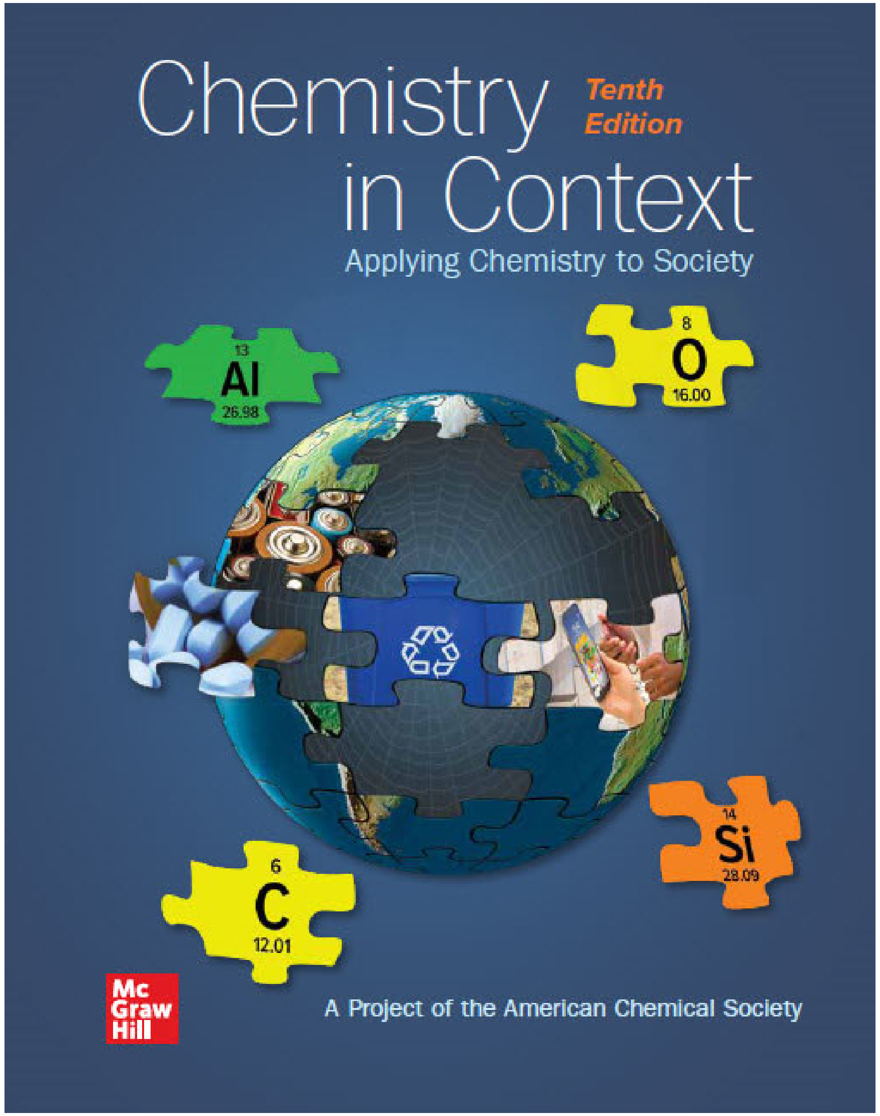
General Chemistry (CH101): Chemistry around Us

Department of Chemistry

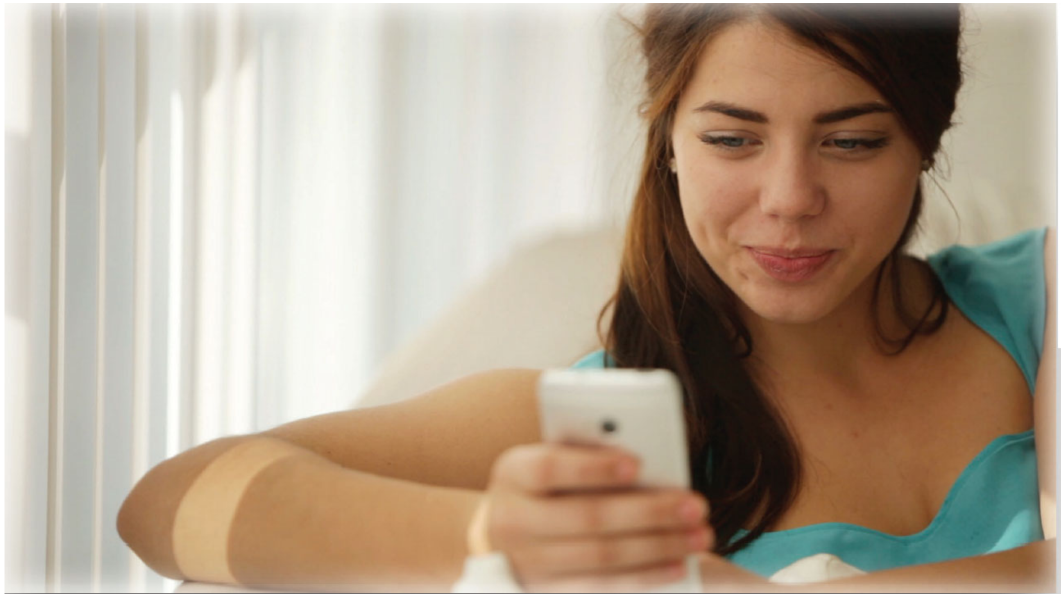
KAIST

Chapter 01

Portable Electronics: The Periodic Table in the Palm of Your Hand



Reflect



What's in Your Cell Phone?

Watch the Chapter 1 opening video to get a glimpse of how chemistry plays a central role in controlling the properties of electronic devices.

a. List some desirable attributes of a cell phone, and some that you would like to see in the future.

b. Cite two elements that combine to form a substance important to your cell phone.

c. What is the expected lifespan of your cell phone?

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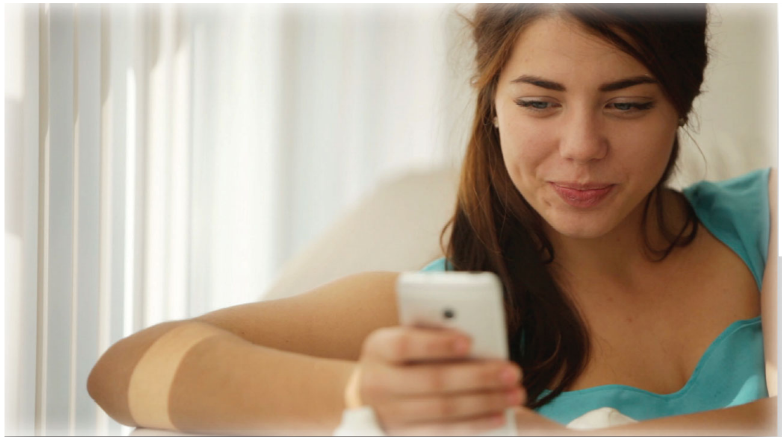
Chapter 1
Portable Electronics: The Periodic Table in the Palm of Your Hand



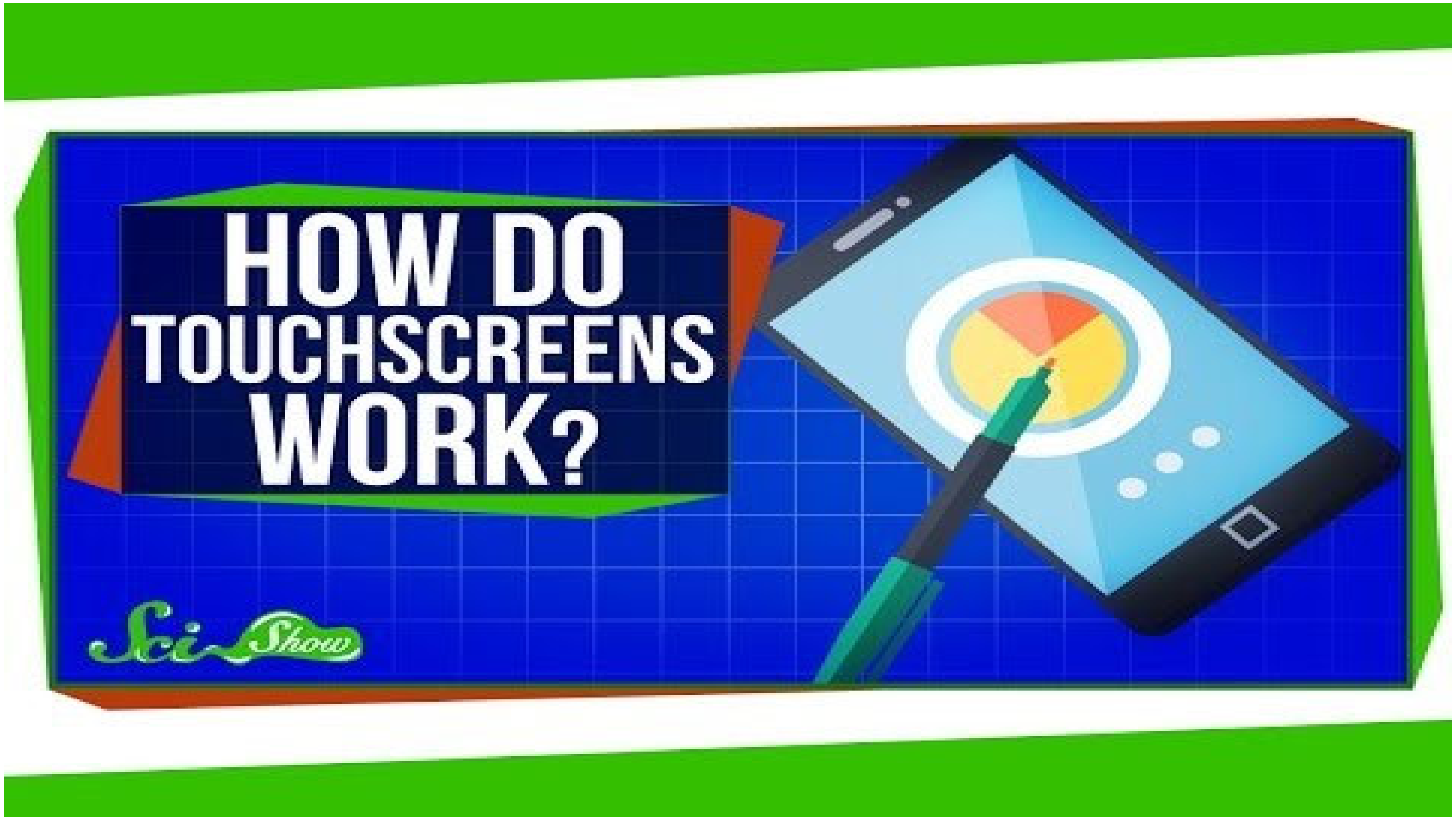
- What are the different components in your portable electronic device made from?
- How does the periodic table of elements guide us in the design of your device?
- What are rocks, and how do we isolate and purify metals from these natural sources?
- How is ordinary sand converted into silicon—the fundamental component of processor chips?
- How is sand converted into glass, and how can its structure be modified for crack-resistant screens?
- What are the environmental implications of fabricating and recycling your portable electronic device?

How Do Touchscreens Work?

- Electronic devices and other consumer goods rely upon **properties** that are based on the **materials** from which they are made.
- **Structure and composition** lead to physical and chemical properties.

Your Turn 1.1 Touchscreen Response

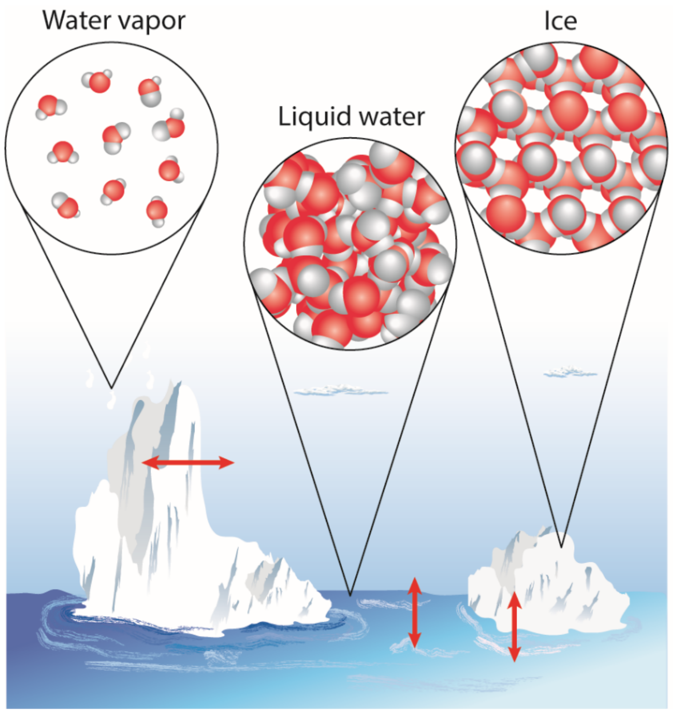
Taking care not to damage your screen, use a variety of materials to touch the screen of your portable electronic device. In addition to your finger, items that may be used include a paper clip, a plastic pen, a key, a battery, fabrics, pencil lead, a sponge (wet and dry), a pencil eraser, a coin, a glass marble, paper, cardboard, or any other items. Did any of these materials other than your finger cause a response?



https://youtu.be/wKuqNuzM1oM?si=UfOo4XShOSj6IWI4

What's the Matter with Materials?

- Everything around you is **matter**.
- Matter is considered to be anything that occupies space and has mass.



Properties of Matter

Check out an interactive simulation of atoms and molecules in different states:

States of Matter: Basics

Answer the following questions for solids, liquids, and gases. Provide an example to support each of your answers.

a. Does the phase have a definite volume?

b. Does the phase have a definite shape?

c. Will the phase take the shape of its container?

d. Will the phase completely fill its container?

What’s the Matter with Materials? 2

Matter can be classified by *phase*…

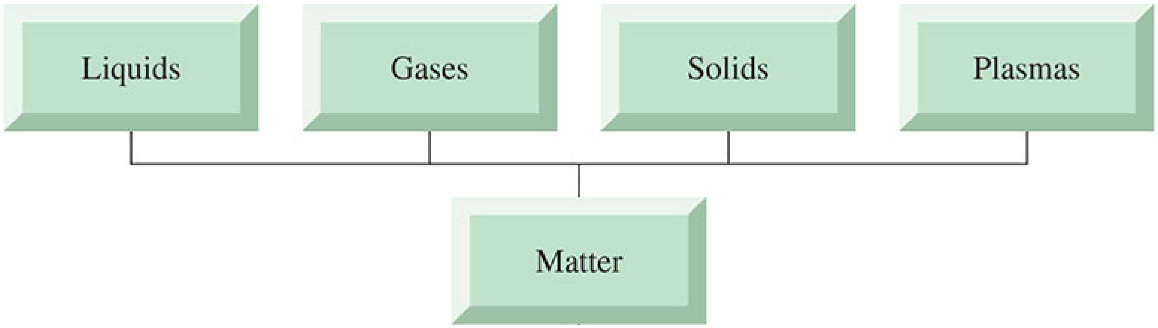
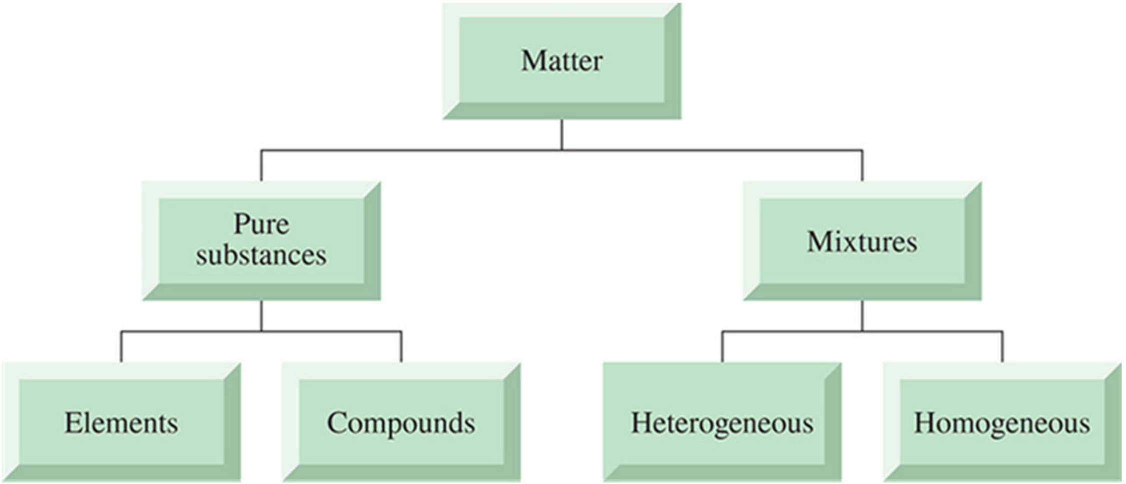


Table 1.1 Macroscopic Properties of Solids, Liquids, and Gases

Phase	Takes the shape of its container?	Completely fills its container?	Definite volume?	Definite shape?
Solid	No	No	Yes	Yes
Liquid	Yes	No	Yes	No
Gas	Yes	Yes	No	No

What's the Matter with Materials?

…or can be classified by *composition:*



Pure substances may be

elements (containing atoms of the same type – for instance, silicon (Si)).

compounds (containing 2 or more different types of atoms – for example, silicon dioxide (SiO_2.))

Mixtures may be

- ***Heterogeneous*** (with a composition that varies throughout, such as gravel).
- ***Homogeneous*** (with a uniform composition throughout, such as solutions of sugar dissolved in water).

A substance that cannot be broken down into two or more simpler substances by chemical methods is called a(n):

A. compound
B. mixture
C. element
D. isotope

Which of the following substances below are considered molecules?

A. AgCl
B. $FeCl_3$
C. NO_2
D. LiCl

Classifying Matter

Classify each of these as an element, a compound, or a mixture:

carbon dioxide

nickel

cocaine

water

fluorine

table salt

soap

sea water

What differentiates a compound from a mixture of two or more elements?

A. The elements in a compound may be present in varying proportions.
B. A compound does not exhibit the individual properties of the elements of which it is composed.
C. A compound is made up of only one element.
D. A compound cannot be made up of more than two elements.

More Practice with Classifying Matter

Your Turn 1.4 Classification of Matter

Watch a video (www.acs.org/cic) to further familiarize yourself with classifying matter. Then use the classification scheme shown in Figure 1.2 to categorize the following:

a. Your cell phone.

b. Aluminum foil.

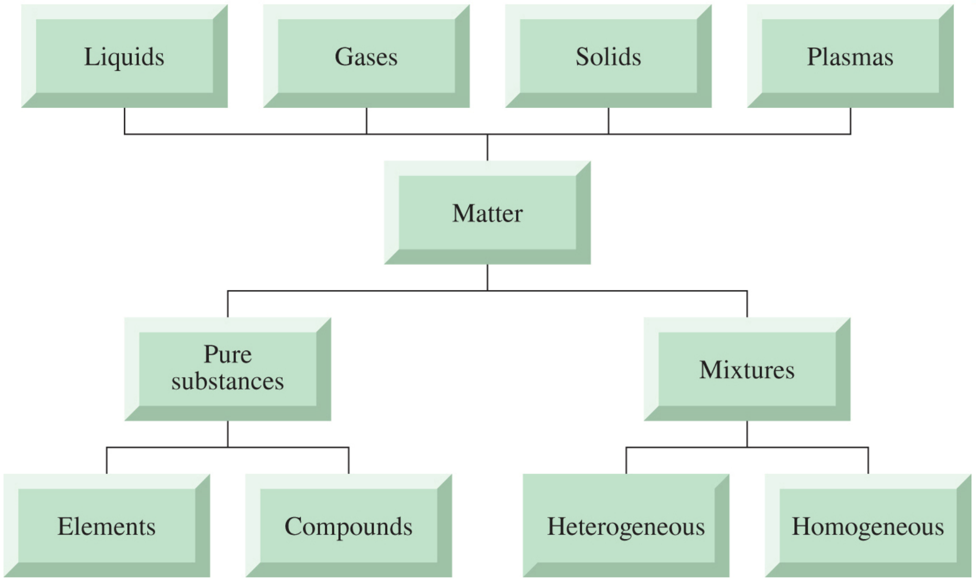
c. Red wine.

d. Chlorine gas.

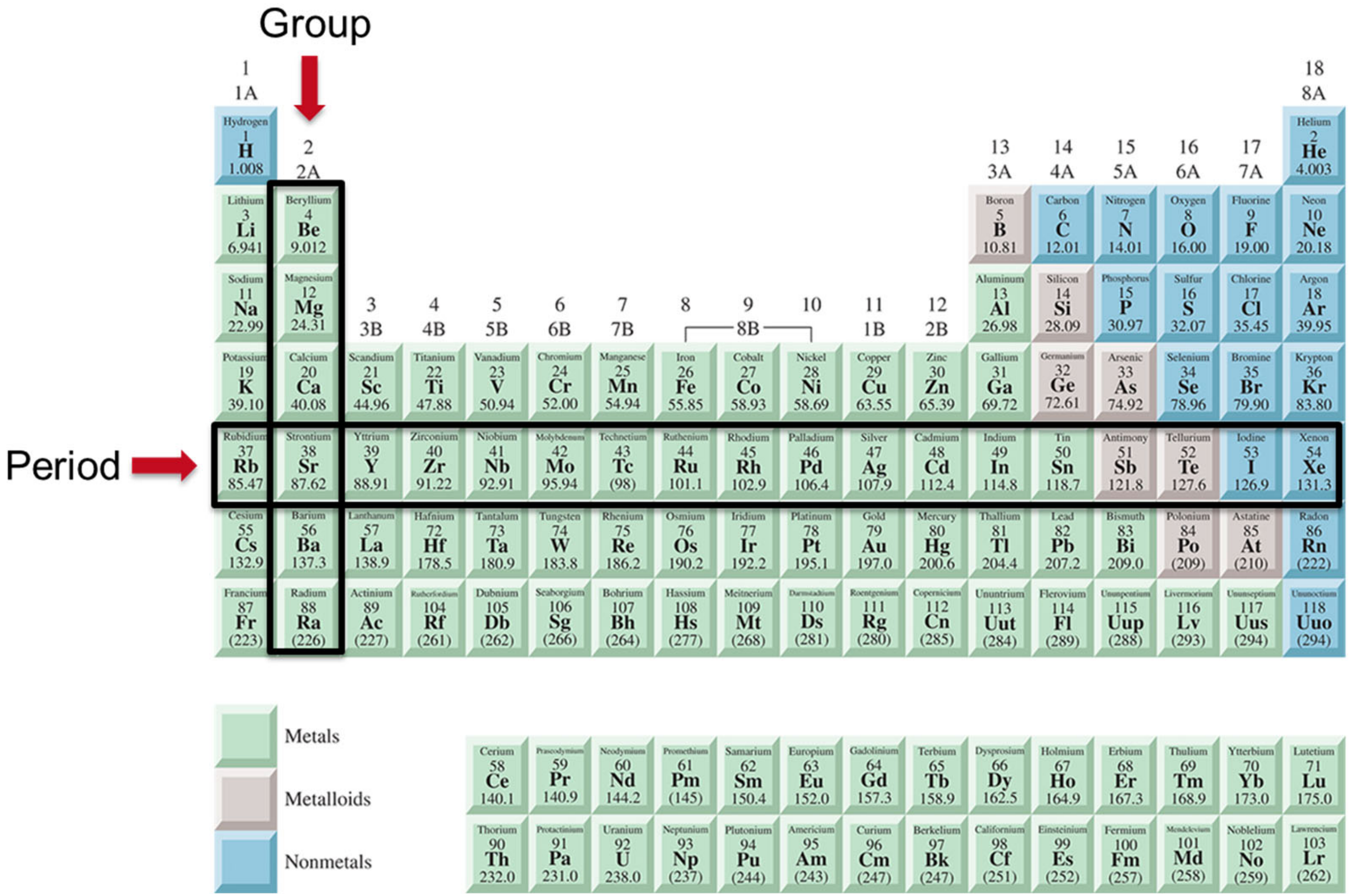
e. Stainless steel.

f. Table salt.

g. Sugar.



The Periodic Table



Most elements are metals; the metalloids include: B, Si, Ge, As, Sb, Te, Po

Groups of the Periodic Table

Group 1: alkali metals

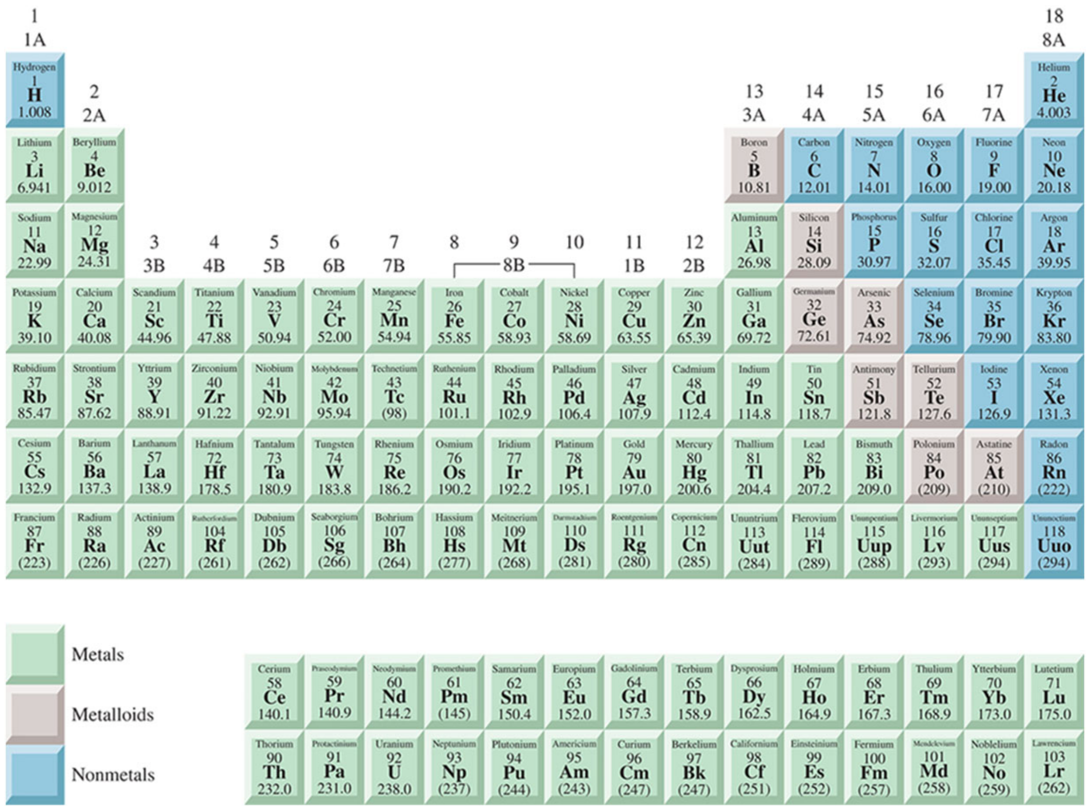
Group 2: alkaline earth metals

Group 15: pnictogens

Group 16: chalcogens

Group 17: halogens

Group 18: Noble gases



https://youtu.be/-ojcm3IIf98

The Periodic Table: Chemical Symbols

1 to 2 letter abbreviations for elements.

Most are straightforward (O = oxygen, Si = silicon, etc.).

Others are based on Latin or Greek names. For instance:

- Pb = lead (*plumbum* in Latin).
- Hg = mercury (hydrargyrum in Greek).
- Cu = copper (cuprum in Latin).
- Fe = iron (ferrum in Latin).
- K = potassium (kalium in Latin).
- Sb = antimony (stibium in Latin).
- Ag = silver (argentum in Latin).
- Au = gold (aurum in Latin).

https://youtu.be/-ojcm3IIf98?si=niF8zQf2Y4ebIH-R

Your Turn [1]

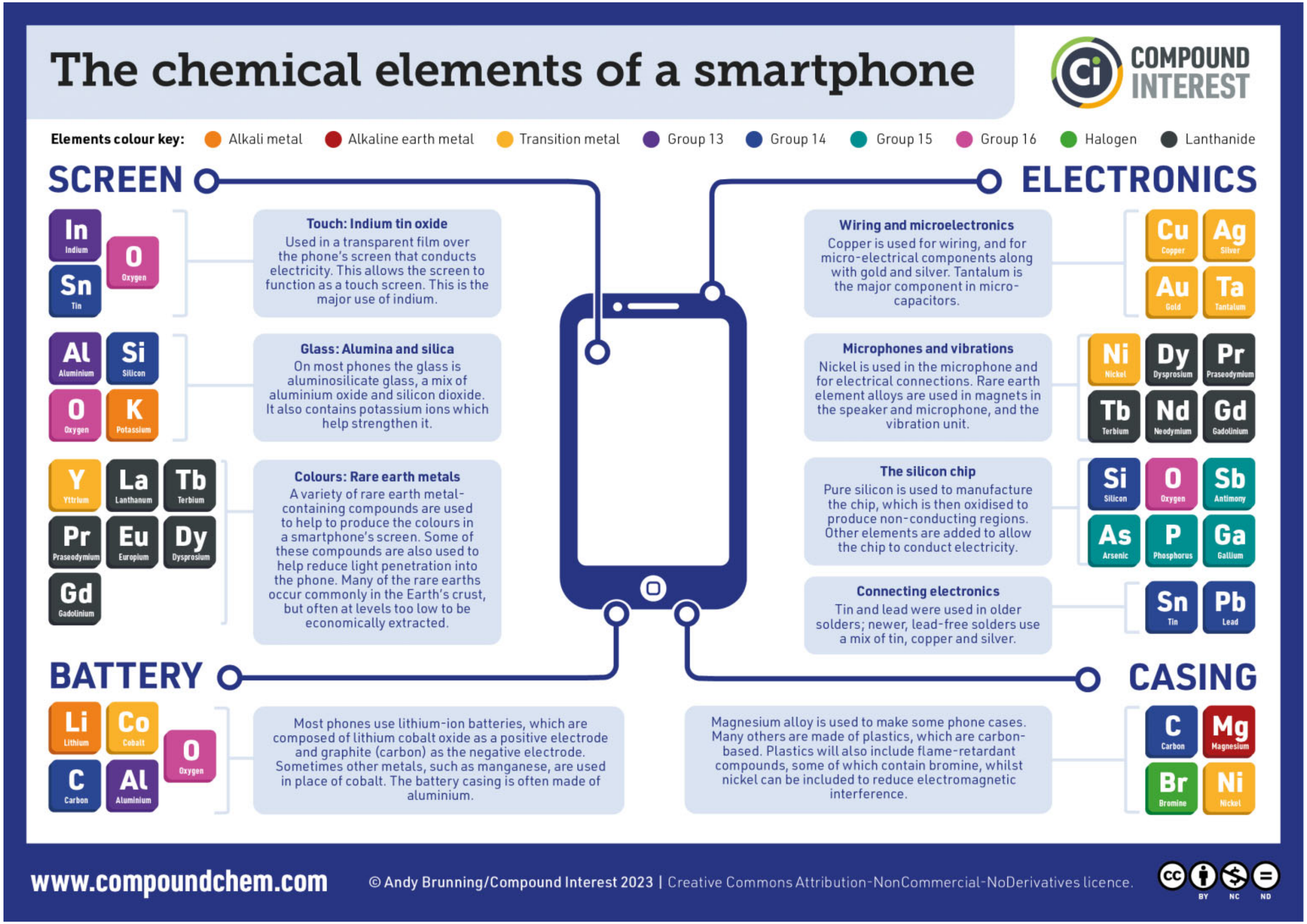
Your Turn 1.3 The Periodic Table Inside Your Cell Phone

a. Survey the periodic table shown in Figure 1.3. Which elements do you think are found in your cell phone?

b. The majority of materials that comprise your cell phone may be classified as metals, plastics, or glass. Using the Web as a resource, describe where these materials come from (both the region(s) of the world where they are produced, and the raw materials used in their fabrication).

The chemical elements of a smartphone

https://youtu.be/66SGcBAs04w



The chemical elements of a smartphone
COMPOUND INTEREST
Elements colour key: Alkali metal | Alkaline earth metal | Transition metal | Group 13 | Group 14 | Group 15 | Group 16 | Halogen | Lanthanide
SCREEN
In Indium | O Oxygen | Sn Tin
Touch: Indium tin oxide
Used in a transparent film over the phone's screen that conducts electricity. This allows the screen to function as a touch screen. This is the major use of indium.
Al Aluminium | Si Silicon | O Oxygen | K Potassium
Glass: Alumina and silica
On most phones the glass is aluminosilicate glass, a mix of aluminium oxide and silicon dioxide. It also contains potassium ions which help strengthen it.
Y Yttrium | La Lanthanum | Tb Terbium | Pr Praseodymium | Eu Europium | Dy Dysprosium | Gd Gadolinium
Colours: Rare earth metals
A variety of rare earth metal-containing compounds are used to help to produce the colours in a smartphone's screen. Some of these compounds are also used to help reduce light penetration into the phone. Many of the rare earths occur commonly in the Earth's crust, but often at levels too low to be economically extracted.
ELECTRONICS
Wiring and microelectronics
Copper is used for wiring, and for micro-electrical components along with gold and silver. Tantalum is the major component in micro-capacitors.
Cu Copper | Ag Silver | Au Gold | Ta Tantalum
Microphones and vibrations
Nickel is used in the microphone and for electrical connections. Rare earth element alloys are used in magnets in the speaker and microphone, and the vibration unit.
Ni Nickel | Dy Dysprosium | Pr Praseodymium | Tb Terbium | Nd Neodymium | Gd Gadolinium
The silicon chip
Pure silicon is used to manufacture the chip, which is then oxidised to produce non-conducting regions. Other elements are added to allow the chip to conduct electricity.
Si Silicon | O Oxygen | Sb Antimony | As Arsenic | P Phosphorus | Ga Gallium
Connecting electronics
Tin and lead were used in older solders; newer, lead-free solders use a mix of tin, copper and silver.
Sn Tin | Pb Lead
BATTERY
Li Lithium | Co Cobalt | O Oxygen | C Carbon | Al Aluminium
Most phones use lithium-ion batteries, which are composed of lithium cobalt oxide as a positive electrode and graphite (carbon) as the negative electrode. Sometimes other metals, such as manganese, are used in place of cobalt. The battery casing is often made of aluminium.
CASING
Magnesium alloy is used to make some phone cases. Many others are made of plastics, which are carbon-based. Plastics will also include flame-retardant compounds, some of which contain bromine, whilst nickel can be included to reduce electromagnetic interference.
C Carbon | Mg Magnesium | Br Bromine | Ni Nickel
www.compoundchem.com
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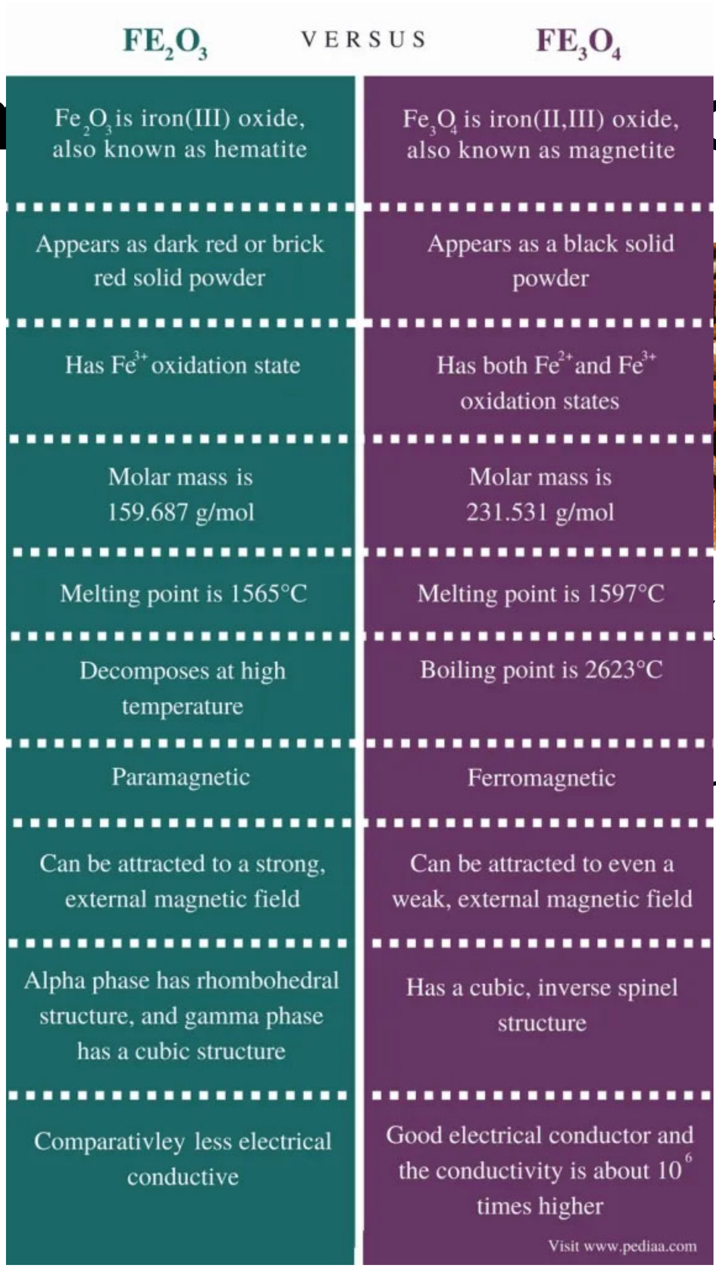
Fron ompounds



FE_2O_3	VERSUS	FE_3O_4
Fe_2O_3 is iron(III) oxide, also known as hematite		Fe_3O_4 is iron(II,III) oxide, also known as magnetite
Appears as dark red or brick red solid powder		Appears as a black solid powder
Has Fe^{3+} oxidation state		Has both Fe^{2+} and Fe^{3+} oxidation states
Molar mass is 159.687 g/mol		Molar mass is 231.531 g/mol
Melting point is 1565°C		Melting point is 1597°C
Decomposes at high temperature		Boiling point is 2623°C
Paramagnetic		Ferromagnetic
Can be attracted to a strong, external magnetic field		Can be attracted to even a weak, external magnetic field
Alpha phase has rhombohedral structure, and gamma phase has a cubic structure		Has a cubic, inverse spinel structure
Comparativley less electrical conductive		Good electrical conductor and the conductivity is about 10^6 times higher

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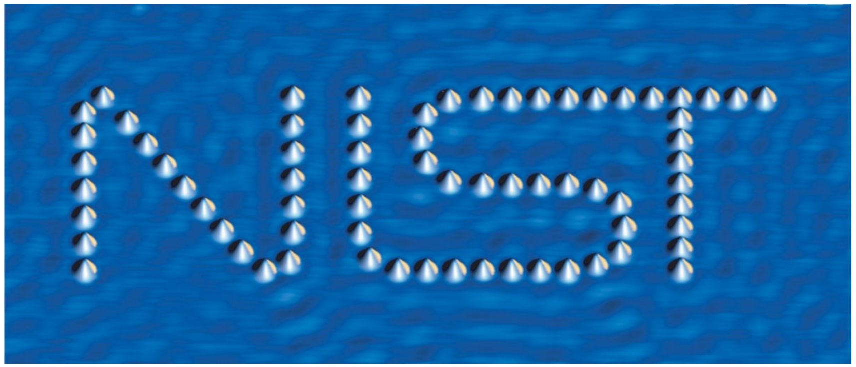
Measuring the Invisible

Elements and compounds are made up of atoms – the smallest building block that can exist as a stable, independent entity.

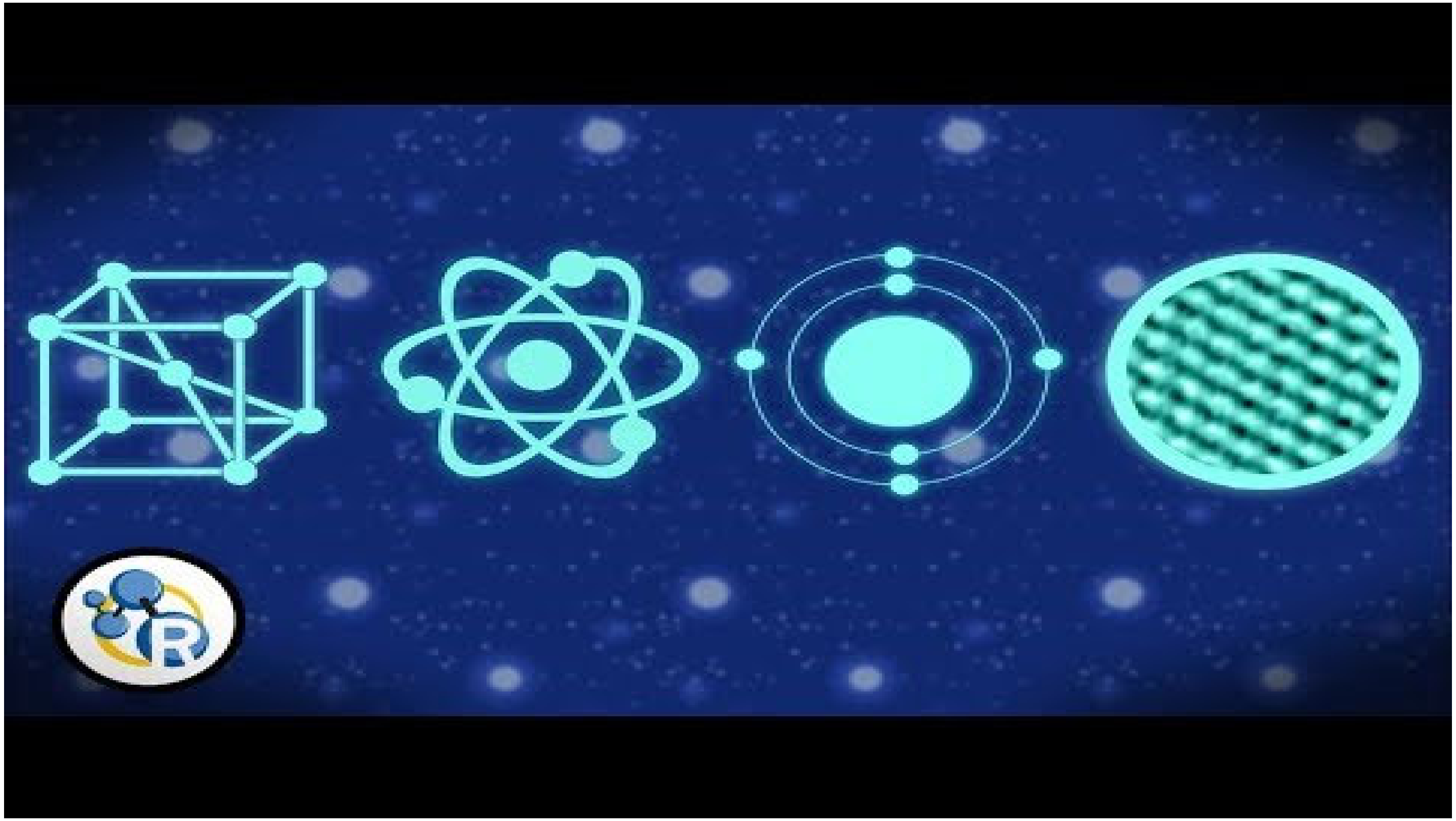
Atoms are extremely small – the cobalt atoms that make up the logo below are each 0.00000000014 meters in diameter!



Check out this link to see how scientists “see” atoms:

[How Can You See an Atom?]

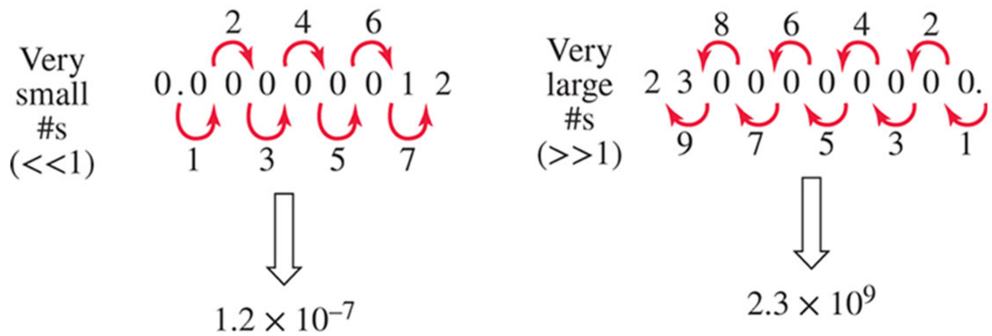
Source: US National Institute of Standards and Technology.



https://youtu.be/ipzFnGRfsfE

Scientific Notation

Scientific notation makes working with very small or very large numbers easier Use powers of ten to account for zeroes in a number.



Other examples:

$$11000 = 1.1 \times 10^{4}$$

$$0.00021 = 2.1 \times 10^{-4}$$

$$0.001021 = 1.021 \times 10^{-3}$$

$$1730 = 1.73 \times 10^{3}$$

$$602{,}200{,}000{,}000{,}000{,}000{,}000{,}000 = 6.022 \times 10^{23}$$

Shortcutting the Shortcut: Prefixes

- In the metric system, prefixes are used to shorten written numbers even further than scientific notation.
- Prefix symbols are used in conjunction with the base unit (for example, m, g, or A).
- For example,

  $1 \times 10^{3} g$ is 1 kg and 1×10^{-6}m is 1 μm

- **Dimensional analysis** is used to convert between units:

$$32\ \cancel{\text{nm}} \times \frac{1\times10^{-9}\ \text{m}}{1\ \cancel{\text{nm}}} = 3.2\times10^{-8}\ \text{m}$$

Table 1.2 Metric Conversions

Multiplication Factor	Prefix	Symbol
10^{9}	giga	G
10^{6}	mega	M
10^{3}	kilo	k
10^{2}	hecto	h
10^{1}	deka	da
1*	—	—
10^{-1}	deci	d
10^{-2}	centi	c
10^{-3}	milli	m
10^{-6}	micro	μ
10^{-9}	nano	n

What Makes Atoms Tick? Atomic Structure

- Although indivisible by chemical and physical means, atoms are composed of yet smaller pieces called **subatomic particles**.
- ***Protons*** and ***neutrons*** are found in the center of the atom, the nucleus.
- ***Electrons*** are located outside the nucleus.

Table 1.3 Properties of Subatomic Particles.

Particle	Relative Charge	Relative Mass	Actual Mass, kg
proton	$+1$	1	1.67×10^{-27}
neutron	0	1	1.67×10^{-27}
electron	-1	0*	9.11×10^{-31}

* This value is zero when rounded to the nearest whole number. The electron does indeed have mass, though very small!

Atomic Structure

For neutral atoms, the # electrons = # protons (charges must balance).

Hydrogen atom (left):

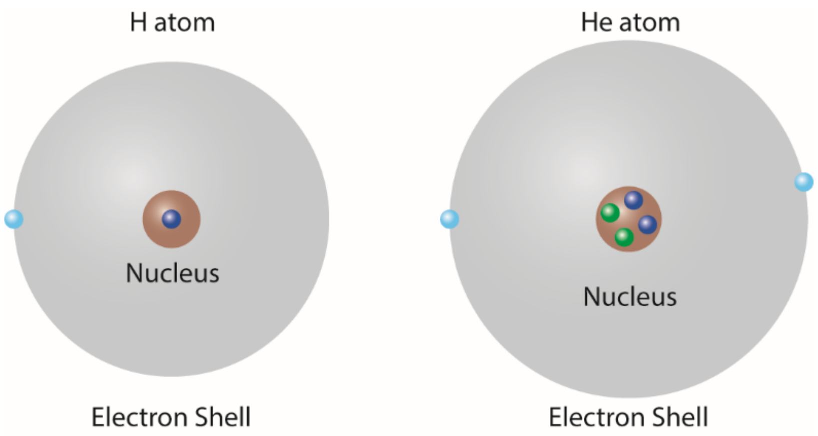
Atomic #: 1 (1 proton)

Mass #: 1 (1 proton, 0 neutrons)

Helium atom (right):

Atomic #: 2 (2 protons)

Mass #: 4 (2 protons, 2 neutrons)



Comparison of the atomic structures for hydrogen and helium, showing the location of protons (●), Neutrons (●), and electrons (●).

Your Turn

Your Turn 1.8 Atomic Structure.

Determine the number of protons and electrons in each of the following atoms:

a. Ga **b.** Sn **c.** Pb **d.** Fe

Determine the number of protons, neutrons, and electrons in each of the following atoms:

a. H (mass number of 2).

b. Cr (mass number of 52).

c. Al (mass number of 27).

d. As (mass number of 75).

1 1A	2 2A	3 3B	4 4B	5 5B	6 6B	7 7B	8	9 8B	10	11 1B	12 2B	13 3A	14 4A	15 5A	16 6A	17 7A	18 8A
Hydrogen 1 **H** 1.008																	Helium 2 **He** 4.003
Lithium 3 **Li** 6.941	Beryllium 4 **Be** 9.012											Boron 5 **B** 10.81	Carbon 6 **C** 12.01	Nitrogen 7 **N** 14.01	Oxygen 8 **O** 16.00	Fluorine 9 **F** 19.00	Neon 10 **Ne** 20.18
Sodium 11 **Na** 22.99	Magnesium 12 **Mg** 24.31											Aluminum 13 **Al** 26.98	Silicon 14 **Si** 28.09	Phosphorus 15 **P** 30.97	Sulfur 16 **S** 32.07	Chlorine 17 **Cl** 35.45	Argon 18 **Ar** 39.95
Potassium 19 **K** 39.10	Calcium 20 **Ca** 40.08	Scandium 21 **Sc** 44.96	Titanium 22 **Ti** 47.88	Vanadium 23 **V** 50.94	Chromium 24 **Cr** 52.00	Manganese 25 **Mn** 54.94	Iron 26 **Fe** 55.85	Cobalt 27 **Co** 58.93	Nickel 28 **Ni** 58.69	Copper 29 **Cu** 63.55	Zinc 30 **Zn** 65.39	Gallium 31 **Ga** 69.72	Germanium 32 **Ge** 72.61	Arsenic 33 **As** 74.92	Selenium 34 **Se** 78.96	Bromine 35 **Br** 79.90	Krypton 36 **Kr** 83.80
Rubidium 37 **Rb** 85.47	Strontium 38 **Sr** 87.62	Yttrium 39 **Y** 88.91	Zirconium 40 **Zr** 91.22	Niobium 41 **Nb** 92.91	Molybdenum 42 **Mo** 95.94	Technetium 43 **Tc** (98)	Ruthenium 44 **Ru** 101.1	Rhodium 45 **Rh** 102.9	Palladium 46 **Pd** 106.4	Silver 47 **Ag** 107.9	Cadmium 48 **Cd** 112.4	Indium 49 **In** 114.8	Tin 50 **Sn** 118.7	Antimony 51 **Sb** 121.8	Tellurium 52 **Te** 127.6	Iodine 53 **I** 126.9	Xenon 54 **Xe** 131.3
Cesium 55 **Cs** 132.9	Barium 56 **Ba** 137.3	Lanthanum 57 **La** 138.9	Hafnium 72 **Hf** 178.5	Tantalum 73 **Ta** 180.9	Tungsten 74 **W** 183.8	Rhenium 75 **Re** 186.2	Osmium 76 **Os** 190.2	Iridium 77 **Ir** 192.2	Platinum 78 **Pt** 195.1	Gold 79 **Au** 197.0	Mercury 80 **Hg** 200.6	Thallium 81 **Tl** 204.4	Lead 82 **Pb** 207.2	Bismuth 83 **Bi** 209.0	Polonium 84 **Po** (209)	Astatine 85 **At** (210)	Radon 86 **Rn** (222)
Francium 87 **Fr** (223)	Radium 88 **Ra** (226)	Actinium 89 **Ac** (227)	Rutherfordium 104 **Rf** (261)	Dubnium 105 **Db** (262)	Seaborgium 106 **Sg** (266)	Bohrium 107 **Bh** (264)	Hassium 108 **Hs** (277)	Meitnerium 109 **Mt** (268)	Darmstadtium 110 **Ds** (281)	Roentgenium 111 **Rg** (280)	Copernicium 112 **Cn** (285)	Ununtrium 113 **Uut** (284)	Flerovium 114 **Fl** (289)	Ununpentium 115 **Uup** (288)	Livermorium 116 **Lv** (293)	Ununseptium 117 **Uus** (294)	Ununoctium 118 **Uuo** (294)

Cerium 58 **Ce** 140.1	Praseodymium 59 **Pr** 140.9	Neodymium 60 **Nd** 144.2	Promethium 61 **Pm** (145)	Samarium 62 **Sm** 150.4	Europium 63 **Eu** 152.0	Gadolinium 64 **Gd** 157.3	Terbium 65 **Tb** 158.9	Dysprosium 66 **Dy** 162.5	Holmium 67 **Ho** 164.9	Erbium 68 **Er** 167.3	Thulium 69 **Tm** 168.9	Ytterbium 70 **Yb** 173.0	Lutetium 71 **Lu** 175.0
Thorium 90 **Th** 232.0	Protactinium 91 **Pa** 231.0	Uranium 92 **U** 238.0	Neptunium 93 **Np** (237)	Plutonium 94 **Pu** (244)	Americium 95 **Am** (243)	Curium 96 **Cm** (247)	Berkelium 97 **Bk** (247)	Californium 98 **Cf** (251)	Einsteinium 99 **Es** (252)	Fermium 100 **Fm** (257)	Mendelevium 101 **Md** (258)	Nobelium 102 **No** (259)	Lawrencium 103 **Lr** (262)

Metals

Metalloids

Nonmetals

A Look at the Elements in Their Natural States 1

Metals are isolated from natural rock formations.

- For example, aluminum is isolated from bauxite ore.

A 200.0 g of bauxite sample contains several minerals:

100.0 g gibbsite, 50.5 g boehmite, 49.5 g iron oxide.

As a percentage, these minerals are:

$$\frac{100.0\ \text{g gibbsite}}{200.0\ \text{g bauxite ore}} \times 100\% = 50.00\%\ \text{gibbsite}$$

$$\frac{50.5\ \text{g boehmite}}{200.0\ \text{g bauxite ore}} \times 100\% = 25.3\%\ \text{boehmite}$$

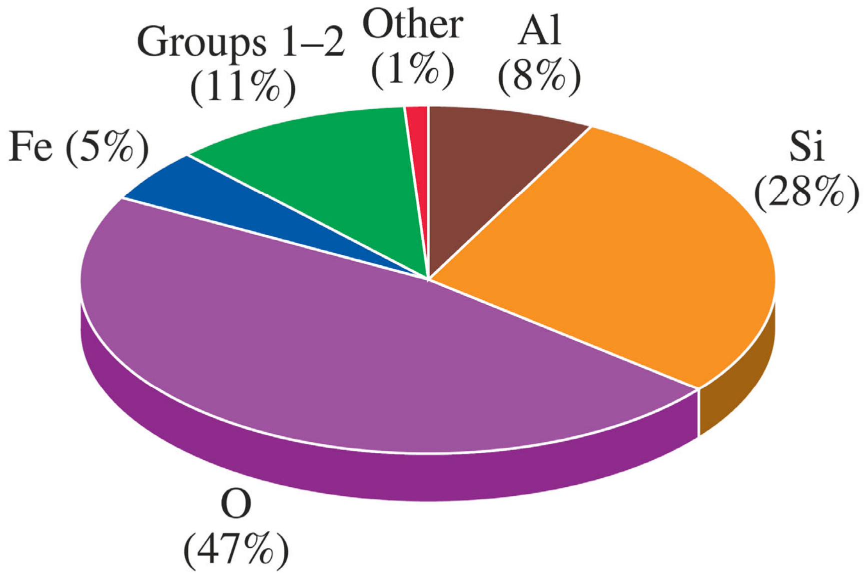
$$\frac{49.5\ \text{g iron oxide}}{200.0\ \text{g bauxite ore}} \times 100\% = 24.7\%\ \text{iron oxide}$$

A Look at the Elements in Their Natural States

Earth's crust is mostly composed of O, Si, Al, and alkali/alkaline earth metals.

- But these aren't as pure elements!
- Present as rocks or ores:

Ore	Formula
Galena	PbS
Chalcocite	Cu_2S
Magnesite	$MgCO_3$
Cinnabar	HgS
Sphalerite	ZnS
Hematite	Fe_2O_3
Magnetite	Fe_3O_4
Dolomite	$CaMg(CO_3)_2$



Chemical Change to Obtain Pure Metals

- Smelting chemically reacts metal ores with reactants such as carbon with high temperatures to produce pure metal:

$$CuO(\mathrm{s}) + C(\mathrm{s}) \rightarrow Cu(\mathrm{l}) + CO(\mathrm{g})$$

- Since the chemical composition of the copper oxide is changed, this is a ***chemical change***.
- If the physical state is changed without changing the composition, such as melting solid copper to liquid copper, it is a ***physical change***.

Minnesota Iron Mining Process

https://youtu.be/7foK-wVNSMw

Your Turn

Your Turn 1.10 Physical versus Chemical Change.

For each of the following, indicate whether a physical or chemical change has occurred:

a. Burning a match.

b. Baking a cake.

c. Cracking a piece of glass.

d. A piece of apple darkens after being cut.

e. Boiling water.

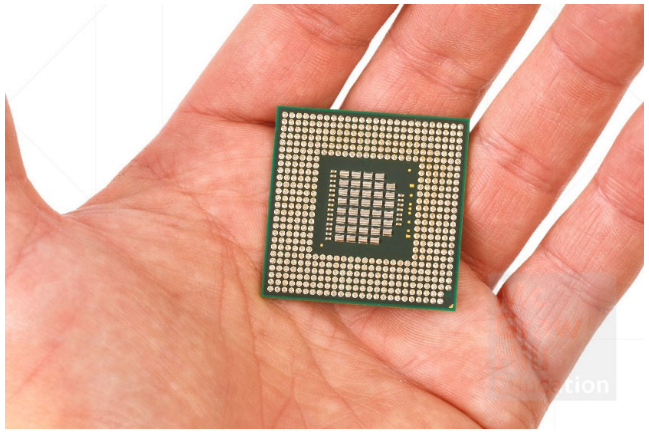
f. Rusting of iron.

From Sand to Silicon

- The processing chips in your electronic devices are made primarily of very pure silicon … which comes from sand, SiO_2:

$$SiO_{2(s)} + 2\,C_{(s)} \rightarrow Si_{(s)} + CO_{(g)}$$

- This produces metallurgical grade silicon (95 to 98% pure).
- However, higher purity is needed for processing chips, so additional purification is needed.
- Purities of up to 99.9999999999% can be achieved, or 12N!



[From Sand to Silicon: the Making of a Chip]

Shutterstock / Peter Gudella

https://youtu.be/Q5paWn7bFg4?si=veXhLrpes_lwfq4r

From Sand to Glass [1]

Sand is also used as a raw material to make glass.

- S i O_x the primary component of many gemstones.
- Colored crystals are due to the presence of trace amounts of metals.

Citrine (above) and amethyst (below) both have trace amounts of iron that give them their color

What Causes the Colour of Gemstones?

Gemstones

THE CHEMISTRY OF GEMSTONE COLOURS

Gemstone colours stem from their chemical structures, which absorb different wavelengths of light. Their hardness is measured on the Mohs hardness scale (1-10).

PEARL
Formula: $CaCO_3$
Mohs hardness: 2.5–4.5
Produced in soft tissue of shelled molluscs. The thinner the layers of the pearl, the finer the lustre.

TURQUOISE
Formula: $Al_6(PO_4)_4(OH)_8.4H_2O$
Mohs hardness: 5.0–6.0
Colour caused by the presence of copper ions coordinated to the hydroxide ions and water.

OPAL
Formula: $SiO_2.nH_2O$
Mohs hardness: 5.5–6.0
'Play of colours' caused by interference and diffraction of light passing through structure.

JADE
Formula: $NaAlSi_2O_6$
Mohs hardness: 6.5–7.0
Colour from chromium and iron impurities. The mineral nephrite is also referred to as jade.

PERIDOT
Formula: Mg_2SiO_4
Mohs hardness: 6.5–7.0
Colour caused by iron 2+ ions replacing magnesium ions in some locations in the structure.

GARNET
Formula: $Mg_3Al_2(SiO_4)_3$
Mohs hardness: 6.5–7.5
Colour caused by iron 2+ ions replacing magnesium ions in some locations in the structure.

AMETHYST
Formula: SiO_2
Mohs hardness: 7.0
Colour caused by irradiation of iron 3+ ions in place of silicon in some locations in the structure.

CITRINE
Formula: SiO_2
Mohs hardness: 7.0
The yellow colour of citrine is due to the presence of either aluminium or iron impurities.

TOURMALINE
Formula: $Na_3Li_3Al_6(BO_3)_3(SiO_3)_6F_4$
Mohs hardness: 7.0–7.5
Colour due to manganese ions replacing lithium and aluminium ions in some sites.

ZIRCON
Formula: $ZrSiO_4$
Mohs hardness: 7.5
Many colours depending on impurities. Colourless forms are popular diamond substitutes.

AQUAMARINE
Formula: $Be_3Al_2(SiO_3)_6$
Mohs hardness: 7.5–8.0
Colour caused by iron 2+/3+ ions replacing aluminium ions in some locations in the structure.

EMERALD
Formula: $Be_3Al_2(SiO_3)_6$
Mohs hardness: 7.5–8.0
Colour caused by chromium ions replacing aluminium in some locations in the structure.

SPINEL
Formula: $MgAl_2O_4$
Mohs hardness: 7.5–8.0
A variety of colours are possible, caused by impurities such as iron, chromium and nickel.

TOPAZ
Formula: $Al_2SiO_4(F,OH)_2$
Mohs hardness: 8.0
Pure topaz is colourless; blue & brown varieties are caused by atomic level imperfections.

ALEXANDRITE
Formula: Al_2BeO_4
Mohs hardness: 8.5
Colour caused by chromium ions replacing aluminium in some sites. Colour varies in different light.

RUBY
Formula: Al_2O_3
Mohs hardness: 9.0
Colour caused by chromium ions replacing aluminium ions in some locations in the structure.

SAPPHIRE
Formula: Al_2O_3
Mohs hardness: 9.0
Colour caused by titanium and iron ions replacing aluminium ions in some locations in the structure.

DIAMOND
Formula: C_n
Mohs hardness: 10
Colourless; can be faintly coloured by the trapping of nitrogen or boron atoms in the crystal.

From Sand to Glass 2

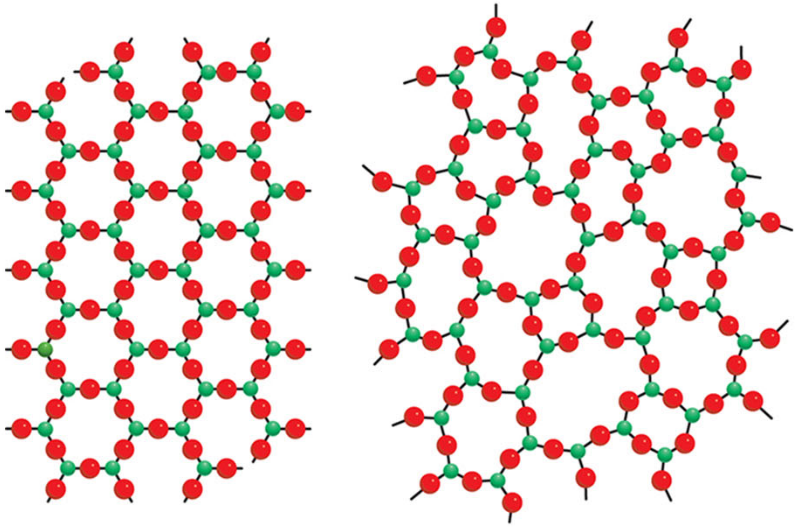
Properties depend on composition and structure.

- Most glass is amorphous, but quartz is crystalline:

Sharp melting point

Straight fractures

Tend to be harder



Broad melting point

Likely to shatter

Crystalline SiO_2 Amorphous SiO_2

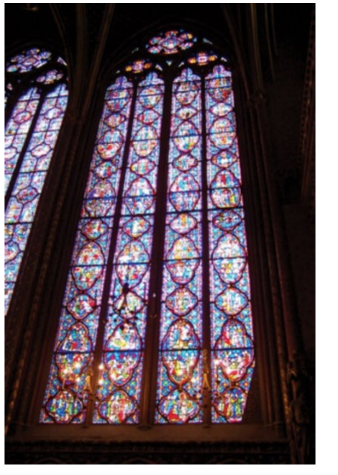
From Sand to Glass

Sand is heated to temperatures in excess of 1000°C and cooled rapidly to form a disordered glass.

- Quartz sand has a very high melting point (>1300°C), so additives are used to lower the melting point, so the glass is easier to mold.
- Additives to lower the melting point such as Na_2CO_3, $CaCO_3$, and $MgCO_3$ are called *flux*.
- Other additives are used to give other properties such as color and thermal stability.

ex) Pyrex glass contains Si, O, B, Na, Al and K.

https://www.acs.org/education/resources/undergraduate/chemistryincontext/interactives/portable-electronics/formation-prince-ruperts-drop.html



THE CHEMISTRY OF COLOURED GLASS

Glass is coloured in 3 main ways. It can have transition or rare earth metal ions added; it can be due to colloidal particles formed in the glass; or it can be due to particles which are coloured themselves. This graphic shows some of the typical chemical elements that are used to colour glass.

SODA-LIME GLASS

COMPOSITION

SiO_2 70-74%
SILICON DIOXIDE

CaO 10-14%
CALCIUM OXIDE

Na_2O 13-16%
SODIUM OXIDE

Soda-lime glass is the most common glass type, making up an estimated 90% of all manufactured glass. Its uses include containers, windows, bottles, and drinking glasses. The above percentages are a general composition only; other compounds are also present in smaller amounts.

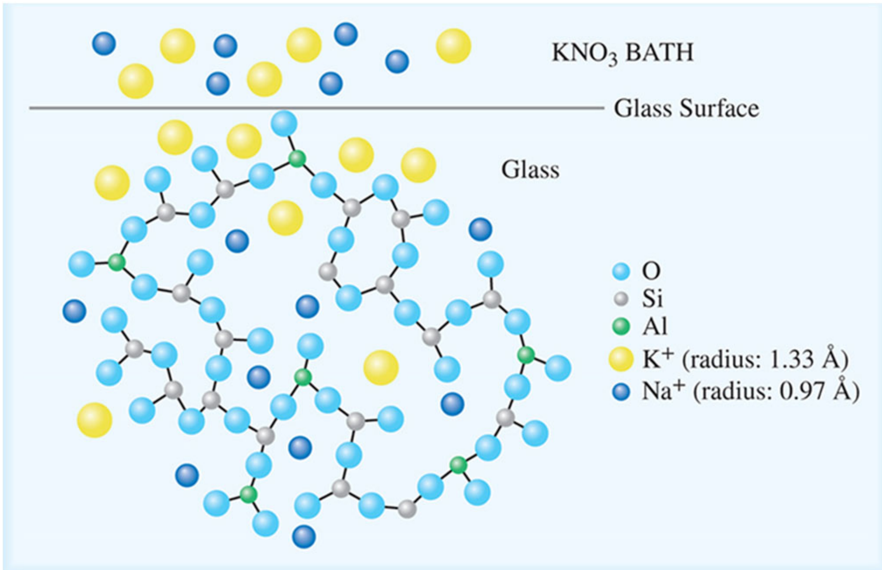
These are typical colours, and can be affected by the type of glass as well as the concentration of the colourant. Combination with other elements and compounds can also have an effect on the final colouration of the glass.

From Sand to Glass [4]

To increase strength of glass, the structure of the glass is changed at the surface.

- Corning's Gorilla Glass soaks glass in molten KNO_3 bath to replace sodium ions with larger potassium ions, increasing compression at the surface.

Whereas normal glass can withstand a force of 7000 psi, Gorilla Glass can withstand >100,000 psi!



https://www.acs.org/education/resources/undergraduate/chemistryincontext/interactives/portable-electronics/creation-gorilla-glass.html

Apple Watch Series 9

Apple Watch Hermès

Apple Watch Series 9

Apple Watch Series 9

Ion-X glass

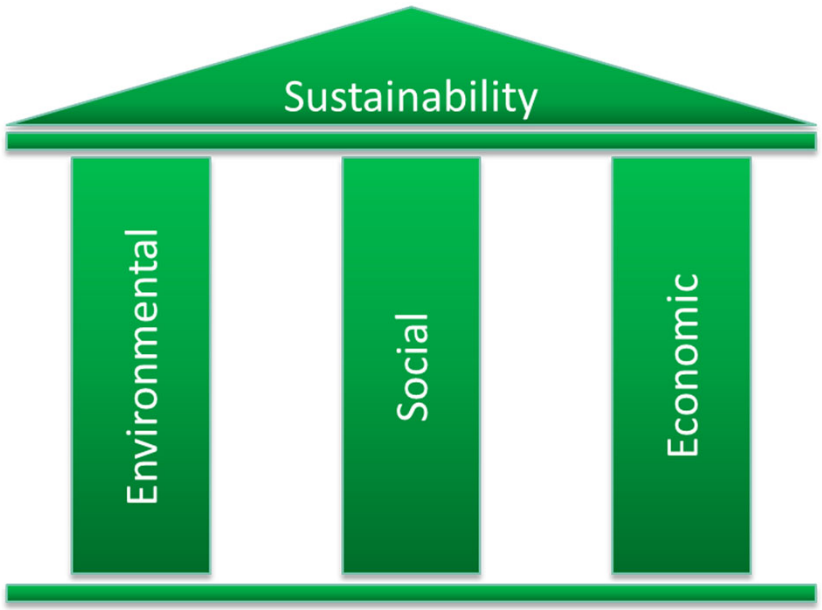
Sapphire glass

Three Pillars of Sustainability

Environmental: pollution prevention, natural resource use.

Social: better quality of life for all members of society.

Economic: fair distribution and efficient allocation of resources.



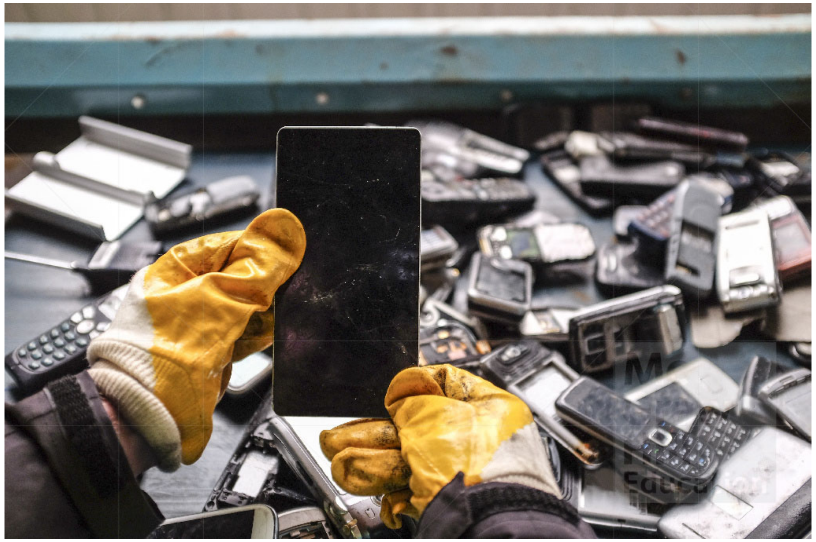
Cradle-to-Cradle Recycling [1]

A sustainable life cycle for portable electronics is “cradle-to-cradle.”

- End of usefulness of one product dovetails with the beginning of the life cycle for another product.

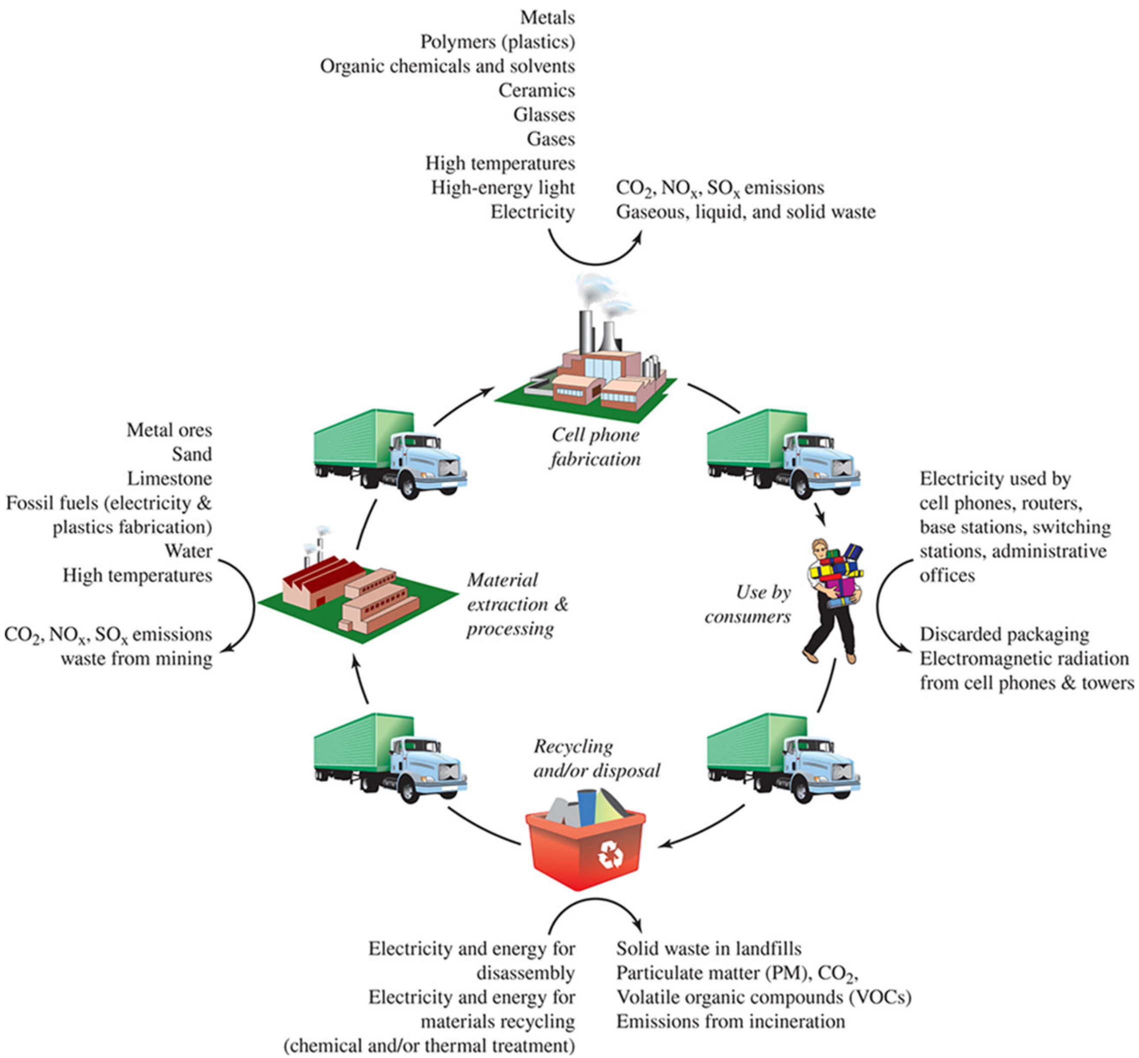
Over 90% of cell phones are sent to landfills or are collected at homes.

- Only 3% are recycled!



baranozdemir/Getty Images

Cradle-to-Cradle Recycling 2



Apple has 18 final assembly facilities + >200 raw material suppliers
- Si for chips purified in Michigan, USA
- Circuit board built in CA
- Li in battery mined and purified in Chile
- Plastics synthesized in China

...

Environmental footprint

11-inch iPad Pro (1064 GB)

➔ 184 kgCO2e (kg of equivalent CO2) during its lifespan

= **84%** from manufacturing + 11% from transportation + **5%** from consumer use + <1% recycling

The Importance of Recycling

An average cell phone contains:

- 300 mg of silver.
- 30 mg of gold (30 times more concentrated than in gold ore!).

The process of recycling electronics to recover metals is referred to as ***urban mining***

While much electronics recycling is done by hand, some companies are developing disassembly robots to make the process safer and more environmentally friendly.

[The Recycling Rates of Smartphone Metals]

E.D. Torial / Alamy Stock Photo

RECYCLING RATES OF SMARTPHONE METALS

COLOUR KEY: < 1% RECYCLE RATE | 1–10% RECYCLE RATE | 10–25% RECYCLE RATE | 25–50% RECYCLE RATE | > 50% RECYCLE RATE | NON-METAL (OR RECYCLE RATE UNKNOWN)

SCREEN

In, O, Sn

TOUCH: INDIUM TIN OXIDE
Used in a transparent film over the phone's screen that conducts electricity. This allows the screen to function as a touch screen. This is the major use of indium.

Al, Si, O, K

GLASS: ALUMINA & SILICA
On most phones the glass is aluminosilicate glass, a mix of aluminium oxide & silicon dioxide. It also contains potassium ions which help strengthen it.

Y, La, Tb, Pr, Eu, Dy, Gd

COLOURS: RARE EARTH METALS
A variety of rare earth metal-containing compounds are used to help to produce the colours in a smartphone's screen. Some of these compounds are also used to help reduce light penetration into the phone. Many of the 'rare earths' occur commonly in the Earth's crust, but often at levels too low to be economically extracted.

ELECTRONICS

WIRING & MICROELECTRONICS
Copper is used for wiring, and for micro-electrical components along with gold and silver. Tantalum is the major component in micro-capacitors.

Cu, Ag, Au, Ta

MICROPHONES & VIBRATIONS
Nickel is used in the microphone and for electrical connections. Rare earth element alloys are used in magnets in the speaker and microphone, and the vibration unit.

Ni, Dy, Pr, Tb, Nd, Gd

THE SILICON CHIP
Pure silicon is used to manufacture the chip, which is then oxidised to produce non-conducting regions. Other elements are added to allow the chip to conduct electricity.

Si, O, Sb, As, P, Ga

CONNECTING ELECTRONICS
Tin & lead were used in older solders; newer, lead-free solders use a mix of tin, copper & silver.

Sn, Pb

BATTERY

Li, Co, O, C, Al

Most phones use lithium ion batteries, composed of lithium cobalt oxide as a positive electrode and graphite (carbon) as the negative electrode. Sometimes other metals, such as manganese, are used in place of cobalt. The battery casing is often made of aluminium.

CASING

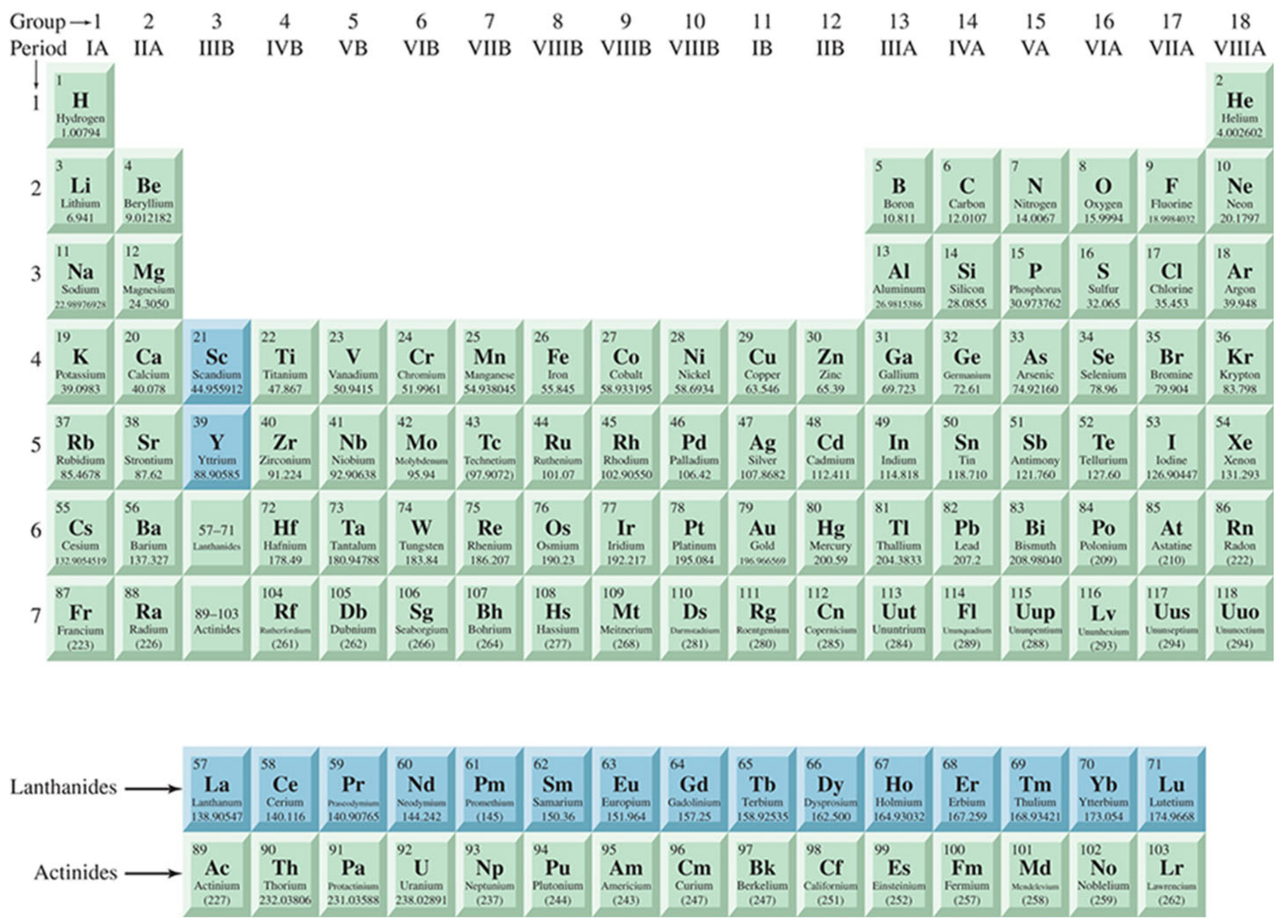
Magnesium alloy is used to make some phone cases, whilst many others are made of plastics, which are carbon-based. Plastics will also include flame retardant compounds, some of which contain bromine, whilst nickel can be included to reduce electromagnetic interference.

C, Mg, Br, Ni

Rare Earth Metals: A Needed Resource

Rare earth metals are used for applications such as:

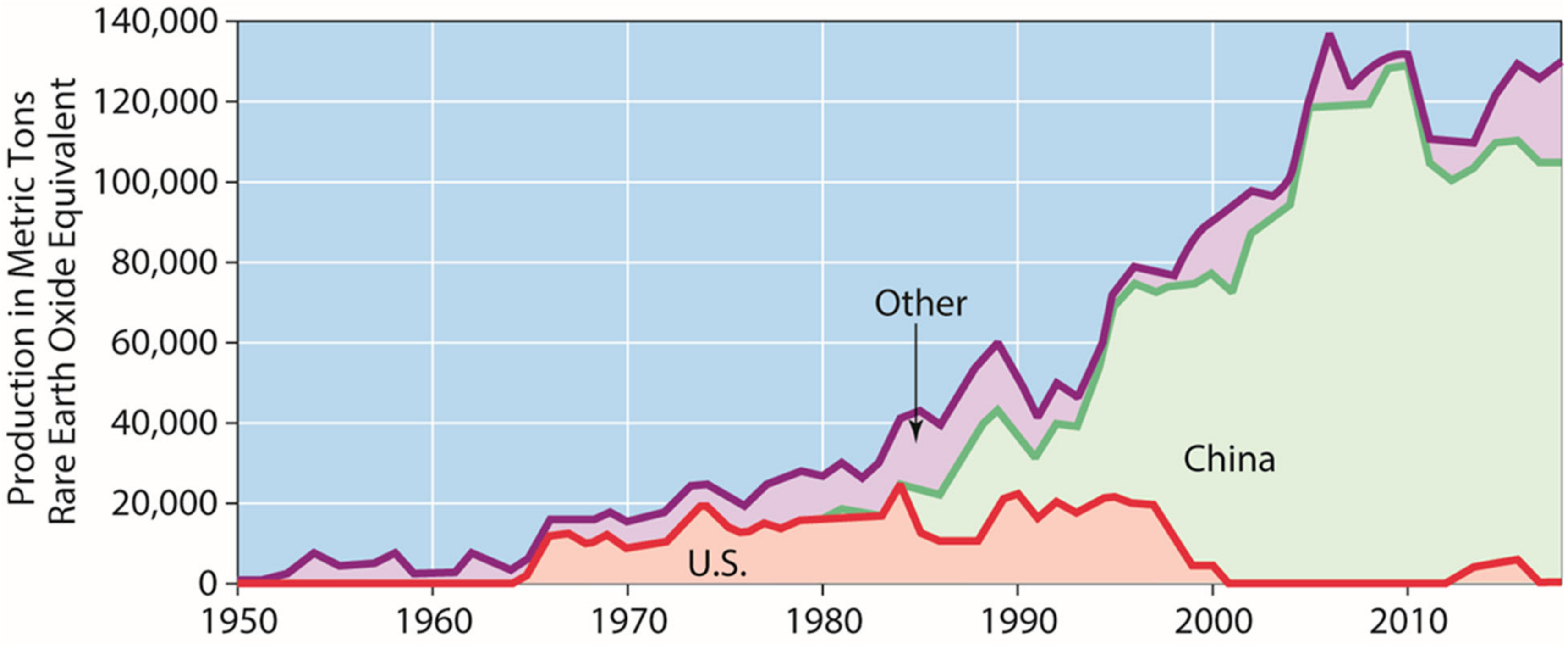
- Rechargeable batteries.
- Magnets.
- Speakers.
- Memory chips.
- Fluorescent lighting.
- Catalytic converters.
- Advanced electronics.
- Advanced weaponry.



Where Are the Rare Earths?

China controls most of the world's supply of the rare earth metals.

- Over 90% comes from China who holds 50% of the world's reserves.



Your Turn 5

Your Turn 1.15 Group Activity.

Now that you have learned about how your portable device works and what it is made from, form a group to think about the impact that replacing these devices every year or two has on people and Earth.

a. What are the most significant challenges that face the widespread adoption of urban mining for electronics?

b. Using the Internet as a resource, find out whether we would be able to meet our rising needs for new electronic devices by urban mining practices alone.

c. How does the fabrication and use of portable electronics affect air quality (the topic of our next chapter)?

<u>Example topics that you can delve into further</u>

1) Study more details about your smartphone materials
What are their components? What elements are required? How has each element been purified and fabricated? What are the economic and environmental costs involved in each process? Which process needs to be improved? What ideas are people testing and researching? What's your idea?

2) For your future phone, what attributes are desired? Which material or component of your phone needs to be improved for them? What are researchers doing for improving those properties? Will the new techniques or materials cost more environmental footprints?