KENAN FELLOWS PROGRAM FOR TEACHER LEADERSHIP NC STATE

Journal of Interdisciplinary Teacher Leadership 2023, Vol. 7, No. 1, pp. 1-27

Call Me Mendeleev: A Middle Grades Science Lesson on the Periodic Properties of Elements

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Each year, in middle and high school classrooms, secondary science teachers introduce their students to the periodic table of elements (herein the periodic table). According to the Next Generation Science Standards (NGSS Lead States, 2013), one of the performance expectations states that high school students should be able to, "Use the periodic table as a model to predict the relative properties of elements based on the patterns of electrons in the outermost energy levels." Thus, building an understanding of how elements vary in properties is foundational knowledge for middle grades science students.

As college science educators, we cringe when our students, in-service and pre-service teachers (PST's), recount the horrors of memorizing element names, symbols, atomic weights, and numbers in high school chemistry. To support a better approach to teaching this content so that middle grades students build important foundational knowledge and appreciate the usefulness of the periodic table, we worked with our colleague, an experienced middle grades science teacher, to teach an eighth-grade science lesson using an inquiry-based approach. In this paper, we provide context around the importance of having middle grades students participate in the scientific practices of evaluating data and model-building, just as Dimitri Mendeleev and his contemporaries did. Having students use data on elemental properties to find patterns helps them develop their understanding of the nature of scientific discovery as well as aid in their comprehension of the periodicity of elements. Middle grades students are rarely engaged in the

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process of scientific model-building (Schwarz et al., 2009). Involving learners in model development leads to deeper understanding of key models in science and the nature of disciplinary knowledge in science (Lehrer & Schauble, 2007). By explaining this novel lesson, we evidence how this activity engaged students in the practices of scientists as they learned about this fundamental model.

Background

Despite periodicity of elements being a middle and high school science concept, we have noted deficits in understanding among our PST's. Many factors have been shown to lead to students' lack of comprehension. Due to periodicity being an abstract concept (Agustin et al., 2017), students need but may not have had concrete experiences to develop their understandings. Additionally, their knowledge of elemental properties is insufficient to be able to identify patterns in properties (Goh & Chia, 1989). The two-dimensional periodic table "fails" to support science teachers in helping students comprehend the usefulness of this tool unless students are provided opportunities for them to discover for themselves how its arrangement reflects elemental properties (Goh & Chia, 1989).

We discussed our PSTs' issues with our colleague at the middle school level. As she shared her experiences teaching elemental properties, our colleague admitted her recurring struggles helping students grasp how changes in atomic structure result in these different properties. We asked ourselves, what foundational knowledge of the periodic table do students need? Rather than a static two-dimensional chart, how could this document come alive to them by engaging them in scientific practices? How could we help middle grades students build the proper foundation to support their understanding of the periodic table in high school, college and beyond?

The result of this thoughtful reflection is the lesson detailed here. In this lesson, students were challenged to think like scientists, just like Mendeleev and chemists had before and after him by considering a single guiding question: how are elemental substances related to one another? As middle grades students analyzed the information provided about groups of elements on the periodic table, they were tasked to identify patterns among elements and ultimately develop explanations to support an organizational system of elements using their own design. Just as Mendeleev challenged himself to arrange the elements based on their behaviors, students created a model that reflects similarities in elemental properties by comparing provided data.

Lesson Plan

This lesson was taught in an eighth-grade classroom in rural Southeastern United States. School demographics suggest that 100% of students qualified for free or reduced lunch. Black and Latino students represented 80% of the school population. Prior to this lesson, students had learned that matter is composed of atoms, unique forms of which are called elements. To acquire that knowledge, they engaged in activities in which they explored different properties of materials. Understanding properties of materials is essential so that students understand the uniqueness of each element but also recognize that certain properties are shared by multiple elements.

Standards Alignment

The presented lesson supported student understanding of *NGSS* Physical Science disciplinary core idea MS-PS1.A, "Each pure substance has characteristic physical and chemical properties.…that can be used to identify it" (2013). The lesson used the 5E format (Bybee et al., 2006) to engage students in hands-on, minds-on activities to scaffold learning prior to teacher explanation. In the Explore phase, students engaged in the specific scientific practices encouraged by the *Next Generation Science Standards* (2013) of analyzing and interpreting data and creating and using models.

Preparation

Prior to this lesson, the teacher prepared the following materials:

1. Made two or three copies (depending on the total number of students in the class periods) of the Periodic Table Pyramids Template and assembled them into pyramids (see Appendix A).
2. Prepared two or three sets of four-quart plastic bins labeled A, B, and C. Each bin contained three specific four-sided pyramids, glue, and scissors. Note that students *were NOT informed of the group numbers or names within each bin.*
   i. Bin A contained the pyramids representing Groups 1, 2 and 3-12 (alkali, alkaline earth, and transition metals).
   ii. Bin B had pyramids representing Groups 14, 15 and 16.
   iii. Bin C contained Groups 13, 17 and 18.
3. Copied one set of Blank Trend Cards per group (see Appendix B).
4. Gathered enough colored paper for each group to have one sheet.
5. Copied Mendeleev's Trends Cards, enough for one set per group (see Appendix C).

Engage (10 minutes)

To begin this lesson, the teacher asked if students are required to clean their bedrooms and what the 'dreaded task' of bedroom cleaning entailed for them? As a class, we discussed why we as humans organize the stuff in our lives. In groups, students considered items that

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people organize (e.g., clothing, library books, MLB leagues and teams, etc.) and shared with the whole class. We reintroduced the definition of "element" and how 92 naturally occurring elements make up all our everyday materials. We noted that, as humans are prone to do, we organize materials to help us make sense of them.

Explore (30-40 minutes)

In this step, we introduced Dmitri Mendeleev, the father of our modern periodic table with a discussion. We explained in 1869, Mendeleev, a Russian scientist, was working under pressure and facing a deadline to complete the second volume of his chemistry textbook. Students were challenged to imagine how Mendeleev responded to the 56 known elements being 'dumped' in his lap as he faced the task of organizing them. What properties of the elements would he consider as important and why? Was there one "right" way to organize them? As he prepared the manuscript, he revisited the known elements. He tried different organizational schemes but was dissatisfied until he tried something new that led him to organize them into a table that made sense (Baralew, 2019). We discussed then how the process of trial and error he engaged in reflects the nature of science.

Just as Mendeleev had before them, students worked with their small groups to organize a set of elements based upon a chosen 'feature' of the elements themselves. To begin, each group was given one set of nine blank trend cards. The students were then provided with a bin containing three pyramids; each pyramid displayed information about certain elements. Unknown to the students, each pyramid represented a specific group on the periodic table. Students were instructed that they had three and a half minutes to analyze the information provided on the three pyramids, decide what data might help them organize their elements, and record that information onto the trend cards. *Teachers may want to use*

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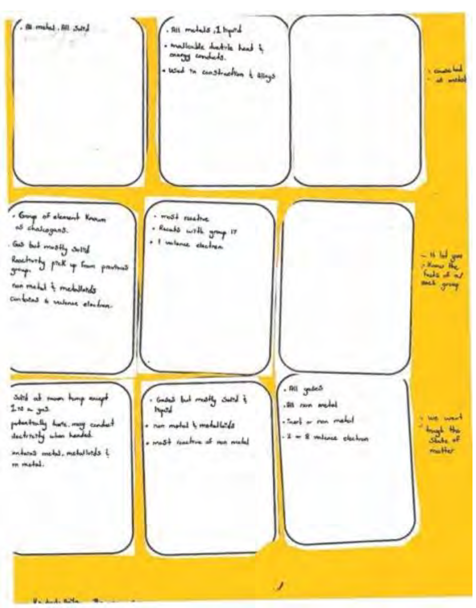
discretion when setting these time limits; classes may require additional time to record observations, especially with the first bin (A). We instructed students to think like Mendeleev and to record the most pertinent information and be attentive to the clock. An online timer was displayed on the screen, and the countdown began.

As students accumulated data, they were encouraged to compare information within their groups to identify trends and patterns. At the buzzer, bins were moved to another table. Once the bin left their group, students only had access to the information that they had recorded. The data and comparison step with bin A was repeated twice more with bins B and C respectively. Once groups had access to all three bins, students had 10 minutes to analyze their collected data. Data included nine different pyramids and nine trend cards. If students were unable to record information on all nine pyramids, that was okay; however, the teacher advised them to hold onto those empty cards and to consider how they might incorporate missing data into their models. Students were then instructed to cut out their trend cards. We distributed colored paper to provide contrast and instructed students to organize their cards to reflect the trends they recognized (Figure 1).

Figure 1. *Example of Student Arrangement of Trend Cards*



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Students were encouraged to act like scientists by reflecting on their data, looking for relationships and patterns, and using that information to create a model. Students were also encouraged to discuss with their peers how to use the data to organize the elements into a model reflecting these relationships. We circulated, asking students to explain their models and justify their choices using their collected data. We reminded them that there was not one correct answer or model, as organizational models are human constructs. Although not inherently imperfect, models possess strengths and weaknesses. Consider map projections, for example, which take a three-dimensional model and make it two-dimensional. In this process, distortions occur. When students decided on a model that best reflected relationships among the groups, they glued the trend cards on the colored sheet and explained beneath them the rationale behind their organizational structure.

Explain (30-40 minutes)

During this portion of the lesson, each group shared their models and justifications for the models using their data. First, we asked students to share trends that they observed during data collection and analysis. Was there information that they gathered that was not particularly helpful? Why was some data more beneficial? What information helped them organize the materials, and how did they come to consensus on an organizational structure? Collected group responses were placed on the board (see sample of responses in Figure 2).

Figure 2. *Sample of Collected Group Responses During Explain Phase*

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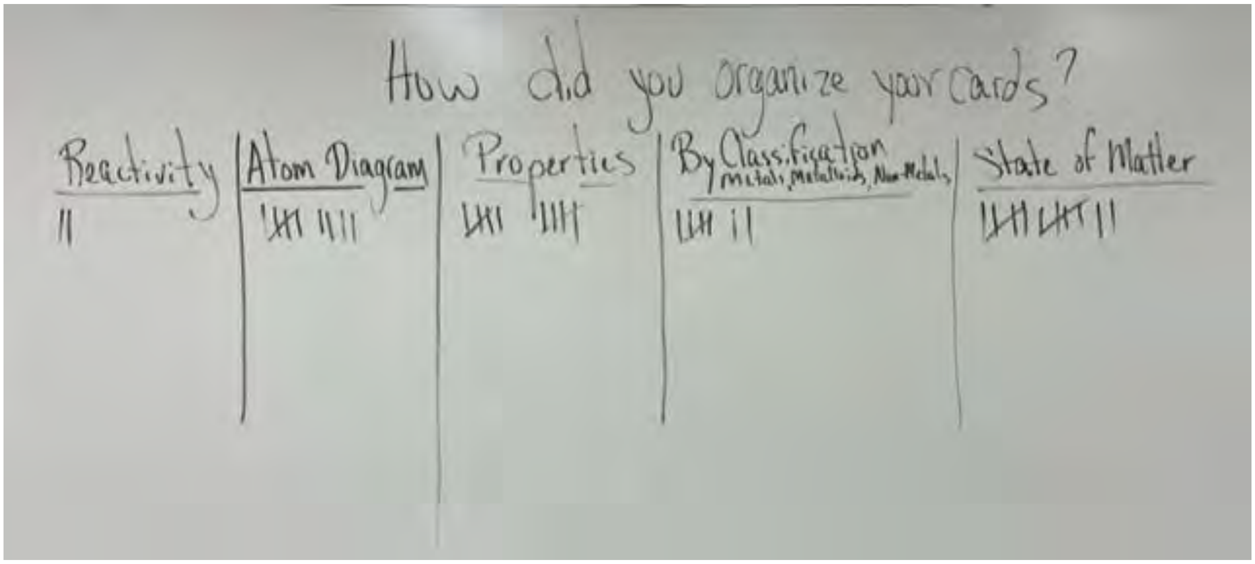

Some groups noted how reactivity varied and organized their model from least to most reactive. Another group selected a model based on metallic and non-metallic properties. As groups shared their models of organizational structures, groups were encouraged to constructively critique the viability of their peers' rationales and were required to accompany each critique with empirical data rather than opinion. Finally, we asked students that if after seeing their peers' models, they would revise their own or how this new information (data) affirmed or refuted their model.

We asked students how they felt when faced with this task. What frustrations did they experience? Do they think Mendeleev might have felt this way? We discussed and recorded how engaging in this process reflected the various ways that scientists do their work. We reiterated the scientific practices of analyzing and interpreting data and obtaining, evaluating, and communicating information (within their group) to develop and use a model. Additionally, students constructed explanations to justify their rationale to their peers (within the greater community). We discussed how these practices reflect how a scientist like Mendeleev worked when faced with this same basic task, even though he did not have all the information they had, like atomic structure, for example. We emphasized how our work reflected the main tenets of the nature of science such as the use of models, the tentative nature of scientific knowledge, that science knowledge assumes an order and consistency in natural systems, that science is a human endeavor, and how science addresses questions about the natural and material world (NSTA, 2020).

We engaged in a discussion about how many scientists had attempted to design models prior to Mendeleev and explained that he did something no one else before him had done. The pattern in the elements' chemical properties led him to leave some spaces within his model. He predicted properties of 'missing' elements based on his model, including attributes like their states of matter and how reactive they would be. We explained that the validity of his model was affirmed when these elements were later discovered, and their properties matched his predictions. We discussed with the students how their missing information (should they not have had time to record all nine cards) related to the gaps in Mendeleev's original periodic table.

Elaborate (10-15 minutes)

Following the discussion, we played a short clip (30 seconds) of *The New Periodic Table Song (Updated)* by ASAP Science (2018). The video included a song and visually displayed the elements, showing their placement on the periodic table. This video was selected because it was engaging and used every day, relevant objects to represent each element. The video provided another opportunity to showcase the periodic table beyond a two-dimensional image. We instructed students to pay special attention to the characteristics of the elements in the video and the organizational structure of the periodic table. They were provided with a periodic table (NCDPI, 2009) and were encouraged to notice patterns as they listened to the descriptions of elements 1-18. At first students did not see patterns. It was not until they had recorded helium, neon and argon as being gases that gave off light that they noticed a pattern. It is at this point students were introduced to the concept that groups were organized by characteristic properties like an element's reactivity. Referring to the modern-day periodic table, we briefly discussed the rationale behind Mendeleev's arrangement.

At this point in the lesson, each group received a deck of "Mendeleev's Cards," representing the modern-day periodic table (see Appendix C). These cards contained information from the pyramids used in the Explore portion of the activity plus information on physical and chemical properties previously excluded. These new cards represented the nine different groups of the periodic table. Students were instructed to organize the cards based on our current periodic table. Students also recorded responses to two questions on this sheet which the teacher used to assess student learning:

- How is the periodic table organized to help us understand the relationships among elements?
- How did this activity reflect the nature and practices of science?

Evaluate (15 minutes)

As we reviewed students' responses to the above questions, we looked for explanations which included that the current periodic table was organized using the periodic repetition of properties and that these properties were determined by the atomic structure of the elements. Within students' reflections we noted if they were able to describe how scientists observed elements, compared their properties looking for patterns and used trial and error as they developed their models. Students were able to compare their models in this activity and observe

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how the models had become more sophisticated through their increased knowledge of atomic structure. We concluded with a discussion of how our current periodic table compared to earlier models and the models they created.

Conclusion

The purpose of this lesson was to engage students in the practices of scientists by enhancing their understanding and appreciation of the periodic table. As scientists recognize that visual representations like the periodic table help us organize matter and understand relationships, students developed their own periodic table model by collecting data on elements, used observations to discern patterns, and discussed to referee ideas for a model of the elements. The initial development and subsequent evolution of the periodic table as context demonstrated to students the tentative nature of science. As scientists discovered more elements and learned more about atomic structure, their new knowledge informed the design of the table. Rather than asking students to memorize the statistics on the table, students were challenged to think and do using established scientific processes. After implementing this activity, our colleague noted overwhelmingly that students better understood the periodic table, its evolution and how it helps us organize the stuff of our world.

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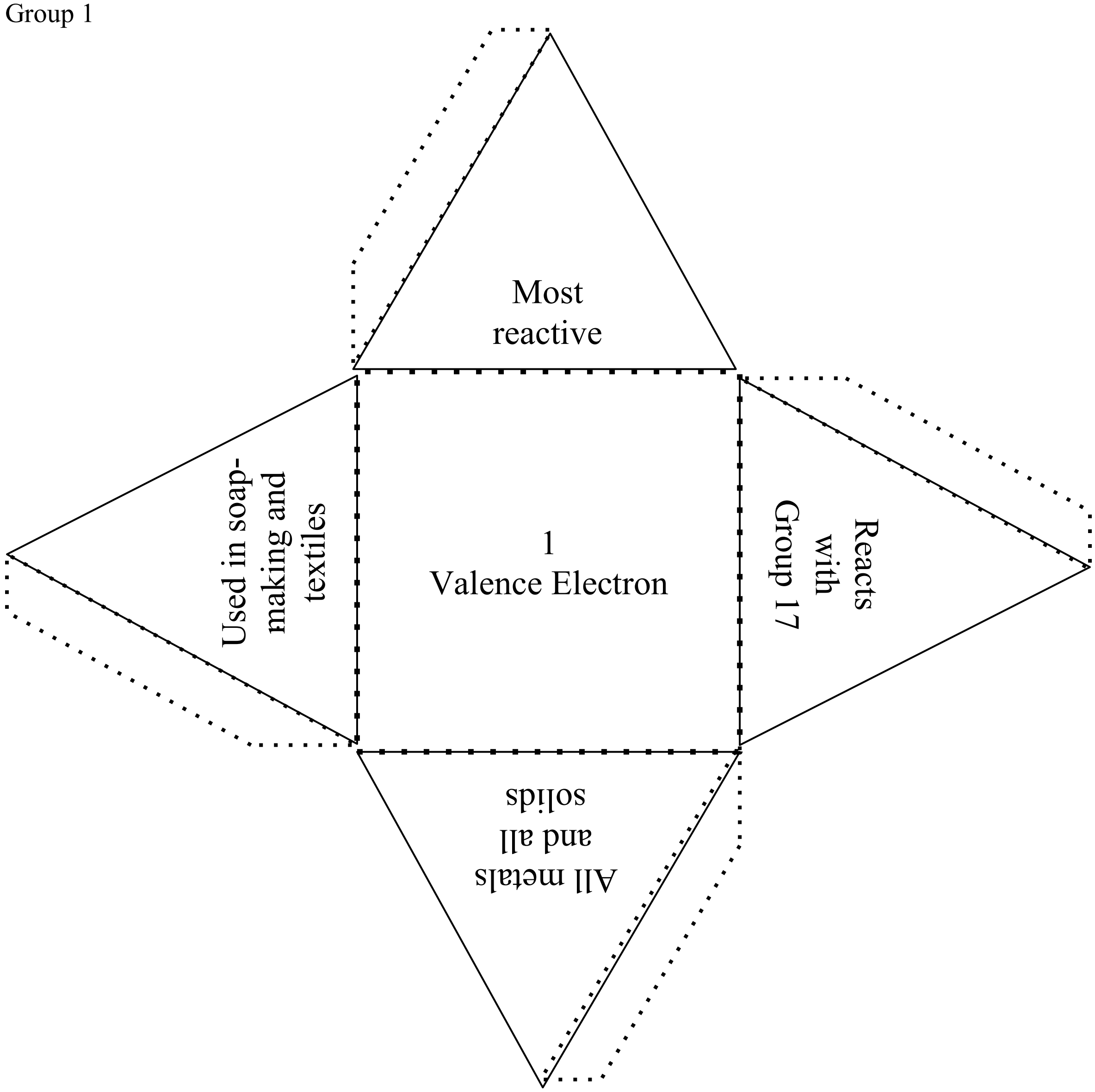
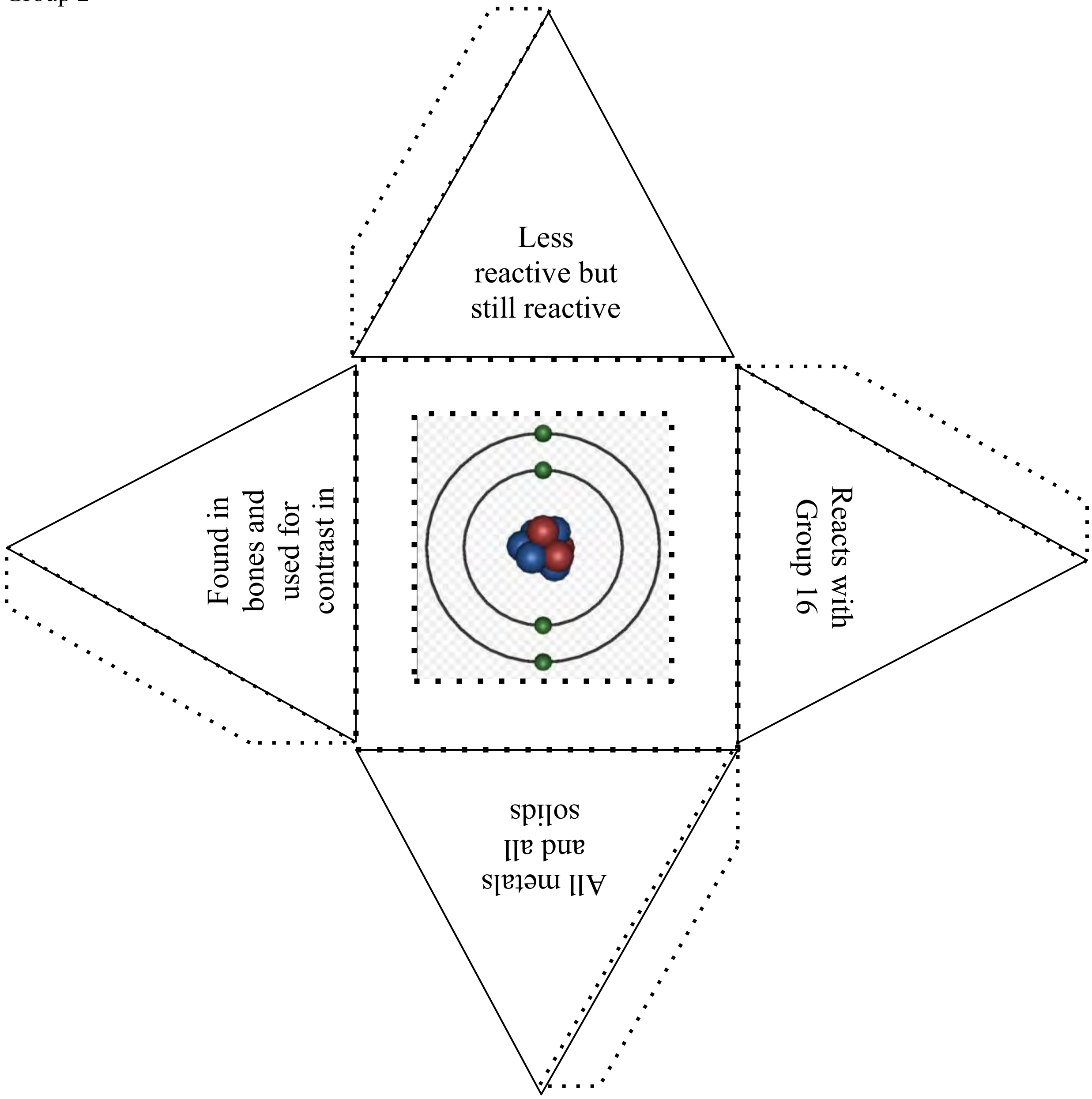
Appendix A Periodic Table Pyramids Template

Group 1



Group 2


Less reactive but still reactive
Found in bones and used for contrast in
Reacts with Group 16
All metals and all solids

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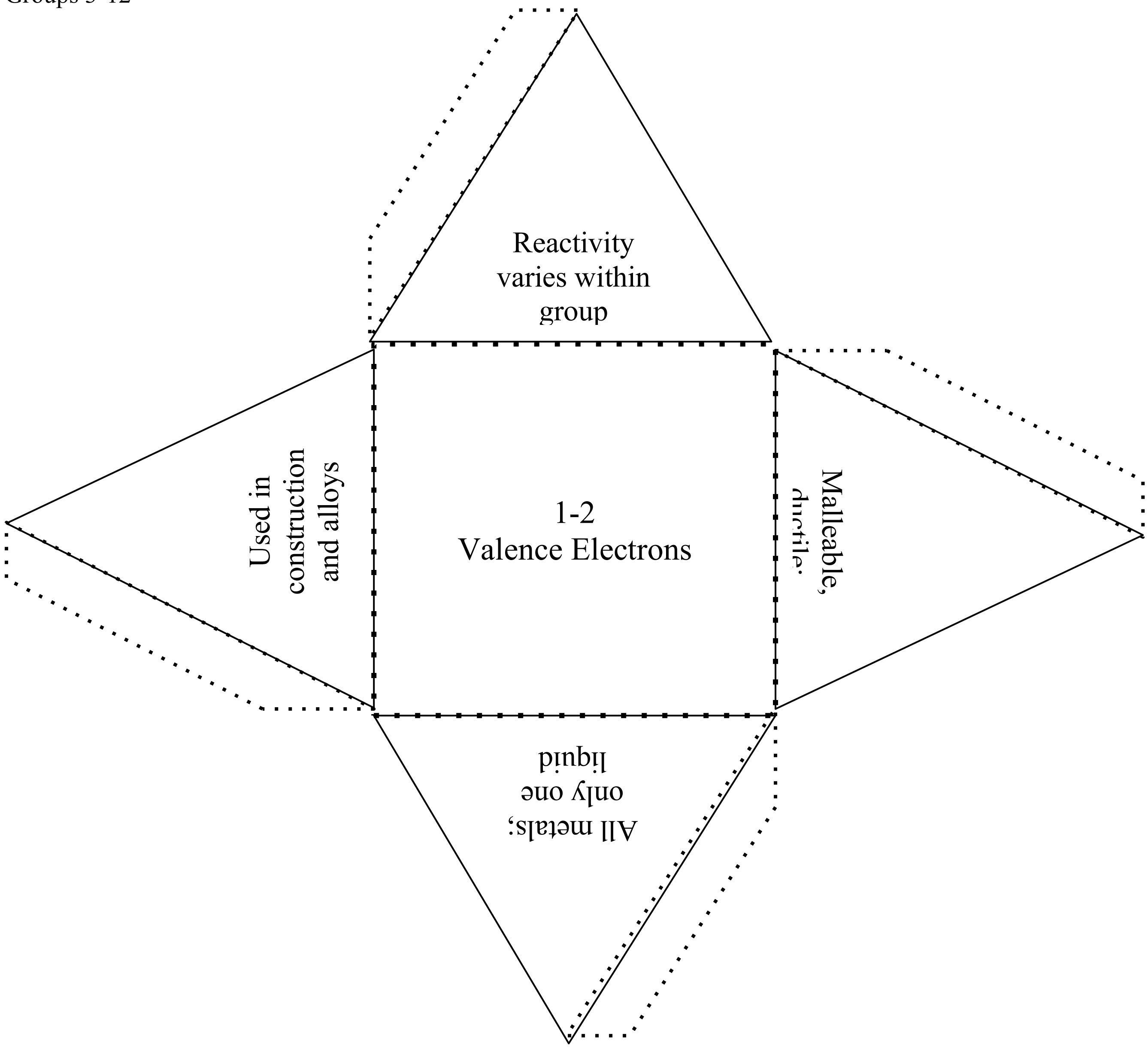
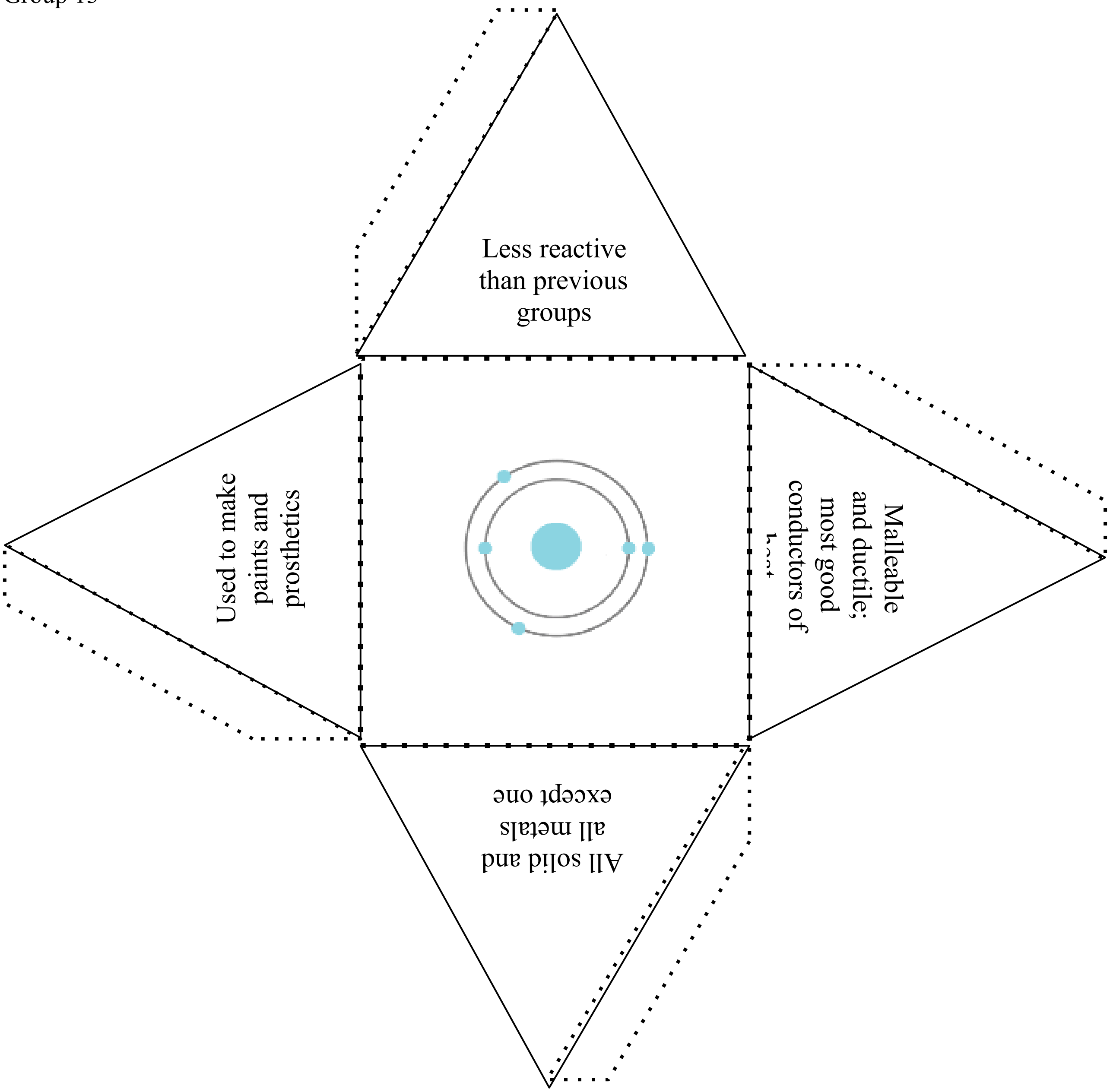
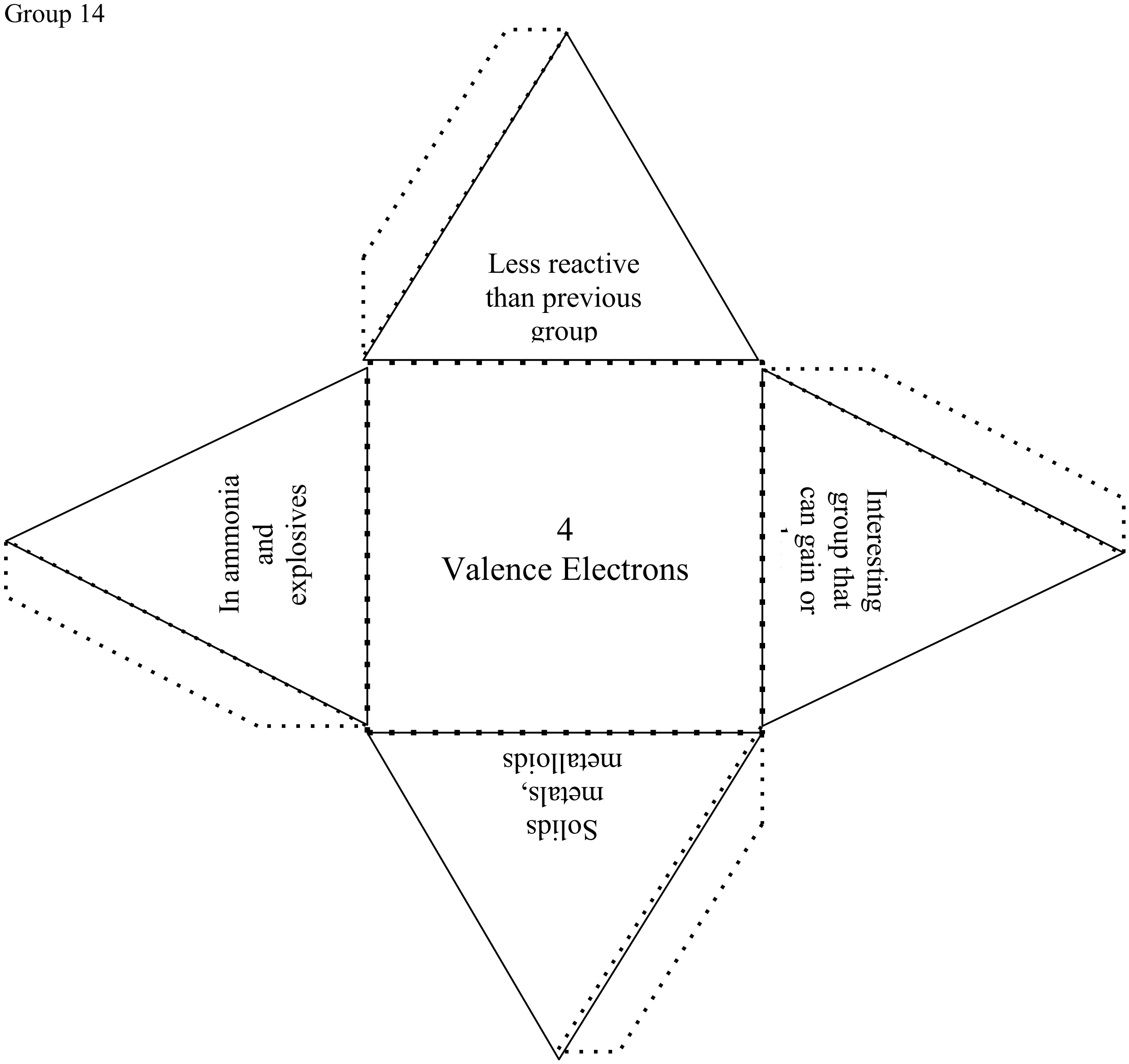
Groups 3-12



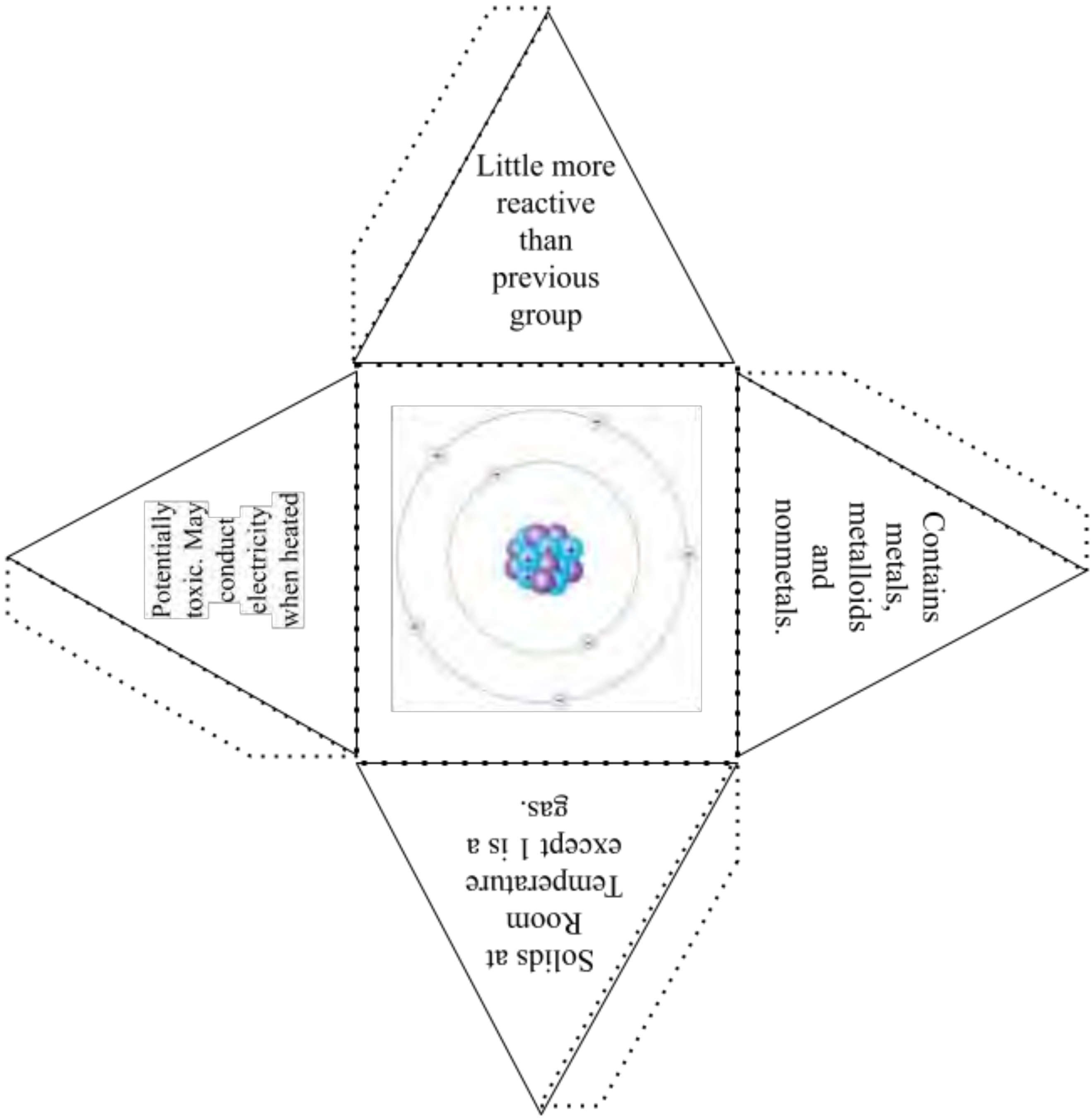
Group 13


Less reactive than previous groups
Used to make paints and prosthetics
Malleable and ductile; most good conductors of heat
All solid and all metals except one

Group 14

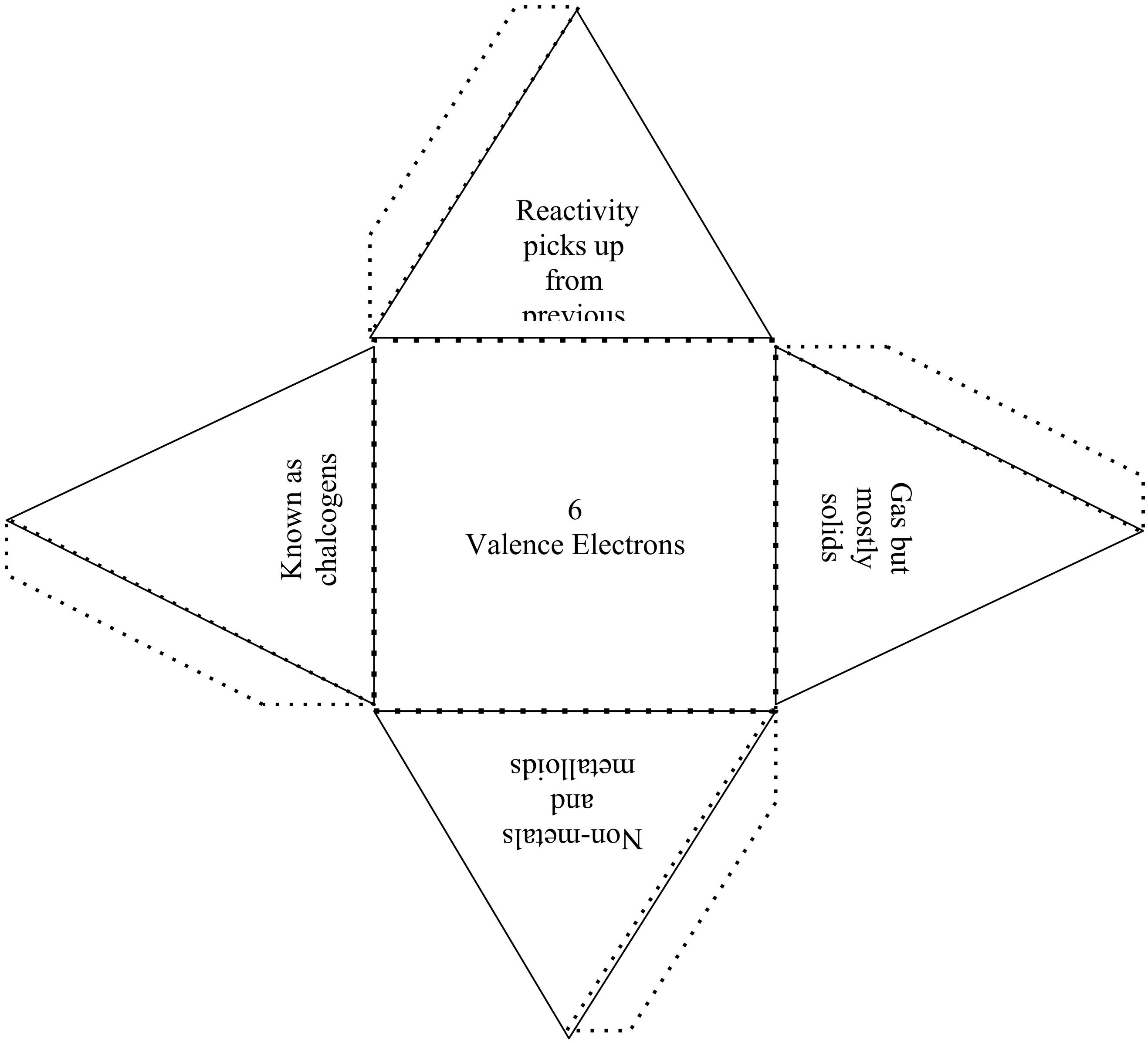

Less reactive
than previous
group
4
Valence Electrons
In ammonia
and
explosives
Interesting
group that
can gain or
Solids
metals,
metalloids

Group 15

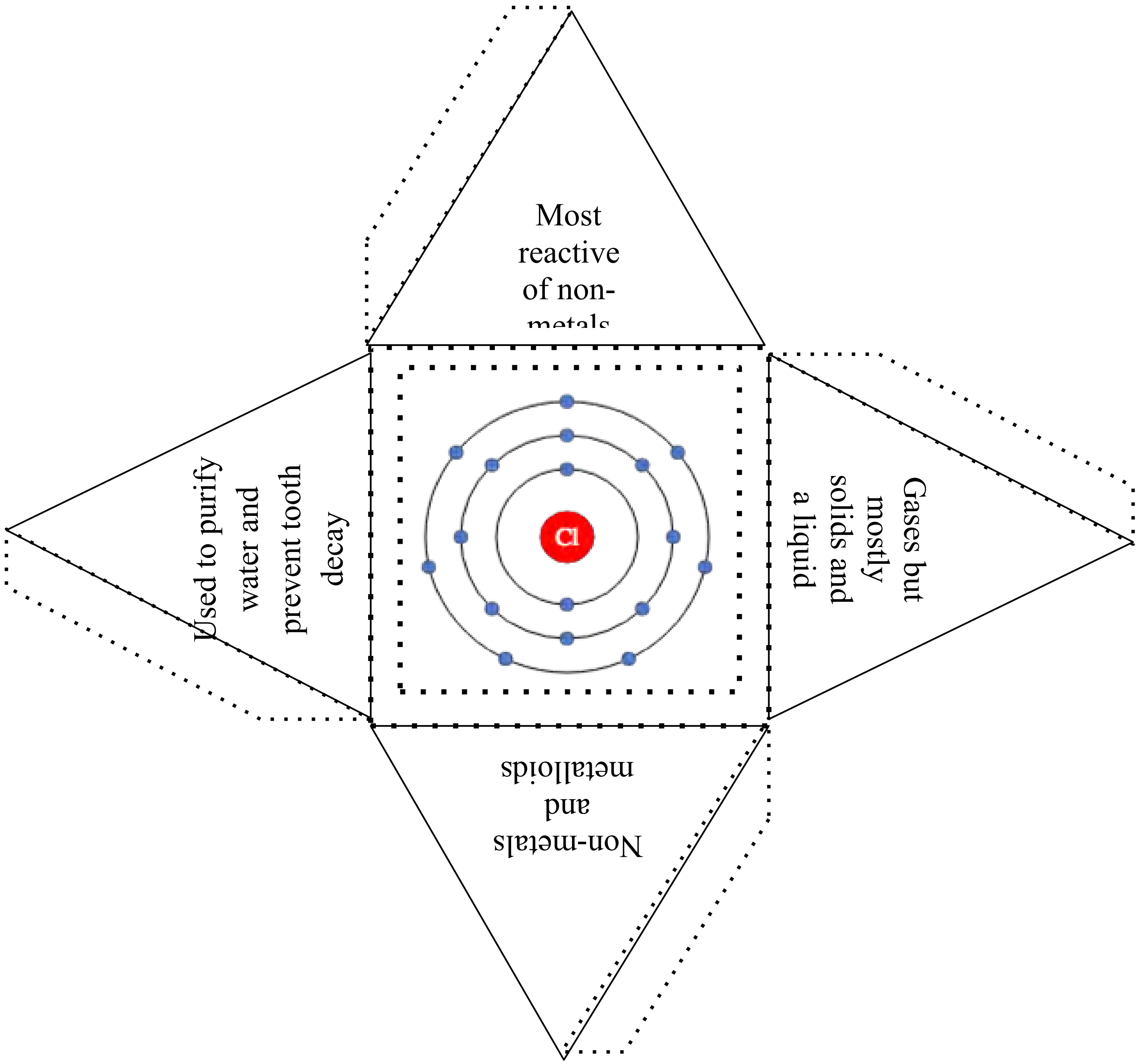


Little more reactive than previous group
Potentially toxic. May conduct electricity when heated
Contains metals, metalloids and nonmetals.
Solids at Room Temperature except 1 is a gas.

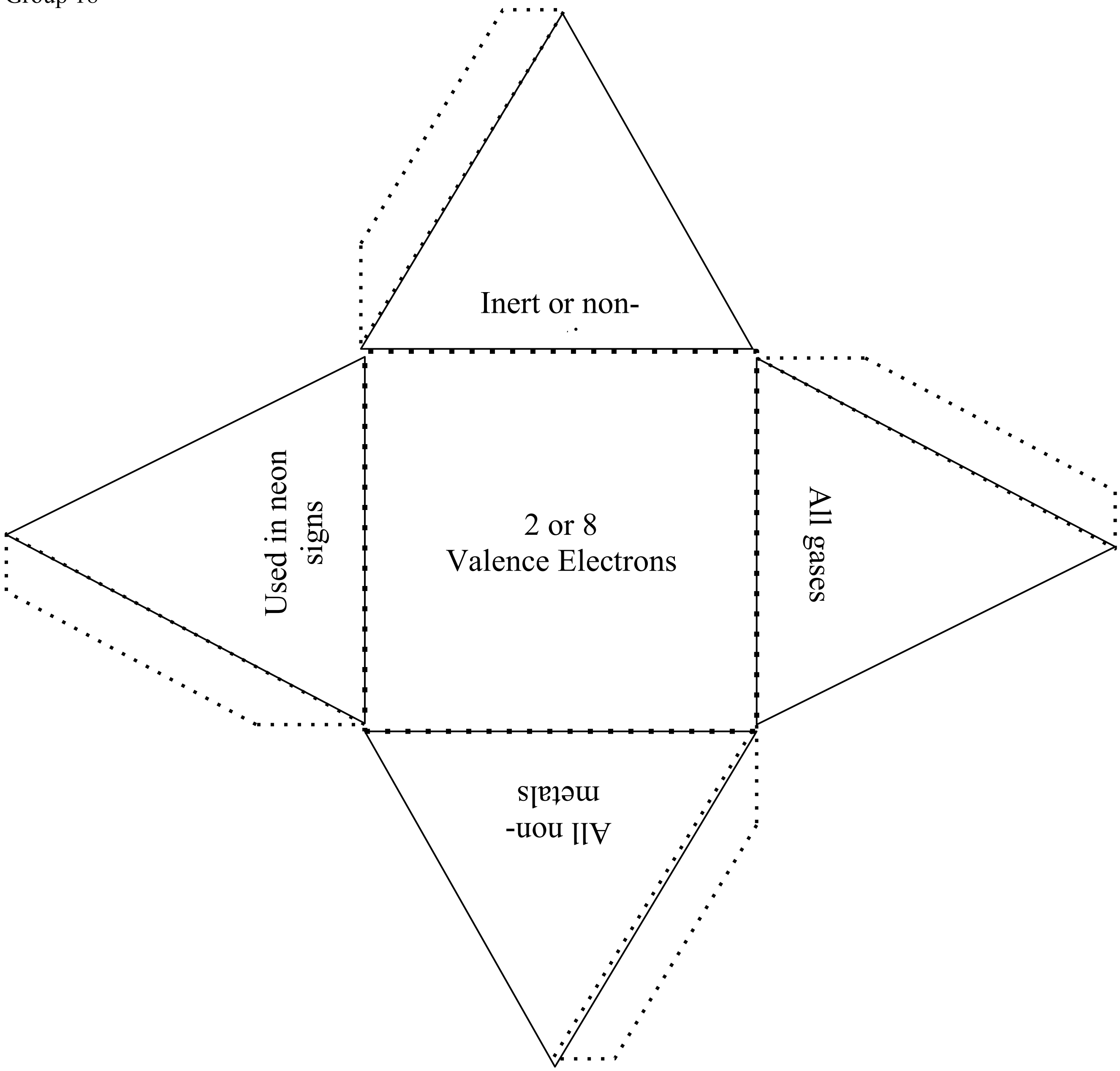
Group 16


Reactivity
picks up
from
previous
6
Valence Electrons
Known as
chalcogens
Gas but
mostly
solids
Non-metals
and
metalloids

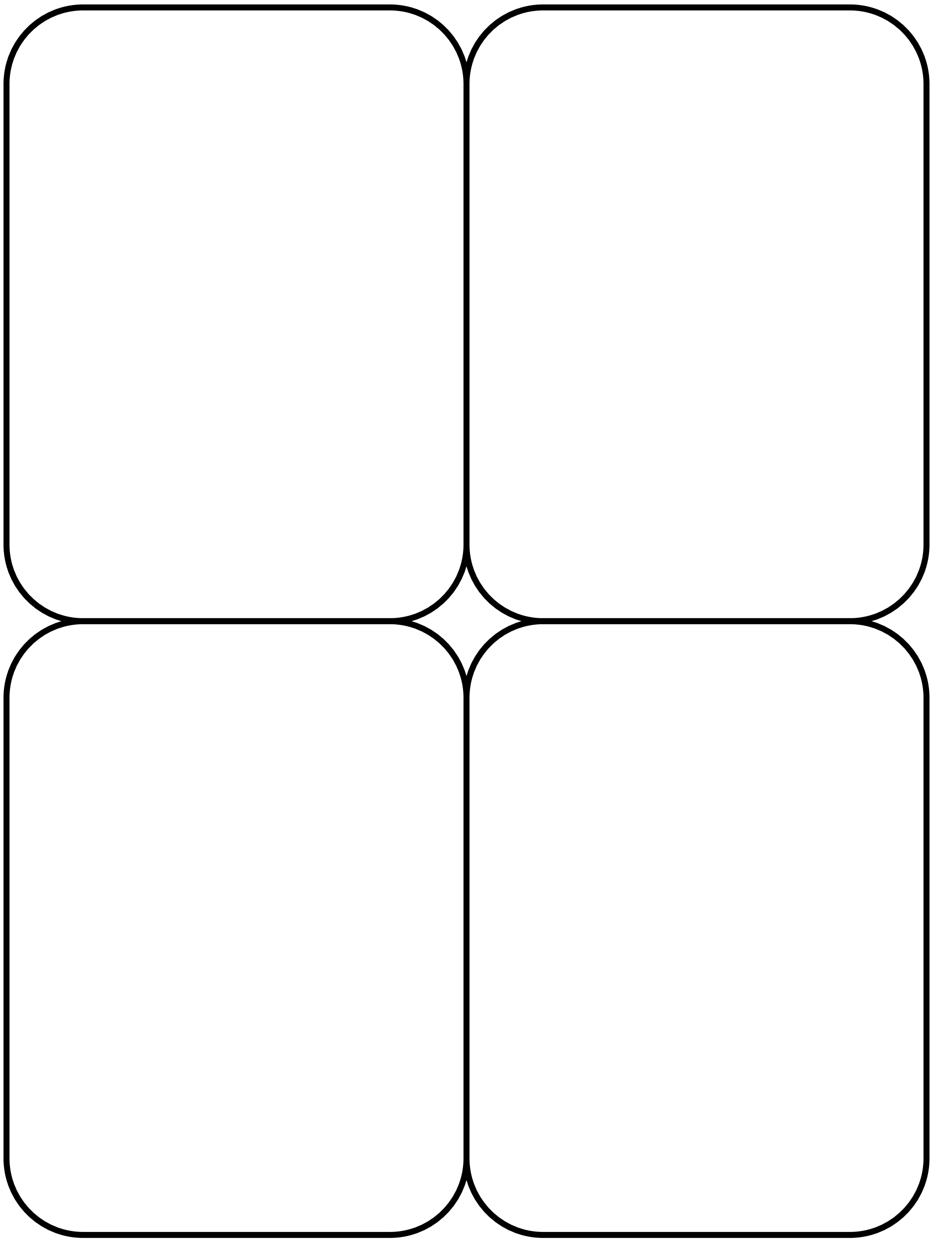
Group 17

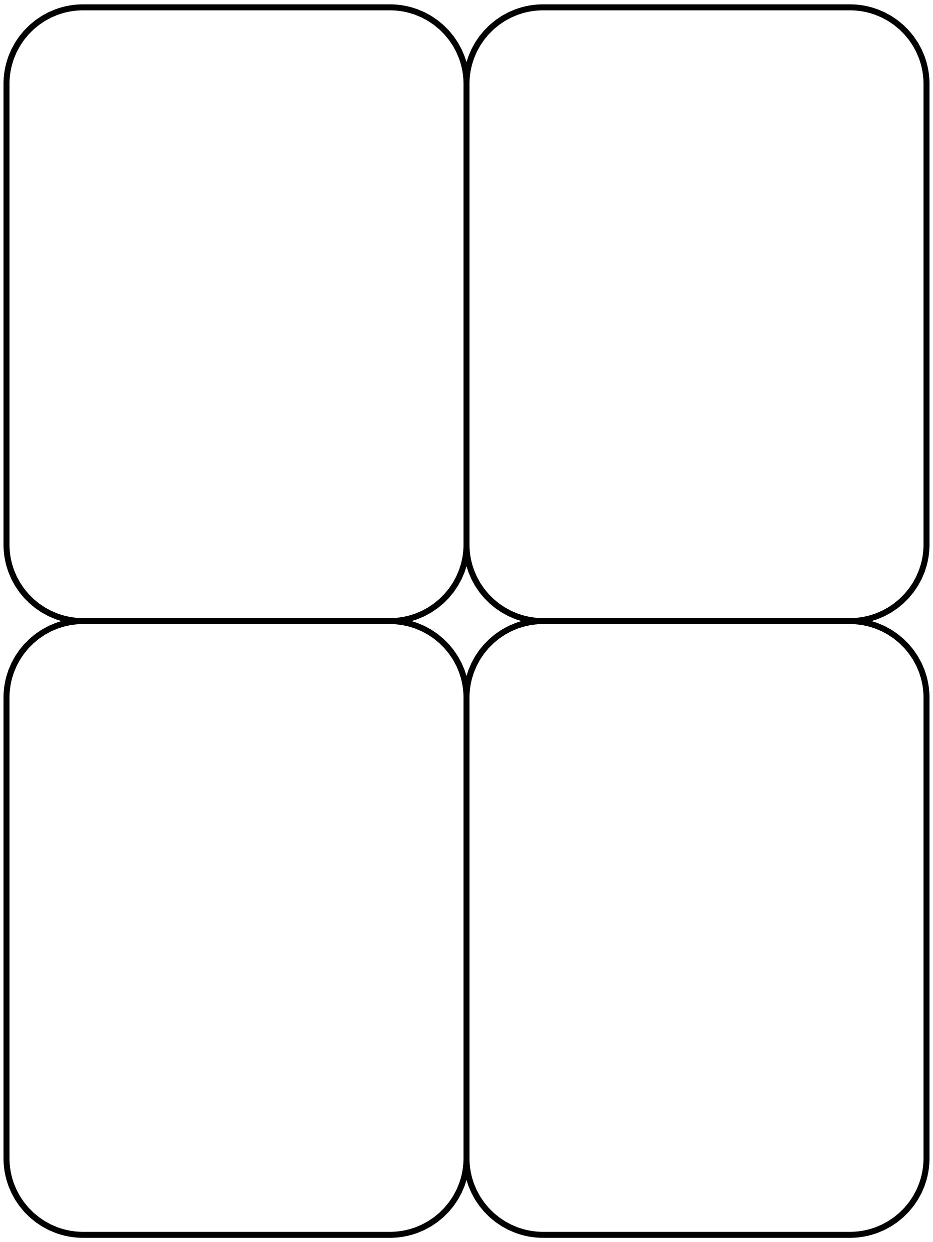

Most reactive of non-metals
Used to purify water and prevent tooth decay
Cl
Gases but mostly solids and a liquid
Non-metals and metalloids

Group 18


Inert or non-
Used in neon signs
2 or 8
Valence Electrons
All gases
All non-metals

Appendix B Blank Trend Cards





Appendix C Mendeleev's Trends Cards

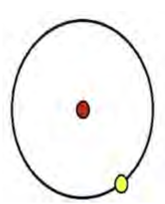
Group 1

1 Valence Electrons

Most Reactive of the Periodic Table

Reacts with those in Group 17

soft, shiny, low-melting, highly reactive metals, which tarnish when exposed to air



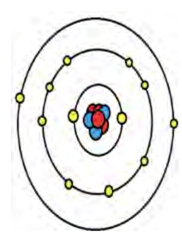
Group 2

2 Valence Electrons

Less Reactive than Group 1

Reacts with those in Group 16

form oxides when reacting with air, leading to a dull appearance in pure form



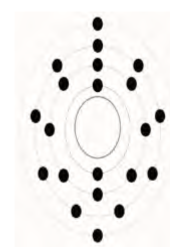
Group 3-12

1-2 Valence Electrons

Reactivity Varies

Less Reactive than Group 2

don't react quickly with water or oxygen, which explains why they resist corrosion



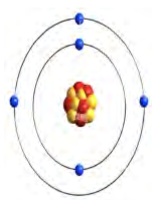
Group 13

3 Valence Electrons

Reactivity increases down the group

High Reactivity towards Oxygen

Good electrical and thermal conductors.



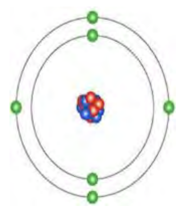
Group 14

4 Valence Electrons

Reactivity decreases down the group

All React with Oxygen on heating

Important Family for semiconductor technology



Group 15

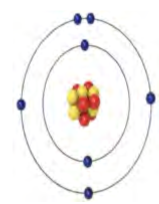
5 Valence Electrons

Reactivity decreases down the group

Metallic Character increases down the group

Different elements act like Metals, Metalloids and Nonmetals

form



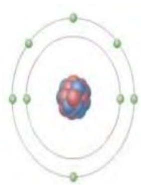
Group 16

6 Valence Electrons

Reactivity decreases from heaviest to lightest

Stable Metallic Group

Important Groups for living organisms and Industry



Group 17

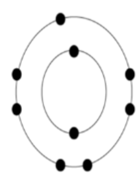
7 Valence Electrons

Most Reactive Nonmetals

Reacts with those in Group 1

Forms salts when reacting with a metal

Exist in a variety of states at room temperature



Group 18

2 or 8 Valence Electrons

Non Reactive/Inert Group

odorless, colorless, nonflammable, and monatomic gases that have low chemical reactivity

Stable configuration