rod Activity Pack

Contents of this pack

1. Overview

Canals were a great way of transporting heavy cargo including coal, pottery, grain and limestone but toll clerks needed to know how much tax to charge each boat on the water. In this activity, pupils use a gauging rod to see how Archimedes' principle of upthrust was applied to life on the canal networks.

2. National Curriculum links

- Science - Forces, pressure in liquids, upthrust effects, floating and sinking, conducting a science experiment including formulating a hypotheses, and reasoning behind observations, opposing forces and equilibrium.
- Maths - Substitution of values into a formula, correlation, converting units of measure, averages.

3. Resources and materials

- **Leaders activity notes for Volume Activity**
  - 15kg scale
  - 1kg / 10 Newtons spring scale
  - Cargo
  - Cargo' net/bag full of marbles
- **Student activity kit (including the box itself)**
  - 12 inch ruler
  - Plastic box to represent a boat
  - Selection of cargos
- **Supporting materials included in box:**
  - Experiment instructions
  - Laminated copy of experiment sheet
  - Laminated photos

Developed with support from

Rolls-Royce

Gauging Rod

4. Lesson Plan

Learning objectives

- Describe and understand upthrust.
- Apply the concept of upthrust to measuring mass.
- Understand how gauging rods and locks were used.

Activity objectives

- Explain the objectives of the lesson and the reason for those objectives (see overview of pack).

1. Demonstrate that an object immersed in a container of water increases the volume of material in the container, raising the water level.
2. Demonstrate "upthrust" (buoyant force) by suspending the object from a spring scale and immersing it in water, and watching its weight decrease. There should also be a scale under the container of water. Ask the group to describe what has happened and to suggest a reason why.

- The volume of material in the container has increased so the water has risen.
- The weight suspended from the spring scale presses down on and into the water.
- The effect is shown on the scale under the container (Add the values on both scales together to produce the same result as before).
- But it has lifted its own volume of water.
- Explain that this produces an equal and opposite reaction called "upthrust", equal to the weight of water lifted. (See PPT slide 2).

3. Describe/display the objectives of the lesson and the reason for those objectives using the question in green. Establish through Socratic questioning that:

- Water has a density of 1kg/litre so, there is a 1 (litre) to 1 (kg) relationship between upthrust and volume of water displaced.

4. Describe how Archimedes discovered the principle, and used it to trap a dishonest goldsmith. Use PPT if available. (See Background Notes).
5. Explain that the principle used to confirm gold is pure is the same as that which determines whether something sinks or floats. Revise Floating and Sinking (See PPT).
6. Establish that floating represents two forces in equilibrium (Upthrust = weight of object).
7. Introduce the gauging rod exercise using PPT. Each group is then to take a kit and experiment instructions. Then follow the instructions to complete the exercise.
8. Summarise the exercise by asking the following questions.

What did you find?

Establish that students found that the position of the cargo was important and that the corner closest to the cargo was lowest in the water.

Establish that students found there was a relationship between the weight of the cargo and the depth the boat sank to, in that a heavier weight made it sink more.

What do you think this means?

- Establish that, in terms of force, the closest corner to the cargo was lowest because the weight (force), and therefore the pressure, was highest on that corner of the boat. State that the boat sinks to the point where the average pressure is balanced by the pressure of the water displaced (lifted).

- Identify (they won't work this out for themselves) that the depth to which the boat sinks is proportional to the square root of the weight of the cargo and ask students to identify why. (Because the bottom of the boat has an area. The mathematical formula for the area of any shape can be expressed as constant x length². For example, area of a circle is π x r²). Note that the hull of a real boat is more complex and that is why they needed to 'characterise' every boat (gauge it).

Summary

What have you learnt from this lesson?

- Establish that they have learnt:
  1. Upthrust is the equal and opposite reaction of the water to the action of beinglifted by an object (Newton's third law)
  2. The upthrust is equivalent to the weight of the water lifted.
  3. A floating object represents two forces in equilibrium (the weight of the boat is equal to the weight of water lifted).
  4. Since the area of the base of the boat is the same as the area of the water in contact with it, the average water pressure is equal to the average pressure exerted by the boat.
  5. Archimedes used upthrust to measure volume by measuring the weight of water displaced.
  6. Upthrust can be used to measure mass by measuring the volume of water displaced.

5. Activity sheet

See Measure of Volume Activity at the end of the pack.

6. Background information

Why do this workshop?

This is an example of using scientific principles to think "outside the box" (or to engineer an elegant solution). Suppose Fred sells you a "pure gold" object, and you want to get it valued. How does the valuer confirm that it is pure gold? We can use upthrust to solve this problem and more!

Establish that weight is the downward force exerted by the mass, due to the Earth's gravity.

Weight = mass x 9.8m/s² (Newtons)

Force = mass x acceleration

The National Curriculum for Science at KS3 includes this text:

Pressure in fluids

- Atmospheric pressure decreases with increase of height, as weight of air above decreases with height.
- Pressure in liquids increases with depth; upthrust affects floating and sinking.
- Pressure is measured by ratio of force over an area.

Balanced forces

- Opposing forces and equilibrium: a weight held by stretched spring or supported on a compressed surface.

So, this lesson is delivering the topics:

- Upthrust effects, floating and sinking.
- Opposing forces and equilibrium, because upthrust is an opposing force and "floating" is actually two forces (weight vs upthrust) in equilibrium.

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IMPORTANT NOTE

If students have completed our water pressure exercise (Lock Design), we can relate upthrust to that. That is, a body placed on fluid will sink into it until the pressure it exerts on the fluid is the same as the pressure the fluid exerts on it. The two pressures are in equilibrium and the body floats. If the pressure exerted by the fluid never matches the pressure exerted by the body, the body will sink.

The lesson divides into three parts:

1. A demonstration that "upthrust" is, in fact, caused by the body placed in water lifting the weight of water it displaces. The demonstration shows that the weight of water lifted is exactly the same as the upthrust. NB: weight is force. The SI (standard international) unit of weight is the Newton.
2. An experiment which quantitatively relates the volume of water lifted to the upthrust.
3. A summary which recalls the relationship between force (weight) and pressure, allowing the students to draw the conclusion that a body immersed in or floating on water experiences an upthrust equal to the weight of water it lifts. (Just like a balance scale, really).

Let's get this straight!

Definition of **Mass**:

A measure of the amount of matter in an object. We measure mass in kilograms (Kg)

Definition of **Weight**:

Weight is the **Force** due to **Gravity**.

Earth's **Gravity** accelerates other masses towards it at 9.8 metres/second² (m/s²).

Einstein demonstrated that **Gravity** is [effectively] equivalent to **Acceleration**.

Newton's second law of motion is:

Force (Newtons) = **Mass** (kg) x **Acceleration** (m/s²)

ie: **Weight** (N) = **Mass** (kg)x **Gravity** (m/s²)

We should also remember that force, like acceleration, is a **Vector** quantity. That is, it has direction. Force due to gravity has the direction **Down**. Upthrust, the force opposing the body sinking into the water, has the direction UP.

Finally, do not confuse 'Upthrust', the buoyant force experienced by a body in fluid [constrained by gravity], with 'upward thrust', the reaction of a body to ejecting mass downward (in the case of a rocket) or deflecting mass downward (in the case of an aircraft wing).

Use questions to help establish that mass doesn't change when immersed in water.

For example to develop analytical/critical thinking. We use Socratic questioning to do this. This workshop offers a lot of opportunities to do this. For example, the scales we use are graduated in kg, but they do not measure mass, they measure force. So, if we put a bag of marbles on a hook scale, and it "weighs" 0.83kg, then immerse the bag in water, it "weighs", say 0.5kg. The scale is telling us that the bag has lost 0.33kg of mass. The students can see that the mass hasn't changed at all, so you can get them to make the distinction between mass and weight. Here's the sequence:

- Has the bag lost any mass? (No. But if anyone says yes, ask them to identify what's missing).
- If it hasn't lost any mass what has it lost? (Downward force, but weight will do).
- So what is the scale actually measuring? (Weight).
- What is weight? (The downward force a mass exerts due to gravity).

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NOTE FOR TEACHERS

In this workshop, we demonstrate the difference between weight and mass by applying upthrust to reduce the overall effect of the force acting downwards.

Force = weight - upthrust.

This reduces the reading on the scale, but we know the mass is conserved. We go on to demonstrate or state that:

- An object immersed in water [that is constrained in a container] must lift the water it displaces.
- That upthrust is the equal and opposite reaction of that water to being lifted. ie the water is pushing back. (There is an interesting corollary to this. See below*)
- That the upthrust is equal to the weight of the [volume of] water lifted.
- The weight of the water displaced is equal to its volume multiplied by its density.

We can use upthrust to determine:

- The weight (and hence the mass) of a floating object by measuring the volume of water lifted.
- The volume of an immersed object by measuring the upthrust.

The water in the container is obviously constrained, so it must rise when you increase its volume by immersing something in it, and that causes upthrust. But an object immersed in water always experiences upthrust, which means it always lifts water, which means that the water is always constrained. In fact, gravity causes water to move as far down as it can, and it will move as far out as it can (ignoring surface tension) because it is a liquid. Therefore, it can only move one way - UP.

7. Possible follow up work

More able students could be asked to research the story of the Archimedes Principle and discuss what this demonstrates.

The story of the Archimedes Principle

The King of Syracuse gave a pound of gold to a smith to make a new crown. The smith made the crown and returned it to the King. The King liked the crown a lot, but later heard that the smith was dishonest, so he asked Archimedes to prove that the smith had swapped some of the gold for lead. A condition was that Archimedes was not allowed to damage the crown because the King liked it so much.

One day, as Archimedes was getting into the bath, he noticed that the water level rose as he got in but he floated on the water. He extrapolated this idea as [what we call] the Archimedes Principle, and realised he could use it to measure the volume of the crown. He got so excited that he ran directly from the bath to the palace shouting “Eureka” which means “I’ve found it”. The problem was, he forgot to put his clothes on.

The Archimedes Principle is: An object immersed in fluid experiences a buoyant force [upthrust] equal to the weight of the fluid it displaces.

Archimedes then put the crown on one side of a balance scale, and a pound of gold on the other. It balanced because the crown weighed one pound. Then he submerged the scale, and the crown, being bigger than the pound of gold displaced more water. By adding gold to the side of the scale of the crown (above the wateline) until it balanced, Archimedes was able to determine exactly how much gold had been replaced.

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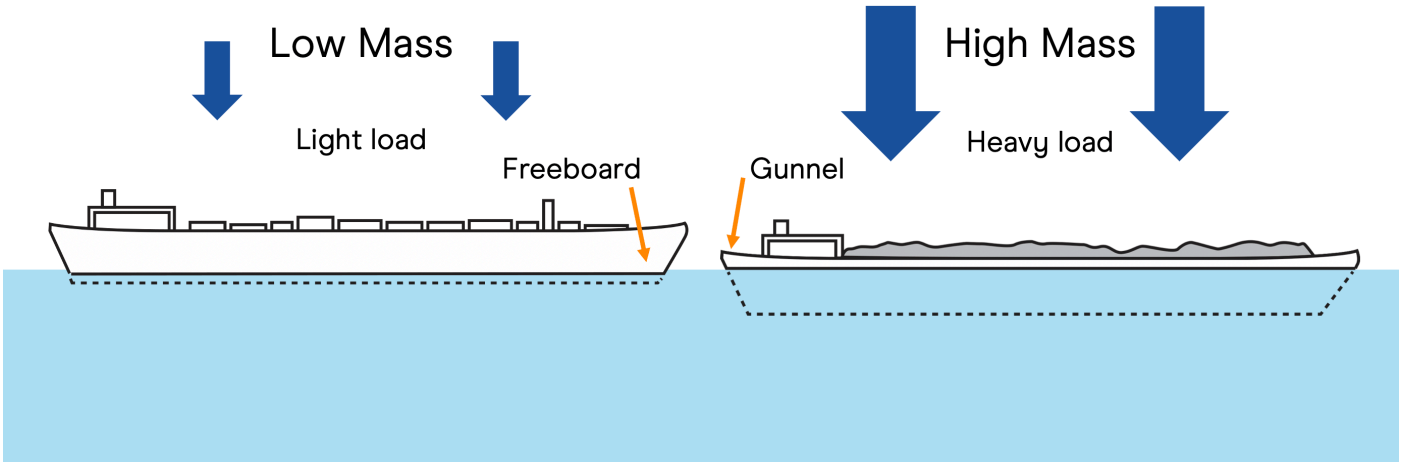
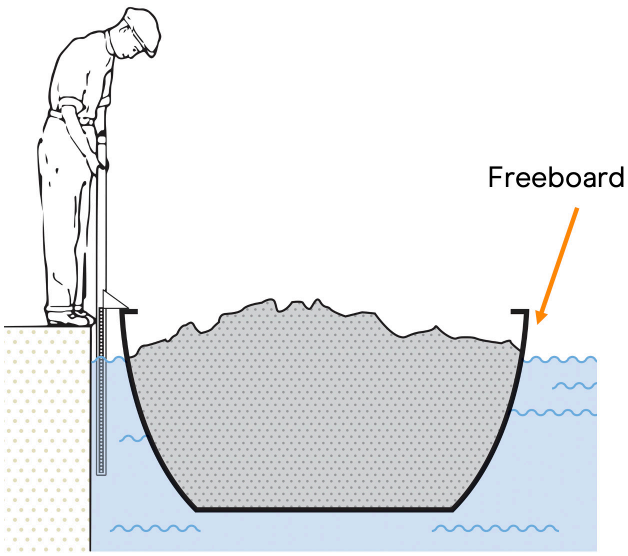
Activity Sheet

Measurement of volume

Canal Companies charged a toll based on the weight and type of cargo being transported by canal boat, and how far it was travelling.



The Toll Clerk could tell how much cargo was in the boat by measuring how low the boat was in the water by measuring the distance between the gunwale and the water level at 4 points – one in each corner of a boat.



The gauging experiment

Fill the tank to about 10cm. Place the 'boat' (ice cream tub) into the tank. Place your hand on the boat and press down. Watch the water level rise and feel the upthrust. Remove your hand from the boat.