

**Teacher’s Guide**

**The Measure of a Mole**

***October 2019***

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Activate students’ prior knowledge and engage them before they read the article.

[Reading Comprehension Questions](#_Student_Reading_Comprehension) 3

These questions are designed to help students read the article (and graphics) carefully. They can help the teacher assess how well students understand the content and help direct the need for follow-up discussions and/or activities. You’ll find the questions ordered in increasing difficulty.

[Graphic Organizer 5](#_Graphic_Organizer)

Thishelps students locate and analyze information from the article. Students should use their own words and not copy entire sentences from the article. Encourage the use of bullet points.

[Answers 6](#_Answers_to_Reading)

Access the answers to reading comprehension questions and a rubric to assess the graphic organizer.

[Additional Resources 9](#_Additional_Resources_1)

Here you will find additional labs, simulations, lessons, and project ideas that you can use with your students alongside this article.

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# Anticipation Guide

Name: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**Directions: *Before reading the article*,** in the first column, write “A” or “D,” indicating your **A**greement or **D**isagreement with each statement. Complete the activity in the box.

As you read, compare your opinions with information from the article. In the space under each statement, cite information from the article that supports or refutes your original ideas.

|  |  |  |
| --- | --- | --- |
| **Me** | **Text** | **Statement** |
|  |  | 1. The mole is a metric unit used to count things.
 |
|  |  | 1. The mass of a kilogram was set as the mass of an iridium-platinum cylinder (IPK) made in 1889.
 |
|  |  | 1. Today’s definition of a mole is related to carbon-12.
 |
|  |  | 1. A unit cell of silicon has 18 atoms inside.
 |
|  |  | 1. The concept of a mole is based on a fundamental constant of nature (Avogadro’s constant).
 |
|  |  | 1. To simplify the math, Einstein used the Avogadro constant in his doctoral thesis.
 |
|  |  | 1. Natural silicon has only one isotope.
 |
|  |  | 1. The silicon sphere used to determine the Avogadro constant had the same mass as the IPK that defined the kilogram for more than a century.
 |
|  |  | 1. The silicon spheres used to calculate the Avogadro constant in the 21st century required the collaboration of scientists from Russia, Germany, and Australia.
 |
|  |  | 1. The new definition of the kilogram is based on Planck’s constant.
 |

# Student ReadingComprehension Questions

Name: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**Directions**: Use the article to answer the questions below.

1. How many atoms are in 2-dozen atoms? How many molecules are in 1.5-dozen molecules?
2. What physical object was used to define a kilogram before the new system was created?
3. Why is the old definition of a mole related to the definition of a kilogram?
4. Why can’t you work with a single water molecule in your lab?
5. How do you calculate the volume of a cube?
6. What is the difference between 28Si and 29Si?
7. Why did scientists use only one of silicon’s three isotopes to make the new standard sphere?
8. Why is the silicon sphere a better measurement standard than the original IPK?
9. Explain how density is used to calculate the number of atoms in a mole.

**Student Reading Comprehension Questions, cont.**

**Questions for Further Learning**

***Write your answers on another piece of paper if needed.***

1. Pure solids often have well-known structures based on how the atoms or ions are arranged. If the arrangement is orderly and repeating, it is crystalline. If there is no regular or repeating arrangement, it is amorphous.
	1. Research the following allotropes of carbon and classify them as having crystalline or amorphous structure:

|  |  |
| --- | --- |
| **Allotrope** | **Crystalline or Amorphous?** |
| Diamond |  |
| Coal |  |
| Graphite |  |
| Buckminsterfullerene |  |

* 1. Silicon has two allotropes, simply called crystalline silicon and amorphous silicon. Propose a reason that scientists would choose to use silicon instead of carbon when creating an ideal crystal.
1. Many units that are used in science are derived units. That means that they are dependent on two or more of the seven base SI units. Some of these have a special name and others are simply a derivation of the units. When redefining the kilogram, a different method was used to set the standard. This method used an instrument called a watt balance. The watt balance relies on the interrelationships between several of the SI units. The equation used was:

$$UI=ma\_{g}v$$

where *U* = electric potential; *I* = current; *m* = mass; *ag* = gravitational acceleration; and $ v$= velocity.

Using the tables below, show that the units on each side of the equation are equivalent to watts.

**SI Derived Units**

|  |  |  |  |
| --- | --- | --- | --- |
| **Quantity** | **Name** | **Symbol** | **SI units** |
| Energy | Joule | J | $$\frac{kg‧m^{2}}{s^{2}}$$ |
| Power | Watt | W | $$\frac{J}{s}$$ |
| Electric charge | Coulomb | C | A‧s |
| Electric potential | Volts | V | $$\frac{J}{C}$$ |
| Velocity | - | v | $$\frac{m}{s}$$ |
| Acceleration | - | a | $$\frac{m}{s^{2}}$$ |

**SI Base Units**

|  |  |  |
| --- | --- | --- |
| **Quantity** | **Name** | **Symbol** |
| Length | meter | m |
| Mass | kilogram | kg |
| Time | second | s |
| Electric current | ampere | A |
| Temperature | kelvin | K |
| Amount of substance | mole | mol |
| Luminous intensity | candela | cd |

1. Write an essay with at least two resources cited to answer the question: Why is it important for scientists to develop definitions for standard measurements that do not rely on a physical object?

# Graphic Organizer

Name: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**Directions**: As you read, complete the graphic organizer below to describe a mole in chemistry.

|  |  |  |
| --- | --- | --- |
|  | **Description, including chemicals used and problems encountered (if applicable)** | **Year** |
| **International Prototype of the Kilogram (IPK)** |  |  |
| **Jean Perrin’s experiments** |  |  |
| **Ideal Crystal –Attempt by NIST** |  |  |
| **Ideal Crystal – Effort by International Avogadro coordination** |  |  |
| **New definition of the kilogram** |  |  |
| **New definition of the mole** |  |  |

**Summary:** Write a short summary (18 words or less) explaining why the standard for the kilogram (and therefore the mole) had to change.

# Answers to Reading Comprehension Questions & Graphic Organizer Rubric

1. **How many atoms are in 2 dozen atoms? How many molecules are in 1.5 dozen molecules?**

*24 atoms; 18 molecules. These can be calculated as follows:*

$$2 dozen ×\frac{12 atoms}{1 dozen} =24 atoms$$

$$1.5 dozen ×\frac{12 molecules}{1 dozen} =18 molecules$$

1. **What physical object was used to define a kilogram before the new system was created?**

*The International Prototype of a Kilogram (IPK), which was an iridium-platinum cylinder created in 1889 and kept in a vault.*

1. **Why is the definition of a mole related to the definition of a kilogram?**

*A mole is based on the mass of a sample of carbon atoms. If the definition of a kilogram were changed, then the mass of those carbon atoms would change, and therefore the definition of a mole would change.*

1. **Why can’t you work with a single water molecule in your lab?**

*One water molecule is extremely tiny. You are not able to see or feel it, so it is impossible to manipulate it or measure it in any way.*

1. **How do you calculate the volume of a cube?**

*Take the length of one side and cube it. (length x width x height, with all sides equal).*

1. **What is the difference between 28Si and 29Si?**

*Both have 14 protons, but 29Si has one more neutron (15) than 28Si (14). This makes 29Si heavier than 28Si.*

1. **Why did scientists use only one of silicon’s three isotopes to make the new standard sphere?**

*If multiple isotopes were allowed in the sphere, there would be no way of knowing with certainty how many of each there were, thus preventing an accurate accounting for the mass.*

1. **Why is the silicon sphere a better measurement standard than the original IPK?**

*The silicon sphere can be measured by scientists and related to some fundamental constants of nature. Once the relationship is known reliably and consistently, there is no further need to use the sphere, because the definition will not be based on the sphere (which could change) but on the constants (which remain stable). Anyone with the right equipment could reproduce these results.*

1. **Explain how density is used in calculating the number of atoms in a mole.**

*Density here is used in two ways, atoms/cm3 and mol/cm3. The number of atoms in one cubic centimeter can be derived from the unit cell, which is a repeating unit of a specific crystal structure. The number of atoms in the unit cell are known, as is the length of the sides of the cube comprising the unit cell. The number of moles in one cubic centimeter can be derived using a measured density, along with molar mass. Dividing density (g/cm3) by molar mass (g/mol) gives mol/cm3. If you know both the atoms and the number of moles in a cubic centimeter, then these two quantities are also equivalent, giving the number of atoms per mole.*

**Questions for Further Learning**

1. **Pure solids often have well-known structures based on how the atoms or ions are arranged. If the arrangement is orderly and repeating, it is crystalline. If there is no regular or repeating arrangement, it is amorphous.**
	1. **Research the following allotropes of carbon and classify them as having crystalline or amorphous structure:**

|  |  |
| --- | --- |
| **Allotrope** | **Crystalline or Amorphous?** |
| Diamond | *Crystalline* |
| Coal | *Amorphous* |
| Graphite | *Crystalline* |
| Buckminsterfullerene | *Crystalline*  |

* 1. **Silicon has two allotropes, simply called crystalline silicon and amorphous silicon. Propose a reason that the scientists would choose to use silicon instead of carbon when creating their ideal crystal.**

*There are several allotropes of carbon as well as several isotopes of carbon, so it would be difficult to coax the atoms into a single crystalline structure containing mostly pure 12C (which is the most abundant isotope of carbon). With silicon, there are only the amorphous and the crystalline arrangement, so with careful conditions, and after enriching it to be almost entirely 28Si, there is only one crystalline form for the atoms to take on. Techniques involving pure silicon crystallization are already known from the semiconductor industry.*

1. **Many units that are used in science are derived units. That means that they are dependent on two or more of the seven base units. Some of these have a special name and others are simply a derivation of the units. When redefining the kilogram, a different method was also being used in setting the standard. This method used an instrument called a watt balance. The watt balance relied on the interrelationships between several of the SI units. The major equation used was**

$$UI=ma\_{g}v$$

where *U* = electric potential; *I* = current; *m* = mass; *ag* = gravitational acceleration; and $v $= velocity.

**Using the tables below, show that the units on each side of the equation are equivalent to watts.**

**SI Base Units**

|  |  |  |
| --- | --- | --- |
| **Quantity** | **Name** | **Symbol** |
| Length | meter | m |
| Mass | kilogram | kg |
| Time | second | s |
| Electric current | ampere | A |
| Temperature | kelvin | K |
| Amount of substance | mole | mol |
| Luminous intensity | candela | cd |

**SI Derived Units**

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| **Quantity** | **Name** | **Symbol** | **SI units** |
| Energy | Joule | J | $$\frac{kg‧m^{2}}{s^{2}}$$ |
| Power | Watt | W | $$\frac{J}{s}$$ |
| Electric charge | Coulomb | C | A‧s |
| Electric potential | Volts | V | $$\frac{J}{C}$$ |
| Velocity | - | v | $$\frac{m}{s}$$ |
| Acceleration | - | a | $$\frac{m}{s^{2}}$$ |

 *UI would have units of V‧A; V can be reduced to J/C, and C=* A‧s, so (J/ A‧s)‧A = J/s = Watt.

 $ma\_{g}v$ *would have units of kg‧*$\frac{m}{s^{2}}$*‧*$\frac{m}{s}$ *=* $\frac{kg‧m^{2}}{s^{3}}$ *= J/s = Watt.*

1. **Write an essay with at least two resources cited to answer the question:**

**Why is it important for scientists to develop definitions for standard measurements that do not rely on a physical object?**

*Some good points to mention:*

* *It is impossible to predict what will happen over time to a physical object. It is impossible to claim that a physical object can be kept safe from all disasters.*
* *If there are fundamental constants that can be used to reliably and consistently describe a standard measurement, then that is a better method to use because the constants will not change.*
* *So many of the measurements we use rely on other measurements that it is important to have one standard way of measuring the base units or every other unit will be inconsistent.*
* *There are many sources that discuss the various measurements and how they have historically changed. Students can reference these as examples.*

**Graphic Organizer Rubric**

If you use the Graphic Organizer to evaluate student performance, you may want to develop a grading rubric such as the one below.

|  |  |  |
| --- | --- | --- |
| **Score** | **Description** | **Evidence** |
| 4 | Excellent | Complete; details provided; demonstrates deep understanding. |
| 3 | Good | Complete; few details provided; demonstrates some understanding. |
| 2 | Fair | Incomplete; few details provided; some misconceptions evident. |
| 1 | Poor | Very incomplete; no details provided; many misconceptions evident. |
| 0 | Not acceptable | So incomplete that no judgment can be made about student understanding |

# Additional Resources

**Labs and demos**

Target Mole Lab: A common chemical reaction used in chemistry class is zinc and hydrochloric acid. In this lab, students calculate how many zinc and chlorine atoms take place in the reaction, and then predict the mass of the solid product. The final grade will be determined by the electronic balance.  [www.flinnsci.com/target-mole-lab/dc91660/](http://www.flinnsci.com/target-mole-lab/dc91660/)

**Simulations**

Simple interactive showing the relationship between mass, moles, and particles.

<http://employees.oneonta.edu/viningwj/sims/compounds_molecules_moles_s.html>

Visualize some different crystal structures:

[www.chemtube3d.com/category/inorganic-chemistry/solid-state-cubic-structures/](https://www.chemtube3d.com/category/inorganic-chemistry/solid-state-cubic-structures/)

**Videos**

Excellent and simple description of how the kilogram was redefined using the watt balance. The mole and the kilogram redefinitions were linked together. [www.youtube.com/watch?v=Oo0jm1PPRuo](http://www.youtube.com/watch?v=Oo0jm1PPRuo)

Short video about various types of crystals in our world. [www.acs.org/content/acs/en/pressroom/reactions/videos/2014/salt-diamonds-and-dna-5-surprising-facts-about-crystals.html](https://www.acs.org/content/acs/en/pressroom/reactions/videos/2014/salt-diamonds-and-dna-5-surprising-facts-about-crystals.html)

Short video that shows representatives from the many countries involved in this long-term project. This could serve to engage students for a research project on the contributions of the 60 countries to this project.

[www.youtube.com/watch?v=V7myhT\_CwYc](http://www.youtube.com/watch?v=V7myhT_CwYc)

**Lessons and lesson plans**

Short video on Avogadro with an accompanying worksheet:

<https://teachchemistry.org/classroom-resources/amedeo-avogadro-video>

AACT Lesson: Calculating moles in daily life:

<https://teachchemistry.org/classroom-resources/calculating-moles-in-daily-life>

**Projects and extension activities**

For a simple activity that explains some different crystal systems, students can read the information, answer the questions, and follow the link from this site: <https://courses.lumenlearning.com/cheminter/chapter/unit-cells/>

Several Mole Day activities here: [www.acs.org/content/acs/en/education/students/highschool/chemistryclubs/activities/mole-day.html](https://www.acs.org/content/acs/en/education/students/highschool/chemistryclubs/activities/mole-day.html)

# Concepts, Standards, and Teaching Strategies

**Connections to Chemistry Concepts**

The following chemistry concepts are highlighted in this article:

* Chemistry Basics
	+ Accuracy
	+ Physical properties
* Quantitative Chemistry
	+ Mole concept
	+ Measurement
	+ SI units

**Correlations to Next Generation Science Standards**

This article relates to the following performance expectations and dimensions of the NGSS:

**HS-PS1-8**

Develop models to illustrate the changes in the composition of the nucleus of the atom and the energy released during the processes of fission, fusion, and radioactive decay.

**Disciplinary Core Ideas:**

* PS1.A: Structure and Properties of Matter
* PS1.C: Nuclear Processes

**Crosscutting Concepts:**

* Scale, Proportion, and Quantity
* Energy and Matter
* Stability and Change

**Science and Engineering Practices:**

* Developing and using models
* Asking questions (for science) and defining problems (for engineering)

**Nature of Science:**

* Science models, laws, mechanisms, and theories explain natural phenomena.
* Science addresses questions about the natural and material world

Student Reading Comprehension Questions – connections to NGSS Crosscutting Concepts:

* Q3 + Q4: Scale, Proportion, and Quantity
* Q7 Further Learning Q1: Structure and Function

**Correlations to Common Core State Standards**

See how *ChemMatters* correlates to the[**Common Core State Standards** online](https://www.acs.org/content/acs/en/education/resources/highschool/chemmatters/teachers-guide.html).

**Teaching Strategies**

Consider the following tips and strategies for incorporating this article into your classroom:

* Encourage students to complete the calculation to determine Avogadro’s constant provided in the article. The calculation is outlined below:

If you know how many atoms are in a cubic centimeter, and you know how many moles are in the same volume, then the number of atoms per mole—the **Avogadro constant NA**—is just the ratio of these two numbers:

**NA = Atoms per cm3/mol per cm3**

= **(4.994033964 x 1022 atoms/cm3)/(0.08292788506 mol/cm3)**

= **6.02214076 x 1023 atoms/mol**

* Discuss the meaning of “viscosity” with students prior to reading the article.
* Use this with a lesson on calculations involving units, like unit conversions or creating and using complex units. Density is an easy complex unit that students will know, but may not recognize as “complex”, or made of other units. Speed is another. These can lead to a demonstration of other more complicated units they will use in chemistry.
* Use this as an engagement for a lesson on isotopes.
* This could lead to a lesson on how structure affects properties, where different crystal packing arrangements are shown, and this can be identified as another factor (other than atom size and electronegativity) involved in the strength of interaction between atoms in a metal or nonmetal. This could be related to properties of solids in terms of melting point or lattice energy for ionic compounds.
* **Engagement Ideas**
	+ Alternative to Anticipation Guide: Before reading, ask students why the mole is so important in chemistry, and how the mole is defined. As they read, students can find information to confirm or refute their original ideas.
	+ You could do a short activity to have the students use their (hands, feet, fingers, whatever you choose) to measure something in the classroom, maybe a desktop or a textbook. Have them all report their measurements. You could also give a few examples of historical measurements like a cubit or using “hands” to show that this really is how measurements started. Let this begin a discussion of the importance of standardized measurements.