MATERIALS™ EXPLORERS

SMARTPHONES

If you're like a lot of people today, you just can't imagine life without your smartphone. But have you ever thought about what it takes to make the device that never leaves your side? In this module you'll learn about the materials that make smartphones possible and explore the implications of using rare materials in such a common item.

In this module students will be able to:

- Identify the materials used to create a smartphone
- Test the chemical and physical properties of some of the metals used to create smartphones
- Write an evidence-based conclusion identifying each metal based on the physical and chemical properties
- Explore the uses of rare earth metals and the challenges created by a reliance on them
- Illustrate a metallic bond and explain how the bonding arrangement affects physical properties

MATERIALS™ EXPLORERS

Class Activity

THE MATERIALS THAT MAKE UP SMARTPHONES

Background:
According to the Minerals Education Coalition©, each baby born in the U.S. will use 3.188 million pounds of minerals, metals, and fuels in their lifetime. The 3.188 million pounds include 968 pounds of copper, 419 pounds of zinc, 828 pounds of lead, and 48,856 pounds of other minerals and metals. Many of the minerals and metals are utilized in technological devices such as smartphones. Smartphones are composed of about 40% metals (including copper, silver, gold, platinum, and tungsten), 40% plastics, and 20% ceramics. Most phones use lithium-ion batteries, which are generally composed of lithium cobalt oxide, although other metals, such as manganese, are sometimes used in place of cobalt.

Cellular phones also contain many **rare earth elements** such as neodymium, terbium, and dysprosium which provide phones with the power to vibrate. This heavy reliance on rare earth elements poses a challenge to future smartphone development since there is a limited supply of these elements and no suitable substitutions. Rare earth elements are essential for miniaturization of products like computers and smartphones. Without them, computers would still be the size of a classroom, instead of a pocket. Rare earth elements are also valuable because of their magnetic and conductive properties. These properties allow technological devices to be faster, stronger, lighter, and more efficient.

Problem

Your school is organizing a recycling initiative around discarded smartphones. In order to send materials to the right recycling facilities, your class must first identify the types of materials used in various components.

Task:
Using the directions provided, you will test four unknown samples and record your observations of their physical and chemical properties in order to determine the materials being tested.

Requirements:
1. Safety goggles and an apron must be worn at all times.
2. Hair must be pulled back.
3. No loose or baggy clothing is permitted and closed-toe shoes must be worn.

Class Activity

4. Do not stare directly at burning samples.
5. Physical properties being examined should include appearance, mass, volume, and magnetism.
6. Chemical properties being examined should include reactivity with room temperature water, reactivity with hydrochloric acid, and reactivity with oxygen.
7. Samples should be tested using the following procedures and observations should be recorded in the data tables provided:

Complete each of the required tests for a sample before moving on to the next.

NOTE: The reaction with oxygen is performed only on samples A and D.

i. **Appearance:** Observe the chemical and record your observations.

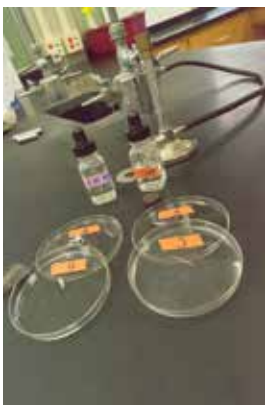
ii. **Volume and Density:** Determine volume and density via the water displacement method.

iii. **Magnetism:** Slowly wave the magnet over the sample and record any reaction.

iv. **Ability to React with Water:** Place a "pea-sized" amount of the sample in a petri dish and apply 15 drops of water. Look for evidence of a chemical change. If there is evidence, cite evidence. If there is no evidence, record "no evidence of a chemical change."

v. **Ability to react with an acid:** Place a "pea-sized" amount of the sample on a clean watch glass and add a few drops of acid. Look for evidence of a chemical change. If there is evidence, cite evidence. If there is no evidence, record "no evidence of a chemical change."

vi. **Reaction with Oxygen (with heat):** PERFORM THIS TEST ONLY ON SAMPLES A AND D. Light and adjust the burner. Use crucible tongs to burn a piece of Sample A while looking for evidence of a chemical change. Turn off the flame. If there is evidence, cite evidence. If there is no evidence, record "no evidence of a chemical change."
Repeat this procedure for Sample D but begin by vigorously rubbing the sample with steel wool to remove surface (oxide) impurities.



Class Activity

Questions

1. **Fill out the following data tables with your observations from the experiments above.**

Data Table: Samples A-D				
	Sample A	**Sample B**	**Sample C**	**Sample D**
Appearance				
Mass				
Volume	Initial: Final: Difference:	Initial: Final: Difference:	Initial: Final: Difference:	Initial: Final: Difference:
Calculated Density				
Magnetism Is sample magnetic?	Yes or No Evidence:	Yes or No Evidence:	Yes or No Evidence:	Yes or No Evidence:

Class Activity

Reaction with Water Does sample react?	Yes or No Evidence:	Yes or No Evidence:	Yes or No Evidence:	Yes or No Evidence:
Reaction with Acid Does sample react?	Yes or No Evidence:	Yes or No Evidence:	Yes or No Evidence:	Yes or No Evidence:
Reaction with Oxygen Does sample react?	Yes or No Evidence:	DO NOT PERFORM TEST ON SAMPLE B	DO NOT PERFORM TEST ON SAMPLE C	Yes or No Evidence:

2. **Write a response (including a claim, evidence, and reasoning) identifying Samples A through D based on their physical and chemical properties.**

3. **Sixteen out of the seventeen rare earth elements are used in cell phones. Select one of the sixteen elements and design a poster about the advantages and challenges of utilizing that rare earth element. Include information about how that element can be recycled or reused, or if there is a potential substitute for it. Be sure to include other uses of the element apart from smartphones.**

Activity Grading Rubric

Rare Earth Elements

Rare earth elements, or rare earth metals, refers to a set of seventeen elements which includes the fifteen lanthanides plus scandium and yttrium. Despite their name, most of these elements are not particularly rare but they are difficult to economically extract and process.

Teacher Resources & Answer Key

Standards:	NGSS	HS-PS1-1	HS-PS1-3	HS-PS2-6

Notes:

1. Provide the following materials to students for testing: **Sample A:** copper shot, **Sample B:** zinc, **Sample C:** iron, and **Sample D:** magnesium.
2. Students must be reminded to observe all safety precautions. Additionally, as magnesium burns with a bright white flame, students should be told not to look directly into the flames as they test their samples.
3. Students should be reminded not to perform a flame test on samples B and C.
4. Students should be supervised to ensure proper clean-up of each station.
5. As an optional follow up service project, encourage students to seek out reputable recycling locations and host a cell phone recycling drive for the community.

Data Table: Samples A-D

	Sample A Copper Shot	**Sample B** Zinc	**Sample C** Iron	**Sample D** Magnesium
Appearance	Reddish/brown	Gray	Silver	Silver
Mass	Answer will vary based on class sample.	Answer will vary based on class sample.	Answer will vary based on class sample.	Answer will vary based on class sample.
Volume	Answer will vary based on class sample.	Answer will vary based on class sample.	Answer will vary based on class sample.	Answer will vary based on class sample.
Calculated Density	8.78 g/mL	7.14 g/mL	7.87 g/mL	1.74 g/mL

Teacher Resources & Answer Key

Magnetism Is sample magnetic?	Yes or No Evidence: No. Copper does not stick to the magnet.	Yes or No Evidence: No. Zinc does not stick to the magnet.	Yes or No Evidence: Yes. Iron does stick to the magnet.	Yes or No Evidence: No. Magnesium does not stick to the magnet.
Reaction with Water Does sample react?	Yes or No Evidence: No. No evidence of a chemical change.	Yes or No Evidence: No. No evidence of a chemical change.	Yes or No Evidence: No. No evidence of a chemical change.	Yes or No Evidence: No. No evidence of a chemical change.
Reaction with Acid Does sample react?	Yes or No Evidence: No. No evidence of a chemical change.	Yes or No Evidence: Yes. Hydrogen gas produced	Yes or No Evidence: Yes. Hydrogen gas produced	Yes or No Evidence: Yes. Hydrogen gas produced
Reaction with Oxygen Does sample react?	Yes or No Evidence: Yes. Flame changes to a bluish/green color	DO NOT PERFORM TEST ON SAMPLE B	DO NOT PERFORM TEST ON SAMPLE C	Yes or No Evidence: Yes. Bright white light produced.

2. Write a response (including a claim, evidence, and reasoning) identifying Samples A through D based on their physical and chemical properties.

Metal	Color	Density (g/mL)	Magnetic	Reacts with Room Temperature Water	Reacts with HCl
Copper	Reddish/Brown	8.78	No	No	No
Zinc	Gray	7.14	No	No	Yes
Iron	Silver	7.87	Yes	No	Yes
Magnesium	Silver	1.74	No	No	Yes

3. Sixteen out of the seventeen rare earth elements are used in cell phones. Select one of the sixteen elements and design a poster about the advantages and challenges of utilizing that rare earth element. Include information about how that element can be recycled or reused, or if there is a potential substitute for it. Be sure to include other uses of the element apart from smartphones.

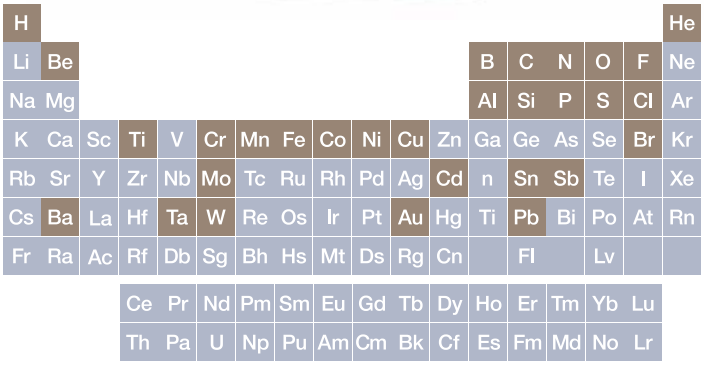
Student answers will vary.

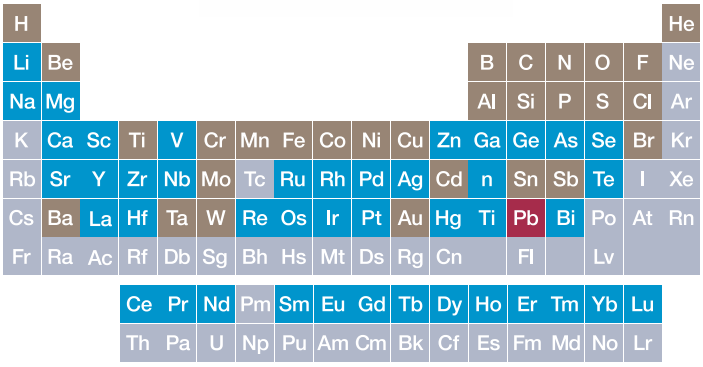
Teacher Resources & Answer Key

Activity Grading Rubric					
CATEGORY	**5**	**4**	**3**	**2**	**1-0**
Graphics - Clarity	Graphics are all in focus and the content can be easily viewed and identified.	Most graphics are in focus and the content can be easily viewed and identified.	Most graphics are in focus and the content is easily viewed and identified.	Many graphics are not clear or are too small.	Incomplete assignment.
Graphics - Relevance	All graphics are related to the topic and make it easier to understand. All borrowed graphics have a source citation.	All graphics are related to the topic and most make it easier to understand. All borrowed graphics have a source citation.	All graphics relate to the topic. Most borrowed graphics have a source citation.	Graphics do not relate to the topic OR several borrowed graphics do not have a source citation.	Incomplete assignment.
Content - Accuracy	At least 5 accurate facts are displayed on the poster.	4-3 accurate facts are displayed on the poster.	2-1 accurate facts are displayed on the poster.	No accurate facts are displayed on the poster.	Incomplete assignment.
Attractiveness	The poster is exceptionally attractive in terms of design, layout, and neatness.	The poster is attractive in terms of design, layout and neatness.	The poster is acceptably attractive though it may be a bit messy.	The poster is distractingly messy or very poorly designed. It is not attractive.	Incomplete assignment.
Grammar/ Spelling	There are no mistakes on the poster.	There are 1-3 mistakes on the poster.	There are 4-6 mistakes on the poster.	There are more than 6 mistakes on the poster.	Incomplete assignment.

Extension Activity

WHAT'S IN YOUR POCKET?





Original Cell Phone Elements Additional Elements Required for Smartphones Elements that are no longer used.

Motorola DynaTAC 8000X

1. Released in 1983, this was the world's first commercial cell phone.
2. It weighed 1.75 pounds, stood 13 inches high, stored 30 phone numbers, and took 10 hours to recharge to support 30 minutes of talk time.

30 Elements

Smartphone

Today's smartphone uses exponentially more elements than early mobile devices to support numerous functions and digital features, more storage capacity, and an extended battery life in a lighter, smaller body.

75 Elements

CMI Critical Materials Institute

(Chart reproduced with permission from the Critical Materials Institute, The Ames Laboratory, U.S. Department of Energy)

Questions

1. **Today's smartphones are dependent on a much wider variety of elements than early cellular phones. What are some of the major challenges that result from this?**

2. **The chart above indicates that only one element that was used in early mobile phones is no longer used in smartphones. Identify the element and suggest possible reasons why its use was discontinued.**

3. **Select one element used in the circuit board of both a smartphone and traditional cellular phone and discuss its importance to the phone's functioning.**

4. **Select one interesting feature of a smartphone and research some of the materials that make it possible. You may choose to discuss touchscreens, batteries, or vibration.**

Extension Activity Answer Key

1. **Today's smartphones are dependent on a much wider variety of elements than early cellular phones. What are some of the major challenges that result from this?**
   Some of these elements are in very limited supply or difficult to mine with no real alternatives to replace them when they run out.

2. **The chart above indicates that only one element that was used in early mobile phones is no longer used in smartphones. Identify the element and suggest possible reasons why its use was discontinued.**
   Lead is no longer used due to concerns about its toxic nature. It has now been replaced by alternative materials such as lead-free solders made with metals such as tin, silver, and copper are now used instead.

3. **Select one element used in the circuit board of both a smartphone and traditional cellular phone and discuss its importance to the phone's functioning.**
   Student answers will vary but a possible example is the use of gold as a coating where wires will later be inserted in the circuit boards.

4. **Select one interesting feature of a smartphone and research some of the materials that make it possible. You may choose to discuss touchscreens, batteries, or vibration.**
   Touchscreens: Indium oxide and tin oxide are commonly used because of their ability to conduct electricity.

   Batteries: Most smartphones use lithium-ion batteries which are made up of lithium cobalt oxide and graphite, though other elements are also used by many producers.

   Vibration: Rare earth metals such as neodymium, terbium, and dysprosium are used to give smartphones the ability to vibrate.

Materials Explorers™ is a STEM educational outreach initiative of The Minerals, Metals & Materials Society (TMS). TMS is non-profit, international professional society with a mission to promote the global science and engineering professions concerned with minerals, metals, and materials.

TMS
The Minerals, Metals & Materials Society