ACTIVITIES WITH ARCHIE

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1. CHANGING ARCHIE’S MASS IN WATER

THEORETICAL BACKGROUND

GOALS

The student should:

- get acquainted to working with Archie,
- find the relation between an object’s mass and its immersed volume in water,
- get familiarized with the basics of floating and sinking.

KEY CONCEPTS

Mass, volume, floating, sinking.

TIME REQUIREMENTS

20 – 30 minutes.

ASSIGNMENT

Find out the relationship between Archie's immersed volume and its mass in water.

Only one part of Archie is needed for this activity.

INSTRUMENTS

Archie, measuring cylinder (or a different transparent container), water, coins (or small weights), scales.

PROCESS

- Student write down their predictions of what is going to happen when we increase Archie's mass,
- students measure the mass of one coin (can be done an independent activity),
- students pour water into the measuring cylinder,
- students measure Archie's mass when empty and write it down in a table (can be written down manually or on a computer using a spreadsheet program),
- students release Archie into the measuring cylinder and write down the value of its immersed volume into the table,
- students increase Archie's mass using coins, then they write down the new mass and immersed volume into the table,
- students repeat the last step until they fill the table,
- students prepare a graph using the data in the table,
- students interpret the data in the graph together, if needed with the help of the teacher,
- students answer the follow up questions and achieve a conclusion with the teacher's help.

SAMPLE VALUES

Mass *m* (g)	**Immersed Volume *Vi* (ml)**	**Behaviour**
30	30	Floating
36	36	Floating
42	42	Floating
48	48	Floating
54	54	Floating
60	61	Floating
66	67	Floating
72	72	Floating
78	79	Floating
84	80	Sinking
90	80	Sinking
96	80	Sinking

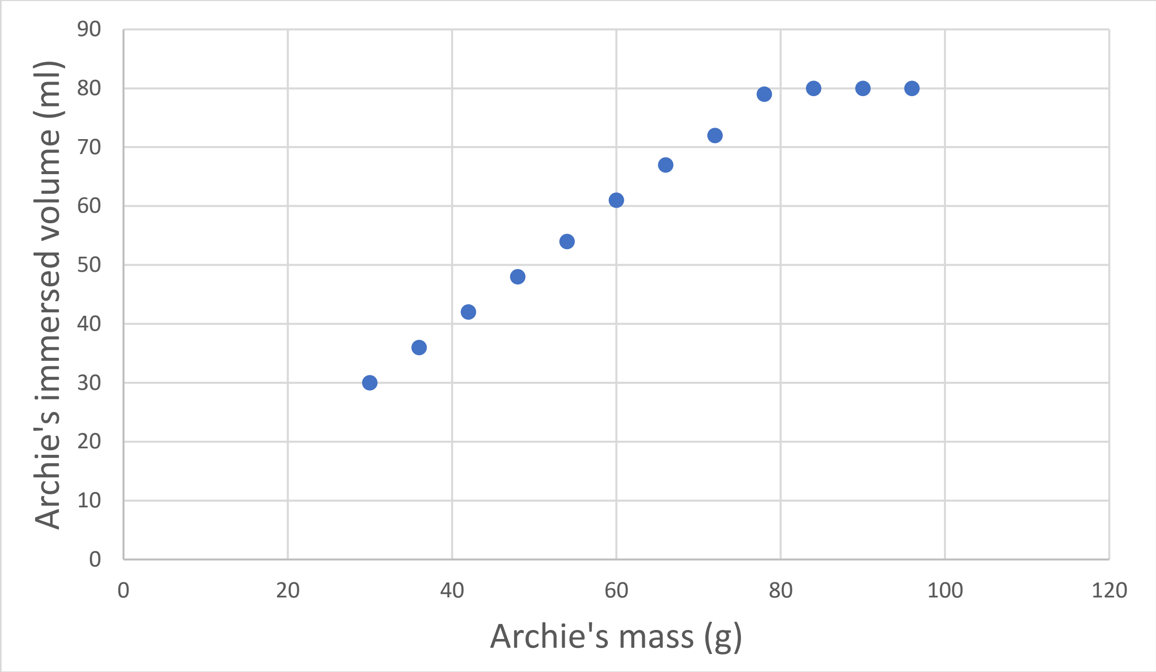


Figure 1. The relation between Archie's immersed volume and its mass in water.
When Archie's mass is lower than 80 g, it is floating, when it is higher than 80 g it is sinking.

FOLLOW UP QUESTIONS AND EXPECTED ANSWERS

1. What should Archie's mass be, so half of its volume is immersed? Verify experimentally.

   Archie's mass should be 40 g.

2. What should Archie's mass be, so 60 ml of its volume is immersed? Verify experimentally.

   Archie's mass should be 60 g.

3. What is the mass of displaced water, when Archie is floating?

   The same as its own mass.

4. What is the volume of displaced water, when Archie is sinking?

   The same as its own total volume.

5. Discuss how the graph would look like if we repeated the experiment with Archie's second part, or if Archie was whole.

   The mass at which Archie would start to sink would be 100 ml for Archie's other part, and dependant on Archie's total volume for a whole Archie.

EXPECTED CONCLUSIONS

- When an object is floating, the numerical value of its immersed volume is equal to the numerical value of its mass, or:

$$\{V_p\} = \{m\}$$

- When an object is sinking in water, it displaces its own volume of water.

As the first conclusion is dependent on the density of water and it is only apparent that the numerical values of the immersed volume and mass are equal, we recommend teachers to start a discussion asking if the numerical values would still be equal if we used different units (e.g. kg and m^3) and try to explain the reason.

1. CHANGING ARCHIE'S MASS IN WATER

ASSIGNMENT

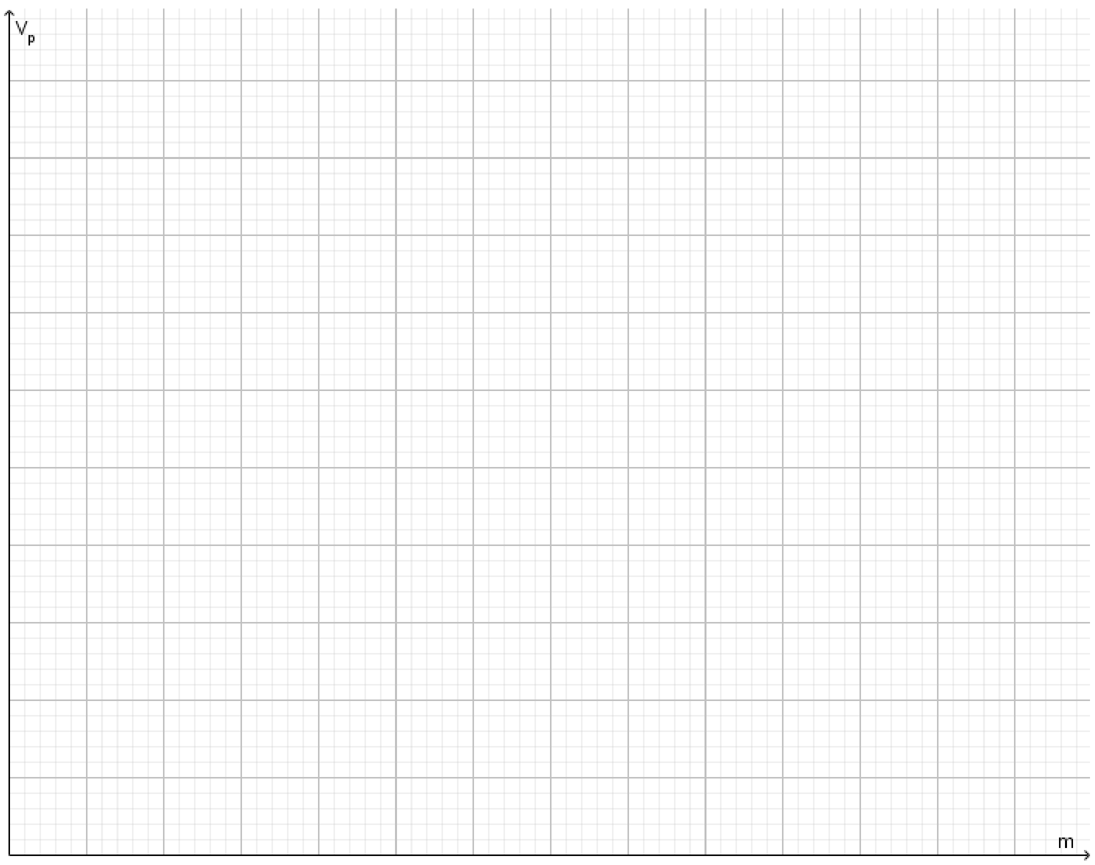
Find out the relationship between Archie's immersed volume and its mass in water.

Only one part of Archie is needed for this activity.

PREDPOKLAD

TABLE AND GRAPH

Mass ***m*** **(g)**	**Immersed Volume** V_i **(ml)**	**Behaviour**



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1. What should Archie's mass be, so half of its volume is immersed? Verify experimentally.

2. What should Archie's mass be, so 60 ml of its volume is immersed? Verify experimentally.

3. What is the mass of displaced water, when Archie is floating?

4. What is the volume of displaced water, when Archie is sinking?

5. Discuss how the graph would look like if we repeated the experiment with Archie's second part, or if Archie was whole.

CONCLUSION

2 CHANGING ARCHIE'S MASS IN ALCOHOL

THEORETICAL BACKGROUND

GOALS

The student should:

- find the relation between an object's mass and its immersed volume in a liquid with known density,
- get familiarized with the basics of floating and sinking.

KEY CONCEPTS

Mass, volume, floating, sinking.

TIME REQUIREMENTS

20 minutes.

ASSIGNMENT

Find out the relationship between Archie's immersed volume and its mass in alcohol.

INSTRUMENTS

Archie, measuring cylinder (or a different transparent container), alcohol, coins (or small weights), scales.

PROCESS

- The process is the same as in the 1st activity, but with alcohol instead of water,
- in this activity, students should discuss the reason of different results in alcohol and in water. Mainly that the value of immersed volume does not equal the value of Archie's mass,
- the discussion should lead to the identification of the effect of a liquid's density on floating and sinking.

SAMPLE VALUES

Mass *m* (g)	**Immersed Volume V_i (ml)**	**Behaviour**
30	33	Floating
36	40	Floating
42	46	Floating
48	53	Floating
54	60	Floating
60	68	Floating
66	75	Floating
72	80	Sinking
78	80	Sinking
84	80	Sinking
90	80	Sinking
96	80	Sinking

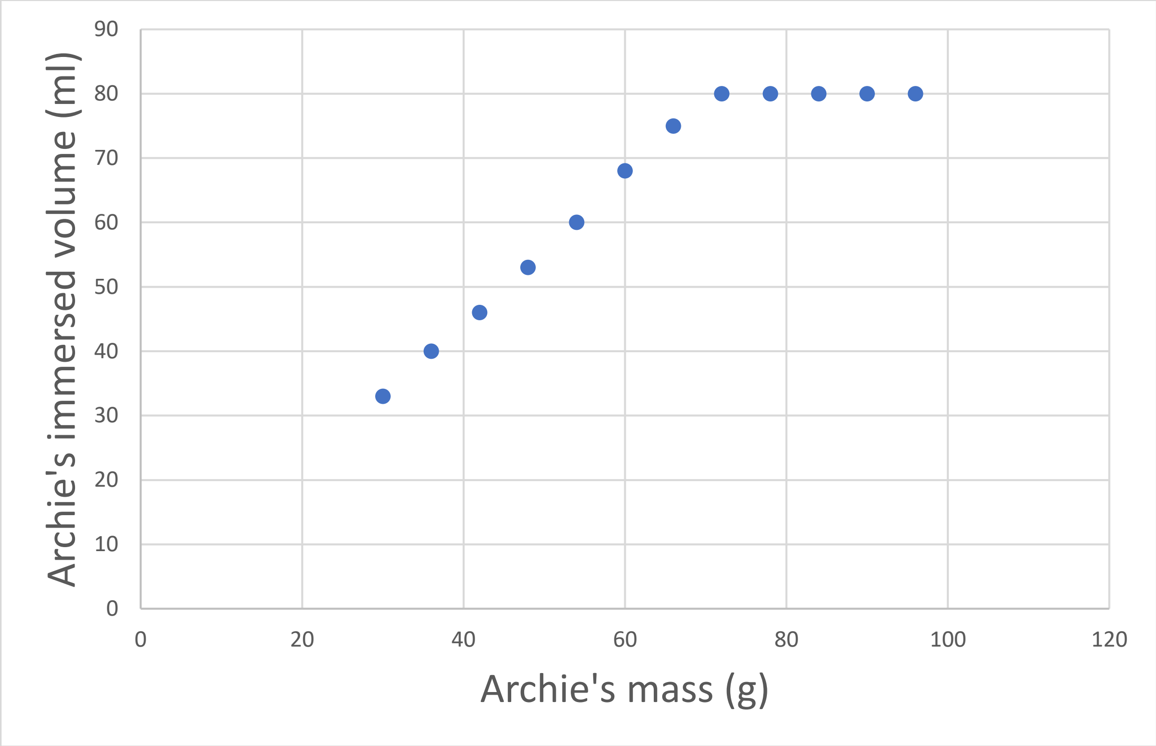


Figure 2. The relation between Archie's immersed volume and its mass in alcohol.
The mass where Archie tips from floating to sinking changes depending on the alcohol's density.

FOLLOW UP QUESTIONS AND EXPECTED ANSWERS

1. What should Archie's mass be, so half of its volume is immersed? Verify experimentally.

   Archie's mass should be approximately 36 g

2. What should Archie's mass be, so 60 ml of its volume is immersed? Verify experimentally.

   Archie's mass should be approximately 54 g

3. What is the mass of displaced alcohol, when Archie is floating?

   Using the alcohol's density (van be measured using a curve fit), it can be shown that the mass of displaced water is the same as Archie's mass.

4. What is the volume of displaced alcohol, when Archie is sinking?

   The same as its own total volume.

EXPECTED CONCLUSIONS

- When an object is floating, it displaces the same mass of liquid as is its own mass:

$$m_l = \rho_l V_i = m_a$$

- When an object is sinking, it displaces the same volume of liquid as is its own volume.

2 CHANGING ARCHIE'S MASS IN ALCOHOL

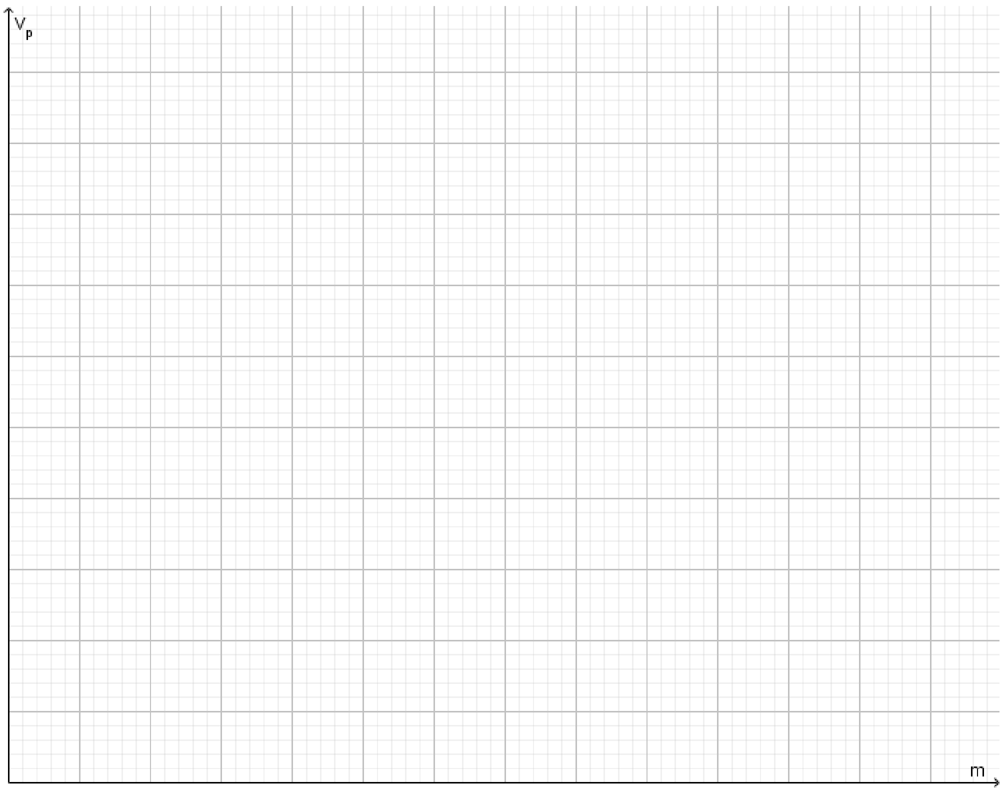
ASSIGNMENT

Find out the relationship between Archie's immersed volume and its mass in alcohol.

PREDICTIONS

TABLE AND GRAPH

Mass *m* (g)	Immersed Volume V_i (ml)	Behaviour



FOLLOW UP QUESTIONS

1. What should Archie's mass be, so half of its volume is immersed? Verify experimentally.

2. What should Archie's mass be, so 60 ml of its volume is immersed? Verify experimentally.

3. What is the mass of displaced alcohol, when Archie is floating?

4. What is the volume of displaced alcohol, when Archie is sinking?

CONCLUSION

3 CHANGING ARCHIE'S VOLUME IN WATER

THEORETICAL BACKGROUND

GOALS

The student should:

- confirm the conclusions from the 1st activity and interpret them using the conclusions from the 2nd activity,
- get familiarized with the basics of floating and sinking.

KEY CONCEPTS

Mass, volume, floating, sinking.

TIME REQUIREMENTS

20 minutes.

ASSIGNMENT

Find out the relationship between Archie's immersed volume and its total volume in water.

Note: set Archie's mass to 145 g

INSTRUMENTS

Archie, measuring cylinder (or a different transparent container), water, coins (or small weights), scales.

PROCESS

- Student write down their predictions of what is going to happen when we change Archie's volume instead of its mass,
- students set Archie's mass to 145 g using coins,
- students combine the two parts of Archie using a small rubber band put on the smaller cylinder,
- students set Archie's volume to the smallest possible setting (e.g. 120 ml),
- students release Archie into water and write down its immersed volume in the table (if Archie is totally submerged, then its immersed volume is its total volume),
- students gradually increase Archie's volume and write down its total and immersed volume in the table,
- students repeat the measurement until the reach the highest possible volume for Archie,
- students answer the follow up questions and form conclusions based on them.

SAMPLE VALUES

Total Volume V (ml)	**Immersed Volume V_i (ml)**	**Behaviour**
120	120	Sinking
125	125	Sinking
130	130	Sinking
135	135	Sinking
140	140	Sinking
145	144	Floating
150	145	Floating
155	146	Floating
160	144	Floating

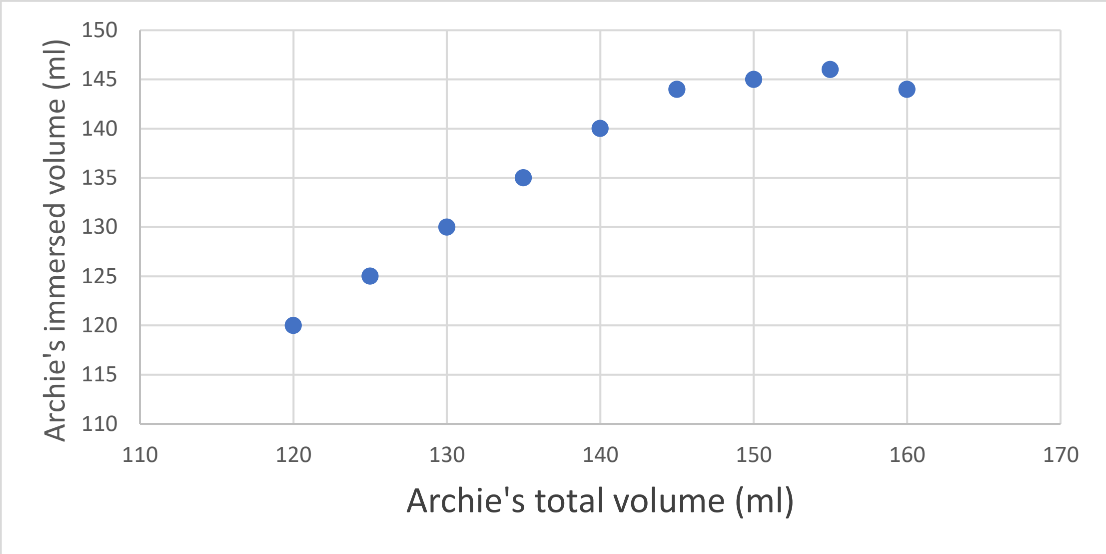


Figure 3. The relation between Archie's immersed volume and its total volume in water.
The volume where Archie tips from floating to sinking is around 145 ml, which corresponds to the conclusions of activities 1 & 2.

FOLLOW UP QUESTIONS AND EXPECTED ANSWERS

1. What should Archie's total volume be so 130 ml of its volume are immersed? Verify experimentally.

   Archie's volume should be 130 ml.

2. What should Archie's total volume be so 150 ml of its volume are immersed?

   With Archie's mass set to 145 g, it is impossible.

3. What is the mass of displaced water, when Archie is floating?

   The same as its own mass.

4. What is the volume of displaced water, when Archie is sinking?

   The same as its own total volume.

5. Discuss how would the graph change, if we repeated the experiment with Archie's mass set to 100 g. Verify experimentally.

   Archie would be floating the whole time, with its immersed volume being 100 ml.

EXPECTED CONCLUSIONS

Students should confirm the conclusion they got from the 1st activity, but they should interpret them using the results from the 2nd activity, i.e. using the density of water.

3 CHANGING ARCHIE’S VOLUME IN WATER

ASSIGNMENT

Find out the relationship between Archie’s immersed volume and its total volume in water.

Note: set Archie’s mass to 145 g

PREDPOKLAD

TABLE AND GRAPH

Total Volume *V* (ml)	**Immersed Volume V_i (ml)**	**Behaviour**

FOLLOW UP QUESTIONS AND EXPECTED ANSWERS

1. What should Archie's total volume be so 130 ml of its volume are immersed? Verify experimentally.

2. What should Archie's total volume be so 150 ml of its volume are immersed?

3. What is the mass of displaced water, when Archie is floating?

4. What is the volume of displaced water, when Archie is sinking?

5. Discuss how would the graph change, if we repeated the experiment with Archie's mass set to 100 g. Verify experimentally.

CONCLUSION

4 CHANGING ARCHIE'S VOLUME IN ALCOHOL

THEORETICAL BACKGROUND

GOALS

The student should:

- confirm the conclusions from the 2nd activity,
- get familiarized with the basics of floating and sinking.

KEY CONCEPTS

Mass, volume, floating, sinking.

TIME REQUIREMENTS

20 minutes.

ASSIGNMENT

Find out the relationship between Archie's immersed volume and its total volume in alcohol.

INSTRUMENTS

Archie, measuring cylinder (or a different transparent container), alcohol, coins (or small weights), scales.

PROCESS

- The teacher tells the students to set the mass of their Archie to 120 g,
- the rest of the process is the same as in the 3rd activity, but with alcohol instead of water,
- students discuss the reason for the different results between alcohol and water and the form a conclusion based on the discussion.

Alternative procedure:

- Instead of the teacher assigning the students a mass 120 g, he can tell them to try to reach similar results as in the 3rd activity. In such a case, Archie should float up to a volume 145 ml. Meaning students should consider the density of alcohol.

SAMPLE VALUES

Total Volume *V* (ml)	**Immersed Volume V_i (ml)**	**Behaviour**
120	120	Sinking
125	125	Sinking
130	130	Sinking
135	135	Sinking
140	139	Floating
145	140	Floating
150	140	Floating
155	140	Floating
160	139	Floating

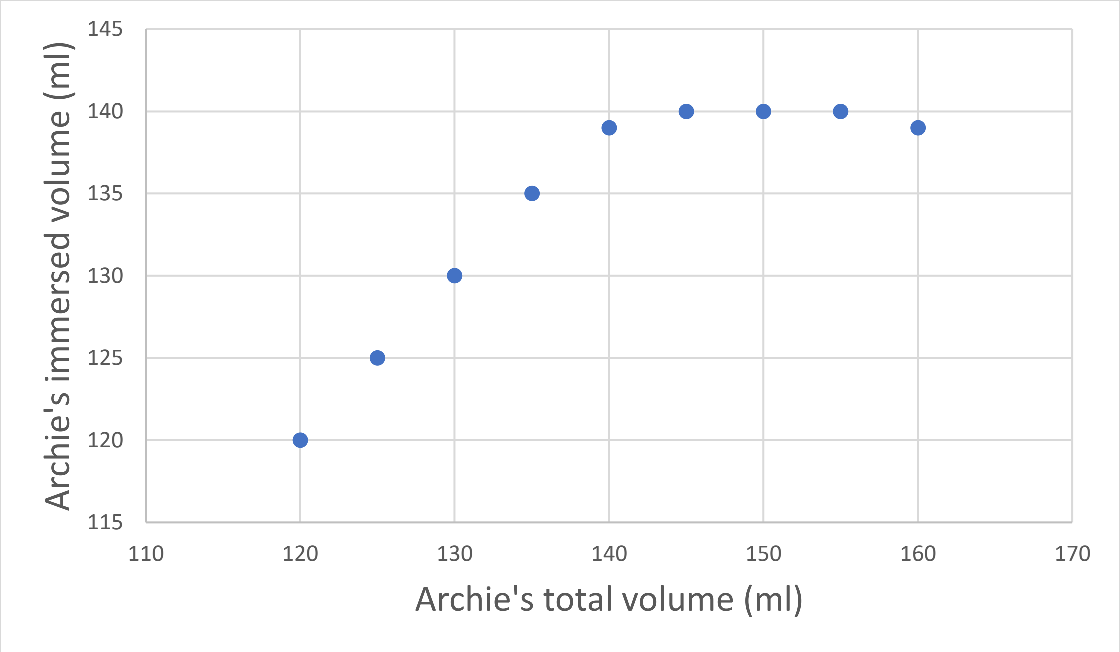


Figure 4. The relation between Archie's immersed volume and its total volume in alcohol. While Archie's mass was set to 120 g, the tipping volume between floating and sinking is around 140 ml corresponding to the conclusions of the 2nd activity.

FOLLOW UP QUESTIONS AND EXPECTED ANSWERS

1. What should Archie's total volume be so 120 ml of its volume are immersed? Verify experimentally.

   Archie's volume should be 120 ml.

2. What should Archie's total volume be so 150 ml of its volume are immersed?

   With Archie's mass set to 120 g and immersing in alcohol, it is impossible.

3. What is the mass of displaced alcohol, when Archie is floating?

   The same as its own mass.

4. What is the volume of displaced alcohol, when Archie is sinking?

   The same as its own total volume.

EXPECTED CONCLUSIONS

Students should confirm the conclusion they got from the 2st activity.

4 CHANGING ARCHIE'S VOLUME IN ALCOHOL

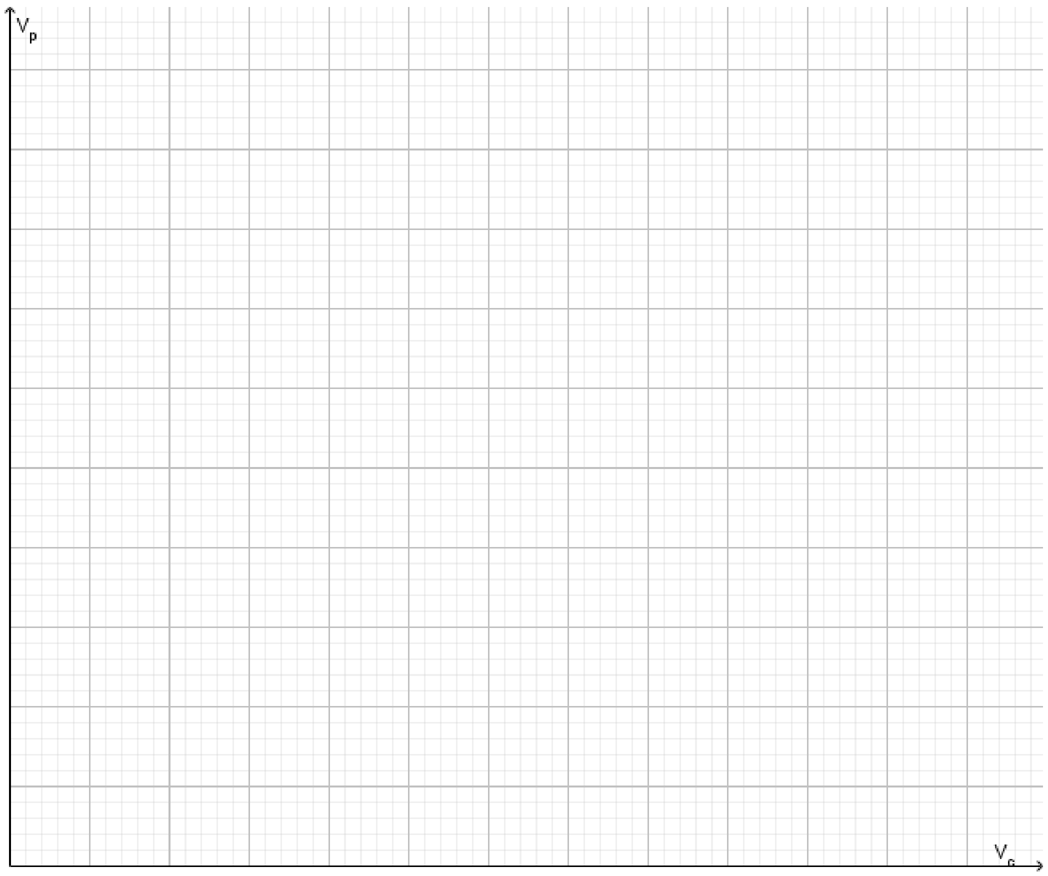
ASSIGNMENT

Find out the relationship between Archie's immersed volume and its total volume in alcohol.

PREDPOKLAD

TABUĽKA A GRAF

Total Volume V (ml)	Immersed Volume V_i (ml)	Behaviour



FOLLOW UP QUESTIONS

1. What should Archie's total volume be so 120 ml of its volume are immersed? Verify experimentally.

2. What should Archie's total volume be so 150 ml of its volume are immersed?

3. What is the mass of displaced alcohol, when Archie is floating?

4. What is the volume of displaced alcohol, when Archie is sinking?

CONCLUSIONS

5 DISCOVERING BUOYANT FORCE

THEORETICAL BACKGROUND

GOALS

The student should:

- use the conclusions from activities 1-4 to discover buoyant force affecting and object immersed in a liquid,
- find out that buoyant force is not dependant on depth but only on immersed volume,
- get familiarized with Archimedes' principle.

KEY CONCEPTS

Mass, volume, floating, sinking.

TIME REQUIREMENTS

20 – 30 minutes.

ASSIGNMENT

How large are the force affecting an iron ball with a volume 400 cm^3 and a mass 3 kg at the bottom of the sea (sea water density 1020 $kg.m^{-3}$).

INSTRUMENTS

Archie, measuring cylinder (or a different transparent container), water, coins (or small weights), Newton-meter, thread.

PROCEDURE

- The activity's main goal is the discovery of buoyant force,
- the teacher can suggest starting by analysing forces affecting a floating object,
- when an object is floating, the forces affecting are gravitational force and an unknown force the same magnitude in the opposite direction,
- the teacher can name the unknown force as buoyant force, the activity turns to analysing that force,
- students know the following equation from the results of the 2nd activity:

$$\rho_l V_i = m$$

- the teacher asks if we can change something about the equation to make it about forces,
- students should conclude, alone or after a discussion, that the equation should be multiplied by gravitational acceleration,
- after the multiplication, students should get the following equation:

$$\rho_l V_i g = mg$$

- the right side of the equation is apparently gravitational force, while the left side is a different force but with the same magnitude,
- the teacher can start a discussion about those forces leading to the definition of the left force as buoyant force:

$$F_b = \rho_l V_i g$$

- students now can find out how this force affects object immersed in liquids,
- students set Archie's volume to a fixed value and they weigh it down using coins so Archie's density becomes higher than the density of water (meaning it will sink on its own),
- students hang Archie on the Newton meter using the thread,
- students write down the value of the force of the Newton meter in to the table with an immersed value 0 ml,

- students gradually immerse Archie into the water while writing down the value of the immersed volume and the force of the newton meter in the table,
- as the Newton meter measures the difference between gravitational force and buoyant force students can calculate the value of buoyant force and write it down in the table,
- students also try to find out how buoyant force will change after submerging the object,
- students answer the follow up questions, form conclusions and calculate the answer to the assignment.

SAMPLE VALUES

Immersed Volume (ml)	Force on Newton Meter (N)	Buoyant Force (N)
0	1,4	0
10	1,3	0,1
20	1,2	0,2
30	1,1	0,3
40	1,0	0,4
50	0,9	0,5
60	0,8	0,6
70	0,7	0,7
80	0,6	0,8
90	0,5	0,9
100	0,4	1,0
110	0,3	1,1
120	0,2	1,2

FOLLOW UP QUESTIONS AND EXPECTED ANSWERS

1. How did buoyant force change when we released the submerged Archie deeper into water?

   It did not change. The buoyant force does not depend on the depth in which the object is, only on its immersed volume. Once Archie was totally submerged in water, the buoyant force did not change anymore.

2. Was the equation you got using previous activities confirmed?

   Yes. For example, when the immersed volume was 20 ml, which is 0.00002 m^3, the buoyant force should be: $F_b = \rho_l V_i g = 1000\,.\,0.00002\,.\,10 = 0{,}2\ N$, which is the value we got from the measurement.

EXPECTED CONCLUSIONS

- The equation for calculating the buoyant force affecting an object immersed into a liquid is:

$$F_b = \rho_l V_i g$$

- The buoyant force is not dependant on the depth of the object in the liquid but on its immersed volume.
- The forces affecting the iron ball are gravitational and buoyant force, which have the following values:

$$F_g = 29\ N$$

$$F_b = 4\ N$$

5 DISCOVERING BUOYANT FORCE

ASSIGNMENT

How large are the force affecting an iron ball with a volume 400 cm^3 and a mass 3 kg at the bottom of the sea (sea water density 1020 $kg.m^{-3}$).

THEORETICAL INTRODUCTION AND PREDICTIONS

MEASURED VALUES

Immersed Volume (ml)	Force on Newton Meter (N)	Buoyant Force (N)

FOLLOW UP QUESTIONS

1. How did buoyant force change when we released the submerged Archie deeper into water?

2. Was the equation you got using previous activities confirmed?

CONCLUSIONS

6 MEASURING THE DENSITY OF A LIQUID

THEORETICAL BACKGROUND

GOALS

The student should:

- use the conclusions from activities 1-5 to solve a practical problem.

KEY CONCEPTS

Mass, volume, floating, sinking.

TIME REQUIREMENTS

10 – 20 minutes.

ASSIGNMENT

How can we use Archie to measure the density of an unknown liquid?

INSTRUMENTS

Archie, measuring cylinder (or a different transparent container), unknown liquid, coins (or small weights), scales.

PROCEDURE

- Students use the conclusions of previous activities to find out the density of an unknown liquid using Archie,
- the conclusion can be achieved in two ways:
  - using the equality between gravitational and buoyant force for floating objects,
  - or using the conclusion from the 2nd activity.
- In both cases the result should be:

$$\rho_k = \frac{m}{V_p}$$

- The activity can continue in two possible ways:
  - quick measurement: students weigh Archie using coins and measure its weight, they immerse it in the liquid, measure the immersed volume, and then they calculate the density. Obviously, this is a less accurate measurement, but as the point of the activity is students applying Archiemdes' principle in practice, it is adequate if the teacher is pressed for time.
  - slow measurement: students gradually change Archie's mass and release it into the water, similarly as in the 1st and 2nd activity. Using a curve fit, they can measure the density of the unknown liquid. This measurement is more accurate, but requires more time.

6 MEASURING THE DENSITY OF A LIQUID

ASSIGNMENT

How can we use Archie to measure the density of an unknown liquid?

SOLUTION

7 ANCHOR IN A BOAT

THEORETICAL BACKGROUND

GOALS

The student should:

- use the conclusions from activities 1-5 to solve a practical problem.

KEY CONCEPTS

Mass, volume, floating, sinking.

TIME REQUIREMENTS

10 – 20 minutes.

ASSIGNMENT

A small boat with an anchor is floating in a swimming pool. What would happen to the water level if the anchor is thrown from the boat into the swimming pool?

PROCEDURE

- The student prepares the demonstration of the activity (figure 5 left):
    - Archie represents the boat,
    - the coins/weight represents the anchor,
    - the measuring cylinder represents the swimming pool.

Figure 5. Left: The beginning of the demonstration. The coins are inside Archie while Archie is afloat. Right: The coins are in the water. The water level visibly drops.

- Students discuss what should happen to the water level if the anchor is released,
- student form their own prediction and try to explain them on their own,
- the teacher marks the water level with an erasable marker on the measuring cylinder,
- the teacher thrown the coins from Archie into the measuring cylinder,
- the water level visibly drops (figure 5 right),
- students try to explain the phenomenon using Archimedes' principle.

EXPLANATION

- According to Archimedes' principle, a floating object displaces its own mass of a liquid, while a sinking object displaces its own volume of liquid.
- When the anchor was in the boat, it was afloat, therefore it displaced its mass.
- When the anchor was in the water, it displaced its volume.
- As the density of the anchor is higher than water, then it displaces more water when it is afloat than when it is sinking. Therefore, the water level drops.

7 ANCHOR IN A BOAT

ASSIGNMENT

A small boat with an anchor is floating in a swimming pool. What would happen to the water level if the anchor is thrown from the boat into the swimming pool?

PREDICTIONS

RESULTS

Describe the procedure of verifying your predictions and the achieved results.

8 A MELTING PIECE OF ICE

THEORETICAL BACKGROUND

GOALS

The student should:

- use the conclusions from activities 1-5 to solve a practical problem.

KEY CONCEPTS

Mass, volume, floating, sinking.

TIME REQUIREMENTS

10 – 20 minutes.

ASSIGNMENT

A piece of ice is floating in water. How will the water level change when the piece of ice melts?

PROCEDURE

- Students write down their predictions and try to explain them,
- students put a piece of ice in water,
- students mark the water level after the addition of ice,
- students observe the water level while the ice is melting,
- students explain the results using Archimedes' principle.

EXPLANATION

- When the piece of ice was afloat it displaced its mass of water,
- when ice melts, it become a liquid with the same mass and different volume,
- a liquid displaces its **mass** and its volume because it displaces exactly itself,
- before melting the ice displaced its mass, after melting it displaced its mass, meaning the water level did not change.

8 A MELTING PIECE OF ICE

ASSIGNMENT

A piece of ice is floating in water. How will the water level change when the piece of ice melts?

SOLUTION

9 A MELTING PIECE OF FROZEN OIL

THEORETICAL BACKGROUND

GOALS

The student should:

- use the conclusions from activities 1-5 to solve a practical problem.

KEY CONCEPTS

Mass, volume, floating, sinking.

TIME REQUIREMENTS

20 – 30 minutes.

ASSIGNMENT

A piece of frozen oil is put into liquid oil. How will the oil level change when the frozen oil melts?

PROCEDURE

- Before solving this activity, we offer a few recommendations based on the fact that the difference between the density of frozen and liquid oil is small:
  - use the narrowest available cylinder,
  - do not pour liquid oil first and then add frozen oil,
  - first insert the frozen oil and wait until some of it melts and that will be the oil level,

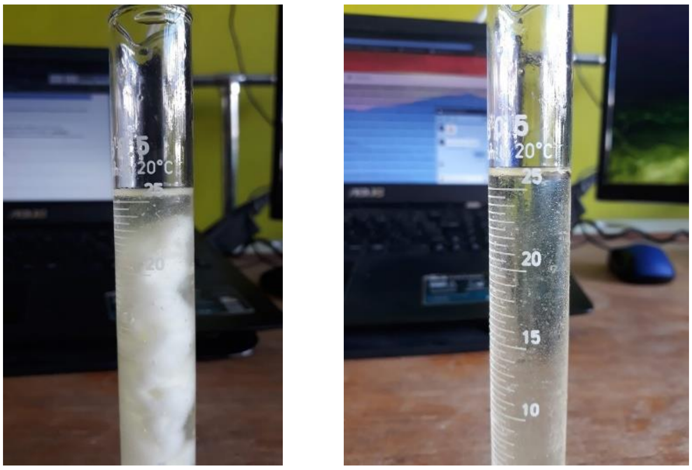


Figure 6. Left: The frozen oil does not float in oil. Right: The frozen oil melted; the oil level has risen.

- Before the students form their predictions, the teacher should reveal that frozen oil does not float in oil.
- Students write down their prediction and try to explain them,
- the teacher inserts the frozen oil in to the measuring cylinder, a small part melts quickly so it is not necessary to add oil, the oil level can be marked,
- students observe how the oil level changes when the frozen oil melts,
- the oil level slightly rises after the frozen oil melts.

EXPLANATION

- When the frozen oil is sinking, it displaces its volume of oil,
- when the oil melts, it displaces its mass and volume, but its volume becomes larger, because it had a larger density when it was frozen,
- as the oil's volume increases the oil level rises.

9 A MELTING PIECE OF FROZEN OIL

ASSIGNMENT

A piece of frozen oil is put into liquid oil. How will the oil level change when the frozen oil melts?

SOLUTION