It’s Elemental! Sampling from the Periodic Table

Matth Malloure
Grand Valley State University
Matt.malloure@gmail.com

Mary Richardson
Grand Valley State University
richamar@gvsu.edu

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Overview of Lesson Plan

This lesson plan includes an interactive activity to illustrate various sampling methods. Using the periodic table of elements, students will collect real data implementing simple random and systematic sampling. With both samples collected, students will calculate appropriate descriptive statistics and use the sampling distributions to compare the performance of the methods. They will also determine how to set up a stratified random sample and a cluster sample, but will only perform the cluster sample in this activity.

GAISE Components

This activity follows all four components of statistical problem solving put forth in the *Guidelines for Assessment and Instruction in Statistics Education (GAISE) Report.* The four components are: formulate a question, design and implement a plan to collect data, analyze the data by measures and graphs, and interpret the results in the context of the original question. This is a GAISE Level C Activity.

Common Core State Standards for Mathematical Practice

1. Make sense of problems and persevere in solving them.
2. Reason abstractly and quantitatively.
3. Construct viable arguments and critique the reasoning of others.
4. Model with mathematics.
5. Use appropriate tools strategically.
6. Attend to precision.

Common Core State Standard Grade Level Content (High School)

S-ID. 1. Represent data with plots on the real number line (dot plots, histograms, and box plots).
S-ID. 2. Use statistics appropriate to the shape of the data distribution to compare center (median, mean) and spread (interquartile range, standard deviation) of two or more different data sets.
S-ID. 3. Interpret differences in shape, center, and spread in the context of the data sets, accounting for possible effects of extreme data points (outliers).
S-IC. 1. Understand statistics as a process for making inferences about population parameters based on a random sample from that population.

S-IC. 3. Recognize the purposes of and differences among sample surveys, experiments, and observational studies; explain how randomization relates to each.
S-IC. 4. Use data from a sample survey to estimate a population mean or proportion; develop a margin of error through the use of simulation models for random sampling.
S-IC. 5. Use data from a randomized experiment to compare two treatments; use simulations to decide if differences between parameters are significant.

NCTM Principles and Standards for School Mathematics
Data Analysis and Probability Standards for Grades 9-12

Formulate questions that can be addressed with data and collect, organize, and display relevant data to answer them:

- understand the differences among various kinds of studies and which types of inferences can legitimately be drawn from each;
- understand histograms and parallel box plots and use them to display data;
- compute basic statistics and understand the distinction between a statistic and a parameter.

Select and use appropriate statistical methods to analyze data:

- for univariate measurement data, be able to display the distribution, describe its shape, and select and calculate summary statistics;
- display and discuss bivariate data where at least one variable is categorical.

Develop and evaluate inferences and predictions that are based on data:

- use simulations to explore the variability of sample statistics from a known population and to construct sampling distributions;
- understand how sample statistics reflect the values of population parameters and use sampling distributions as the basis for informal inference.

Understand and apply basic concepts of probability:

- use simulations to construct empirical probability distributions.

Prerequisites

Before students begin the activity they will have some experience in random sampling methods such as simple random, systematic, stratified, and cluster sampling. They should also be familiar with univariate descriptive statistics, stem plots, and sampling distributions.

Learning Targets

After completing the activity, students will be able to appropriately design and carry out simple random, cluster, systematic, and stratified samples. In addition to the sampling methods, students will also know how to calculate simple univariate descriptive statistics including the mean, standard deviation, and the five number summary. Then, using stem plots, students will be able to compare the sampling distributions for sample means to determine the optimal sampling strategy.

Time Required

This activity will require roughly 2 class periods.

Materials Required

The students will only need to bring a pencil and a graphing calculator. The instructor will provide the activity sheet, complete with a periodic table of elements.

Instructional Lesson Plan

The GAISE Statistical Problem-Solving Procedure

I. Formulate Question(s)

Start the activity by passing out the Activity Worksheet (page 9) explaining that the overall goal of the activity is to determine which sampling method is the most appropriate for estimating the mean atomic weight of elements in the periodic table. The main question of interest for this activity is: After performing a simple random sample and a systematic sample on the periodic table of elements, which of the two is the most appropriate method for this scenario? All other aspects of this investigation will be based on this specific question.

II. Design and Implement a Plan to Collect the Data

The various sampling methods the students will implement in this activity are based on the periodic table of elements, so give a *basic* description of the periodic table as this will be important in the design. The following description is available in the Worksheet, but go ahead and summarize it for the students. Dmitri Mendeleev created the periodic table in 1869 and the table is structured in order to reflect the "periodic" trends in the elements. The most up to date table has 117 confirmed elements, 92 of them occurring naturally on Earth with scientists producing the rest artificially in a laboratory. Based on the location of the elements in the table, scientists can determine specific properties of an element. The atomic number of the element in the table is the number of protons in the nucleus and the elements are ordered according to this property. Each of the rows of the table are called periods and elements within a period have the same valence electron shell based on quantum mechanical theory. The groups contain elements with similar physical properties due to the number of electrons in the respective valence shell. The value that the students will be most interested in is the atomic weight of elements, which can be determined using a weighted average of the weights for each elements various isotopes.

The periodic table the students will use comes from the National Institute of Standards and Technology. This table only comes with 114 elements, so for the purposes of this activity the population size is $N = 114$ and the population mean atomic weight is $\mu = 141.09$ grams per mole. The last two pages of the Activity Worksheet contain a text version of the periodic table that may be easier for some students to use.

Once the description of the periodic table has been covered, have the students all start with Strategy 1: finding a simple random sample (without replacement) of 25 elements using the same seed of 1967. This way, all of the students should get the same random sample, and hence, the same sample mean. Using a TI-84 PLUS calculator, students should first set their seed to 1967. To do this, students need to enter 1967 → STO-> → MATH → Scroll to PRB → Select 1:rand → ENTER → ENTER. This will set the random integer value to 1967. Then they must go back into MATH → PRB, but now select "5:randInt(". In order to get a sample of 25 elements from the 114 on the table, have the students enter randInt(1, 114, 25). The resulting elements in the sample can be found in Table 1.

Table 1. Elements in the simple random sample with seed 1967.

60	64	33	111	83	6	56	34	27
65	57	69	46	79	18	81	32	75
108	59	90	61	91	103	49		

Note: If an instance occurs where the sample produces duplicate elements, have the students continue to sample elements until the sample is comprised of 25 unique elements.

With the 25 elements now sampled, students need to find the mean atomic weight of the sample: $\bar{x} = 152.83$ grams per mole.

Now, students should complete Strategy 2: finding a 1-in-5 systematic sample of elements using the seed of 1985. Students should be able to set the seed using the same method as in Strategy 1. Instead of sampling 25 from the 114 as in the simple random sample, the students will sample one integer $1 \leq k \leq 5$ and then select every 5th element from the ordered list of elements by atomic weight starting at k. The sample size will be determined by the value of k picked since 114 is not divisible by 5. Students may think that 25 elements need to also be in this systematic sample, but that is impossible. With the seed of 1985, randInt(1, 5, 1) = 5. So the sample will contain the 22 elements in Table 2.

Table 2. Elements in the 1-in-5 systematic sample with seed 1985.

5	10	15	20	25	30	35	40	45
50	55	60	65	70	75	80	85	90
95	100	105	110					

From the 22 elements in Table 2, the 1-in-5 systematic sample produces a sample mean of 140.73 grams per mole.

After the students complete Strategies 1 and 2, check to make sure all students obtained the same sample means of 152.83 for the simple random sample and 140.73 for the systematic sample.

For Strategy 3 the students should explain how to take a stratified random sample of 25 elements from the 114 using the following 4 strata: solid, liquid, gas, and artificial. Students are also given that there are 77 solids, 2 liquids, 11 gases, and 24 artificial elements. In order to take a stratified sample, students should divide each population stratum size by the population size and then multiply 25 and this percentage. For example, there are 77 solids, so $\frac{77}{114} \times 100\% = 67.5\%$ of the population are solids. This means that there should be $.675 \times 25 = 16.875 \approx 17$ solids in the sample. This same process will lead students to discover that the sample will have 17 solids, 1 liquid, 2 gases, and 5 artificial elements. Now, a student may ask how the 1 liquid made the sample because they will see that .43 liquids should be included in the sample and based on the rounding used for the other three strata, this would lead to 0 liquids. However, it could be argued that the sample should have at least 1 representative element of the liquids and by rounding up to 1; the resulting sample has 25 elements.

Finally, Strategy 4 asks students to take a cluster sample using the columns of elements as clusters. Therefore, there are 18 clusters in total and the goal is to take a random sample of 4 clusters. Now, the sample itself is not difficult to obtain, but students need to understand why the columns are the clusters and not the rows. The main reason however, is the variability in atomic weight in a column is more representative of all elements and a row will have very similar weights across all elements.

Using 33 as the seed, have the students take a random sample of 4 of the 18 clusters. Finding this sample should be second nature to students at this point, and the 4 clusters they should include in the sample are 11, 5, 8, and 9. Therefore, Table 3 includes all the elements that are in these 4 clusters.

Table 3. Elements in the cluster sample of 4 groups with seed 33.

23	26	27	29	41	44	45	47
58	61	62	64	73	76	77	79
90	93	94	96	105	108	109	111

With the elements in Table 3 as the sample of 24 elements, the sample mean for the cluster sample with seed 33 is 167.76 grams per mole.

Now that the students have a thorough understanding of how to take a simple random and a systematic sample, have them continue further with the activity. Ask the students which of the two sampling methods they think will produce the least variable mean atomic weight estimate after repeated sampling. It seems reasonable that most students will suspect the simple random sample to have the least variable estimate, but since there are only 5 possible systematic samples, the repeated systematic sampling should produce the more precise estimate. With the samples roughly ordered by atomic weight, the systematic sample should be more representative of the population of elements. The students don't have to be correct in their response to this question because they will know the answer at the conclusion of the activity.

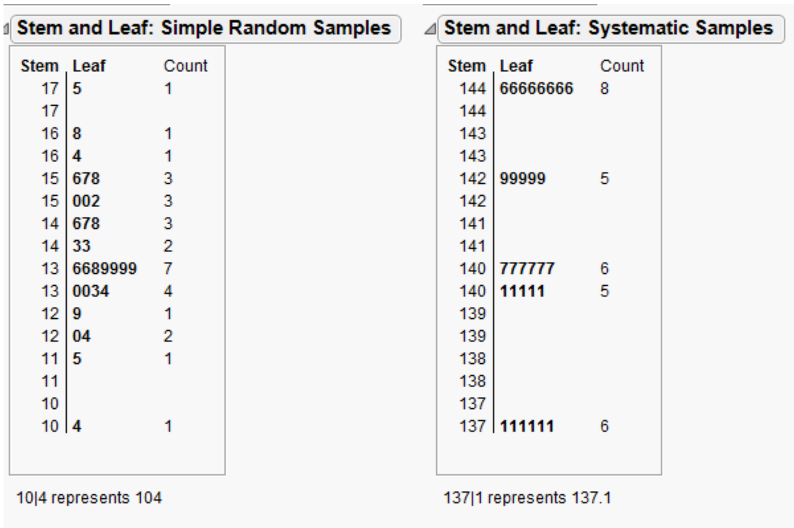
Each student will use the last 4 digits of their phone number as their seed for the simple random and systematic samples. Then, they will determine the mean atomic weight for both samples and record their means on the board under the appropriate heading. So divide the board into two sections such that students can compile a list of means needed for the sampling distribution portion of the activity. Table 4 below contains example data from 30 students. Note that the samples below were obtained using R v2.13.0 and will not match a sample with the same seed found using the calculator.

Table 4. Mean atomic weights for simple random and systematic samples for 30 students.

Seed	$\bar{x}_{srs}$	$\bar{x}_{sys}$	**Seed**	$\bar{x}_{srs}$	$\bar{x}_{sys}$	**Seed**	$\bar{x}_{srs}$	$\bar{x}_{sys}$	**Seed**	$\bar{x}_{srs}$	$\bar{x}_{sys}$
3149	133.70	142.86	2562	136.03	140.10	5736	151.91	142.86	6306	143.44	144.64
8995	150.10	137.13	6402	168.06	144.64	2400	130.21	144.64	3844	142.97	140.10
8419	175.44	137.13	5635	104.24	144.64	2175	146.36	144.64	2095	129.85	137.13
3860	156.46	140.73	3497	163.85	144.64	3000	156.55	137.13	6815	120.39	140.73
9590	135.53	140.73	6629	137.62	142.86	5922	133.23	144.64	1963	115.46	140.10
6955	139.34	140.73	8197	150.40	142.86	8468	124.48	140.73	2646	158.40	140.10
1426	139.43	137.13	1786	128.72	140.73	3236	147.88	142.86			
3424	138.58	140.10	4055	139.48	137.13	9974	146.95	144.64			

III. Analyze the Data

Once all students have completed their individual samples and copied them to the board, have them create stem plots for both types of samples. Additionally, descriptive statistics should be calculated for each type of sample. The stem plots should look similar to those in Figure 1.



```
Stem and Leaf: Simple Random Samples

Stem  Leaf      Count
  17 | 5         1
  17 |
  16 | 8         1
  16 | 4         1
  15 | 678       3
  15 | 002       3
  14 | 678       3
  14 | 33        2
  13 | 6689999   7
  13 | 0034      4
  12 | 9         1
  12 | 04        2
  11 | 5         1
  11 |
  10 |
  10 | 4         1

10|4 represents 104
```

```
Stem and Leaf: Systematic Samples

Stem  Leaf       Count
 144 | 66666666   8
 144 |
 143 |
 143 |
 142 | 99999      5
 142 |
 141 |
 141 |
 140 | 777777     6
 140 | 11111      5
 139 |
 139 |
 138 |
 138 |
 137 |
 137 | 111111     6

137|1 represents 137.1
```

Figure 1. Stem plots for the sampling distributions of the sample mean atomic weights.

Table 5 shows descriptive statistics for the example data in Table 4.

Table 5. Descriptive statistics for the sampling distributions.

Statistic	Simple Random Samples	Systematic Samples
Mean	141.50	141.30
Standard Deviation	15.44	2.72
1st Quartile	132.48	140.10
Median	139.46	140.73
3rd Quartile	150.78	144.64

IV. Interpret the Results

The students should be able to see right away that the standard deviation for the simple random samples is quite large compared to that for the systematic samples. Also, the average mean atomic weights for both types of samples are nearly equal at 141.50 and 141.30. Therefore, students should conclude that the systematic sample produces a mean atomic weight that is more accurate. In the periodic table, the elements are ordered according to the number of protons and this is directly related to the atomic weight of the elements. So for the most part, the elements are ordered according to the atomic weight, which was the measure of interest.

Assessment

1. Identify the type of sampling method used in the following 4 scenarios. The possible response options are:

A. Systematic Sample
B. Cluster Sample
C. Simple Random Sample
D. Stratified Random Sample.

Scenario 1: In a factory producing television sets, every 100th set produced is inspected.

Scenario 2: A class of 200 students is numbered from 1 to 200, and a table of random digits is used to choose 60 students from the class.

Scenario 3: A class of 200 students is seated in 10 rows of 20 students per row. Three students are randomly selected from every row.

Scenario 4: An airline company randomly chooses one flight from a list of all international flights taking place that day. All passengers on that selected flight are asked to fill out a survey on meal satisfaction.

2. Suppose a state has 10 universities, 25 four-year colleges, and 50 community colleges, each of which offer multiple sections of an introductory statistics course each year. Researchers want to conduct a survey of students taking introductory statistics in the state. Explain a method for collecting each of the following types of samples:

A. Stratified Random Sample

B. Cluster Sample

C. Simple Random Sample

Answers:

1. Scenario 1 – A, Scenario 2 – C, Scenario 3 – D, Scenario 4 – B

2. First, compile a list of all the introductory statistics courses taught in the state at each type of learning institution.
(A) Randomly sample a representative proportion of introductory statistics courses from each of the 3 strata: universities, four-year colleges, and community colleges.
(B) Randomly sample one of the 3 types of learning institutions and then take a census of all introductory courses within that type of institution.
(C) Simply take a random sample of *n* introductory courses from the list of *N* offerings without considering the type of learning institution.

Possible Extensions

1. Carry out a cluster sample and stratified random sample to compare the variability and precision of the mean atomic weight after repeated sampling.

2. Demonstrate the Central Limit Theorem by taking various sized samples of the simple random sample. So repeatedly sample 5, 10, 25, and 50 elements and compare the sampling distributions of the mean atomic weights.

3. Begin with the 114 elements and calculate the sample size needed to reach a specified margin of error for the four sample methods.

References

1. *Guidelines for Assessment and Instruction in Statistics Education* (GAISE) Report, ASA, Franklin et al., ASA, 2007 http://www.amstat.org/education/gaise/.

2. Assessment questions from: *Mind on Statistics*, Fourth Edition by Utts/Heckard, 2012. Cengage Learning.

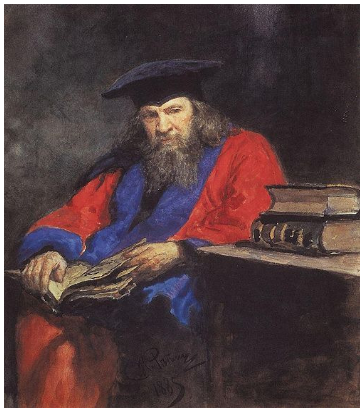
3. Activity background adapted from: http://en.wikipedia.org/wiki/Periodic_table.

It’s Elemental! Sampling from the Periodic Table Activity Sheet

Background

Adapted from Wikipedia: http://en.wikipedia.org/wiki/Periodic_table

The **periodic table of the chemical elements** is a tabular method of displaying the chemical elements. Although precursors to this table exist, its invention is generally credited to Russian chemist Dmitri Mendeleev in 1869.



Mendeleev intended the table to illustrate recurring (“periodic”) trends in the properties of the elements. The layout of the table has been refined and extended over time, as new elements have been discovered, and new theoretical models have been developed to explain chemical behavior.

The periodic table provides an extremely useful framework to classify, systematize and compare all the many different forms of chemical behavior. The table has also found wide application in physics, biology, engineering, and industry. The current standard table contains 117 confirmed elements as of January 27, 2008 (while element 118 has been synthesized, element 117 has not). Ninety-two are found naturally on Earth, and the rest are synthetic elements that have been produced artificially in particle accelerators.

The main value of the periodic table is the ability to predict the chemical properties of an element based on its location on the table. It should be noted that the properties vary differently when moving vertically along the columns of the table, than when moving horizontally along the rows. The layout of the periodic table demonstrates recurring (“periodic”) chemical properties. Elements are listed in order of increasing atomic number (i.e. the number of protons in the atomic nucleus). Rows are arranged so that elements with similar properties fall into the same vertical columns (**groups**). According to quantum mechanical theories of electron configuration within atoms, each horizontal row (**period**) in the table corresponded to the filling of a quantum shell of electrons. There are progressively longer periods further down the table.

In printed tables, each element is usually listed with its element symbol and atomic number; many versions of the table also list the element's atomic weight and other information. The **atomic weight** is the average mass of the atoms of an element. It is a weighted average of the naturally-occurring isotopes. For example, the atomic weight of Hydrogen is 1.00794 grams per mole.

Part 1. Taking Samples

Instructions: Refer to the Periodic Table produced by the National Institute of Standards and Technology (NIST) in 2003. This Periodic Table displays **114** elements, along with their corresponding atomic numbers and atomic weights.

Notice that **the atomic weight of the elements generally increases with the atomic number of the elements**. Thus, the first element listed, Hydrogen, with an atomic number of 1, has the lowest atomic weight of 1.01 grams per mole -- and the last element listed, Ununhexium, with an atomic number of 116, has the highest atomic weight of 292 grams per mole.

In order to practice selecting different types of samples and to compare the performance of different types of samples, we are going to consider our Population of interest to be all of the elements shown on the NIST 2003 Periodic Table (thus, $N = 114$) and the variable of interest is atomic weight. Let's assume that we are interested in selecting samples from this population in order to estimate the population mean atomic weight. The true mean atomic weight of the 114 elements on the NIST Periodic Table is $\boldsymbol{\mu} = \mathbf{141.09}$ grams per mole.

Strategy #1:

Select a **simple random sample** of 25 elements. Sample without replacement. **Use a SEED of 1967.**

What is the mean atomic weight for the 25 sampled elements? $\bar{x} =$ ________________

Strategy #2:

Select a **1-in-5 systematic sample** of elements. **Use a SEED of 1985.**

What is the mean atomic weight for the sampled elements? $\bar{x} =$ ________________

Strategy #3:

To select a **stratified random sample** of 25 elements, without replacement, we could divide the table into **4 strata: Solid, Liquid, Gas, and Artificial**. Note that there are 77 Solids, 2 Liquids, 11 Gases, and 24 Artificial elements. We would then sample 17 Solids, 1 Liquid, 2 Gases, and 5 Artificial elements.

Briefly explain why it makes sense to sample 17 of the Solids:

Strategy #4:

Select a **cluster sample** of elements. Use the **columns** of elements as the clusters. Thus, there are 18 clusters. Randomly select **4 clusters**. **Use the SEED 33.**

Briefly explain why it makes sense to use the columns as clusters, but it does not make sense to use the rows as clusters:

What is the mean atomic weight for the sampled elements? $\bar{x} =$ ________________

Part 2. Comparison of Sampling Strategies

We want to use class data to determine if *repeated* **simple random sampling** of 25 elements will result in sample mean atomic weights that are less variable than the sample mean weights resulting from *repeated* **1-in-5 systematic sampling** of elements.

Do you think that *repeated* simple random sampling of elements will be likely to produce less variable sample mean atomic weights than will *repeated* 1-in-5 systematic sampling of elements? Why? Or, why not?

Using the last 4 digits of your telephone number as your SEED, select a **simple random sample** of 25 elements. Sample without replacement.

What is your sample mean atomic weight? $\bar{x} =$ ________________

Write your sample mean atomic weight on the white board in the column labeled "Sample Means from Simple Random Samples."

Using the last 4 digits of your telephone number as your SEED, select a 1-in-5 systematic sample of elements.

What is your sample mean atomic weight? $\bar{x}$ = ________________

Write your sample mean atomic weight on the white board in the column labeled "Sample Means from Systematic Samples."

Record the class sample means for each of the sampling techniques below.

Simple random sampling:

Systematic sampling:

Create stem plots and calculate descriptive statistics for the class sample means.

Simple Random Samples **Systematic Samples**

<u>Simple Random Sampling</u> **<u>Systematic Random Sampling</u>**

mean = ___________

standard deviation = ___________ standard deviation = ___________

first quartile = __________

median = __________

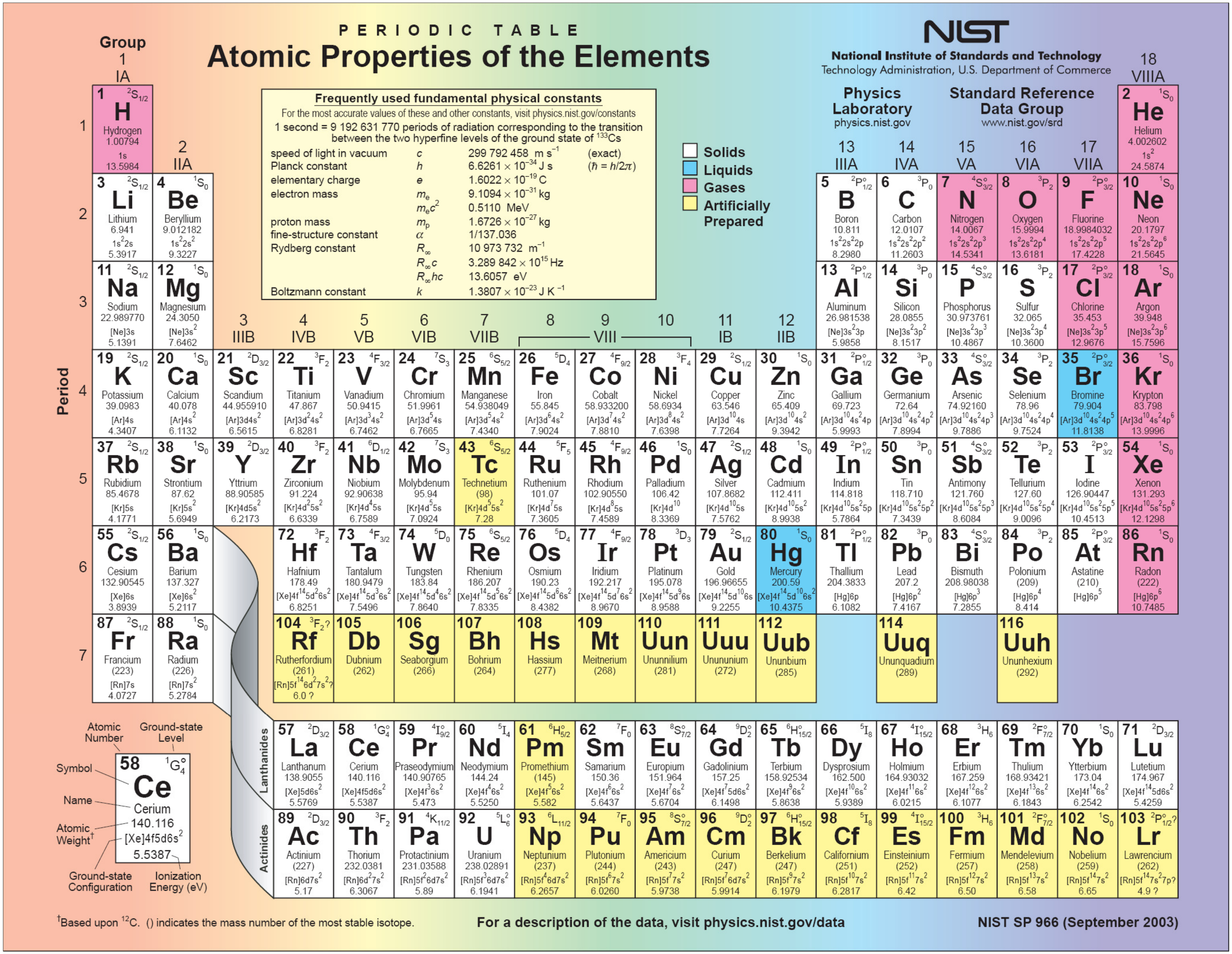
third quartile = __________

first quartile = __________

median = __________

third quartile = __________

Based upon the above calculations, do you think that *repeated* simple random sampling of elements from the Periodic Table would most likely produce a more accurate estimate of the population mean atomic weight than would *repeated* 1-in-5 systematic sampling of elements? Why? Or, why not?



PERIODIC TABLE
Atomic Properties of the Elements

NIST
National Institute of Standards and Technology
Technology Administration, U.S. Department of Commerce

Physics Laboratory
physics.nist.gov

Standard Reference Data Group
www.nist.gov/srd

Frequently used fundamental physical constants

For the most accurate values of these and other constants, visit physics.nist.gov/constants

1 second = 9 192 631 770 periods of radiation corresponding to the transition between the two hyperfine levels of the ground state of ^{133}Cs

speed of light in vacuum	c	299 792 458 m s^{-1}	(exact)
Planck constant	h	6.6261×10^{-34} J s	($\hbar = h/2\pi$)
elementary charge	e	1.6022×10^{-19} C	
electron mass	m_e	9.1094×10^{-31} kg	
	m_ec^2	0.5110 MeV	
proton mass	m_p	1.6726×10^{-27} kg	
fine-structure constant	α	1/137.036	
Rydberg constant	R_∞	10 973 732 m^{-1}	
	$R_\infty c$	$3.289\,842 \times 10^{15}$ Hz	
	$R_\infty hc$	13.6057 eV	
Boltzmann constant	k	1.3807×10^{-23} J K^{-1}	

☐ **Solids**
🟦 **Liquids**
🟥 **Gases**
🟨 **Artificially Prepared**

Period	Group 1 IA	2 IIA	3 IIIB	4 IVB	5 VB	6 VIB	7 VIIB	8	9 VIII	10	11 IB	12 IIB	13 IIIA	14 IVA	15 VA	16 VIA	17 VIIA	18 VIIIA
1	1 $^2S_{1/2}$ **H** Hydrogen 1.00794 $1s$ 13.5984																	2 $^1S_0$ **He** Helium 4.002602 $1s^2$ 24.5874
2	3 $^2S_{1/2}$ **Li** Lithium 6.941 $1s^22s$ 5.3917	4 $^1S_0$ **Be** Beryllium 9.012182 $1s^22s^2$ 9.3227											5 $^2P^\circ_{1/2}$ **B** Boron 10.811 $1s^22s^22p$ 8.2980	6 $^3P_0$ **C** Carbon 12.0107 $1s^22s^22p^2$ 11.2603	7 $^4S^\circ_{3/2}$ **N** Nitrogen 14.0067 $1s^22s^22p^3$ 14.5341	8 $^3P_2$ **O** Oxygen 15.9994 $1s^22s^22p^4$ 13.6181	9 $^2P^\circ_{3/2}$ **F** Fluorine 18.9984032 $1s^22s^22p^5$ 17.4228	10 $^1S_0$ **Ne** Neon 20.1797 $1s^22s^22p^6$ 21.5645
3	11 $^2S_{1/2}$ **Na** Sodium 22.989770 $[Ne]3s$ 5.1391	12 $^1S_0$ **Mg** Magnesium 24.3050 $[Ne]3s^2$ 7.6462											13 $^2P^\circ_{1/2}$ **Al** Aluminum 26.981538 $[Ne]3s^23p$ 5.9858	14 $^3P_0$ **Si** Silicon 28.0855 $[Ne]3s^23p^2$ 8.1517	15 $^4S^\circ_{3/2}$ **P** Phosphorus 30.973761 $[Ne]3s^23p^3$ 10.4867	16 $^3P_2$ **S** Sulfur 32.065 $[Ne]3s^23p^4$ 10.3600	17 $^2P^\circ_{3/2}$ **Cl** Chlorine 35.453 $[Ne]3s^23p^5$ 12.9676	18 $^1S_0$ **Ar** Argon 39.948 $[Ne]3s^23p^6$ 15.7596
4	19 $^2S_{1/2}$ **K** Potassium 39.0983 $[Ar]4s$ 4.3407	20 $^1S_0$ **Ca** Calcium 40.078 $[Ar]4s^2$ 6.1132	21 $^2D_{3/2}$ **Sc** Scandium 44.955910 $[Ar]3d4s^2$ 6.5615	22 $^3F_2$ **Ti** Titanium 47.867 $[Ar]3d^24s^2$ 6.8281	23 $^4F_{3/2}$ **V** Vanadium 50.9415 $[Ar]3d^34s^2$ 6.7462	24 $^7S_3$ **Cr** Chromium 51.9961 $[Ar]3d^54s$ 6.7665	25 $^6S_{5/2}$ **Mn** Manganese 54.938049 $[Ar]3d^54s^2$ 7.4340	26 $^5D_4$ **Fe** Iron 55.845 $[Ar]3d^64s^2$ 7.9024	27 $^4F_{9/2}$ **Co** Cobalt 58.933200 $[Ar]3d^74s^2$ 7.8810	28 $^3F_4$ **Ni** Nickel 58.6934 $[Ar]3d^84s^2$ 7.6398	29 $^2S_{1/2}$ **Cu** Copper 63.546 $[Ar]3d^{10}4s$ 7.7264	30 $^1S_0$ **Zn** Zinc 65.409 $[Ar]3d^{10}4s^2$ 9.3942	31 $^2P^\circ_{1/2}$ **Ga** Gallium 69.723 $[Ar]3d^{10}4s^24p$ 5.9993	32 $^3P_0$ **Ge** Germanium 72.64 $[Ar]3d^{10}4s^24p^2$ 7.8994	33 $^4S^\circ_{3/2}$ **As** Arsenic 74.92160 $[Ar]3d^{10}4s^24p^3$ 9.7886	34 $^3P_2$ **Se** Selenium 78.96 $[Ar]3d^{10}4s^24p^4$ 9.7524	35 $^2P^\circ_{3/2}$ **Br** Bromine 79.904 $[Ar]3d^{10}4s^24p^5$ 11.8138	36 $^1S_0$ **Kr** Krypton 83.798 $[Ar]3d^{10}4s^24p^6$ 13.9996
5	37 $^2S_{1/2}$ **Rb** Rubidium 85.4678 $[Kr]5s$ 4.1771	38 $^1S_0$ **Sr** Strontium 87.62 $[Kr]5s^2$ 5.6949	39 $^2D_{3/2}$ **Y** Yttrium 88.90585 $[Kr]4d5s^2$ 6.2173	40 $^3F_2$ **Zr** Zirconium 91.224 $[Kr]4d^25s^2$ 6.6339	41 $^6D_{1/2}$ **Nb** Niobium 92.90638 $[Kr]4d^45s$ 6.7589	42 $^7S_3$ **Mo** Molybdenum 95.94 $[Kr]4d^55s$ 7.0924	43 $^6S_{5/2}$ **Tc** Technetium (98) $[Kr]4d^55s^2$ 7.28	44 $^5F_5$ **Ru** Ruthenium 101.07 $[Kr]4d^75s$ 7.3605	45 $^4F_{9/2}$ **Rh** Rhodium 102.90550 $[Kr]4d^85s$ 7.4589	46 $^1S_0$ **Pd** Palladium 106.42 $[Kr]4d^{10}$ 8.3369	47 $^2S_{1/2}$ **Ag** Silver 107.8682 $[Kr]4d^{10}5s$ 7.5762	48 $^1S_0$ **Cd** Cadmium 112.411 $[Kr]4d^{10}5s^2$ 8.9938	49 $^2P^\circ_{1/2}$ **In** Indium 114.818 $[Kr]4d^{10}5s^25p$ 5.7864	50 $^3P_0$ **Sn** Tin 118.710 $[Kr]4d^{10}5s^25p^2$ 7.3439	51 $^4S^\circ_{3/2}$ **Sb** Antimony 121.760 $[Kr]4d^{10}5s^25p^3$ 8.6084	52 $^3P_2$ **Te** Tellurium 127.60 $[Kr]4d^{10}5s^25p^4$ 9.0096	53 $^2P^\circ_{3/2}$ **I** Iodine 126.90447 $[Kr]4d^{10}5s^25p^5$ 10.4513	54 $^1S_0$ **Xe** Xenon 131.293 $[Kr]4d^{10}5s^25p^6$ 12.1298
6	55 $^2S_{1/2}$ **Cs** Cesium 132.90545 $[Xe]6s$ 3.8939	56 $^1S_0$ **Ba** Barium 137.327 $[Xe]6s^2$ 5.2117		72 $^3F_2$ **Hf** Hafnium 178.49 $[Xe]4f^{14}5d^26s^2$ 6.8251	73 $^4F_{3/2}$ **Ta** Tantalum 180.9479 $[Xe]4f^{14}5d^36s^2$ 7.5496	74 $^5D_0$ **W** Tungsten 183.84 $[Xe]4f^{14}5d^46s^2$ 7.8640	75 $^6S_{5/2}$ **Re** Rhenium 186.207 $[Xe]4f^{14}5d^56s^2$ 7.8335	76 $^5D_4$ **Os** Osmium 190.23 $[Xe]4f^{14}5d^66s^2$ 8.4382	77 $^4F_{9/2}$ **Ir** Iridium 192.217 $[Xe]4f^{14}5d^76s^2$ 8.9670	78 $^3D_3$ **Pt** Platinum 195.078 $[Xe]4f^{14}5d^96s$ 8.9588	79 $^2S_{1/2}$ **Au** Gold 196.96655 $[Xe]4f^{14}5d^{10}6s$ 9.2255	80 $^1S_0$ **Hg** Mercury 200.59 $[Xe]4f^{14}5d^{10}6s^2$ 10.4375	81 $^2P^\circ_{1/2}$ **Tl** Thallium 204.3833 $[Hg]6p$ 6.1082	82 $^3P_0$ **Pb** Lead 207.2 $[Hg]6p^2$ 7.4167	83 $^4S^\circ_{3/2}$ **Bi** Bismuth 208.98038 $[Hg]6p^3$ 7.2855	84 $^3P_2$ **Po** Polonium (209) $[Hg]6p^4$ 8.414	85 $^2P^\circ_{3/2}$ **At** Astatine (210) $[Hg]6p^5$	86 $^1S_0$ **Rn** Radon (222) $[Hg]6p^6$ 10.7485
7	87 $^2S_{1/2}$ **Fr** Francium (223) $[Rn]7s$ 4.0727	88 $^1S_0$ **Ra** Radium (226) $[Rn]7s^2$ 5.2784		104 $^3F_2$? **Rf** Rutherfordium (261) $[Rn]5f^{14}6d^27s^2$? 6.0 ?	105 **Db** Dubnium (262)	106 **Sg** Seaborgium (266)	107 **Bh** Bohrium (264)	108 **Hs** Hassium (277)	109 **Mt** Meitnerium (268)	110 **Uun** Ununnilium (281)	111 **Uuu** Unununium (272)	112 **Uub** Ununbium (285)		114 **Uuq** Ununquadium (289)		116 **Uuh** Ununhexium (292)		

Lanthanides	57 $^2D_{3/2}$ **La** Lanthanum 138.9055 $[Xe]5d6s^2$ 5.5769	58 $^1G^\circ_4$ **Ce** Cerium 140.116 $[Xe]4f5d6s^2$ 5.5387	59 $^4I^\circ_{9/2}$ **Pr** Praseodymium 140.90765 $[Xe]4f^36s^2$ 5.473	60 $^5I_4$ **Nd** Neodymium 144.24 $[Xe]4f^46s^2$ 5.5250	61 $^6H^\circ_{5/2}$ **Pm** Promethium (145) $[Xe]4f^56s^2$ 5.582	62 $^7F_0$ **Sm** Samarium 150.36 $[Xe]4f^66s^2$ 5.6437	63 $^8S^\circ_{7/2}$ **Eu** Europium 151.964 $[Xe]4f^76s^2$ 5.6704	64 $^9D^\circ_2$ **Gd** Gadolinium 157.25 $[Xe]4f^75d6s^2$ 6.1498	65 $^6H^\circ_{15/2}$ **Tb** Terbium 158.92534 $[Xe]4f^96s^2$ 5.8638	66 $^5I_8$ **Dy** Dysprosium 162.500 $[Xe]4f^{10}6s^2$ 5.9389	67 $^4I^\circ_{15/2}$ **Ho** Holmium 164.93032 $[Xe]4f^{11}6s^2$ 6.0215	68 $^3H_6$ **Er** Erbium 167.259 $[Xe]4f^{12}6s^2$ 6.1077	69 $^2F^\circ_{7/2}$ **Tm** Thulium 168.93421 $[Xe]4f^{13}6s^2$ 6.1843	70 $^1S_0$ **Yb** Ytterbium 173.04 $[Xe]4f^{14}6s^2$ 6.2542	71 $^2D_{3/2}$ **Lu** Lutetium 174.967 $[Xe]4f^{14}5d6s^2$ 5.4259
Actinides	89 $^2D_{3/2}$ **Ac** Actinium (227) $[Rn]6d7s^2$ 5.17	90 $^3F_2$ **Th** Thorium 232.0381 $[Rn]6d^27s^2$ 6.3067	91 $^4K_{11/2}$ **Pa** Protactinium 231.03588 $[Rn]5f^26d7s^2$ 5.89	92 $^5L^\circ_6$ **U** Uranium 238.02891 $[Rn]5f^36d7s^2$ 6.1941	93 $^6L_{11/2}$ **Np** Neptunium (237) $[Rn]5f^46d7s^2$ 6.2657	94 $^7F_0$ **Pu** Plutonium (244) $[Rn]5f^67s^2$ 6.0260	95 $^8S^\circ_{7/2}$ **Am** Americium (243) $[Rn]5f^77s^2$ 5.9738	96 $^9D^\circ_2$ **Cm** Curium (247) $[Rn]5f^76d7s^2$ 5.9914	97 $^6H^\circ_{15/2}$ **Bk** Berkelium (247) $[Rn]5f^97s^2$ 6.1979	98 $^5I_8$ **Cf** Californium (251) $[Rn]5f^{10}7s^2$ 6.2817	99 $^4I^\circ_{15/2}$ **Es** Einsteinium (252) $[Rn]5f^{11}7s^2$ 6.42	100 $^3H_6$ **Fm** Fermium (257) $[Rn]5f^{12}7s^2$ 6.50	101 $^2F^\circ_{7/2}$ **Md** Mendelevium (258) $[Rn]5f^{13}7s^2$ 6.58	102 $^1S_0$ **No** Nobelium (259) $[Rn]5f^{14}7s^2$ 6.65	103 $^2P^\circ_{1/2}$? **Lr** Lawrencium (262) $[Rn]5f^{14}7s^27p$? 4.9 ?

Atomic Number — 58
Ground-state Level — $^1G^\circ_4$
Symbol — **Ce**
Name — Cerium
Atomic Weight† — 140.116
Ground-state Configuration — $[Xe]4f5d6s^2$
Ionization Energy (eV) — 5.5387

†Based upon ^{12}C. () indicates the mass number of the most stable isotope.

For a description of the data, visit physics.nist.gov/data

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Atomic Number	Atomic Weight	Element	Abbr.	Type	Period
1	1.01	Hydrogen	H	Gas	1
2	4.00	Helium	He	Gas	1
3	6.94	Lithium	Li	Solid	2
4	9.01	Beryllium	Be	Solid	2
5	10.81	Boron	B	Solid	2
6	12.01	Carbon	C	Solid	2
7	14.01	Nitrogen	N	Gas	2
8	16.00	Oxygen	O	Gas	2
9	19.00	Fluorine	F	Gas	2
10	20.18	Neon	Ne	Gas	2
11	22.99	Sodium	Na	Solid	3
12	24.30	Magnesium	Mg	Solid	3
13	26.98	Aluminum	Al	Solid	3
14	28.09	Silicon	Si	Solid	3
15	30.97	Phosphorus	P	Solid	3
16	32.06	Sulfur	S	Solid	3
17	35.45	Chlorine	Cl	Gas	3
18	39.95	Argon	Ar	Gas	3
19	39.10	Potassium	K	Solid	4
20	40.08	Calcium	Ca	Solid	4
21	44.96	Scandium	Sc	Solid	4
22	47.87	Titanium	Ti	Solid	4
23	50.94	Vanadium	V	Solid	4
24	52.00	Chromium	Cr	Solid	4
25	54.94	Manganese	Mn	Solid	4
26	55.84	Iron	Fe	Solid	4
27	58.93	Cobalt	Co	Solid	4
28	58.69	Nickel	Ni	Solid	4
29	63.55	Copper	Cu	Solid	4
30	65.41	Zinc	Zn	Solid	4
31	69.72	Gallium	Ga	Solid	4
32	72.64	Germanium	Ge	Solid	4
33	74.92	Arsenic	As	Solid	4
34	78.96	Selenium	Se	Solid	4
35	79.90	Bromine	Br	Liquid	4
36	83.80	Krypton	Kr	Gas	4
37	85.47	Rubidium	Rb	Solid	5
38	87.62	Strontium	Sr	Solid	5
39	88.91	Yttrium	Y	Solid	5
40	91.22	Zirconium	Zr	Solid	5
41	92.91	Niobium	Nb	Solid	5
42	95.94	Molybdenum	Mo	Solid	5
43	98.00	Technetium	Tc	Artificial	5
44	101.07	Ruthenium	Ru	Solid	5
45	102.91	Rhodium	Rh	Solid	5
46	106.42	Palladium	Pd	Solid	5
47	107.87	Silver	Ag	Solid	5

48	112.41	Cadmium	Cd	Solid	5
49	114.82	Indium	In	Solid	5
50	118.71	Tin	Sn	Solid	5
51	121.76	Antimony	Sb	Solid	5
52	127.60	Tellurium	Te	Solid	5
53	126.90	Iodine	I	Solid	5
54	131.29	Xenon	Xe	Gas	5
55	132.91	Cesium	Cs	Solid	6
56	137.33	Barium	Ba	Solid	6
57	138.91	Lanthanum	La	Solid	6
58	140.11	Cerium	Ce	Solid	6
59	140.91	Praseodymium	Pr	Solid	6
60	144.24	Neodymium	Nd	Solid	6
61	145.00	Promethium	Pm	Artificial	6
62	150.36	Samarium	Sm	Solid	6
63	151.96	Europium	Eu	Solid	6
64	157.25	Gadolinium	Gd	Solid	6
65	158.93	Terbium	Te	Solid	6
66	162.50	Dysprosium	Dy	Solid	6
67	164.93	Holmium	Ho	Solid	6
68	167.26	Erbium	Er	Solid	6
69	168.93	Thulium	Tm	Solid	6
70	173.04	Ytterbium	Yb	Solid	6
71	174.97	Lutetium	Lu	Solid	6
72	178.49	Hafnium	Hf	Solid	6
73	180.95	Tantalum	Ta	Solid	6
74	183.84	Tungsten	W	Solid	6
75	186.21	Rhenium	Re	Solid	6
76	190.23	Osmium	Os	Solid	6
77	192.22	Iridium	Ir	Solid	6
78	195.08	Platinum	Pt	Solid	6
79	196.97	Gold	Go	Solid	6
80	200.59	Mercury	Hg	Liquid	6
81	204.38	Thallium	Tl	Solid	6
82	207.20	Lead	Pb	Solid	6
83	208.98	Bismuth	Bi	Solid	6
84	209.00	Polonium	Po	Solid	6
85	210.00	Astatine	At	Solid	6
86	222.00	Radon	Rn	Gas	6
87	223.00	Francium	Fr	Solid	7
88	226.00	Radium	Ra	Solid	7
89	227.00	Actinium	Ac	Solid	7
90	232.04	Thorium	Th	Solid	7
91	231.04	Protactini	Pa	Solid	7
92	238.03	Uranium	Ur	Solid	7
93	237.00	Neptunium	Np	Artificial	7
94	244.00	Plutonium	Pu	Artificial	7
95	243.00	Americium	Am	Artificial	7
96	247.00	Curium	Cm	Artificial	7

97	247.00	Berkelium	Bk	Artificial	7
98	251.00	Californium	Cf	Artificial	7
99	252.00	Einsteinium	Es	Artificial	7
100	257.00	Fermium	Fm	Artificial	7
101	258.00	Mendelevium	Md	Artificial	7
102	259.00	Nobelium	No	Artificial	7
103	262.00	Lawrencium	Lr	Artificial	7
104	261.00	Rutherfordium	Rf	Artificial	7
105	262.00	Dubnium	Db	Artificial	7
106	266.00	Seaborgium	Sg	Artificial	7
107	264.00	Bohrium	Bh	Artificial	7
108	277.00	Hassium	Hs	Artificial	7
109	268.00	Meitnerium	Mt	Artificial	7
110	281.00	Ununnilium	Uun	Artificial	7
111	272.00	Unununium	Uuu	Artificial	7
112	285.00	Ununbium	Uub	Artificial	7
114	289.00	Ununquadium	Uuq	Artificial	7
116	292.00	Ununhexium	Uuh	Artificial	7