TEACHER'S GUIDE

SCIENCE KEY CONCEPTS SERIES: CHEMISTRY

THE REACTIVITY OF ELEMENTS

15 minutes, Video

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FOR USE IN: Chemistry
LEVEL: Grades 9-12
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EDUCATIONAL OBJECTIVES:

To help the student understand these key concepts about the reactivity of elements in the periodic table:

- ⇒ highly reactive metals, Group 1
- ⇒ highly reactive halogens, Group 17
- ⇒ the range of reactivity among metals

BACKGROUND INFORMATION:

Alkali Metals:

The reactivity of the alkali metals, Column 1 on the Periodic Table, increases as you move down the family. Since the effective nuclear charge within a family is essentially the same (alkali metals would have an effective nuclear charge of 1) the reactivity increases because of increasing size of the atoms. A size increase occurs because of one additional energy level per row. The larger size makes it easier to remove the ns1 from an element such as sodium vs. lithium to form the positively charged alkali metal ion. Cesium is the most reactive and its reaction with water is very explosive. In fact, cesium will react with moisture in the air and instantaneously ignite.

Lithium is the only alkali metal that reacts with nitrogen in the air to form lithium nitride, Li3N. Sodium reacts with oxygen in the air to form both sodium oxide, Na2O, and sodium peroxide, Na2O2. The other alkali metals react with oxygen to form the superoxide, such as potassium superoxide, KO2. The stability of the ionic compound produced affects which oxide the alkali metal will form based on the attraction of the positively charged alkali metal ion to either the oxide, peroxide, or superoxide ion. Whichever results in the most stable compound (larger lattice energy) will be the predominant oxide produced.

Alkali Metals reacting with air:
6 Li(s) + N2(g) ý 2 Li3N(s)
2Na(s) + O2(g) ý Na2O(s)
2Na(s) + O2(g) ý Na2O2(s)
2K(s) + O2(g) ý KO2(s)
And RbO2 and CsO2 - the superoxides

Alkali Metals reacting with Water:
2 Li(s) + 2HOH(l) ý 2Li+(aq) + 2OH-(aq) + H2(g) + Energy
2 Na(s) + 2HOH(l) ý 2 Na+(aq) + 2OH-(aq) + H2(g) + Energy
2 K(s) + 2HOH(l) ý 2 K+(aq) + 2OH-(aq) + H2(g) + Energy

Reaction of the hydrogen from the reaction with oxygen in the air to produce water vapor: 2H2(g) + O2(g) ý 2H2O(g) + Energy (K, Rb, and Cs reactions produce enough heat for this reaction to occur, whereas Na only does this when the water is at or above room temp.)

References:

Borgstedt, H.U.; Matthews, C.K. Applied Chemistry of the Alkali Metals; Plenum: New York, 1987.
Chang, R. Chemistry; McGraw-Hill, Inc.: New York, 5th Ed., 1994.
Ealy, Julie.B. ; Ealy, James.L. Close-up on Chemistry, American Chemistry Society: Washington, DC. 1991. (70 min. Video of Chemical Demonstrations)
Greenwood, N.N.; Earnshaw, A. Chemistry of the Elements; Pergamon: New York, 1984: pp. 88, 97-98.

McHenry, M.J. J. Chem. Educ. 1929, 6, 1644 (From Cotting, J.R. An Introduction to Chemistry, with Practical Questions: Designed for Beginners in Science; Charles Ewer: Boston, 1822. This is one of the earliest references found for the reaction of alkali metals with water).

Halogens:
The halogens are volatile, diatomic elements,which react predictively with a variety of other elements. Fluorine is the most electronegative and therefore the most reactive, with each successive lower halogen reacting
less vigorously under the same conditions. It is the completion of an almost full outermost energy level containing seven electrons that accounts for the reactivity of the halogens. Fluorine, being the smallest and most dense of the halogens, it most wants electrons in the context of a chemical reaction. F_2 is a pale yellow gas, Cl_2 is a yellowish-green gas, Br_2 is a dark-red liquid, and I_2 is a black crystal with vitreous luster. The abundance of the halogens corresponds to their order in the family. F_2 is the most abundant and I_2 least abundant in compounds, since none are found in the native state in nature. At_2, by some accounts, is considered the least abundant crustal element.

References:
Greenwood, N.N.; Earnshaw, A. Chemistry of the Elements; Pergamon: New York, 1984: pp. 88, 97-98.
Weeks, M. E. Discovery of the Elements, 6th Ed., Journal of Chemical Education, Easton, 1956, 'The halogen family', pp. 729-77.

BEFORE SHOWING THE VIDEO:

Reactions are among the more interesting aspects of chemistry for many students since in many cases they actually see something happening that they can control or manipulate. This video introduces concepts of reactivity using experimental procedures that may not be accessible in schools due to unavailable funds or possible hazards of the reactants and/or products.

To prepare students for the video learning experience, it may be helpful to explore one or both of the following organizing ideas: 1.the idea of reaction rate, and 2. how the atomic structure of elements at different positions in the periodic table may predict their reactivity.

To develop a better understanding of reaction rate, encourage students to consider a marathon race. People run at different rates. Faster people cover more ground per minute than slower people. Chemical reactions also go at different rates, but here it is the amount of product produced per unit time that is important. This can be explored by teacher demonstration or student experimentation. Compare the rate of two reactions: 1.neutralization of alkaline bicarbonate solution with dilute acid and 2.reduction of copper from solution on the surface of iron. Add some powdered sodium bicarbonate (c.1/2 teaspoon) to dilute vinegar solution containing a pH indicator (such as bromophenol blue). The change in color will indicate a change from acid to alkaline. If you are allowing the students to do the experiments, assign the students to work in small groups, one person can record the time, another add the bicarbonate powder to the vinegar while others record observations. The time for completion of the obvious foaming of the reaction when acid is added should be recorded as well as the change in color. Then, using a copper sulfate solution, e.g. 0.01 M (0.25 g cupric sulfate pentahydrate/ 100 ml solution), place some shiny tacks or small nails into the solution in a test tube and observe how long it takes for the nails to become fully coated with a layer of dark copper (c. 1.0 to 1.5 min.). Ask why the initially blue copper sulfate solution turns to a more yellowish green hue as more nails are added. If you have iron sulfate as a solution or crystals to display, this may help students associate the color with the product produced in solution. Discuss which reaction seemed to proceed more rapidly and how the students knew that there was a reaction (based on observations). Also discuss the limitations of these rate experiments. In this case different chemical reactants were being investigated in each experiment, hence several different variables were being manipulated or varied at the same time. In a controlled experiment, only one variable should be changed at a time to determine how that variable affects a reaction. In the video, some experiments are done where only one variable is changed at a time, namely one of the reactants.

Discuss how the atomic structure of an element changes when reading down a group in the periodic table. Focus on some elements in Group 1 (lithium, sodium and potassium) and representative halogens in Group 17 (fluorine, bromine, chlorine and iodine). These are some of the elements examined in the video. Discuss how differences in the number and distribution of electrons surrounding the nucleus may determine how reactive the elements are. Make a chart on the board with two columns, one labeled Group 1 "Alkali metals" and the other Group 17 "Halogens." Enter the names of the elements in boxes beneath each heading and have students describe the atomic structure for each element. Leave enough space in each box to enter some observations and conclusions that the students will make after viewing the video.

CONTENT OF THE VIDEO:

The video contains the following key concepts. To play only concepts 2 or 3, fast forward to its title.

	running time min:sec
1.Highly Reactive Metals, Group 1, Periodic Table	**3:40**
2. Highly Reactive Halogens, Group 17, Periodic Table	**4:40**
3. The Range of Reactivity Among Metals	**5:25**

The concepts are illustrated with imaginative demonstrations, which are too dangerous, costly, or complicated to be done in the classroom. Computer animation, graphics, positioned captions, and live photography clarify and provide context for the concepts.

1. Highly Reactive Metals, Group 1

Lithium, sodium, and potassium are so reactive, they are stored immersed in oil. All are so soft they can be cut with a knife, and when exposed to air, quickly react with oxygen. The degree of softness and speed of reaction increases from lithium to potassium. The reaction of the three with water, is tested. All immediately produce a gas, which tests as hydrogen, and again the most reactive is potassium. The universal indicator shows the resulting solution in all three reactions to be alkaline. Formulas of the interactions are shown. The positions of the three on the Periodic Table, Group 1, shows that the more reactive, the lower the position. Rubidium and caesium are elements below potassium. How reactive would you expect them to be?

2. Highly Reactive Halogens, Group 17

Iodine, bromine, chlorine, and fluorine are so reactive they are not found as free elements in nature. Fluorine is commonly found as calcium fluoride crystals in the rock fluorspar, chlorine as sodium chloride - salt, and bromine and iodine compounds in salt water. Fluorine is too dangerous to handle, The reactivity of the other three elements is tested with the metal iron, as iron wool. Heating iodine crystals in the bottom of a test tube (with a fume hood), creates a vapor. Even strongly heating the iron wool in the upper part of the tube produces a limited reaction, coating only a small amount of iron wool with iron oxide. Bromine in the same experiment, immediately vaporizes, and the with less heating, the iron wool visibly reacts. Iron bromide and unreacted bromine, pour out of the tube. In Group 17, bromine is above iodine, and is more reactive, Chlorine is above bromine, so how reactive will it be? An apparatus allows concentrated hydrochloric acid to drip onto potassium permanganate, which generates chlorine gas. The gas passes through iron wool, where the slightest application of heat initiates a violent reaction, releasing clouds of yellow iron chloride. The halogens also react with aluminum, as aluminum foil. Chlorine reacts violently forming aluminum chloride; and bromine briskly to form aluminum bromide. Iodine and aluminum powder react once a drop of water is added.

The Range of Reactivity Among Metals

Reactivity among metals ranges from the unreactive, such as silver and gold, to the dangerously reactive, such as potassium. The reactivity of four metals strips are tested by placing them in a lead nitrate solution: silver, copper, magnesium, and zinc. Only magnesium and zinc react by displacing lead from the solution, and becoming coated with lead. Which of these two is the most reactive? Zinc placed in a magnesium solution has no reaction, but magnesium in a zinc solution reacts instantly displacing zinc in solution. Which is the least reactive? Silver in a copper solution doesn't react, but copper in a silver solution does, depositing crystals of silver on the copper. So silver is the least reactive, and magnesium the most. Chemical reactions measure reactivity. Zinc mixed with copper oxide and heated yields yellow zinc oxide. The solid residue, immersed in dilute acid, reveals pure copper. Because zinc reacted with the oxygen in copper oxide, leaving copper, zinc is more reactive than copper. Aluminum is a another reactive metal, whose reaction with iron oxide releases enormous energy. The heat needed to initiate a reaction between aluminum and iron oxide, is provided by the addition of, and reaction between, potassium permanganate and glycerol. Thus heated, aluminum violently reacts with the oxygen in iron oxide, leaving pure iron behind. This reaction is so effective, that on railroad tracks it is used to melt and pour pure iron between iron rails to weld them together.

AFTER SHOWING THE VIDEO:

Use the chart created on the chalkboard before showing the video to consolidate what students learned from the video. Invite the students to suggest which element in each group was most reactive and which least reactive. Also, encourage them to describe the events or evidence shown in the video to indicate that a reaction was taking place and how reactive the element was. Where possible, try to explain the differences in reactivity in relation to atomic structure. Explore with the students why the most reactive alkali metals are lower down in group 1 while the most reactive halogens are higher up in group 17. Discuss with them the differences in reactivity of other metals as shown in the latter part of the video and what aspects of their atomic structure as indicated by their position in the periodic chart may account for differences in reactivity.

EXPLORING AND INVESTIGATING:

You may extend student explorations by finding out how heat influences the rate of a reaction. How does heat affect the rate of copper deposition on the iron nails? The 0.01 M copper sulfate solution in the test tube can be heated to near boiling using a flame before adding the nail . The time required for blackening of the nail with copper deposit can be compared to the rate of copper deposition in the same solution at room temperature. The increased rate of deposition of copper can be compared to the heating of the steel wool in the video experiments. What is the role of heat and its consequences in the video experiments and in the students' experiments?

How does the concentration of copper sulfate affect the rate of reaction with the nails? This can be investigated by using different concentrations of copper sulfate solution (e.g., 0.01, 0.005, and 0.001) and observing how long it takes for the nails to become equally darkened with copper deposit in each solution. The time varies from about one minute to 2 to 3 minutes.

Caution: observe all safety regulations of your school when doing experiments in the laboratory. Check with the appropriate officer in your school before doing these experiments.

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