More on Force - Buoyancy

- Why do some things float and other don’t?
- Why does a block of steel sink but a steel boat floats?
- The relevant factor is the average density of an object (the ratio of mass to volume) - units are kg/m³

<table>
<thead>
<tr>
<th>Material</th>
<th>Density</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air</td>
<td>1.21 kg/m³</td>
</tr>
<tr>
<td>Styrofoam</td>
<td>100 kg/m³</td>
</tr>
<tr>
<td>Ice</td>
<td>917 kg/m³</td>
</tr>
<tr>
<td>Pure water</td>
<td>1000 kg/m³</td>
</tr>
<tr>
<td>Sea water</td>
<td>1024 kg/m³</td>
</tr>
<tr>
<td>Iron</td>
<td>7900 kg/m³</td>
</tr>
</tbody>
</table>

Weight is an external force acting on a person. The Earth pulls on the person and the person pulls on the Earth - an action-reaction pair.

The person isn’t accelerating up or down, so there must be a force on her to balance the weight force.

- Her weight causes her feet to push on the ground and so the ground pushes back on her.
- The forces on her are the weight and the reaction of the floor - they are in balance (if the floor is strong enough!)

First - Standing still

- Weight is an external force acting on a person. The Earth pulls on the person and the person pulls on the Earth - an action-reaction pair.

The ship will float if the buoyant force (the weight of the water displaced) equals the weight of the ship

$W = F_{buoyant}$

This applies whether or not an object floats
- an object will float (without assistance) if the buoyant force (the weight of the water displaced) equals the weight of the object

Experiment 1

- Hang an object from a scale - the forces on the object are in balance $W = T_1$
- If you immerse an object in water, what happens to the weight as measured by the scale?
- It decreases! Why? Does it really change?
- The forces on the object are still in balance - there must be a new force - the buoyant force $W = T_2 + F_{buoyant}$

Experiment 2

- If $W_1$ is greater than $W_2$ but the objects are the same size, how do the buoyant forces compare?
- The buoyant force is the same

Archimedes’ Principle

- When an object is immersed in a fluid, there is an upward buoyant force equal to the weight of the volume of fluid displaced by the object

This applies whether or not an object floats
- an object will float (without assistance) if the buoyant force (the weight of the water displaced) equals the weight of the object

Archimedes’ Principle (2)

The ship will float if the buoyant force (the weight of the water displaced) equals the weight of the ship

$W = F_{buoyant}$
Icebergs

- When an object is immersed in a fluid, there is an upward buoyant force equal to the weight of the volume of water displaced.

The Iceberg floats so
\[ W = F_{\text{buoyant}} \]

i.e.
\[ \text{Weight} = \text{Weight sea water displaced} \]
\[ (\text{volume of ice} \times \text{density of ice} \times \text{g}) = (\text{volume of water} \times \text{density of sea water} \times \text{g}) \]

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Icebergs (2)

\[ (\text{volume of ice} \times \text{density of ice}) = (\text{volume of water} \times \text{density of sea water}) \]
\[ (\text{volume of ice} \times 917 \text{kg/m}^3) = (\text{volume of water} \times 1024 \text{kg/m}^3) \]

So volume of ice > volume of water displaced

i.e. not all the ice is under the water

Implications:
- Icebergs float
- Water freezes from the top

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Balloons

- How can we make a hot air balloon rise and fall?
- the Cartesian diver (i.e. the floating bottle inside a bottle)

‘Diver’ – Push

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Archimedes’ Crown experiment

- Archimedes supposedly detected a fraud in the production of a gold crown (wreath?) produced for Hiero II of Syracuse (~250 BC). Did it contain silver?
- He measured the overflow of water produced by the crown and an equal weight of gold.
- How does this help?
- Uses density rather than Archimedes Principle and would have been difficult to do accurately.

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Archimedes’ Crown experiment (2)

- Weight = mass \times g (remember g = 9.8 m/s²)
- So if \( w_{\text{gold}} = w_{\text{rown}} \) then

\[ (\text{Density} \times \text{volume} \times \text{g})_{\text{gold}} = (\text{Density} \times \text{volume} \times \text{g})_{\text{rown}} \]

- If

\[ \text{volume}_{\text{gold}} = \text{volume}_{\text{rown}} \]

Then the densities must also be the same and so the crown is probably pure gold. If the volumes are not the same then the densities can’t be and so the crown is not pure gold.

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Summary

- When an object is immersed in a fluid, there is an upward buoyant force equal to the weight of the volume of fluid displaced by the object.
- an object will float if the buoyant force equals the weight of the object.

- Next… More on balance of forces
- Newton’s 3rd law

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