Grade Level: 6-8
Time Estimate: 3-5 days

OCEARCH PHYSICS: FORCES / INSTRUCTOR INFO

Summary

This lesson includes vocabulary, content, examples and activities to help students learn and understand forces, work, pressure and buoyancy. Students will learn how to identify different forces and use real life OCEARCH data sets to calculate forces using Newton's Laws and Pascal's Principle. Students will also learn how to calculate buoyancy force using Archimedes' Principle. A comprehensive exam is included to give out before and after the lesson to measure the student's learning.

Goals & Objectives

The students will:

- describe and understand how forces affect an object's motion;
- learn the following concepts: forces and Newton's laws of motion;
- be able to demonstrate Archimedes' Principle;
- be able to calculate different variables using Pascal's Law;
- use calculations to demonstrate a ship floating and sinking.

// STANDARDS **This lesson aligns with the following TEKS:**

6th Grade Science: 1A, 1B, 2A, 2B, 3A, 3C, 3D, 4A, 6B, 8B
7th Grade Science: 1A, 1B, 2A, 2B, 2C, 2E, 3A, 3C, 3D, 4A, 7A
8th Grade Science: 1A, 1B, 2A, 2B, 2C, 2D, 2E, 3A, 3C, 3D, 4A, 6A, 6B, 6C

This lesson aligns with the following Next Generation Science Standards:

Framework
1. Asking questions and defining problems
3. Planning and carrying out investigations
4. Analyzing and interpreting data
5. Using mathematics and computational thinking
8. Obtaining, evaluating, and communicating information

MS. Forces and Interactions – MS-PS2-1; MS-PS2-2
Disciplinary Core Ideas
PS2.A: Forces and Motion
- For any pair of interacting objects, the force exerted by the first object on the second object is equal in strength to the force that the second object exerts on the first, but in the opposite direction (Newton's third law). (MS-PS2-1)
- The motion of an object is determined by the sum of the forces acting on it; if the total force on the object is not zero, its motion will change. The greater the mass of the object, the greater the force needed to achieve the same change in motion. For any given object, a larger force causes a larger change in motion. (MS-PS2-2)
- All positions of objects and the directions of forces and motions must be described in an arbitrarily chosen reference frame and arbitrarily chosen units of size. In order to share information with other people, these choices must also be shared. (MS-PS2-2)

Crosscutting Concepts
Stability and Change
- Explanations of stability and change in natural or designed systems can be constructed by examining the changes over time and forces at different scales. (MS-PS2-2)

Connections to Engineering, Technology, and Applications of Science
Influence of Science, Engineering, and Technology on Society and the Natural World
- The uses of technologies and any limitations on their use are driven by individual or societal needs, desires, and values; by the findings of scientific research; and by differences in such factors as climate, natural resources, and economic conditions. (MS-PS2-1)

MS. Energy – MS-PS3-1; MS-PS3-2; MS-PS3-4
Science and Engineering Practices
Planning and Carrying Out Investigations

- Plan an investigation individually and collaboratively, and in the design: identify independent and dependent variables and controls, what tools are needed to do the gathering, how measurements will be recorded, and how many data are needed to support a claim. (MS-PS3-4)

Disciplinary Core Ideas

PS3.A: Definitions of Energy

- Motion energy is properly called kinetic energy; it is proportional to the mass of the moving object and grows with the square of its speed. (MS-PS3-1)
- A system of objects may also contain stored (potential) energy, depending on their relative positions. (MS-PS3-2)

PS2.C: Relationship Between Energy and Forces

- When two objects interact, each one exerts a force on the other that can cause energy to be transferred to or from the object. (MS-PS3-2)

Helpful Tips

1) The content in this lesson related to OCEARCH and the Global Shark Tracker. Spend a few minutes getting familiar with the website and the tracker if you have not done so already. The Global Shark Tracker is also available as an app for iPhone and Android.
2) This lesson plan is designed to be adaptable to suit your specific needs. Use the entire lesson plan or just parts of it. This material can be expanded to be an entire unit or condensed for just one day in the classroom.
3) Vocabulary words will be underlined as they appear in the lesson plan. A complete list of vocabulary words is included as well.
4) Answers to questions and prompts for discussions will appear in *italics*.
5) Optional activities and content (side notes) will appear in a box. Use these to enhance your lesson and adapt it to suit your needs!
6) Have questions for OCEARCH Expedition Leader, Chris Fischer? Email info@OCEARCH.org to schedule a Skype session and let your students/child talk directly to Chris and the OCEARCH crew!
7) Email all questions about this lesson to info@OCEARCH.org.

Vocabulary

Acceleration – An object's acceleration is the rate at which the velocity of an object changes with time. It can be calculated using the formula: $\bar{a} = \Delta v/\Delta t$, where Δv is the change in velocity and Δt is the duration of the period.

Archimedes' Principle – Buoyancy force is equal to the weight of the displaced water.

Buoyancy – Upward force exerted by a fluid that opposes the weight of an immersed object.

Classical Mechanics – Study of the physical laws describing an object's motion under the influence of forces.

Energy – Capability of a system to perform work. Energy exists in many forms such as kinetic, potential, or heat. Energy is neither created nor destroyed. Energy is measured in joules (J) or Newtons (N).

Force – Any influence, such as a push or pull, that causes an object to undergo a certain change in its state. Force is measured in Newtons (N). N = 1 kg * m/s^2.
Gravity – Force that causes two bodies to move towards each other. Gravity times mass (kg) gives an object its' weight. The acceleration of gravity on Earth has an approximate value of $9.81 m/s^2$.
Motion – Any movement or change in position or time.
Newton's Laws of Motion – The three laws that form the basis for classical mechanics are Newton's Laws of Motion. They describe the forces acting on a body and its motion due to those forces.
Pascal's Principle – Pressure exerted anywhere in a body of fluid is transmitted equally in all directions throughout the fluid.
Vector – A quantity that has both magnitude and direction.
Velocity – The rate of change of position of an object along with its direction. Velocity is a vector quantity, meaning it has a magnitude and a direction. Average velocity can be calculated using the following formula: $v = \Delta x / \Delta t$, where Δx is the displacement and Δt is the time interval.
Weight – The force of gravity on an object. It is calculated as the mass times the acceleration of gravity, $w = mg$.
Work – A force is said to do work when it acts on a body so that there is a displacement of the point of application in the direction of the force. $W = Fd$, where F is the force of magnitude and d is the distance the object is displaced in the direction of the force.

Grade Level: 6-8
Time Estimate: 5-15 mins

OCEARCH PHYSICS: FORCES / PRE-LESSON ASSESSMENT

Use the following true/false and multiple choice questions as an introduction/warm-up to the lesson topics. You can do this in a verbal or written format, as a game, individually, or as a whole class! A handout is provided if you wish to hand the questions out in a quiz format.
The questions do not need to be graded. They are intended to give the students an idea of what they will be learning and to see what they already know.

1) True or False A vector is a quantity that has only direction.
Answer: *False*

2) True or False Buoyancy is an upward force exerted by a fluid that opposes the weight of an immersed object.
Answer: *True*

3) While driving in your car a bug hits your windshield and splatters. The force on the bug is:
   a. greater than the force on the car
   b. less than the force on the car
   c. equal to the force on the car

Answer: *c*

4) When there is an increase in pressure at any point in a confined fluid, there is a(n)____________ at every point in the container.
   a. increase
   b. decrease

Answer: *a*

5) The buoyant force of an object is dependent on:
   a. size of object
   b. shape of object
   c. density of object
   d. submerged volume of object

Answer: *d*

6) What determines if an object floats or sinks?
   a. density
   b. weight
   c. shape
   d. volume

Answer: *a*

Name: ______________________________ Date: ________________________

OCEARCH Physics Part 1 - Forces

Select the correct answer(s) to each of the following questions.

1) True or False A vector is a quantity that has only direction.

2) True or False Buoyancy is an upward force exerted by a fluid that opposes the weight of an immersed object.

3) While driving in your car a bug hits your windshield and splatters. The force on the bug is:
   a. greater than the force on the car
   b. less than the force on the car
   c. equal to the force on the car

4) When there is an increase in pressure at any point in a confined fluid, there is a(n)____________ at every point in the container.
   a. increase
   b. decrease

5) The buoyant force of an object is dependent on:
   a. size of object
   b. shape of object
   c. density of object
   d. submerged volume of object

6) What determines if an object floats or sinks?
   a. density
   b. weight
   c. shape
   d. volume

Grade Level: 6-8

OCEARCH PHYSICS: FORCES / LESSON PLAN

INTRODUCTION **3-5 mins**

There are many types of forces that affect everything in the universe. Some forces we can easily observe and experience on a day to day basis, while other forces are more difficult to observe. Forces are commonly represented by diagrams in which the force is shown by an arrow, and the direction of the arrow illustrates the direction the force is acting.

A force is a vector quantity that causes an object to change its state, either by movement or direction. There are many different types of forces that will be discussed in this lesson.

Part 1. Contact Force (30 – 45 minutes)

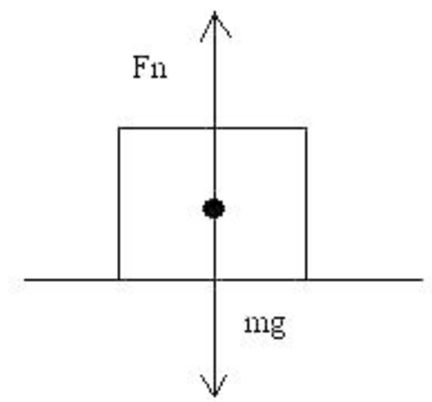
A contact force is one in which there is direct contact between two objects. An example of a contact force is when a shark rams a seal it is hunting from below (Figure 1). There are three types of contact forces: normal force, frictional force, and tension.

Figure 1. Shark ramming seal.
Illustration Credit: Lori Timm, Ph.D. – Landry's Downtown Aquarium

Normal Force

A normal force is a contact force that acts perpendicular to the surface of an object. A normal force acts in the opposite direction to the gravitational force pulling down on the object. For example, if a book is resting on a table, the table exerts an upward force on the book. This force is called the normal force and supports the weight of the book (see Figure 2).

Figure 2. Normal force. Illustration credit: Lori Timm, Ph.D.-Landry's Downtown Aquarium



Normal force is calculated as: $F_n = (m)(g)$

Where F_n is normal force, m is mass, and g is gravity (9.81 m/s^2).

Calculation Example 1.1

If a shark weighing 1,000 kg is resting on the hydraulic lift on the M/V OCEARCH, what is the normal force acting on the shark? Round to a whole number.

Answer: *$F_n = (m)(g) = (1{,}000\ kg) \times (9.81\ m/s^2) = 9{,}810\ N$*

Calculation Example 1.2 (Student Practice Question)

If a shark weighing 1,500 kg is resting on the hydraulic lift on the M/V OCEARCH, what is the normal force acting on the shark? Round to a whole number.

Answer: *$F_n = (m)(g) = (1{,}500\ kg) \times (9.81\ m/s^2) = 14{,}715\ N$*

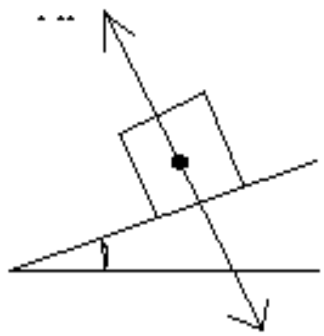
Normal force F_n can also be calculated using vector angles by using the following equation:

$$F_n = (m)(g)\cos(\theta)$$

Calculation Example 1.3

If an object weighs 157 kg and is on a 38° incline, what is the normal force acting on the object? See Figure 3. Round up to the nearest tenth.

Figure 3. Normal force with vector angle.



Answer: $F_n = (m)(g)\cos(\theta) = (157\ kg) \times (9.81 m/s^2) \times (\cos 38°) = 1{,}213.7\ N$

Calculation Example 1.4 (Student Practice Problem)

If an object weighs 351 kg and is on a 23° incline, what is the normal force acting on the object? First draw your image. Round to the nearest whole number.

Answer: $F_n = (m)(g)\cos(\theta) = (157\ kg) \times (9.81 m/s^2) \times (\cos 38°) = 1{,}213.7\ N$

Frictional Force

A frictional force resists or opposes the motion of two surfaces sliding against each other and acts parallel to an object's surface. Friction depends on the amount of contact force pushing the surfaces against each other. The formula to calculate frictional force is:

$$F_f = (\mu)(F_n)$$

Where F_f is the frictional force, μ is the coefficient of friction and F_n is the magnitude of the normal force or mg.

Calculation Example 1.5

A researcher on the M/V OCEARCH vessel is pushing a box with a mass of 25 kg. What is the normal force acting on the box? What is the frictional force? Assume the coefficient of friction μ is 0.5. Round up to the nearest tenth.

Answer:
Normal Force (F_n) = (m)(g) = (25 kg) x (9.81 m/s^2) = 245.3 N

Frictional Force (F_f) = (μ)(F_n) = (0.5) x (245.3 N) = 122.7 N

Calculation Example 1.6 (Student Practice Problem

A deckhand on the M/V OCEARCH vessel wants to move a piece of equipment with a mass of 36 kg. He already calculated the normal force as 353.16 N. What is the frictional force? Assume the coefficientμ is 0.5. Round up to the nearest tenth.

Answer: *Frictional Force* (F_f) = (μ)(F_n) = (0.5) x (353.16 N) = 176.6 N

Tension Force

Tension is described as pulling or stretching an object tight. Tension can be easily described by pulling on a rope or cable. A person pulling on the cable is not applying a direct force to the object being pulled up because they are not in direct contact with the object. Rather the force is being exerted on the cable and the cable is simply transmitting the force to the object.

Tension is calculated by using the following equation:

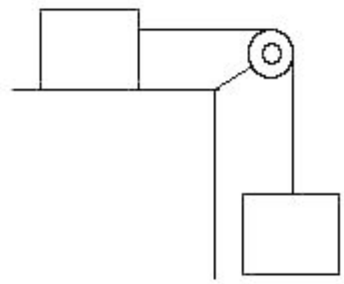
$$F_{tension} = (m)(a_{net})$$

Where $F_{tension}$ is tension force, m is mass, and a_{net} is net acceleration.

Calculation Example 1.7

A 50 kg box is being pulled on a frictionless surface by a hanging 30 kg weight across a frictionless pulley. The acceleration is 3.68 m/s^2. Calculate the tension in the rope (Figure 4).

Figure 4.



Answer:
To calculate tension:

$$F_{tension} = (m)(a_{net})$$
$$F_{tension} = (m)(a_{net})$$
$$F_{tension} = (50\ kg) \times (3.68\ m/s^2) = 184\ N$$

<u>Calculation Example 1.8 (Student Practice Problem)</u>

A 132 kg box is being pulled on a frictionless surface by a hanging a 50 kg weight across a frictionless pulley. The acceleration is 2.70 m/s^2. Calculate the tension in the rope. Round to the nearest tenth.
Answer:

$$F_{tension} = (m)(a_{net})$$
$$F_{tension} = (m)(a_{net})$$
$$F_{tension} = (132\ kg) \times (2.70\ m/s^2) = 356.4\ N$$

<u>Discussion and Activity</u> (optional)

Ask the students to identify the force acting in each of the following scenarios:

1. A researcher on the M/V OCEARCH pulls down on a cable. Tension Force
2. OCEARCH member sitting motionless on a crate. Normal Force
3. A crate is pushed across the deck. Friction Force

Have students split into small groups or partners. Assign each group a type of force (normal, friction, or tension). Each group should find objects and demonstrate the force to the whole class. Let the other students guess what force is being demonstrated.

Part 2. Newton's Laws of Motion (30 – 45 minutes)

Newton's laws of motion were first published in 1686 by Sir Isaac Newton, a highly influential English physicist and mathematician. Newton is also known for his theory of gravity, building the first practical telescope, laying the foundations for calculus, and his work in astronomy and optics.

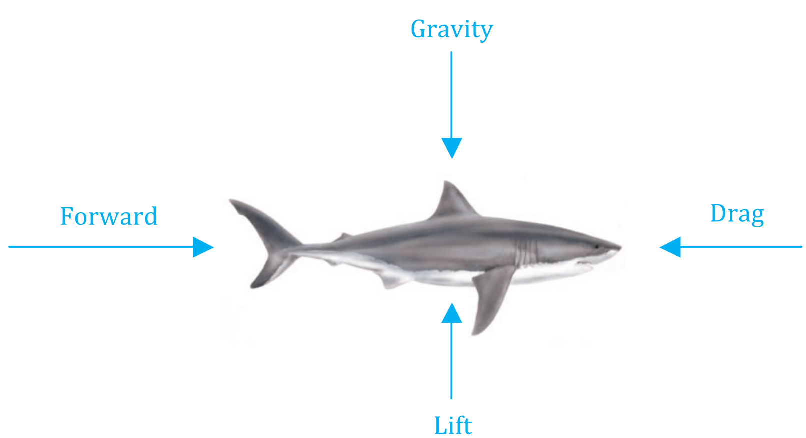
Newton's laws of motion describe all the principles of dynamics. Dynamics studies the interactions between force and motion. Force is any influence, such as a push or pull, which causes an object to undergo a certain change in its state. Motion is a change in position of an object with respect to time and its reference point. It is typically described in terms of displacement, velocity, acceleration, and time. The three statements known as Newton's laws of motion are the base for all principles involved in dynamics and classical mechanics.

Newton's First Law

Newton's first law, or law of inertia, states that an object at rest will stay at rest and an object in motion will stay in motion, unless the object is acted on by an external force. In other words, if the object is initially at rest, it remains at rest; if it is initially in motion, it continues to move with constant velocity. Velocity is the rate of change of position of an object along with its direction. Velocity is a vector quantity, meaning it has a magnitude and a direction.

Imagine a shark swimming in the open ocean. According to the law of inertia, if a shark is swimming at 0.82 m/s^2 and suddenly stops propelling with its tail, the shark should continue moving forward at 0.82 m/s^2 as long as the force of the shark moving forward and the forces working against the shark are balanced. However, we know that if the shark stops swimming, the shark's velocity will slow down and eventually come to a rest. This is because there are external forces acting on the shark in opposite directions of the forward movement.

The external forces acting upon the shark opposite of its forward thrust are gravity, drag, and lift.



The net force is the vector sum of all the individual forces acting upon an object.

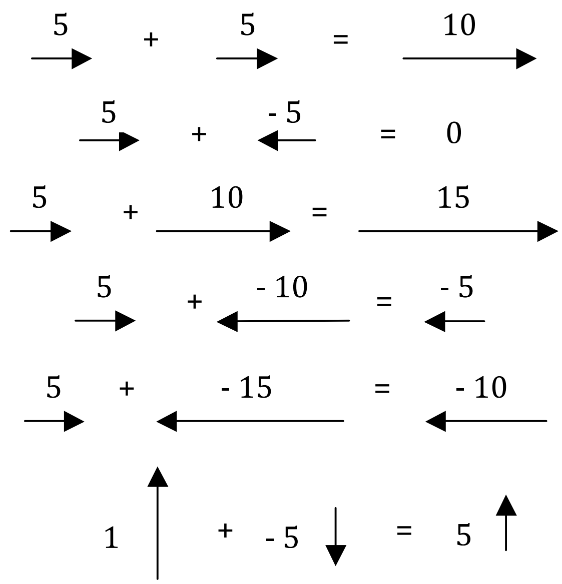
$$F_{net} = F1 + F2 + F3 + ...$$

In other words,

Where F1, F2, and F3 represent the various forces acting upon an object.

Like any force, the net force is a vector and has a direction. Forces acting in opposite directions of other forces will be indicated by a negative sign.

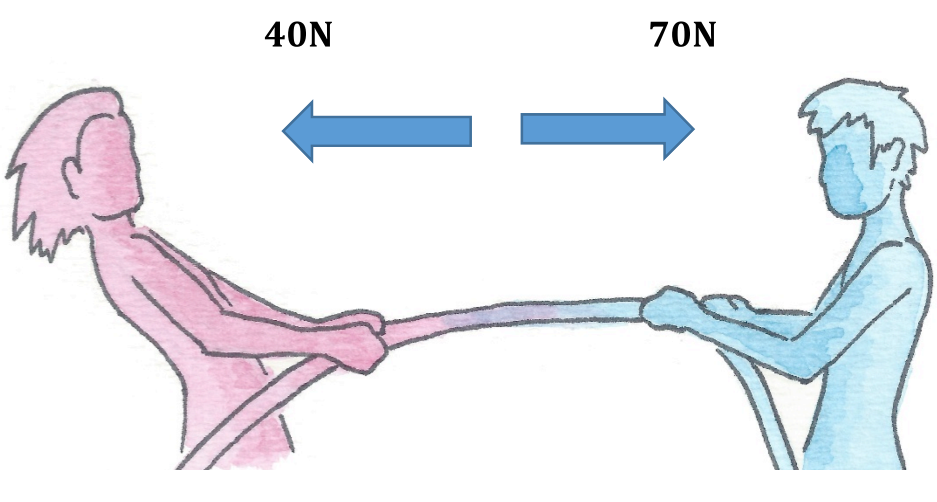
You can add an infinite amount of forces together to calculate net force. But for simplicity purposes, observe the following examples of summing two forces:



Calculation Example 2.1

If two people are playing tug-of-war and one is pulling with 70 N of force and the other is pulling with 40 N of force, what is the net force and which direction is the force going? The net force is the sum of all forces acting on an object (refer to Figure 5).

Figure 5. Tug-of-War.
Illustration Credit: Sarah Rich-Landry's Downtown Aquarium



Answer:
Net force = 70 N – 40 N = 30 N
The force is moving in the direction of the person pulling at 70 N.

Calculation Example 2.2 (Student Practice Problem)

The OCEARCH crew has some downtime and wants to go fishing for their dinner. One of the crew members lands a large tuna, big enough to feed the whole crew! If the tuna bit down on the baited line and was pulling at 100 N and the person on the other end of the line was pulling at 70 N, what is the net force and in which direction is the force going? Did the crew get their dinner?

Answer:
Net force = 100 N – 70 N = 30 N
The force is moving in the direction of the fish pulling at 30 N. The crew had to settle for a canned dinner.

Newton's Second Law

Newton's second law states the acceleration of an object is dependent upon the net force acting on the object and the mass of the object.

The net force acting on an object is equal to the rate at which the object's momentum changes with time. When the net force acting on an object is not zero, the object will accelerate in the direction in which the force was applied.

The acceleration of the object is directly proportional to the net force but inversely proportional to the mass of the object. Therefore, if you push an object forward, it accelerates. If you push harder, with a greater force, the object accelerates more quickly. However, if you push with equal force on a heavier object, it will accelerate more slowly. This is because force applied (F), mass (m), and acceleration (a) are related and expressed as the following equation:

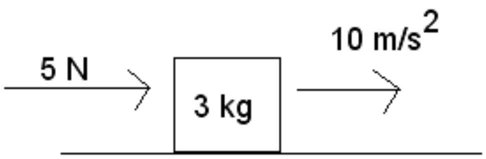
$$\sum F = (m)(a)$$

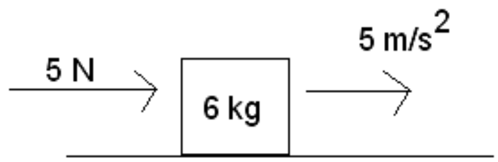
$\sum F$ is the sum of the forces. Units used are Newtons (N) for applied force, kilograms (kg) for mass, and meters per second (m/s^2) for acceleration. 1 N = 1 kg m/s^2.

An example of Newton's second law is a person pushing an empty box across the floor. The box will accelerate and move in the same direction of the force applied by the person (Figure 6). If the person fills the box with bricks and tries pushing the box across the floor with the same amount of force, it will move in the same direction of the force but the acceleration will be significantly smaller due to the larger mass of the box (Figure 7).

Figure 6

Figure 7





<u>Calculation Example 2.3</u>

An OCEARCH researcher wants to know how much force is needed for a large shark to achieve an acceleration of 0.67 m/s^2, which is a typical cruising speed of a large shark. If the mass of the shark is 907 kg, how much net force must the shark develop? Round to the nearest hundredth.
Answer:

$\sum F = (m)(a)$

$F = (907\ kg)(0.67\ m/s^2) = 607.69\ kg\ m/s^2$ *or* $607.69\ N$

<u>Calculation Example 2.4 (Student Practice Problem)</u>

If you apply a net force of 5 N on a 300 kg object, what is the acceleration of the object? Round <u>up</u> to the nearest thousandths.

Answer:
$\sum F = (m)(a)$

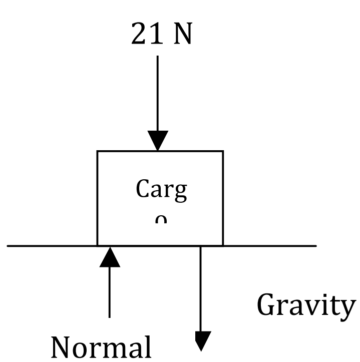
$5\ N = (300\ kg)(a)$

$\frac{5N}{300kg} = 0.016\ m/s^2$

<u>Calculation Example 2.5</u>

If cargo on the OCEARCH vessel weighs 39 kg and an additional 21 N of force is acting on top of the cargo (F_a), what is the normal force (F_n) acting on the cargo? The cargo is sitting on a flat horizontal surface (refer to Figure 8). Round to the nearest hundredths.

Figure 8



Answer: $\sum F = (m)(a)$

Because the object is resting, acceleration is 0. Therefore $\sum F = 0$.

$0=F_n - mg+F_a$

$0=F_n - (39\ kg)(9.81\ m/s^2)+21\ N$

$0=F_n - 382.59+21$

$0=F_n - 403.59\ N$

$403.59\ N = F_n$

Newton's Third Law

Newton's third law states for every action there is an equal and opposite reaction. In other words, when one object applies a force on a second object, the second object applies a force on the first object with an equal force, but in the opposite direction. One force is called the action force and the other force is the reaction force. A simple example would be walking across the floor. You push against the floor and the floor pushes back with an equal force but in the opposite direction.

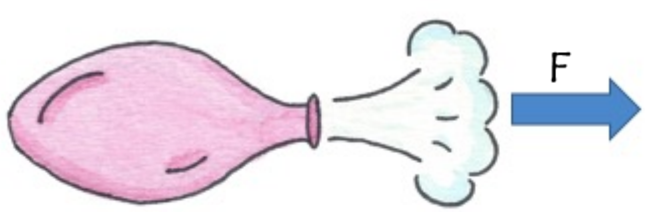
Teacher Demonstration. Action and Reaction (Optional) (5 – 10 minutes)

Fill a balloon with air, but do not tie it shut. What will happen if you let go of the balloon? *The balloon will fly around the room and deflate.*

Let go of the balloon and watch how the balloon flies away. Why does the balloon fly around the room? *Because the air inside the balloon is escaping through the untied end.*

The action is the air escaping from the balloon. As it escapes, it is putting force against the air in the room. This causes the reaction - the balloon flying around the room. This interaction between two forces is an example of Newton's third law: for every action, there is an equal and opposite reaction (refer to Figure 9).

Figure 9. Illustration Credit: Sarah Rich – Landry's Downtown Aquarium



Activity 1. Name the action and reaction. (5 – 10 minutes)

Ask the students to identify the action and reaction forces acting in each of the following scenarios. You may use drawings labeled with vectors to help visualize.

1. The ship captain walks across the deck of the M/V OCEARCH.

Action – The captain's foot pushes down on the deck of the ship.

Reaction – The deck of ship pushes back on the captain's foot.

2. A seagull accidentally flies into the side of the M/V OCEARCH.

Action – The seagull exerts a force against the ship.

Reaction – The ship exerts an equal force against the seagull.

3. A shark rams a seal from below.

Action – The shark exerts a force against the seal.

Activity 2. Action/Reaction Discussion. (5 – 10 minutes)

Brainstorm how the propeller on the M/V OCEARCH pushes the boat forward. Use drawings labeled with vectors to help illustrate.

The propeller pushes water backwards with an action force. Water then exerts an

Calculation Exercise 2.6

What is the net force on a 950,000 gram shark when it attacks a stationary seal on the surface of the water with an acceleration of 1.53 m/s^2? Round to the nearest tenth.

Answer:

You must first convert 950,000 grams to kilograms. $950{,}000 \text{ g} \times \frac{1 \text{ kg}}{1{,}000 \text{ g}} = 950 \text{ kg}$

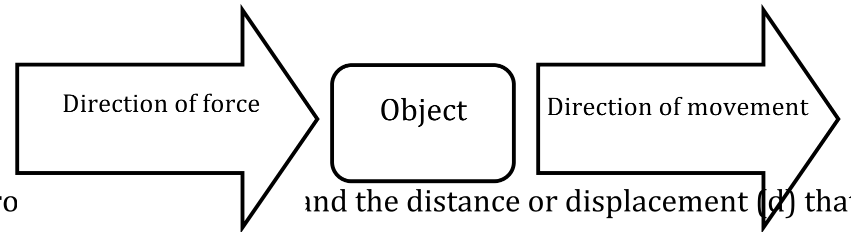
$\sum F = (m)(a)$

$F = (950 \text{ kg}) \times (1.53 \text{ m/s}^2) = 1{,}453.5 \text{ N}$

Newton's laws of motion help us understand how objects and forces interact with each other and how they affect one another. They are also the base for other laws in physics such as the Law of Buoyancy, which explains why some objects float and others sink, and Pascal's Law, which states that when there is an increase in pressure at any point in a confined fluid, there is an equal increase at every other point in the container. These and other physics laws will be discussed later in the lesson. But first, we need a better understanding of <u>work</u> and <u>energy</u>.

Part 3. Work and Energy (20 – 25 minutes)

A force is said to do work when it causes a displacement on the object. In other words, if a force is applied on an object and it moves in the same direction of that force, the force did work.



Work is the pro ınd the distance or displacement (d) that the object was displaced:

, where F is $W = (F)(d)$ isplacement.

Work is measured in units of Joules (J)
1 J = (N) (m)
N is for Newton's and m is for meters.

However, if a force makes an angle (θ) with the displacement, work can be calculated as:

$$W = (F\cos\theta)(d)$$

<u>Calculation Exercise 3.1</u>

If a force of 15 N acts along a distance of 20m, what is the work done?

Answer: W = (F)(d) = (15 N) (20 m) = 300 (N)(m) = 300 J

<u>Calculation Exercise 3.2 (Student Practice Problem)</u>

A fork life on the M/V OCEARCH vessel moves equipment weighing 1,473 N across the deck a total of 16 m. How much work is done by the lift?

Answer: *W = (F)(d) = (1,473 N) (16 m) = 23,568 (N)(m) = 23,568 J*

<u>Calculation Exercise 3.3</u>

If an OCEARCH deckhand needs to push a piece of equipment 8 m with a force of 200 N at a 28° angle, how much work does he or she need to apply? Round <u>up</u> to nearest tenth.
Answer:
W = (Fcosθ)d
= (200 N) (cos 28°) (8 m)
= (176.59 N) (8 m) = 1,412.7 J

Part 4. Pascal's Law (30 minutes)

Pascal's Law states that when there is an increase in pressure at any point in a confined fluid, there is an equal increase at every other point in the container. In other words, force that is applied at one point in a fluid is transmitted to another fluid. The force is almost always multiplied in the process.

The OCEARCH team uses Pascal's Law almost every day when tagging sharks! The M/V OCEARCH research ship uses a hydraulic lift to raise sharks out of the water in order to tag the shark, obtain measurements, and record data.

How does a hydraulic lift work?

Two or more pistons are connected to one another by a pipe filled with an incompressible fluid – almost always an oil of some sort. Downward force is applied to one piston and the force is transmitted to the second piston through the oil in the pipe. Almost all of the force transfers to the second piston because oil is an incompressible fluid, meaning it will not absorb the force. The second piston is often larger than the first, which multiplies the original force. This how the hydraulic lift on the M/V OCEARCH can easily lift a 3,000 pound great white shark.

The formula associated with Pascal's Law is: $p = \frac{F1}{A1} = \frac{F2}{A2}$, where p is pressure, a is area, and f is force applied.

The formula for the area of a cylinder is : $A = \pi r^2$ where A is area and r is radius of the cylinder.

<u>Calculation Exercise 4.1</u>

Radius of small piston (R_1) = 15.24 cm
Radius of large piston (R_2) = 17.00 cm
Weight of shark (F_2) = 908 kg
Distance shark is lifted out of water (d2) = 1.83 m
$\pi = 3.14$

Suppose the hydraulic lift on the M/V OCEARCH has a small cylindrical piston with a radius of 15.24 cm and a larger piston with a radius of 17.00 cm. A 908 kg great white shark is guided onto the lift. If you assume the two pistons are of the same height, what force must be exerted to the small piston to lift the shark out of the water? Round force <u>up</u> to nearest tenth. How far must the small piston move down to lift the shark to a height of 1.83 m? Round distance to nearest hundredths.

Answer:

A downward external force with a magnitude of F_2 (equal to the weight of the shark) is exerted on a larger piston.

F_2 = 908 kg

Cross-sectional area of a piston is calculated as: $n\ r^2$, where n =3.14

We assumed the pistons are at the same level, therefore from Pascal's Law the pressure at any given level is the same throughout the hydraulic fluid. The downward force on the smaller piston needed to lift the shark is

$$F1 = \frac{A1}{A2} \times F2 = \frac{(3.14)\ (15.24\ cm)^2}{(3.14)\ \ (17.00\ cm)^2} \times (908\ kg) = 729.7\ N$$

If the small piston moves a distance (d), the volume of the fluid displaced is $V1 = d_1A_1$. V1 must equal V2 displaced by the large piston, because the total volume of the fluid is constant. If the shark is lifted a distance of 1.83 m (d2), the small piston moves a distance of d1:

$$d1 = \frac{n\ r_2^2}{n\ r_1^2} \times (d2) = \frac{(3.14) \times (15.24\ cm)^2}{(3.14) \times (17.00\ cm)^2} \times (1.83\ m) = 1.47\ m$$

Part 5. Archimedes' Principle and the Law of Buoyancy (30 minutes)

In physics, buoyancy is the upward force on an object immersed in a fluid which allows the object to float. If the buoyant force exceeds the weight of the object, then the object will float. If the weight of the object exceeds the buoyant force, then the object will sink.

Archimedes was the ancient Greek physicist who first discovered the Law of Buoyancy, also known as Archimedes' Principle, which states that an object immersed in a fluid is buoyed up by a force equal to the weight of the fluid displaced by the object. In other words, the buoyant force on an object is equal to the weight of the liquid displaced by the object (Figure 10).

For example, if you have 56 mL of water in a graduated cylinder and then add a rock, what do you think will happen? After adding the rock to the cylinder, the water level rises! Suppose the new volume of water in the graduated cylinder is 59 mL.

The water displacement is the difference between the two volume readings:

59 mL – 56 mL = 3 mL

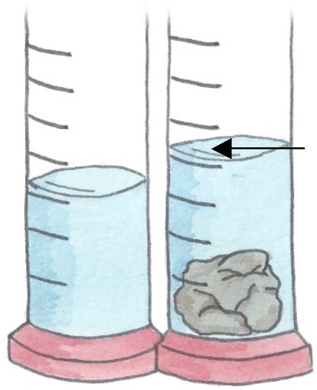
The volume of the displaced water is directly proportional to its weight. To calculate the weight of the displaced water (W), use the following equation:

$$W = \rho_{water}\ \Delta V$$

, where ρ_{water} is the density of water (1.00 g/cm) and ΔV is the volume of the displacement.

Therefore, the weight of the displaced water is:
$W = \rho_{water} \Delta V$ = (1.00 g/cm) x (3 mL) = 3 g/cm^3

Figure 10.
Illustration credit: Sarah Rich – Landry's Downtown Aquarium



Density plays an important role in the buoyancy of an object. Density is essentially an object's mass per unit of volume. Objects with a high mass with a certain volume have a high density, while objects with a small mass with the same volume have a low density. Density determines if an object sinks of floats in a fluid. If the object's density is greater that the fluid's, the object will sink. And if the object's density is less than the fluid's, the object will float.

Teacher Demonstration (Optional) (10-20 minutes)

You will need a large bowl or container, an orange, and water. Fill the container with water. Place the orange in the water and watch what happens. Now peel the orange and place it back in the water. What happens now? An unpeeled orange floats on the surface of water because the peel is full of tiny air pockets, which lowers its density (mass to volume ratio). By peeling the orange, its density increases causing it to sink!

If you have the volume and mass of an object, you can calculate its density using this formula:

Volume = Mass / Density	Density = Mass / Volume	Mass = Volume*Density

Calculation Exercises 5.2 (Student Practice Problems)

Find the unknown value:

a.) density = 3 g/cm^3 volume = 100 cm^3 mass = ?

b.) density = ?   volume = $950\ cm^3$ mass = 95 g

c.) density = $0.5\ g/cm^3$ volume = ?   mass = 20 g

Answer: a.) 300 g, b.) $0.1\ g/cm^3$, c.) $40\ cm^3$

The Law of Buoyancy states that a floating object displaces an equal amount of water to its mass. To keep from sinking, a ship has to displace its own weight in water before it is submerged. Ships are designed and constructed to be less dense than water so that they do not sink!

OCEARCH Physics Part 1 - Forces

ACTIVITY 1. Prove Archimedes' Principle

(45 minutes – 60 minutes)

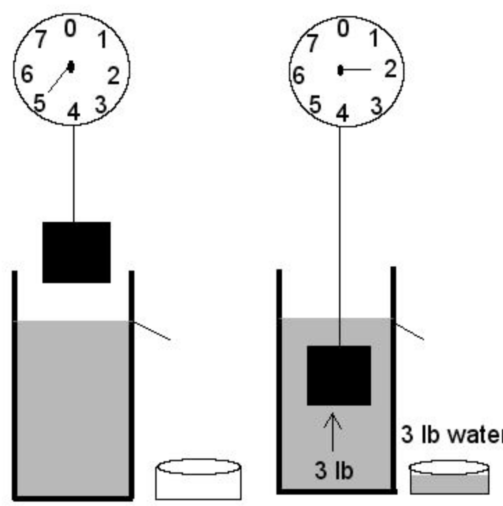
Introduction

Students will prove Archimedes' Principle by conducting an experiment. By immersing an object in a Eureka beaker, students will be able to observe that the displaced water equals the weight of the immersed object.

Materials

- Rock
- String
- Eureka beaker
- Beaker
- Spring scale
- Physical balance
- Water

Figure 11.



Instructions

Students may work individually, in partners, or small groups.

1. Measure and record the weight of a dry beaker using a physical balance.
2. Tie a string around a rock.
3. Attach the string to a spring scale and measure the weight of the rock.
4. Fill a Eureka beaker with water exactly below the spout and place the dry beaker under the spout.
5. Slowly place the weight into the Eureka beaker and watch as the weight on the scale goes down. As the object is being immersed in the water, the weight decreases and it appears that the object is lighter in water than in air. This is due to the buoyancy force.
6. Continue immersing the object until it is completely underwater. Once completely underwater, the object will have displaced a certain amount of water into the dry beaker under the spout.
7. Measure the beaker and water using a physical balance.
8. To measure the amount of water displaced by the object, take the combined weight of the beaker and water and subtract the weight of the dry beaker you previously measured.
9. The amount of weight "lost" by the object being immersed in the water should equal the amount of water displaced by the object. Therefore, the buoyancy force of the object is equal to the weight of the displaced water. (Refer to Figure 11: Illustration credit, Lori Timm Ph.D.- Landry's Downtown Aquarium).

Conclusion

The purpose of this experiment was to demonstrate Archimedes' Principle. Archimedes' Principle demonstrates how the upward buoyant force on an object in a liquid is equal to the weight of the liquid that the object displaces. By immersing an object in a Eureka beaker, students were able to observe that the displaced water equals the weight of the immersed object.

See Handout Provided

Activity 1. Prove Archimedes' Principle

Name: ______________________________

Date: ______________________________

Instructions

Measure and record the weight of a dry beaker. Tie a string around a rock, or other object. Attach a string to a spring scale and measure and record the weight of the rock. Fill a Eureka beaker with water exactly below the spout and place the dry beaker under the spout. Place the weight into the Eureka beaker. Record your observations: Does the weight go up or down or stay the same? Once the rock is completely submerged, weigh the beaker and displaced water. Lastly, measure the displaced water (beaker and water – dry beaker). The extra spaces are for you to repeat the procedure and record your results. Were the results the same?

Object	**Weight (g)**
Dry beaker	
Rock	
Beaker and water	
Displaced Water (beaker and water – dry beaker)	

Conclusions (Record your observations)

____

____

____

OCE rces

ACTIVITY 2. A Sinking Ship

(45 minutes – 60 minutes)

Introduction

A floating ship experiences a downward gravitational pull, but also experiences an upward thrust or force called the buoyancy force. The buoyancy force pushes up with an equal force to the weight of the water the object displaces. This displacement of water and the buoyancy of the ship are dependent on the ship's density. The density of the ship must be less than the density of the water in order to float. This activity uses calculations to demonstrate how density affects a ship's buoyancy.

Problem Solving

Ship Information

Ship Weight = 30,000 tons = 60,000,000 lbs = 27,215,540 kg
Ship Volume = 169,901 m^3
Ship Density = mass/volume = 160 kg/m^3
Water Density = 1,000 kg/m^3

1. In the water, the water displaced by the ship is equal to 27,215,540 kg. If you add 54,431,080 kg of weight to the ship, the ship's mass changes to 81,646,620 kg (27,215,540 kg + 54,431,080 kg) and volume remains 169,901 m^3. A.) What is the ship's new density? B.)What is the volume of the water displaced by the ship's hull? C.)Does the ship float or sink?

A.) The new density or total mass of ship is:

$$\text{Density} = \frac{\text{Mass}}{\text{Volume}} = \frac{81{,}646{,}620\ \text{kg}}{169{,}901\ \text{m}^3} = 481\ \text{kg/m}^3$$

B.) The volume of the displaced water is 81,646,620 kg (displaced water equals weight of the ship).

C.) The density of the ship at 480 kg/m^3 is still less than the density of water at 1,000 kg/m^3. The ship still floats.

2. If you add an additional 81,646,620 kg, the ship's mass is now equal to 163,293,240 kg, while the volume remains 169,901 m^3. A.) What is the new density of the ship? B.) What is the volume of water displaced by the ship's hull? C.) Does the ship float or sink?

A.) The new density of the ship is:

$$\text{Density} = \frac{\text{mass}}{\text{volume}} = \frac{163{,}293{,}240\ \text{kg}}{169{,}901\ \text{m}^3} = 961\ \text{kg/m}^3$$

B.) The volume of the displaced water is now 163,293,240 kg.

C.) The new density of the ship at 961 kg/m^3 is less than the density of water at 1,000 kg/m^3. Therefore, the ship still floats.

3. What happens if you add 20,000,000 kg more weight to the ship? The ship's new mass is 1,832,932,240 kg and the volume of the ship remains at 169,901 m^3. A.) What is the new density of the ship? B.) Does the ship float or sink?

A.) The new density of the ship is:

$$Density = \frac{mass}{volume} = \frac{1,832,932,240\ kg}{169,901\ m^3} = 1,079\ kg/m^3$$

B.) The ship's new density of 1,079 kg/ m^3 is greater than the density of water at 1,000 kg/m m^3. Thus, the ship sinks!

By changing the mass of the ship, you change the density of the ship. If the density of the ship is greater than the density of the water, the ship will sink. This is something engineers must know and keep in mind when designing a ship.

See Handout Provided

Name: ______________________

Activity 2. A Sinking Ship

Date: ______________________

Ship Information

Ship Weight = 30,000 tons = 60,000,000 lbs = 27,215,540 kg
Ship Volume = 169,901 m^3
Ship Density = mass/volume = 160 kg/m^3
Water Density = 1,000 kg/m^3

1. In the water, the water displaced by the ship is equal to 27,215,540 kg. If you add 54,431,080 kg of weight to the ship, the ship's mass changes to 81,646,620 kg (27,215,540 kg + 54,431,080 kg) and volume remains 169,901 m^3. A.) What is the ship's new density? B.)What is the volume of the water displaced by the ship's hull? C.)Does the ship float or sink?

A.)

B.)

C.)

2. If you add an additional 81,646,620 kg, the ship's mass is now equal to 163,293,240 kg, while the volume remains 169,901 m^3. A.) What is the new density of the ship? B.) What is the volume of water displaced by the ship's hull? C.) Does the ship float or sink?

A.)

B.)

C.)

3. What happens if you add 20,000,000 kg more weight to the ship? The ship's new mass is 1,832,932,240 kg and th m^3. A.) What is the new density of the ship? B.) I

A.)

B.)

C.)

Calculation Example 1.2

If a shark weighing 1,500 kg is resting on the hydraulic lift on the M/V OCEARCH, what is the normal force acting on the shark? Round to a whole number.

Calculation Example 1.4

If an object weighs 351 kg and is on a 23° incline, what is the normal force acting on the object? First draw your image. Round to the nearest whole number.

Calculation Example 1.6

A deckhand on the M/V OCEARCH vessel wants to move a piece of equipment with a mass of 36 kg. He already calculated the normal force as 353.16 N. What is the frictional force? Assume the coefficientμ is 0.5. Round up to the nearest tenth.

Calculation Example 1.8

A 132 kg box is being pulled [illegible] ght across a frictionless pulley. The acceleration is 2.7[illegible] m/s². Calculate the tension in the rope. Round to the nearest tenth.

Calculation Example 2.4

If you apply a net force of 5 N on a 300 kg object, what is the acceleration of the object? Round up to the nearest thousandths.

Calculation Exercise 3.2

A fork life on the M/V OCEARCH vessel moves equipment weighing 1,473 N across the deck a total of 16 m. How much work is done by the lift?

Calculation Exercise 4.1

Radius of small piston (R_1) =
Radius of large piston (R_2) = 17.00 cm
Weight of shark (F_2) = 908 kg
Distance shark is lifted out of water (d2) = 1.83 m
π = 3.14

Suppose the hydraulic lift on the M/V OCEARCH has a small cylindrical piston with a radius of 15.24 cm and a larger piston with a radius of 17.00 cm. A 908 kg great white shark is guided onto the lift. If you assume the two pistons are of the same height, what force must be exerted to the small piston to lift the shark out of the water? Round force <u>up</u> to nearest tenth. How far must the small piston move down to lift the shark to a height of 1.83 m? Round distance to nearest hundredths.

Calculation Exercises 5.2

Find the unknown value:

a.) density = 3 g/cm^3 volume = 100 cm^3 mass =

b.) density = ne = 950 cm^3 mass = 95 g

c.) density = 0.5 g/cm^3 volume = ass = 20 g