LESSON 2
WATER PRESSURE AT WORK IN LONDON

THE BIG IDEA

Students will look at the related concepts of pressure and force (*pressure = Force/ Area*), units used and measurement and how a large force can result from pressure acting over a given area. They will move from calculating the weight (under gravity) of a column of water or air to the pressure of this as weight over unit area. This will also bring in the idea of density.

LEARNING OUTCOMES

Could: evaluate the result of a simple calculation of height of the atmosphere based on their existing science knowledge and understanding.

Should: relate pressure increases with depth in a fluid to the weight of the fluid above under the action of gravity.

Must: explain that pressure is a measurement or calculation of force acting over a unit area and use the units of N/m^2 correctly.

RESOURCES

Resource 2.1: Kew Bridge standpipe and Shooters Hill water tower

Resource 2.2: Enfield Lock pressure calculation

MATHEMATICAL SKILLS

- Units – Newtons per metre squared (N/m^2), Pascals (Pa, 1 Pa = 1 N/m^2)
- Calculation of pressure

KEY WORDS

- Pressure
- Density
- Fluid (liquid or gas)

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PRACTICAL WORK

Collapsing can under air pressure for example:

www.sciencedemo.org/2014/01/collapsing-can/ – either using a vacuum pump or heating a small amount of water in a can then dipping in cold water or sealing the lid.

Visualising pressure:

1kg masses, 1cm sided cubes, 1m rulers are required.

Introducing pressure:

www.nuffieldfoundation.org/practical-physics/introducing-pressure

Pressure of a water column:

www.nuffieldfoundation.org/practical-physics/investigating-pressure-water-column

Pressure and force:

www.nuffieldfoundation.org/practical-physics/pressure-and-force

LESSON 2: WATER PRESSURE AT WORK IN LONDON

SETTING THE SCENE

STANDPIPE TOWER AT LONDON MUSEUM OF WATER & STEAM

As London grew in size and industrial power during the 18th and 19th century, the transport route provided by the River Thames was increasingly supplemented by a number of man-made canals, to manage the transit of materials and produce. At the same time, water supply became increasingly important both to support the industries and the needs of the growing population. Water towers were built to pressurise the water supply system to distribute drinking water. Kew Bridge Works, a pumping station which transferred water from the Thames to supply Ealing and Paddington was built during the 19th century. The building, with its impressive standpipe tower, now houses the London Museum of Water and Steam.

Drawing on practical examples relating to the London's water ways and infrastructure, as well as simple and visual classroom based experiments, this lesson explores the differences between pressure and force and the units used for pressure.

In science liquids and gases are both considered as fluids. They both have similar properties of 'flowing' and not keeping a shape but gases are much less dense than liquids and are compressible. This means gases increase in density, and therefore reduce in volume, with increasing pressure or reduce in density with reducing pressure, resulting in the air getting 'thinner' at altitude. Liquids are incompressible so keep the same density, and volume as pressure increases or decreases.

An example of calculating the pressure at the bottom of a London lock is given based on real data. The common calculation method *pressure = force/area* is given first then an equivalent method based on density is given as an extension. The scientific understanding of increasing density meaning matter being more compressed is useful when learning science concepts, but for calculations the more mathematical understanding of density being simply mass per unit volume leads to a better conception of the working of the calculations. This will be reinforced with calculations on our London diver example.

Finally a simple calculation based on the density of air at sea level is used to estimate the height of the atmosphere by working out the height of air that is needed to provide a weight matching the air pressure at sea level. This gives a very quick simple estimate but is smaller than the true value as it does not account reducing density of air with altitude. The pressure of a liquid at depth can be calculated directly as there is no change in density with depth.

LESSON 2: WATER PRESSURE AT WORK IN LONDON

ACTIVITIES

STARTER

Show the class Resource 2.1: Kew Bridge standpipe and Shooters Hill water tower (page 35). Ask the class whether they recognise them. What were they for? Why would you store water high up in towers rather than in tanks on the ground? Explain that the Kew Bridge standpipe, now part of the London Museum of Water and Steam, is a 61 m high tower which contains vertical pipes through which water was pumped up before going into the mains water supply to Ealing and Paddington. The height of water in the standpipe maintained a high constant pressure of water supply.

Imagine the cross section area of the standpipe is 1 m^2. Ask students to work out or guess the mass of water in the pipe if it is full up to 61 m. Compare answers – the answer will be given in the plenary.

MAIN 1

This activity introduces pressure and contrasts it with force.

Ask students to work in small groups and answer the questions in Introducing Pressure **www.nuffieldfoundation.org/practical-physics/introducing-pressure**.

Share answers with the class. Note 'the items are similar but with a difference' – at the end of the sequence you should bring out the idea that the force is the same (e.g. weight of girl in example A) but the pressure is different.

Discuss the difference between force and pressure. You may wish to draw force arrow diagrams for one of the examples to stress that the force does not change but the pressure decreases with area. For example with flat shoes vs high heeled shoes the force acting through the shoes is equivalent to the weight of the person in both cases, therefore the same size of force arrow, but the pressure is much larger from the high heels which have a very small area.

Differentiation

All students may find it useful to draw diagrams of the situations in their groups. More able students may make an estimate of the different areas in one or more examples and calculate the pressures. Less able students should create their own example statements similar to the introducing pressure example.

MAIN 2

This activity shows that pressure in liquids increases with depth due to the action of gravity and introduces density.

Show Resource 2.1: Kew Bridge standpipe and Shooters Hill water tower (page 35).

Demonstrate pressure of water column increasing with depth – pressure at different depths only.

www.nuffieldfoundation.org/practical-physics/investigating-pressure-water-column

You do not need to do the pressure in different directions or the velocity of water calculations in this example.

Explain that:

- The mass of $1m^3$ of a liquid or gas is called its density. So density is measured in kg/m^3 or sometimes in g/cm^3. So for example water has a density of about $1000kg/m^3$ (this is equivalent to $1g/cm^3$) and air has a density of about $1kg/m^3$.
- Density gives a measure of the difference in mass of the same unit volume for different substances – water is 1000 times 'heavier' than air. Similarly pressure gives a measure of how much force is acting on the same unit area in different situations.
- Pressure is calculated as the force in (N) over $1m^2$ (unit) area and the unit $1N/m^2$ is also known as the Pascal.
- Therefore to calculate pressure over a larger area we usually calculate the total force over the whole area and then divide by the area to find the force on $1m^2$.

MAIN 3

Ask students calculate the pressure at the bottom of a typical London lock. Use the example data given in Resource 2.2: Enfield lock pressure calculation (page 36–37) or similar data for a local lock.

Differentiation

Resource 2.2: Enfield lock pressure calculation (pages 36–37) gives a problem solving framework for higher ability students and scaffolded solution method for lower ability students. You might also talk through the summary method below with lower ability students before they attempt the solution. Worked examples for each scaffold and based on the Enfield lock data may be given to students if data from a local lock is used, or after they have attempted the calculations.

A summary of the method used is as follows:

The force on the bottom of the lock is the total weight of water. This is calculated from the total volume of water multiplied by the density to give the mass in kg, then multiply by 10 to give the weight in N. To get the pressure in N/m^2 divide the force by the area of the lock. You may wish to reinforce this by working through the example lock calculation on the board after students have attempted the calculation.

Extension

Give more able students the ‘calculation based on density and depth only’ example and ask them to read through the calculation and compare to their previous calculation.

Less able students can be given further examples based on the force divided by area calculation, researching the sizes of other local locks or swimming pools themselves.

MAIN 4

This activity visually demonstrates the large forces generated by pressure.

Show the value for atmospheric pressure as approximately *100,000 N/m^2 = 100,000 Pa* on the board. Explain that this is like a weight of 100,000N resting on a 1m^2 area, which is equivalent to a mass of 10,000 kg or 10 tonnes (remember weight in N is approximately 10 x mass in kg).

Question

Why aren't we all crushed by this pressure?

Give students a chance to discuss in groups and suggest some answers but before responding yourself carry out the collapsing can demonstration – for example:

sciencedemo.org/2014/01/collapsing-can/

Answer

Air pressure is acting in all directions and is 'inside' us as well as 'outside'. The can experiment removes air from inside the can by heating and when suddenly cooled without allowing more air back inside the air pressure inside drops.

The collapsing can provides a visual demonstration that air pressure can in fact produce large forces. It is actually the difference in pressure on either side of an object that produces an unbalanced force which in this case causes the can to collapse. Pressure differences have many applications, for example planes can fly because they have a wing shape that causes a drop in pressure on the top surface compared to the bottom.
The unbalanced force resulting from this is called the lift.

Further visualise this by using 1kg masses and 1cm sided cubes. Rest a 1kg mass on the 1cm cube on a student's hand and explain air pressure is equivalent to 10N (the weight of 1kg mass) on every square centimetre. The pressure multiplied over the total surface area of the can is large enough to collapse it very quickly.

Use 1m rulers to create a 1m sided square and explain that scaling up from a 1cm sided square, this is the same as having 10,000kg masses (10 tonnes) resting on the 1m^2 area. This is because *1m^2 = 100cm x 100cm = 10 000cm^2* so there are 10,000 1cm sided squares in a 1m sided square

For further examples students might consider the shape and strength of materials needed in the Port of London Authority diver's helmet shown in the video or the Drebbel submarine and modern submarines. More examples of extreme pressures at depth are given in the further reading.

MAIN 5

This activity demonstrates how to make a rough estimate of a real world quantity using scientific knowledge and calculation.

Before starting on the calculation ask students to guess how high the atmosphere goes. Ask them also to guess the radius of the Earth or state its value if they know. Then ask them to calculate the answer to the following question.

Question

We know that air pressure at sea level is approximately 100,000 N/m^2 and that the density of air is approximately 1 kg/m^3.

From this data, calculate the height of air that must be above us to produce this pressure (this is the height of the atmosphere).

Differentiation

As usual, scaffolding for the less able and problem solving for more able. You might also point them to look at the Enfield Lock Pressure Calculation as a similar problem.

Answer

$1 \times 10 \times H = 100{,}000\ N/m^2$
$H = 10{,}000\ m$
$= 10\ km$

This example shows how by using scientific understanding and simple calculation, scientists can discover things about the world. They can use this knowledge to base future investigations and creations on.

The real answer for the height of the atmosphere is approximately 100km. This may seem much larger than the calculation but it is really of a good comparable size given the simple calculation used. We did not get result of a few metres or of millions of km which would have been poor estimates. The reason the real value is larger is because the pressure reduces with altitude and this causes the air to reduce in density (become thinner) as gases are compressible. This means a greater height of air is needed to produce the pressure.

Mercury barometers use the pressure of column of mercury (density 13,600 kg/m^3) to show the current air pressure as the rising and falling of air pressure is an indicator for weather prediction. The Thames water barometer on Holland Park roundabout uses water as the fluid balancing the air pressure instead of mercury. Note the pressure calculation of *density x acceleration* of *gravity x height* as in our examples shown in:

www.damianosullivan.com/page21/page22/

More able students should consider the density calculation. Less able students should be able to appreciate the height of the water barometer compared to the mercury barometer is due to the difference in density of the fluids.

Plenary

Answer to starter question

Ask students to make up their own 'introducing pressure' type examples and discuss whether they clearly distinguish force from pressure.

Mass of 61m height of water with cross section area $1m^2 = 61m^3 \times 1000kg/m^3 = 61{,}000\ kg = 61\ tonnes$

This then produces a pressure of $61{,}000 \times 10\ N/m^2 = 610{,}000\ N/m^2$ or about 6 times atmospheric pressure.

Assessment questions

Adapt or extend questions based on the activities or use the following examples (please note that for question 3 students will need their copy of Resource 1.5: Diver working in the Thames Barrier, handed out in lesson one):

1. State the units for force and pressure and explain the difference between force and pressure.
2. Using the syringes, drawing pins or other examples explain how a small force can be made into a large pressure or a small pressure can be made into a large force.
3. Calculate the mass of water above the diver at the different depths and annotate the diagram in Resource 1.5: Diver working on the Thames Barrier. Assume that the area of the diver's body is 1m2.
4. Other calculation problems for pressure at given depths of water.

Homework ideas

Work out what depth of water will give the same pressure as air pressure ($100{,}000\ N/m^2$)?

Research a London waterway that has a number of locks on it. Find out the number of locks and the fall on the locks to find the total fall of the waterway coming into or out of London. Find out what the waterway was used for in the past and what it is used for now.

Research altitude sickness in mountaineers (reducing air pressure with height) – state heights and pressures.

Further reading

Examples of extreme pressure deep in water:

Natural History Museum ocean pressure on deep sea animals, follow other links on the site to find the depths that some of the animals live at:
www.nhm.ac.uk/nature-online/earth/oceans/deep-ocean-life/challenges/ocean-pressure/index.html

Article on the Drebbel Submarine:
www.nmmc.co.uk/index.php?/collections/archive/the_drebbel_submarine

Thresher Submarine crushing accident, engaging reads for students:
www.nationalgeographic.com/k19/disasters_detail2.html

LESSON 2: WATER PRESSURE AT WORK IN LONDON

RESOURCE 2.1: KEW BRIDGE STANDPIPE AND SHOOTERS HILL WATER TOWER

STANDPIPE TOWER AT LONDON MUSEUM OF WATER & STEAM

Ed Stannard © Wikimedia Commons

SHOOTERS HILL WATER TOWER, GREENWICH

Angus McLellan © Wikimedia Commons

LESSON 2: WATER PRESSURE AT WORK IN LONDON

RESOURCE 2.2: ENFIELD LOCK PRESSURE CALCULATION

Enfield lock is 4.9m wide, 25.6m long and has a fall (depth) of 2.9m. Calculate the pressure at the bottom of Enfield Lock when full of water. If you know the method needed then follow the general problem solving steps to create your own answer or if you are unsure of the method then follow the calculation steps.

1. **Understand the problem**
   What do you want to find out (the unknown) – what quantities do you know (data)?

2. **Devise a plan**
   Describe the steps you will use to convert the known data into the unknown answer.

3. **Carry out the plan**
   Write down your calculations step by step and check each step is correct.

4. **Look back**
   Check the result is correct or at least looks correct in comparison to other things you know.

ENFIELD LOCK DETAILS	
Waterway	River Lee Navigation
Constructed	1725
Operation	Manual
Maintained by	British Waterways
Length	25.6m
Width	4.9m
Fall	2.9m
Coordinates	51.667319° N 0.018207° W
Distance to Bow Creek	18.5 km (11.5 miles)
Distance to Hertford Castle Weir	14.8 km (23.8 miles)

ENFIELD LOCK, COTTAGES AND OFFICE
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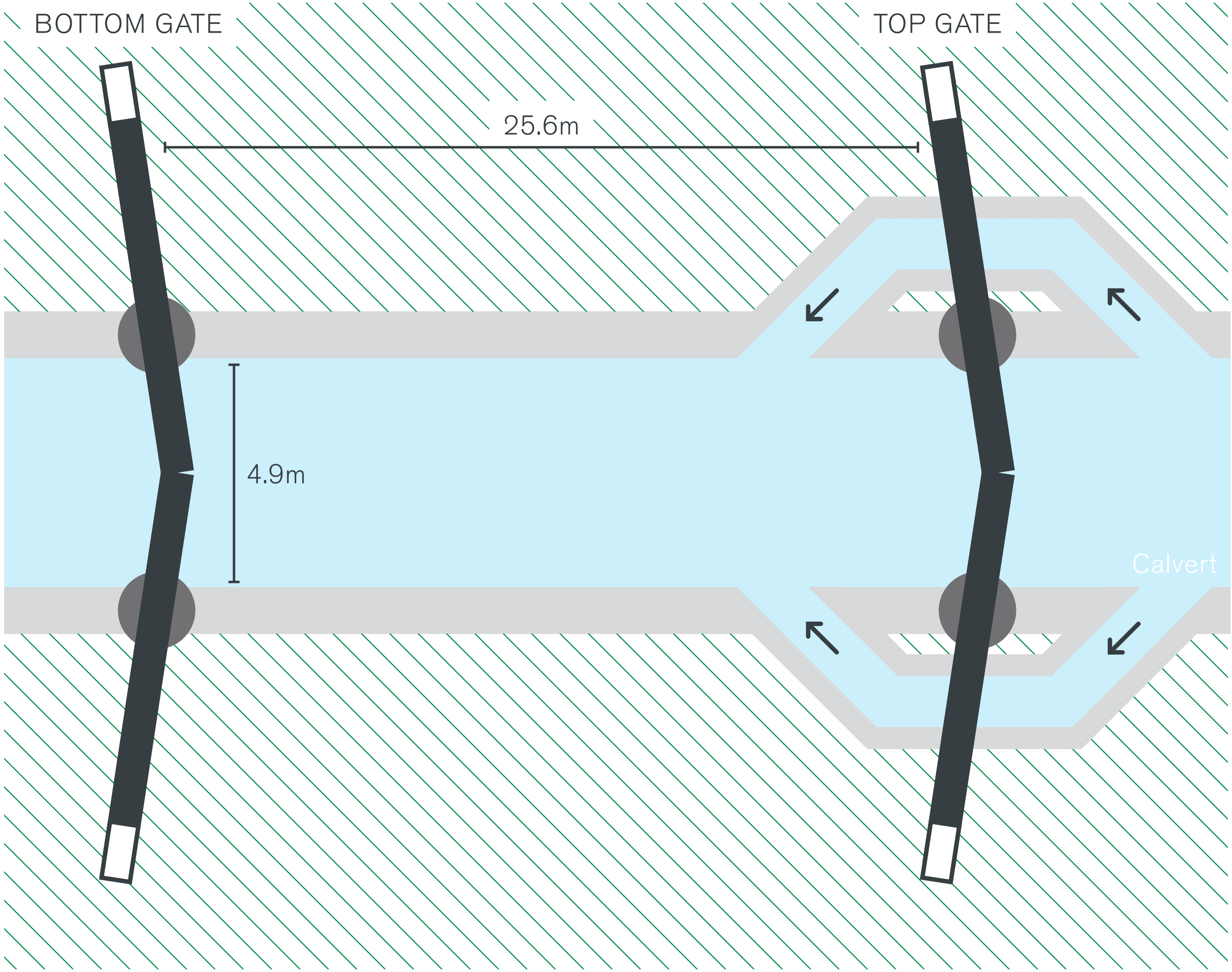
LESSON 2: WATER PRESSURE AT WORK IN LONDON

RESOURCE 2.2: ENFIELD LOCK PRESSURE CALCULATION CONTINUED

SCAFFOLDED SOLUTION METHOD	
Volume of lock	= *length x width x depth* =___*m x*___*m x*___*m* =___m^3
Total mass of water	= *volume x density* =___m^3 *x*___*kg/*m^3 =___*kg* (=___*tonnes*)
Total weight of water	= *mass x 10* =___*N*
Area for lock	= *length x width* =___*m x*___*m* =___m^2
Pressure	= *force / area* (the force is the weigh of water) =___*N* / ___m^2 =___*N* / m^2



LESSON 2: WATER PRESSURE AT WORK IN LONDON

RESOURCE 2.2: ENFIELD LOCK PRESSURE CALCULATION CONTINUED

Problem solving framework – worked example

1. **Understand the problem**
   Unknown – pressure per m^2
   known – dimensions of lock:
   Width 4.9m
   Height 25.6m
   Depth (fall) 2.9m and we need to know the density of water 1000kg/m^3

2. **Devise a plan**
   Pressure = Force x Area. The force is the weight of water in the lock so calculate the volume of water and multiply by the density, then x10 to convert kg to N for weight, then divide by the lock area for the pressure.

3. **Carry out the plan**
   Volume of water = 4.9 x 25.6 x 2.9 = 364 m^3
   Mass of water = 364 x 1000 = 364,000 kg (= 364 tonnes)
   Weight of water = 364,000 x 10 = 3,640,000N
   Area of lock = 4.9 x 25.6 = 125 m^2
   Pressure = 3,640,000 / 125 = 29,100 N/m^2

4. **Look back**
   Check the result is correct or at least looks correct in comparison to other things you know.

LESSON 2: WATER PRESSURE AT WORK IN LONDON

RESOURCE 2.2: ENFIELD LOCK PRESSURE CALCULATION CONTINUED

Worked example: Scaffolded solution method

Pressure = Force / Area

For the lock we will need to calculate the total weight of water in the lock and divide by the area of the lock.

Volume of lock = length x width x depth
= 25.6 x 4.9 x2.9
= 363.776 m^3
= 364 m^3 (3 s.f.)

Total mass of water = volume x density
= 364 x 1000
= 364,000 kg (364 tonnes)

Total weight of water = 10 x 364,000
= 3,640,000 N

Area of lock = length x width
= 25.6 x 4.9
= 125 m^2 (3 s.f.)

Pressure = force / area (the force is the weight of water)
= 3,640,000 / 125
= 29,120 N/m^2

LESSON 2: WATER PRESSURE AT WORK IN LONDON

RESOURCE 2.2: ENFIELD LOCK PRESSURE CALCULATION CONTINUED

Extension: Calculation based on density and depth only

1. **Problem**
   To calculate the pressure at the bottom of the lock when it is full of water.

2. **Understanding the problem**
   The unknown is the pressure – the data for the height of water is the fall = 2.9m, the density of water is $1000 kg/m^3$

3. **Devise the plan**
   Calculate the pressure from the density and height:
   Pressure = density x 10 x height

4. **Carry out the plan**
   Pressure = 1000 x 10 x 2.9
   = 29 000 N/m^2

5. **Look back**
   As before this is a sensible answer in relation to the value for air pressure.

The result is the same as before allowing for the rounding to 3s.f. If you examine the calculation you will see that the length x width calculation for the area cancels out the length x width part of the volume calculation leaving only the depth, so in fact the two calculations are equivalent. This is also equivalent to showing that the pressure is the same as the force per 1m2 of area if you consider the density to be the mass of a 1m cube.

The general calculation for pressure at any depth is *pressure = density x 10 x depth* where 10 represents the approximate value for acceleration due to gravity g used to convert mass to weight.