SCOPE, SEQUENCE, and COORDINATION

A National Curriculum Project for High School Science Education

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National Science Education Standard—Physical Science
Structure and Properties of Matter
An element is composed of a single type of atom. When elements are listed in order according to the number of protons (called the atomic number), repeating patterns of physical and chemical properties identify families of elements with similar properties. This "Periodic Table" is a consequence of the repeating pattem of outermost electrons and their permitted energies.

Teacher Materials

Learning Sequence Item:

1041

Periodicity of the Elements

January 1997
Adapted by: Gary Freebury and George Miller

Elements, Atoms, and the Periodic Table. Students should understand that when elements are listed in ascending of the number of protons (atomic number), the periodic table is seen to be a consequence of a repeating pattern of the elements' outermost electrons (valence electrons) (*Chemistry, A Framework for High School Science Education, p. 54).*

Contents

This micro-unit was adapted by **Gary Freebury** (Flathead High School, Kalispell, Mont.) and **George Miller** (University of California, Irvine)

1041

Learning Sequence

Elements, Atoms, and the Periodic Table. Students should understand that when elements are listed in ascending of the number of protons (atomic number), the periodic table is seen to be a consequence of a repeating pattern of the elements' outermost electrons (valence electrons) (*Chemistry, A Framework for High School Science Education, p. 54).*

Science as Inquiry	Science and Technology	Science in Personal and Social Perspectives	History and Nature of Science
Periodicity **Activity 1** Graphing the Elements **Activity 2** Exceptions to the Rule **Assessment 1** Ionization Energy **Assessment 2** Second Ionization Energy **Assessment 3**			

Suggested Sequence of Events

Event #1

Lab Activity

1. Periodicity

Event #2

Lab Activity

2. Graphing the Elements

Event #5

Readings from Science as Inquiry, Science and Technology, Science in Personal and Social Perspectives, and History and Nature of Science

Readings to be added.

Assessment items are at the back of this volume.

Assessment Recommendations

This teacher materials packet contains a few items suggested for classroom assessment. Often, three types of items are included. Some have been tested and reviewed, but not all.

1. Multiple-choice questions accompanied by short essays, called justification, that allow teachers to find out if students really understand their selections on the multiple choice.

2. Open-ended questions asking for essay responses.

3. Suggestions for performance tasks, usually including laboratory work, questions to be answered, data to be graphed and processed, and inferences to be made. Some tasks include proposals for student design of such tasks. These may sometimes closely resemble a good laboratory task, since the best types of laboratories are assessing student skills and performance at all times. Special assessment tasks will not be needed if measures such as questions, tabulations, graphs, calculations, etc., are incorporated into regular lab activities.

Teachers are encouraged to make changes in these items to suit their own classroom situations and to develop further items of their own, hopefully finding inspiration in the models we have provided. We hope you may consider adding your best items to our pool. We also will be very pleased to hear of proposed revisions to our items when you think they are needed.

Science as Inquiry

Periodicity

How can we discover patterns?

Overview:

Students at this level probably have used the periodic table and know how to locate elements. However, this activity does not assume that they have had this experience. Here students arrange the elements in an order that leads them to some repetitive pattern and a table of periodicity. Keep in mind they will develop their periodic table with much more information than Mendeleev had when he developed his table in 1869.

The objective of this activity is to look for repeating patterns of properties such as mass and density, to compare these patterns, and to determine how they relate to one another. Students are given a table of the alphabetized elements with values for properties but no atomic numbers. Included here for your reference is the same table with atomic numbers and a list in atomic number sequence. Do not give the standard periodic table to students until they have determined some patterns and grouped the elements accordingly.

Materials:

Per lab group:

table of elements in alphabetical order with properties but no atomic numbers (included in Student Materials)

Post-it® Notes, 1 pad (different color for each team, if possible)

periodic table, notebook size (Sargent Welch, catalog number s-18806, or any other standard periodic table with properties listed)

Procedure:

Have students work in teams of two or three. Assign each team a physical or chemical property—mass, boiling point, melting point, density, atomic radius, ionization potential, specific heat, electronegativity, or heat of fusion. Students then order the elements listed in their alphabetized table according to the values of the elements for the assigned property. They will need to decide how to organize the information. For example, for boiling point they might organize elements by placing them in increasing order.

When teams have the 88 elements organized, have them write the name of each element and its value for the assigned property on a Post-it® sheet and place these notes on the wall. After all of the properties have been posted, have the class compare the different arrangements and look for a pattern to form the basis of a periodic table. There are certain elements that are missing values for some of the properties. This will create a situation similar to that Mendeleev had to face when he was developing his periodic table.

After students have developed their table, have them compare it to the modern periodic table. Atomic number is the property that determines the order of elements on the standard table.

The second part of this activity is a class discussion focusing on student understanding of the periodic table and the physical states in which elements exist at the temperature assumed on the periodic table (room temperature). On most periodic tables the color of the element symbol changes depending on its state. How can you tell an element's physical state from the properties provided on the periodic table? Many students do not think of mercury as a metal since it is a liquid at room temperature. How would the appearance of elements change if the periodic table were rewritten for some other temperature, for example 100 ^{o}C? Students should note that some alkali metals exist as liquids at 100 ^{o}C.

Background:

Dimitri Ivanovich Mendeleev was a Russian chemist who developed a system of classifying elements. In 1869 he devised "The Periodic Table of Elements" by building upon the work of two other chemists—Johann Dobereiner and John Newlands.

Periodicity refers to the observation that when chemical elements are arranged in a certain way, their properties appear to repeat periodically. In 1817 Dobereiner observed that a number of groups of three elements (for example, calcium, strontium, and barium) had similar properties, with the middle element having properties that seemed to be approximately the average of the others in the trio. By 1863 more than 60 elements had been discovered, and there was a growing need to organize them in some fashion. Newlands arranged elements in ascending order by atomic weight, observing that the pattern of properties repeated with every eighth element. This pattern was called the "law of octaves" (a term borrowed from music). Newlands' table grouped elements in families and periods. Newlands did not receive much recognition for his work until 23 years later, some five years after Mendeleev was honored by the same organization.

A unique feature of Mendeleev's table was his use of blank spaces, or place holders, for elements that had not been discovered but were predicted by him to exist. The missing elements were later discovered, and their physical and chemical properties were found to be very similar to those he predicted. Mendeleev concentrated on the chemical properties of elements, arranging the elements in order of increasing atomic mass.

At about the same time as Mendeleev developed his periodic tablle, Julius Lothar Meyer of Germany independently devised a similar arrangement of the 57 elements known at that time, including place holders for the missing elements. Meyer focused on physical properties, such as atomic volume, malleability, and brittleness.

Vertical columns of elements in the periodic table are called groups or families, and horizontal rows of elements are called periods. Mendeleev's original table had 17 columns. Later, when the noble gases (helium, eon) were discovered, Mendeleev and other scientists suggested adding another column to the table. This group is 18 (VIIIA) of the modern table. Elements belonging to a group or family exhibit similar properties and have the same number of electrons in their outer electron shells. Elements in a period show a shift in properties from strongly metallic to strongly nonmetallic, with metalloids in between. Metalloids such as silicon and germanium exhibit properties of both metals and nonmetals.

The modern periodic table is arranged in ascending order by atomic number (not atomic mass) and has more than 100 elements. Henry Moseley, a British physicist, is credited for this arrangement. A number of newly discovered elements are synthetic and were made in laboratories. Element 101 was named mendelevium in honor of Mendeleev. Physicists have predicted the existence of elements with atomic numbers as high as 170.

An examination of the periodic table reveals that the densities of metals in a period increase as you move from left to right, with a few exceptions. The figure below shows the densities of elements 19–29 located in Period 4 and the densities of elements 37–45 located in Period 5. Note that density increases as atomic number increases.

Elements of Period 4 showing increasing density

19	20	21	22	23	24	25	26	27	28	29
0.89	1.54	2.99	4.50	6.00	7.15	7.30	7.87	8.86	8.90	8.96

Increasing density

Elements of Period 5 showing increasing density

37	38	39	40	41	42	43	44	45
1.53	2.64	4.47	6.52	8.57	10.22	11.00	12.10	12.40

Increasing density

Similarly, the atomic radius (particle size) of elements increases as you move from left to right in a period. This is because as you move from left to right, each element has an additional proton, which tends to bring the electron cloud a little closer to the nucleus and results in a smaller atomic radius. Atomic radius is a measure of the size of that particular atom. The figure below indicates that the atomic radii of elements 11-18 in Period 3 and elements 19-28 in Period 4 decrease as the atomic number increases.

Elements of Period 3 showing decreasing particle size

11	12	13	14	15	16	17
154	136	125	117	110	104	99

Decreasing particle size

Elements of Period 4 showing decreasing particle size

19	20	21	22	23	24	25	26	27	28
203	174	144	132	132	125	117	117	116	115

Decreasing particle size

Variations:

Students can actually test the physical and chemical properties of elements. Samples can be easily obtained.

Answers to Student Questions:

1. Compare your periodic table to the standard periodic table. How does your periodic table differ?

Answer: The students' periodic table should be very close to Mendeleev's table. Some exceptions will be noted in masses and densities.

2. How can you determine the physical state of an element (gas, liquid, or solid) at room temperature from the values in the periodic table? How many elements are there in each form?

Answer: The values listed for melting and boiling points tell us how elements would exist at room temperature (251°C or 298 K) and one atmosphere of pressure. In a 110-element table, 77 elements exist as solids, 2 exist as liquids, 11 exist as gases, and 20 exist synthetically.

3. The periodic table shows the state in which elements exist at room temperature. How many elements would exist in each form (solid, liquid, or gas) on a planet where room temperature is 100 °C?

Answer: Using a 110-element table, 70 elements would exist as solids, 9 would exist as liquids, and 12 would exist as gases (20 elements exist synthetically).

Adapted from: none

Table A

Element	Mass (amu)	Boiling Point (K)	Melting Point (K)	Density (g/cc)	Atomic Radii (angstroms)	Ionization Potential (electron voltage)	Specific Heat (J/g/K)	Electronegativity (Pauling's scale)	Heat of Fusion (kJ/mol)	Atomic Number
Aluminum	26.98	2740	933.5	2.7	1.82	5.986	0.9	1.61	10.7	13
Antimony	121.8	1860	903.91	6.69	1.53	8.641	0.207	2.05	19.83	51
Argon	39.95	87.45	83.95	0.001784	0.88	15.759	0.52	—	1.188	18
Arsenic	74.92	876 (subl.)	1090 (28 atm)	5.78	1.33	9.81	0.33	2.18	27.7	33
Astatine	210	610	575	—	1.43	—	—	2.2	12	85
Barium	137.3	2078	1002	3.59	2.78	5.212	0.204	0.89	8.01	56
Beryllium	9.01	3243	1560	1.85	1.4	9.322	1.825	1.57	11.71	4
Bismuth	209.0	1837	544.59	9.75	1.63	7.289	0.122	2.02	11	83
Boron	10.81	4275	2365	2.34	1.17	8.298	1.026	2.04	22.6	5
Bromine	79.9	331.85	265.95	3.12	1.12	11.814	0.226	2.96	5.286	35
Cadmium	112.4	1040	594.26	8.65	1.71	8.993	0.232	1.69	6.07	48
Calcium	40.08	1757	1112	1.55	2.23	6.113	0.647	1	8.53	20
Carbon	12.01	5100	3825	2.26	0.91	11.26	0.709	2.55	—	6
Cerium	140.1	3715	1071	6.77	2.7	5.47	0.19	1.12	9.2	58
Cesium	132.9	944	301.54	1.87	3.34	3.894	0.24	0.79	2.092	55
Chlorine	35.45	239.18	172.17	0.003214	0.97	12.967	0.48	3.16	3.21	17
Chromium	52	2945	2130	7.19	1.85	6.766	0.449	1.66	20	24
Cobalt	58.93	3143	1768	8.9	1.67	7.86	0.421	1.88	16.19	27
Copper	63.55	2840	1356.6	8.96	1.57	7.726	0.385	1.9	13.14	29
Dysprosium	162.5	2840	1685	8.55	2.49	5.93	0.173	1.22	11.96	66

Table A (cont.)

Element	Mass (amu)	Boiling Point (K)	Melting Point (K)	Density (g/cc)	Atomic Radii (angstroms)	Ionization Potential (electron voltage)	Specific Heat (J/g/K)	Electronegativity (Pauling's scale)	Heat of Fusion (kJ/mol)	Atomic Number
Erbium	167.3	3140	1802	9.07	2.45	6.101	0.168	1.24	17.15	68
Europium	152	1800	1095	5.24	2.56	5.67	0.182	1.2	10.46	63
Fluorine	19	85	53.55	0.001696	0.57	17.422	0.824	3.98	0.26	9
Francium	223	950	300	—	—	—	—	0.7	2.1	87
Gadolinium	157.3	3545	1585	7.9	2.54	6.15	0.236	1.2	15.48	64
Galium	69.72	2478	302.92	5.91	1.81	5.999	0.371	1.81	5.59	31
Germanium	72.61	3107	1211.5	5.32	1.52	7.899	0.32	2.01	31.8	32
Gold	197.0	3130	11337.58	19.3	1.79	9.225	0.128	2.54	12.36	79
Hafnium	178.5	4875	2504	13.31	2.16	6.65	0.14	1.3	21.76	72
Helium	4.0	4.216	0.95 (26 atm)	0.0001785	0.49	24.587	5.193	—	0.021	2
Homium	164.9	2968	1747	8.8	2.47	6.02	0.165	1.23	17.15	67
Hydrogen	1.01	20.28	13.81	0.0000899	0.79	13.598	14.304	2.1	0.0585	1
Indium	114.8	2350	429.78	7.31	2	5.786	0.233	1.78	3.26	49
Iodine	126.9	457.5	386.7	4.93	1.32	10.451	0.145	2.66	7.76	53
Iridium	192.2	4700	2720	22.6	1.87	9.1	0.13	2.2	26.36	77
Iron	55.85	3023	1808	7.874	1.72	7.87	0.449	1.83	13.8	26
Krypton	83.8	120.85	116	0.00375	1.03	13.999	0.248	—	1.638	36
Lathanum	138.9	3737	1191	6.15	2.74	5.58	0.19	1.1	11.3	57
Lead	207.2	2023	600.65	11.35	1.81	7.416	0.129	2.33	4.77	82

Table A (cont.)

Element	**Mass** (amu)	**Boiling Point** (K)	**Melting Point** (K)	**Density** (g/cc)	**Atomic Radii** (angstroms)	**Ionization Potential** (electron voltage)	**Specific Heat** (J/g/K)	**Electronegativity** (Pauling's scale)	**Heat of Fusion** (kJ/mol)	**Atomic Number**
Lutedium	175.0	3668	1936	9.84	2.25	5.43	0.15	1.27	18.6	71
Magnesium	24.3	1380	922	1.74	1.72	7.646	1.02	1.31	8.95	12
Manganese	54.94	2235	1518	7.44	1.79	7.435	0.48	1.55	1464	25
Mercury	200.6	629.88	234.31	13.55	1.76	10.437	0.14	2	2.292	80
Molybdenum	95.94	4912	2896	10.22	2.01	7.099	0.25	2.16	36	42
Neodymium	144.2	3347	1294	7.01	2.64	5.49	0.19	1.14	10.88	60
Neon	20.18	27.1	24.55	0.0009	0.51	21.564	1.03	—	0.34	10
Nickel	58.69	3005	1726	8.9	1.62	7.635	0.444	1.91	17.2	28
Nioblum	92.91	5015	2742	8.57	2.08	6.88	0.265	1.6	26.9	41
Nitrogen	14.01	77.344	63.15	0.001251	0.75	14.534	1.042	3.04	0.36	7
Osmium	190.2	5300	3300	22.6	1.92	8.7	0.13	2.2	29.29	76
Oxygen	16	90.188	54.8	0.001429	0.65	13.618	0.92	3.44	0.222	8
Palladium	106.4	3240	1825	12	1.79	8.34	0.244	2.2	16.74	46
Phosphorous	30.97	553	317.3	1.82	1.23	10.486	0.769	2.19	0.63	15
Platinum	195.1	4100	2042.1	21.45	1.83	9	0.13	2.28	19.66	78
Polonium	209	—	527	9.3	1.53	8.42	—	2	13	84
Potassium	39.1	1033	336.8	0.86	2.77	4.341	0.757	0.82	2.33	19
Praseodymium	140.9	3785	1204	6.77	2.67	5.42	0.193	1.13	10.04	59
Promethium	145	3273	1315	7.22	2.62	5.55	—	1.13	—	61
Radium	226	1413	973	5	—	5.279	0.094	0.89	8.37	88

Table A (cont.)

Element	**Mass** (amu)	**Boiling Point** (K)	**Melting Point** (K)	**Density** (g/cc)	**Atomic Radii** (angstroms)	**Ionization Potential** (electron voltage)	**Specific Heat** (J/g/K)	**Electronegativity** (Pauling's scale)	**Heat of Fusion** (kJ/mol)	**Atomic Number**
Radon	222	211.4	202	9.73	1.34	10.748	0.094	—	2.9	86
Rhenium	186.2	5870	3455	21	1.97	7.88	0.137	1.9	33.05	75
Rhodium	102.9	3970	2236	12.41	1.83	7.46	0.242	2.28	21.76	45
Rubidium	85.47	961	312.63	1.532	2.98	4.177	0.363	0.82	2.34	37
Ruthenium	101.1	4425	2610	12.37	1.89	7.37	0.238	2.2	25.52	44
Samarium	150.4	2067	1347	7.52	2.59	5.63	0.197	1.17	11.09	62
Scantium	44.96	3109	1814	2.99	2.09	6.54	0.568	1.36	16.11	21
Selenium	78.96	958	494	4.79	1.22	9.752	0.32	2.55	5.54	34
Silicon	28.09	2630	1683	2.33	1.46	8.151	0.7	1.9	50.2	14
Silver	107.9	2436	1235.08	10.5	1.75	7.576	0.235	1.93	11.3	47
Sodium	22.99	1156	371	0.97	2.23	5.139	1.23	0.93	2.601	11
Strontium	87.62	1655	1042	2.54	2.45	5.695	0.3	0.95	8.2	38
Sulfur	32.07	717.82	392.2	2.07	1.09	10.36	0.71	2.58	1.73	16
Tantalum	180.9	5730	3293	16.65	2.09	7.89	0.14	1.5	36	73
Technetium	98	4538	2477	11.5	1.95	7.28	0.24	1.9	23	43
Tellurium	127.6	1261	722.72	6.24	1.42	9.009	0.202	2.1	17.49	52
Terbium	158.9	3500	1629	8.23	2.51	5.86	0.18	1.1	—	65
Thallium	204.4	1746	577	11.85	2.08	6.108	0.129	2.04	4.27	81
Thullum	158.9	2223	1818	9.32	2.42	6.184	0.16	1.25	16.8	69
Tin	118.7	2876	505.12	7.31	1.72	7.344	0.228	1.96	7.2	50

Table A (cont.)

Element	**Mass** (amu)	**Boiling Point** (K)	**Melting Point** (K)	**Density** (g/cc)	**Atomic Radii** (angstroms)	**Ionization Potential** (electron voltage)	**Specific Heat** (J/g/K)	**Electronegativity** (Pauling's scale)	**Heat of Fusion** (kJ/mol)	**Atomic Number**
Titanium	47.88	3560	1935	4.54	2	6.82	0.523	1.54	18.6	22
Tungsten	183.9	5825	3695	19.3	2.02	7.98	0.13	2.36	35.4	74
Vanadium	50.94	3650	2163	6.11	1.92	6.74	0.489	1.63	22.8	23
Xenon	131.3	165.1	161.39	0.0059	1.24	12.13	0.158	2.6	2.3	54
Ytterbium	173	1469	1092	6.97	2.4	6.254	0.155	1.1	7.7	70
Yttrium	88.91	3611	1795	4.47	2.27	6.38	0.3	1.22	17.15	39
Zinc	65.39	1180	692.73	7.13	1.53	9.394	0.388	1.65	7.38	30
Zirconium	91.22	4682	2128	6.51	2.16	6.84	0.278	1.33	21	40

Table B

Element	Mass (amu)	Boiling Point (K)	Melting Point (K)	Density (g/cc)	Atomic Radii (angstroms)	Ionization Potential (electron voltage)	Specific Heat (J/g/K)	Electronegativity (Pauling's scale)	Heat of Fusion (kJ/mol)	Atomic Number
Hydrogen	1.01	20.28	13.81	0.0000899	0.79	13.598	14.304	2.1	0.0585	1
Helium	4	4.216	0.95 (26 atm)	0.0001785	0.49	24.587	5.193	—	0.021	2
Lithium	6.94	1615	453.7	0.53	2.05	5.382	3.582	0.98	3	3
Beryllium	9.01	3243	1560	1.85	1.4	9.322	1.825	1.57	11.71	4
Boron	10.81	4275	2365	2.34	1.17	8.298	1.026	2.04	22.6	5
Carbon	12.01	5100	3825	2.26	0.91	11.26	0.709	2.55	—	6
Nitrogen	14.01	77.344	63.15	0.001251	0.75	14.534	1.042	3.04	0.36	7
Oxygen	16	90.188	54.8	0.001429	0.65	13.618	0.92	3.44	0.222	8
Fluorine	19	85	53.55	0.001696	0.57	17.422	0.824	3.98	0.26	9
Neon	20.18	27.1	24.55	0.0009	0.51	21.564	1.03	—	0.34	10
Sodium	22.99	1156	371	0.97	2.23	5.139	1.23	0.93	2.601	11
Magnesium	24.3	1380	922	1.74	1.72	7.646	1.02	1.31	8.95	12
Aluminum	26.98	2740	933.5	2.7	1.82	5.986	0.9	1.61	10.7	13
Silicon	28.09	2630	1683	2.33	1.46	8.151	0.7	1.9	50.2	14
Phosphorous	30.97	553	317.3	1.82	1.23	10.486	0.769	2.19	0.63	15
Sulfur	32.07	717.82	392.2	2.07	1.09	10.36	0.71	2.58	1.73	16
Chlorine	35.45	239.18	172.17	0.003214	0.97	12.967	0.48	3.16	3.21	17
Argon	39.95	87.45	83.95	0.001784	0.88	15.759	0.52	—	1.188	18
Potassium	39.1	1033	336.8	0.86	2.77	4.341	0.757	0.82	2.33	19
Calcium	40.08	1757	1112	1.55	2.23	6.113	0.647	1	8.53	20

Table B (cont.)

Element	**Mass** (amu)	**Boiling Point** (K)	**Melting Point** (K)	**Density** (g/cc)	**Atomic Radii** (angstroms)	**Ionization Potential** (electron voltage)	**Specific Heat** (J/g/K)	**Electronegativity** (Pauling's scale)	**Heat of Fusion** (kJ/mol)	**Atomic Number**
Scantium	44.96	3109	1814	2.99	2.09	6.54	0.568	1.36	16.11	21
Titanium	47.88	3560	1935	4.54	2	6.82	0.523	1.54	18.6	22
Vanadium	50.94	3650	2163	6.11	1.92	6.74	0.489	1.63	22.8	23
Chromium	52	2945	2130	7.19	1.85	6.766	0.449	1.66	20	24
Manganese	54.94	2235	1518	7.44	1.79	7.435	0.48	1.55	1464	25
Iron	55.85	3023	1808	7.874	1.72	7.87	0.449	1.83	13.8	26
Cobalt	58.93	3143	1768	8.9	1.67	7.86	0.421	1.88	16.19	27
Nickel	58.69	3005	1726	8.9	1.62	7.635	0.444	1.91	17.2	28
Copper	63.55	2840	1356.6	8.96	1.57	7.726	0.385	1.9	13.14	29
Zinc	65.39	1180	692.73	7.13	1.53	9.394	0.388	1.65	7.38	30
Galium	69.72	2478	302.92	5.91	1.81	5.999	0.371	1.81	5.59	31
Germanium	72.61	3107	1211.5	5.32	1.52	7.899	0.32	2.01	31.8	32
Arsenic	74.92	876 (subl.)	1090 (28 atm)	5.78	1.33	9.81	0.33	2.18	27.7	33
Selenium	78.96	958	494	4.79	1.22	9.752	0.32	2.55	5.54	34
Bromine	79.9	331.85	265.95	3.12	1.12	11.814	0.226	2.96	5.286	35
Krypton	83.8	120.85	116	0.00375	1.03	13.999	0.248	—	1.638	36
Rubidium	85.47	961	312.63	1.532	2.98	4.177	0.363	0.82	2.34	37
Strontium	87.62	1655	1042	2.54	2.45	5.695	0.3	0.95	8.2	38
Yttrium	88.91	3611	1795	4.47	2.27	6.38	0.3	1.22	17.15	39
Zirconium	91.22	4682	2128	6.51	2.16	6.84	0.278	1.33	21	40

Table A (cont.)

Element	Mass (amu)	Boiling Point (K)	Melting Point (K)	Density (g/cc)	Atomic Radii (angstroms)	Ionization Potential (electron voltage)	Specific Heat (J/g/K)	Electronegativity (Pauling's scale)	Heat of Fusion (kJ/mol)	Atomic Number
Nioblum	92.91	5015	2742	8.57	2.08	6.88	0.265	1.6	26.9	41
Molybdenum	95.94	4912	2896	10.22	2.01	7.099	0.25	2.16	36	42
Technetium	98	4538	2477	11.5	1.95	7.28	0.24	1.9	23	43
Ruthenium	101.1	4425	2610	12.37	1.89	7.37	0.238	2.2	25.52	44
Rhodium	102.9	3970	2236	12.41	1.83	7.46	0.242	2.28	21.76	45
Palladium	106.4	3240	1825	12	1.79	8.34	0.244	2.2	16.74	46
Silver	107.9	2436	1235.08	10.5	1.75	7.576	0.235	1.93	11.3	47
Cadmium	112.4	1040	594.26	8.65	1.71	8.993	0.232	1.69	6.07	48
Indium	114.8	2350	429.78	7.31	2	5.786	0.233	1.78	3.26	49
Tin	118.7	2876	505.12	7.31	1.72	7.344	0.228	1.96	7.2	50
Antimony	121.8	1860	903.91	6.69	1.53	8.641	0.207	2.05	19.83	51
Tellurium	127.6	1261	722.72	6.24	1.42	9.009	0.202	2.1	17.49	52
Iodine	126.9	457.5	386.7	4.93	1.32	10.451	0.145	2.66	7.76	53
Xenon	131.3	165.1	161.39	0.0059	1.24	12.13	0.158	2.6	2.3	54
Cesium	132.9	944	301.54	1.87	3.34	3.894	0.24	0.79	2.092	55
Barium	137.3	2078	1002	3.59	2.78	5.212	0.204	0.89	8.01	56
Lathanum	138.9	3737	1191	6.15	2.74	5.58	0.19	1.1	11.3	57
Cerium	140.1	3715	1071	6.77	2.7	5.47	0.19	1.12	9.2	58
Praseodymium	140.9	3785	1204	6.77	2.67	5.42	0.193	1.13	10.04	59
Neodymium	144.2	3347	1294	7.01	2.64	5.49	0.19	1.14	10.88	60

Table B (cont.)

Element	**Mass** (amu)	**Boiling Point** (K)	**Melting Point** (K)	**Density** (g/cc)	**Atomic Radii** (angstroms)	**Ionization Potential** (electron voltage)	**Specific Heat** (J/g/K)	**Electronegativity** (Pauling's scale)	**Heat of Fusion** (kJ/mol)	**Atomic Number**
Promethium	145	3273	1315	7.22	2.62	5.55	—	1.13	—	61
Samarium	150.4	2067	1347	7.52	2.59	5.63	0.197	1.17	11.09	62
Europium	152	1800	1095	5.24	2.56	5.67	0.182	1.2	10.46	63
Gadolinium	157.3	3545	1585	7.9	2.54	6.15	0.236	1.2	15.48	64
Terbium	158.9	3500	1629	8.23	2.51	5.86	0.18	1.1	—	65
Dysprosium	162.5	2840	1685	8.55	2.49	5.93	0.173	1.22	11.96	66
Homium	164.9	2968	1747	8.8	2.47	6.02	0.165	1.23	17.15	67
Erbium	167.3	3140	1802	9.07	2.45	6.101	0.168	1.24	17.15	68
Thullum	158.9	2223	1818	9.32	2.42	6.184	0.16	1.25	16.8	69
Ytterbium	173	1469	1092	6.97	2.4	6.254	0.155	1.1	7.7	70
Lutedium	175.0	3668	1936	9.84	2.25	5.43	0.15	1.27	18.6	71
Hafnium	178.5	4875	2504	13.31	2.16	6.65	0.14	1.3	21.76	72
Tantalum	180.9	5730	3293	16.65	2.09	7.89	0.14	1.5	36	73
Tungsten	183.9	5825	3695	19.3	2.02	7.98	0.13	2.36	35.4	74
Rhenium	186.2	5870	3455	21	1.97	7.88	0.137	1.9	33.05	75
Osmium	190.2	5300	3300	22.6	1.92	8.7	0.13	2.2	29.29	76
Iridium	192.2	4700	2720	22.6	1.87	9.1	0.13	2.2	26.36	77
Platinum	195.1	4100	2042.1	21.45	1.83	9	0.13	2.28	19.66	78
Gold	197.0	3130	11337.58	19.3	1.79	9.225	0.128	2.54	12.36	79
Mercury	200.6	629.88	234.31	13.55	1.76	10.437	0.14	2	2.292	80

Table B (cont.)

Element	**Mass** (amu)	**Boiling Point** (K)	**Melting Point** (K)	**Density** (g/cc)	**Atomic Radii** (angstroms)	**Ionization Potential** (electron voltage)	**Specific Heat** (J/g/K)	**Electronegativity** (Pauling's scale)	**Heat of Fusion** (kJ/mol)	**Atomic Number**
Thallium	204.4	1746	577	11.85	2.08	6.108	0.129	2.04	4.27	81
Lead	207.2	2023	600.65	11.35	1.81	7.416	0.129	2.33	4.77	82
Bismuth	209.0	1837	544.59	9.75	1.63	7.289	0.122	2.02	11	83
Polonium	209	—	527	9.3	1.53	8.42	—	2	13	84
Astatine	210	610	575	—	1.43	—	—	2.2	12	85
Radon	222	211.4	202	9.73	1.34	10.748	0.094	—	2.9	86
Francium	223	950	300	—	—	—	—	0.7	2.1	87
Radium	226	1413	973	5	—	5.279	0.094	0.89	8.37	88

Science as Inquiry

Graphing the Elements

What can graphs reveal about the patterns of elements?

Overview:

Periodicity of the elements is easily seen by graphing their physical and chemical properties. In this activity, students graph a property of elements as a function of atomic number. They then create a three-dimensional model of their data in the form of the periodic table.

It is recommended that student teams be assigned the same property for which they ordered data in Activity 1. Values for most properties can be found in periodic tables. Other sources are the Internet, chemistry handbooks, and textbooks, as well as the students' table of values from Activity 1.

Materials:

Per lab group:

graph paper
colored pencils (optional)
references (periodic tables, textbooks, etc.)
materials for the three-dimensional model:
- option 1:
  - 96-well plates, 2
  - soda straws of different colors (that fit into the 96-well plate), 30–40
- option 2:
  - Styrofoam® block (10 in × 12 in)
  - dowels (1/4 in), skewers, or copper wire)
- option 3:
  - plywood (10 in × 12 in) with drilled holes
  - skewers or copper wire

Procedure:

Have students tabulate values for their assigned property and prepare a graph of the property as a function of atomic number. In almost all cases the first 88 elements (hydrogen to radium) have values listed for the different properties. There are a few exceptions. Some of the noble gases, for example, are missing electronegativity. Students should place property values on the y axis and atomic numbers on the x axis, connecting the points with a smooth line. If they want to be creative, they could use pencils of different colors for the periods. This may help them see periodicity.

The three-dimensional model can be developed in several ways. The most common method uses two 96-well plates taped together. This allows 18 columns, 6 periods, and the lanthanide series, similar to the standard long form of the periodic table. Students should scale straws to be proportional to the units of the assigned property, taking into account the depth of the wells. Straws of different colors could be used for different periods, different states (gas, liquid, solid), different families (columns), or for metals, nonmetals, and semimetals, as is done in many standard textbooks.

Alternative approaches involve inserting lengths of sticks or copper wire into Styrofoam® or plywood. Regardless of which system is used, the depths must be constant. If you choose to use plywood, you will need a drill and bit to make the holes.

Background:

Students will be able to see several patterns in their line graphs. For example, as atomic number increases, density generally increases. This trend can be easily translated into the periodic table. When moving from left to right in a period, the density of the elements increases. As atomic number increases, particle size decreases.

Some definitions of properties may be useful:

Mass: The weighted average of the masses of the isotopes of an element. For example, about 75% of chlorine has a mass of 35 and 25% of chlorine has mass of 37. Therefore, $(0.75 \times 35.0) + (0.25 \times 37.0) = 35.5$.

Boiling point: The temperature at which the vapor pressure of a liquid is just equal to the external pressure on the liquid. In almost all cases we use one atmosphere of pressure (760 mm of Hg) as the external pressure. This is called the normal boiling point. The temperature can be expressed in degrees Celsius or Kelvins. ($K = {}^{o}C + 273$.) Note that absolute temperature is expressed in Kelvins , not in degrees Kelvin.

Melting point: The temperature at which a substance changes from a solid to a liquid. The temperature can be expressed in Kelvins or degrees Celsius.

Density: The ratio of the mass of an object to its volume. Units commonly used are g/mL, g/cc and g/L.

Atomic radius: Theoretically the outer boundary of an atom is never reached. The size of an atom is measured by the most probable distance from the nucleus to the outer-shell electron(s) based on reproducible results. The distance is measured in angstroms. An angstrom = 10^{-8} cm.

Ionization potential: The amount of energy required to remove an electron from a gaseous atom. In measuring this energy, an electron-volt = 1.6×10^{-19} joule (J) or kJ/mole. As an example of converting electron-volts to joules, hydrogen's electron voltage = 13.598 eV. In kJ/mol = $(13.598 \text{ eV} \times 1.6 \times 10^{-19} \text{J/eV}) \times 1 \text{ kJ}/1000 \text{ J} \times 6.02 \times 10^{23}$atoms/mol = 1310. ???

Specific heat: The amount of heat required to raise the temperature of 1 g of a substance by 1°C.

Electronegativity: A scale that was created to measure the tendency of an atom to attract electrons to itself when combined with another element.

Heat of fusion: The amount of heat required to melt 1 mole of a particular substance.

It is amazing that Mendeleev was able to place elements in the correct order while also leaving spaces for chemicals that had not been discovered. However, he encountered some problems in placement, such as with tellurium and iodine. If he put them in order of increasing atomic mass they would be in the wrong order based on other properties. So Mendeleev violated his own rule and placed the two elements in the order currently used. We now realize that atomic mass is not the true basis of periodic repetition of the properties of elements.

Answers to Student Questions:

1. Define the property you were assigned and explain how you would use it to look for a pattern among the elements.

Answer: See the above definitions.

2. Predict the missing values missing on your graph. Use references to check the accuracy of your predictions.

Answer: The periodic table lists acceptable values. Predicted values should be very close to those listed.

3. Based on your graph and three-dimensional model, what value would you assign to a new element with an atomic number of 113?

Answer: Values for element 113 should be similar to those for the boron family, or group III. For example, density should be greater than 11.85, melting point should be greater than 577 K, etc.

4. The Russian chemist Dimitri Mendeleev is given credit for developing the periodic table in 1869. Shortly after, Julius Meyer, a German physicist, published his own periodic table, which was similar to Mendeleev's. Neither of these scientists was aware all of the elements and yet each was able to develop the table. What complete family of elements were they missing, and why?

Answer: The noble gases. It is easy to understand their omission since they are rare and do not readily react with other chemicals under normal conditions due to their stable electron configuration.

5. Since early chemists used atomic mass (called atomic weight at that time) rather than atomic number as the basis for the periodic table, there were at least six elements that didn't seem to fit in the proper places. It was assumed that their masses had been measured incorrectly. In fact, the masses were correct and there was another explanation for the positions of these elements in the table. Scientists can be right for the wrong reason! What were the six elements?

Answer: Cobalt and nickel, tellurium and iodine, and uranium and neptunium.

Adapted from: none

Science as Inquiry

Exceptions

Item:

There are a few exceptions to the rule that atomic mass increases as atomic number increases, for example, tellurium and iodine. Explain why these elements are in the order given in the periodic table.

Answer:

Elements having similar properties are placed in the same column. Iodine behaves like a halogen, the elements of Group VII, and tellurium shares properties with Group VI elements.

Science as Inquiry

Ionization Energy

Item:

As you move down a column of the periodic table, the atomic radius increases and ionization energy decreases. Explain why ionization energy decreases.

Answer:

As an atom gets larger due to new electrons entering shells farther from the nucleus, electrons are more easily removed from the atom. Like the game crack-the-whip, as the chain gets bigger the object at the end of the chain is more easily dislodged.

Science as Inquiry

Second Ionization Energy

Item:

The first ionization energies of potassium and calcium are given in the periodic table. How would the second ionization energy of potassium compare with that of calcium?

Answer:

The second electron to be removed from potassium is its noble gas electron of argon. Whereas, the second electron removed from calcium is its potassium electron. Hence, the second ionization energy of calcium should be less than that of potassium.

Consumables

Item	Quantity per lab group	Activity
alphabetized table of properties of elements (included with Student Materials)	1	1
colored pencils (optional)	—	2
graph paper	—	2
materials for 3-dimensional model		
Option 1:		
96-well plates	2	2
soda straws (of different colors)	30–40	2
Option 2:		
Styrofoam® block (10 in × 12 in)	1	2
dowels (1/4 in), skewers, or copper wire	—	2
Option 3:		
plywood (10 in × 12 in) with drilled holes	1	2
skewers or copper wire	—	2
periodic table, notebook size (Sargent Welch, catalog No. s-18806, or any standard form of the periodic table)	1 per student	1
Post-it® Notes	1 pad (different color for each team)	1

Nonconsumables

Item	Quantity per lab group	Activity
well plates, Styrofoam®, and plywood, see above	—	2
references (periodic tables, textbooks, etc.)	—	2

Key to activities:
1. Periodicity
2. Graphing the Elements