

# Structure of the Atom

## Reading Guide

### What You'll Learn

- **Identify** the names and symbols of common elements.
- **Identify** quarks as subatomic particles of matter.
- **Describe** the electron cloud model of the atom.
- **Explain** how electrons are arranged in an atom.

### Why It's Important

Everything that you see, touch, and breathe is composed of tiny atoms.



### Review Vocabulary

**element:** substance with atoms that are all alike

### New Vocabulary

- atom
- nucleus
- proton
- neutron
- electron
- quark
- electron cloud

## Scientific Shorthand

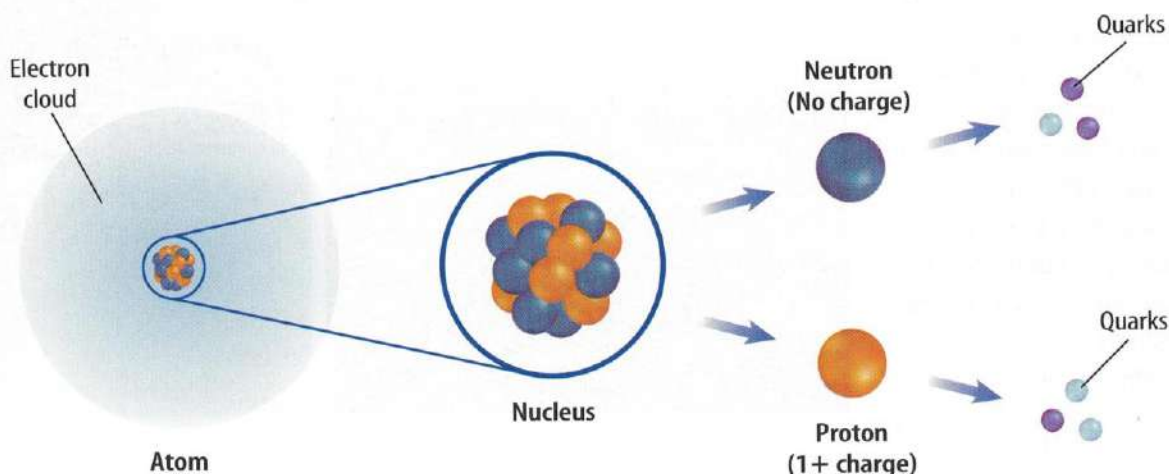
Do you have a nickname? Do you use abbreviations for long words or the names of states? Scientists also do this. In fact, scientists have developed their own shorthand for dealing with long, complicated names.

Do the letters C, Al, Ne, and Ag mean anything to you? Each letter or pair of letters is a chemical symbol, which is a short or abbreviated way to write the name of an element. Chemical symbols, such as those in **Table 1**, consist of one capital letter or a capital letter plus one or two small letters. For some elements,

the symbol is the first letter of the element's name. For other elements, the symbol is the first letter of the name plus another letter from its name. Some symbols are derived from Latin. For instance, *Argentum* is Latin for "silver." Elements have been named in a variety of ways. Some elements are named to honor scientists, for places, or for their properties. Other elements are named using rules established by an international committee. Regardless of the origin of the name, scientists derived this international system for convenience. It is much easier to write H for hydrogen, O for oxygen, and H<sub>2</sub>O for dihydrogen oxide (water). Because scientists worldwide use this system, everyone understands what the symbols mean.

**Table 1 Symbols of Some Elements**

Element	Symbol	Element	Symbol
Aluminum	Al	Iron	Fe
Calcium	Ca	Mercury	Hg
Carbon	C	Nitrogen	N
Chlorine	Cl	Oxygen	O
Gold	Au	Potassium	K
Hydrogen	H	Sodium	Na



## Atomic Components

An element is matter that is composed of one type of **atom**, which is the smallest piece of matter that still retains the property of the element. For example, the element silver is composed of only silver atoms and the element hydrogen is composed of only hydrogen atoms. Atoms are composed of particles called protons, neutrons, and electrons, as shown in **Figure 1**. Protons and neutrons are found in a small, positively-charged center of the atom called the **nucleus** that is surrounded by a cloud containing electrons. **Protons** are particles with an electrical charge of  $1+$ . **Neutrons** are neutral particles that do not have an electrical charge. **Electrons** are particles with an electrical charge of  $1-$ . Atoms of different elements differ in the number of protons they contain.



**Reading Check**

*What are the particles that make up the atom and where are they located?*

## Quarks—Even Smaller Particles

Are the protons, electrons, and neutrons that make up atoms the smallest particles that exist? Scientists hypothesize that electrons are not composed of smaller particles and are one of the most basic types of particles. Protons and neutrons, however, are made up of smaller particles called **quarks**. So far, scientists have confirmed the existence of six uniquely different quarks. Scientists theorize that an arrangement of three quarks held together with the strong nuclear force produces a proton. Another arrangement of three quarks produces a neutron. The search for the composition of protons and neutrons is an ongoing effort.

**Figure 1** The nucleus of the atom contains protons and neutrons that are composed of quarks. The proton has a positive charge and the neutron has no charge. A cloud of negatively charged electrons surrounds the nucleus of the atom.

**Scienceonline**

**Topic: Particle Research**

Visit [gpscience.com](http://gpscience.com) for Web links to information about particle research at Fermi National Accelerator Laboratory.

**Activity** Write a paragraph describing the information that you found at the site.

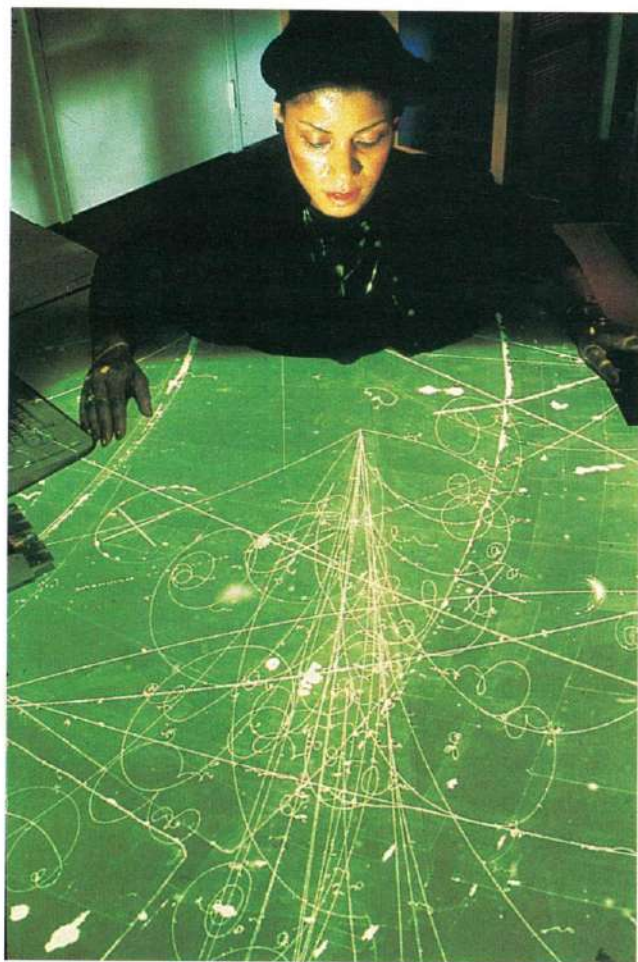


**Figure 2** The Tevatron is a huge machine. The aerial photograph of Fermi National Accelerator Laboratory shows the circular outline of the Tevatron particle accelerator. The close-up photograph of the Tevatron gives you a better view of the tunnel.

**Infer** Why is such a long tunnel needed?



**Figure 3** Bubble chambers can be used by scientists to study the tracks left by subatomic particles.



**Finding Quarks** To study quarks, scientists accelerate charged particles to tremendous speeds and then force them to collide with—or smash into—protons. This collision causes the proton to break apart. The Fermi National Accelerator Laboratory, a research laboratory in Batavia, Illinois, houses a machine that can generate the forces that are required to collide protons. This machine, the Tevatron, shown in **Figure 2**, is approximately 6.4 km in circumference. Electric and magnetic fields are used to accelerate, focus and collide the fast-moving particles.

The particles that result from the collision can be detected by various collection devices. Often, scientists use multiple collection devices to collect the most possible information about the particles created in a collision. Just as police investigators can reconstruct traffic accidents from tire marks and other clues at the scene, scientists are able to examine and gather information about the particles, as shown in **Figure 3**. Scientists use inference to identify the subatomic particles and to reveal information about each particle's inner structure.

**The Sixth Quark** Finding evidence for the existence of the quarks was not an easy task. Scientists found five quarks and hypothesized that a sixth quark existed. However, it took a team of nearly 450 scientists from around the world several years to find the sixth quark. The tracks of the sixth quark were hard to detect because only about one billionth of a percent of the proton collisions performed showed the presence of a sixth quark—typically referred to as the *top* quark.

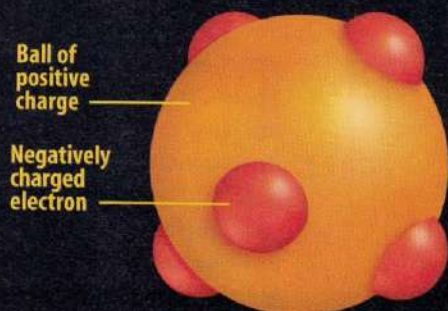


**Figure 5**

**T**he ancient Greek philosopher Democritus proposed that elements consisted of tiny, solid particles that could not be subdivided (A). He called these particles *atomos*, meaning “uncuttable.” This concept of the atom’s structure remained largely unchallenged until the 1900s, when researchers began to discover through experiments that atoms were composed of still smaller particles. In the early 1900s, a number of models for atomic structure were proposed (B-D). The currently accepted model (E) evolved from these ideas and the work of many other scientists.



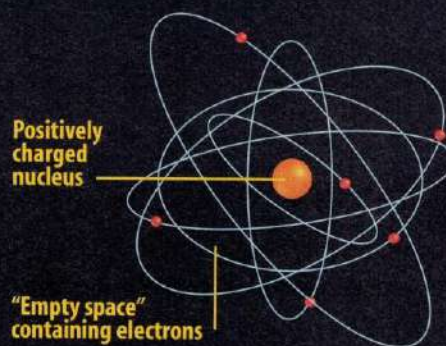
**A** **DEMOCRITUS'S UNCUTTABLE ATOM**



Ball of positive charge

Negatively charged electron

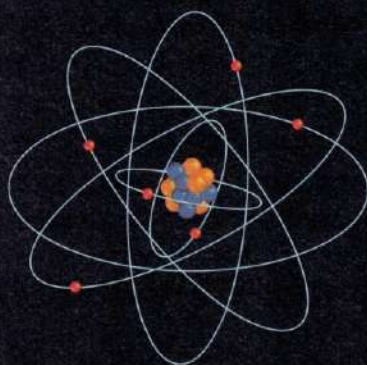
**B** **THOMSON MODEL, 1904** English physicist Joseph John Thomson inferred from his experiments that atoms contained small, negatively charged particles. He thought these “electrons” (in red) were evenly embedded throughout a positively charged sphere, much like chocolate chips in a ball of cookie dough.



Positively charged nucleus

“Empty space” containing electrons

**C** **RUTHERFORD MODEL, 1911** Another British physicist, Ernest Rutherford, proposed that almost all the mass of an atom—and all its positive charges—were concentrated in a central atomic nucleus surrounded by electrons.



**D** **BOHR MODEL, 1913** Danish physicist Niels Bohr hypothesized that electrons traveled in fixed orbits around the atom’s nucleus. James Chadwick, a student of Rutherford, concluded that the nucleus contained positive protons and neutral neutrons.

Electron cloud

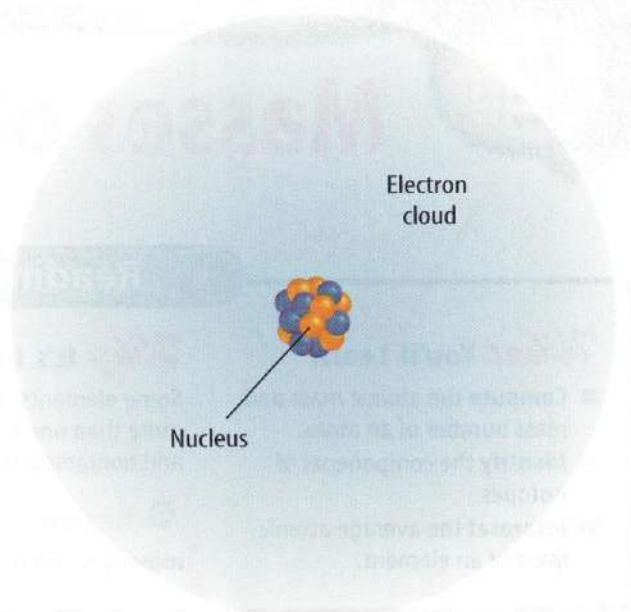
Nucleus

**E** **ELECTRON CLOUD MODEL, CURRENT** According to the currently accepted model of atomic structure, electrons do not follow fixed orbits but tend to occur more frequently in certain areas around the nucleus at any given time.



**The Electron Cloud Model** By 1926, scientists had developed the electron cloud model of the atom that is in use today. An **electron cloud** is the area around the nucleus of an atom where its electrons are most likely found. The electron cloud is 100,000 times larger than the diameter of the nucleus. In contrast, each electron in the cloud is much smaller than a single proton.

Because an electron's mass is small and the electron is moving so quickly around the nucleus, it is impossible to describe its exact location in an atom. Picture the spokes on a moving bicycle wheel. They are moving so quickly that you can't pinpoint any single spoke. All you see is a blur that contains all of the spokes somewhere within it. In the same way, an electron cloud is a blur containing all of the electrons of the atom somewhere within it. **Figure 6** illustrates what the electron cloud might look like.



**Figure 6** The electrons are located in an electron cloud surrounding the nucleus of the atom.

## section

## 1

## review

### Summary

#### Scientific Shorthand

- Scientists use chemical symbols as shorthand when naming elements.

#### Atomic Components

- Atoms are composed of small particles that have known charges.
- The particles that make up the atom are located in predictable locations within the atom.

#### Quarks—Even Smaller Particles

- So far, scientists have confirmed the existence of six different quarks.

#### Models—Tools for Scientists

- Models are used by scientists to simplify the study of concepts and things.
- The current atomic model is an accumulation of over two hundred years of knowledge.
- The electron cloud model is the current atomic model.

### Self Check

1. **List** the chemical symbols for the elements carbon, aluminum, hydrogen, oxygen, and sodium.
2. **Identify** the names, charges, and locations of three kinds of particles that make up an atom.
3. **Identify** the smallest particle of matter. How were they discovered?
4. **Describe** the electron cloud model of the atom.
5. **Think Critically** Explain how a rotating electric fan might be used to model the atom. Explain how the rotating fan is unlike an atom.

### Applying Math

6. **Use Numbers** The mass of a proton is estimated to be  $1.6726 \times 10^{-24}$  g and the mass of an electron is estimated to be  $9.1093 \times 10^{-28}$  g. How many times larger is the mass of a proton compared to the mass of an electron?
7. **Calculate** What is the difference between the mass of a proton and the mass of an electron?



# Masses of Atoms

## Reading Guide

### What You'll Learn

- **Compute** the atomic mass and mass number of an atom.
- **Identify** the components of isotopes.
- **Interpret** the average atomic mass of an element.

### Why It's Important

Some elements naturally exist in more than one form—radioactive and nonradioactive.

### Review Vocabulary

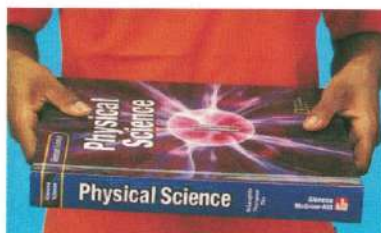
**mass:** amount of matter in an object

### New Vocabulary

- atomic number
- mass number
- isotope
- average atomic mass

**Table 2 Subatomic Particle Masses**

Particle	Mass (g)
Proton	$1.6726 \times 10^{-24}$
Neutron	$1.6749 \times 10^{-24}$
Electron	$9.1093 \times 10^{-28}$



**Figure 7** If you held a textbook and placed a paper clip on it, you wouldn't notice the added mass because the mass of a paper clip is small compared to the mass of the book. In a similar way, the masses of an atom's electrons are negligible compared to an atom's mass.

## Atomic Mass

The nucleus contains most of the mass of the atom because protons and neutrons are far more massive than electrons. The mass of a proton is about the same as that of a neutron—approximately  $1.6726 \times 10^{-24}$  g, as shown in **Table 2**. The mass of each is approximately 1,836 times greater than the mass of the electron. The electron's mass is so small that it is considered negligible when finding the mass of an atom, as shown in **Figure 7**.

If you were asked to estimate the height of your school building, you probably wouldn't give an answer in kilometers. The number would be too cumbersome to use. Considering the scale of the building, you would more likely give the height in a smaller unit, meters. When thinking about the small masses of atoms, scientists found that even grams were not small enough to use for measurement. Scientists need a unit that results in more manageable numbers. The unit of measurement used for atomic particles is the atomic mass unit (amu). The mass of a proton or a neutron is almost equal to 1 amu. This is not coincidence—the unit was defined that way. The atomic mass unit is defined as one-twelfth the mass of a carbon atom containing six protons and six neutrons. Remember that the mass of the carbon atom is contained almost entirely in the mass of the protons and neutrons that are located in the nucleus. Therefore, each of the 12 particles in the nucleus must have a mass nearly equal to one.

### Reading Check

*Where is the majority of the mass of an atom located?*





**Carbon Dating** Living organisms on Earth contain carbon. Carbon-12 makes up 99 percent of this carbon. Carbon-13 and carbon-14 make up the other one percent. Which isotopes are archaeologists most interested in when they determine the age of carbon-containing remains? Explain your answer in your Science Journal.

## Isotopes

Not all the atoms of an element have the same number of neutrons. Atoms of the same element that have different numbers of neutrons are called **isotopes**. Suppose you have a sample of the element boron. Naturally occurring atoms of boron have mass numbers of 10 or 11. How many neutrons are in a boron atom? It depends upon the isotope of boron to which you are referring. Obtain the number of protons in boron from the periodic table. Then use the formula on the previous page to calculate the number of neutrons in each boron isotope. You can determine that boron can have five or six neutrons.



### Reading Check

*Uranium-238 has 92 protons. How many neutrons does it have?*

## Applying Science

### Radioactive Isotopes Help Tell Time

**A**tom s can be used to measure the age of bones or rock formations that are millions of years old. The time it takes for half of the radioactive atoms in a piece of rock or bone to change into another element is called its half-life. Scientists use the half-lives of radioactive isotopes to measure geologic time.

#### Half-Lives of Radioactive Isotopes

Radioactive Element	Changes to This Element	Half-Life
uranium-238	lead-206	4,460 million years
potassium-40	argon-40, calcium-40	1,260 million years
rubidium-87	strontium-87	48,800 million years
carbon-14	nitrogen-14	5,715 years

#### Identifying the Problem

The table above lists the half-lives of a sample of radioactive isotopes and into which elements they change. For example, it would take 5,715 years for half of the carbon-14 atoms in a rock to change into atoms of nitrogen-14. After another 5,715 years, half of the remaining carbon-14 atoms will change, and so on. You can use these radioactive clocks to measure different periods of time.

#### Solving the Problem


1. How many years would it take half of the rubidium-87 atoms in a piece of rock to change into strontium-87? How many years would it take for 75% of the atoms to change?
2. After a long period, only 25% of the atoms in a rock remained uranium-238. How many years old would you predict the rock to be? The other 75% of the atoms are now which radioactive element?

**Table 3 Mass Numbers of Some Atoms**

Element	Symbol	Atomic Number	Protons	Neutrons	Mass Number	Average Atomic Mass*
Boron	B	5	5	6	11	10.81 amu
Carbon	C	6	6	6	12	12.01 amu
Oxygen	O	8	8	8	16	16.00 amu
Sodium	Na	11	11	12	23	22.99 amu
Copper	Cu	29	29	34	63	63.55 amu

\*The atomic mass units are rounded to two decimal places.

**Protons Identify the Element** You learned earlier that atoms of different elements are different because they have different numbers of protons. In fact, the number of protons tells you what type of atom you have and vice versa. For example, every carbon atom has six protons. Also, all atoms with six protons are carbon atoms. Atoms with eight protons are oxygen atoms. The number of protons in an atom is equal to a number called the **atomic number**. The atomic number of carbon is six. Therefore, if you are given any one of the following—the name of the element, the number of protons in the element, or the atomic number of the element, you can determine the other two.

 **Reading Check** Which element is an atom with six protons in the nucleus?

**Mass Number** The **mass number** of an atom is the sum of the number of protons and the number of neutrons in the nucleus of an atom. Look at **Table 3** and see if this is true.

If you know the mass number and the atomic number of an atom, you can calculate the number of neutrons. The number of neutrons is equal to the atomic number subtracted from the mass number.

$$\text{number of neutrons} = \text{mass number} - \text{atomic number}$$

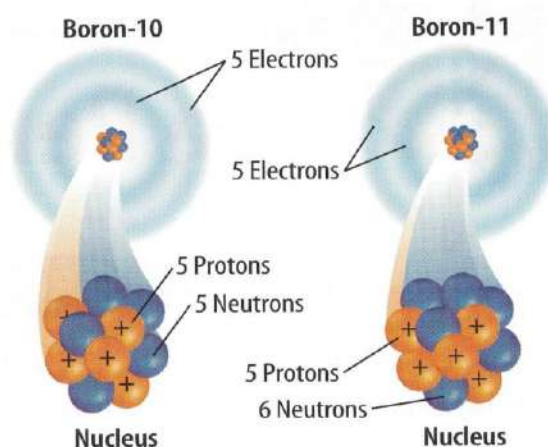
Atoms of the same element with different numbers of neutrons can have different properties. For example, carbon with a mass number equal to 12, or carbon-12, is the most common form of carbon. Carbon-14 is present on Earth in much smaller quantities. Carbon-14 is radioactive and carbon-12 is not.



**Identifying Isotopes** Models of two isotopes of boron are shown in **Figure 8**. Because the numbers of neutrons in the isotopes are different, the mass numbers are also different. You use the name of the element followed by the mass number of the isotope to identify each isotope: boron-10 and boron-11. Because most elements have more than one isotope, each element has an average atomic mass. The **average atomic mass** of an element is the weighted-average mass of the mixture of its isotopes. For example, four out of five atoms of boron are boron-11, and one out of five is boron-10. To find the weighted-average or the average atomic mass of boron, you would solve the following equation:

$$\frac{4}{5}(11 \text{ amu}) + \frac{1}{5}(10 \text{ amu}) = 10.8 \text{ amu}$$

The average atomic mass of the element boron is 10.8 amu. Note that the average atomic mass of boron is close to the mass of its most abundant isotope, boron-11.



**Figure 8** Boron-10 and boron-11 are two isotopes of boron. These two isotopes differ by one neutron.

**Explain** why these atoms are isotopes.

## section 2 review

### Summary

#### Atomic Mass

- The nucleus contains most of the mass of an atom.
- The mass of a proton and neutron are approximately equal.
- The mass of an electron is considered negligible when finding the mass of an atom.
- The unit of measurement for atomic particles is the atomic mass unit.
- The carbon-12 isotope was used to define the atomic mass unit.
- The number of protons identifies the element.

#### Isotopes

- Atoms of the same element with different numbers of neutrons are called isotopes.
- The average atomic mass of an element is the weighted-average mass of the mixture of isotopes.

### Self Check

1. **Identify** the mass number and atomic number of a chlorine atom that has 17 protons and 18 neutrons.
2. **Explain** how the isotopes of an element are alike and how are they different.
3. **Explain** why the atomic mass of an element is an average mass.
4. **Explain** how you would calculate the number of neutrons in potassium-40.
5. **Think Critically** Chlorine has an average atomic mass of 35.45 amu. The two naturally occurring isotopes of chlorine are chlorine-35 and chlorine-37. Why does this indicate that most chlorine atoms contain 18 neutrons?

### Applying Math

6. **Use Numbers** If a hydrogen atom has 2 neutrons and 1 proton, what is its mass number?
7. **Use Tables** Use the information in Table 2 to find the mass in kilograms of each subatomic particle.



## Reading Guide

- periodic table
- group
- electron dot diagram
- period

1891. 1892. 1893. 1894. 1895. 1896. 1897. 1898. 1899. 1900. 1901. 1902. 1903. 1904. 1905. 1906. 1907. 1908. 1909. 1910. 1911. 1912. 1913. 1914. 1915. 1916. 1917. 1918. 1919. 1920. 1921. 1922. 1923. 1924. 1925. 1926. 1927. 1928. 1929. 1930. 1931. 1932. 1933. 1934. 1935. 1936. 1937. 1938. 1939. 1940. 1941. 1942. 1943. 1944. 1945. 1946. 1947. 1948. 1949. 1950. 1951. 1952. 1953. 1954. 1955. 1956. 1957. 1958. 1959. 1960. 1961. 1962. 1963. 1964. 1965. 1966. 1967. 1968. 1969. 1970. 1971. 1972. 1973. 1974. 1975. 1976. 1977. 1978. 1979. 1980. 1981. 1982. 1983. 1984. 1985. 1986. 1987. 1988. 1989. 1990. 1991. 1992. 1993. 1994. 1995. 1996. 1997. 1998. 1999. 2000. 2001. 2002. 2003. 2004. 2005. 2006. 2007. 2008. 2009. 2010. 2011. 2012. 2013. 2014. 2015. 2016. 2017. 2018. 2019. 2020. 2021. 2022. 2023. 2024. 2025. 2026. 2027. 2028. 2029. 2030. 2031. 2032. 2033. 2034. 2035. 2036. 2037. 2038. 2039. 2040. 2041. 2042. 2043. 2044. 2045. 2046. 2047. 2048. 2049. 2050. 2051. 2052. 2053. 2054. 2055. 2056. 2057. 2058. 2059. 2060. 2061. 2062. 2063. 2064. 2065. 2066. 2067. 2068. 2069. 2070. 2071. 2072. 2073. 2074. 2075. 2076. 2077. 2078. 2079. 2080. 2081. 2082. 2083. 2084. 2085. 2086. 2087. 2088. 2089. 2090. 2091. 2092. 2093. 2094. 2095. 2096. 2097. 2098. 2099. 2100. 2101. 2102. 2103. 2104. 2105. 2106. 2107. 2108. 2109. 2110. 2111. 2112. 2113. 2114. 2115. 2116. 2117. 2118. 2119. 2120. 2121. 2122. 2123. 2124. 2125. 2126. 2127. 2128. 2129. 2130. 2131. 2132. 2133. 2134. 2135. 2136. 2137. 2138. 2139. 2140. 2141. 2142. 2143. 2144. 2145. 2146. 2147. 2148. 2149. 2150. 2151. 2152. 2153. 2154. 2155. 2156. 2157. 2158. 2159. 2160. 2161. 2162. 2163. 2164. 2165. 2166. 2167. 2168. 2169. 2170. 2171. 2172. 2173. 2174. 2175. 2176. 2177. 2178. 2179. 2180. 2181. 2182. 2183. 2184. 2185. 2186. 2187. 2188. 2189. 2190. 2191. 2192. 2193. 2194. 2195. 2196. 2197. 2198. 2199. 2200. 2201. 2202. 2203. 2204. 2205. 2206. 2207. 2208. 2209. 2210. 2211. 2212. 2213. 2214. 2215. 2216. 2217. 2218. 2219. 2220. 2221. 2222. 2223. 2224. 2225. 2226. 2227. 2228. 2229. 2230. 2231. 2232. 2233. 2234. 2235. 2236. 2237. 2238. 2239. 2240. 2241. 2242. 2243. 2244. 2245. 2246. 2247. 2248. 2249. 2250. 2251. 2252. 2253. 2254. 2255. 2256. 2257. 2258. 2259. 2260. 2261. 2262. 2263. 2264. 2265. 2266. 2267. 2268. 2269. 2270. 2271. 2272. 2273. 2274. 2275. 2276. 2277. 2278. 2279. 2280. 2281. 2282. 2283. 2284. 2285. 2286. 2287. 2288. 2289. 2290. 2291. 2292. 2293. 2294. 2295. 2296. 2297. 2298. 2299. 2300. 2301. 2302. 2303. 2304. 2305. 2306. 2307. 2308. 2309. 2310. 2311. 2312. 2313. 2314. 2315. 2316. 2317. 2318. 2319. 2320. 2321. 2322. 2323. 2324. 2325. 2326. 2327. 2328. 2329. 2330. 2331. 2332. 2333. 2334. 2335. 2336. 2337. 2338. 2339. 2340. 2341. 2342. 2343. 2344. 2345. 2346. 2347. 2348. 2349. 2350. 2351. 2352. 2353. 2354. 2355. 2356. 2357. 2358. 2359. 2360. 2361. 2362. 2363. 2364. 2365. 2366. 2367. 2368. 2369. 2370. 2371. 2372. 2373. 2374. 2375. 2376. 2377. 2378. 2379. 2380. 2381. 2382. 2383. 2384. 2385. 2386. 2387. 2388. 2389. 2390. 2391. 2392. 2393. 2394. 2395. 2396. 2397. 2398. 2399. 2400. 2401. 2402. 2403. 2404. 2405. 2406. 2407. 2408. 2409. 2410. 2411. 2412. 2413. 2414. 2415. 2416. 2417. 2418. 2419. 2420. 2421. 2422. 2423. 2424. 2425. 2426. 2427. 2428. 2429. 2430. 2431. 2432. 2433. 2434. 2435. 2436. 2437. 2438. 2439. 2440. 2441. 2442. 2443. 2444. 2445. 2446. 2447. 2448. 2449. 2450. 2451. 2452. 2453. 2454. 2455. 2456. 2457. 2458. 2459. 2460. 2461. 2462. 2463. 2464. 2465. 2466. 2467. 2468. 2469. 2470. 2471. 2472. 2473. 2474. 2475. 2476. 2477. 2478. 2479. 2480. 2481. 2482. 2483. 2484. 2485. 2486. 2487. 2488. 2489. 2490. 2491. 2492. 2493. 2494. 2495. 2496. 2497. 2498. 2499. 2500. 2501. 2502. 2503. 2504. 2505. 2506. 2507. 2508. 2509. 2510. 2511. 2512. 2513. 2514. 2515. 2516. 2517. 2518. 2519. 2520. 2521. 2522. 2523. 2524. 2525. 2526. 2527. 2528. 2529. 2530. 2531. 2532. 2533. 2534. 2535. 2536. 2537. 2538. 2539. 2540. 2541. 2542. 2543. 2544. 2545. 2546. 2547. 2548. 2549. 2550. 2551. 2552. 2553. 2554. 2555. 2556. 2557. 2558. 2559. 2560. 2561. 2562. 2563. 2564. 2565. 2566. 2567. 2568. 2569. 2570. 2571. 2572.



**Table 4 Mendeleev's Predictions**

| Predicted Properties of Eka-silicon (Es)            | Actual Properties of Germanium (Ge)                  |
|---|--|
| <i>Existence Predicted—1871</i>                     | <i>Actual Discovery—1886</i>                         |
| Atomic mass = 72                                    | Atomic mass = 72.61                                  |
| High melting point                                  | Melting point = 938°C                                |
| Density = 5.5 g/cm <sup>3</sup>                     | Density = 5.323 g/cm <sup>3</sup>                    |
| Dark gray metal                                     | Gray metal   |
| Density of EsO <sub>2</sub> = 4.7 g/cm <sup>3</sup> | Density of GeO <sub>2</sub> = 4.23 g/cm <sup>3</sup> |

**Mendeleev's Predictions** Mendeleev had to leave blank spaces in his periodic table to keep the elements properly lined up according to their chemical properties. He looked at the properties and atomic masses of the elements surrounding these blank spaces. From this information, he was able to predict the properties and the mass numbers of new elements that had not yet been discovered. **Table 4** shows Mendeleev's predicted properties for germanium, which he called eka-silicon. His predictions proved to be accurate. Scientists later discovered these missing elements and found that their properties were extremely close to what Mendeleev had predicted.

 **Reading Check** *How did Mendeleev organize his periodic chart?*

**Improving the Periodic Table** Although Mendeleev's arrangement of elements was successful, it did need some changes. On Mendeleev's table, the atomic mass gradually increased from left to right. If you look at the modern periodic table, shown in **Table 5**, you will see several examples, such as cobalt and nickel, where the mass decreases from left to right. You also might notice that the atomic number always increases from left to right. In 1913, the work of Henry G.J. Moseley, a young English scientist, led to the arrangement of elements based on their increasing atomic numbers instead of an arrangement based on atomic masses. This new arrangement seemed to correct the problems that had occurred in the old table. The current periodic table uses Moseley's arrangement of the elements.

 **Reading Check** *How is the modern periodic table arranged?*



### Organizing a Personal Periodic Table

#### Procedure

1. Collect as many of the following items as you can find: feather, penny, container of water, pencil, dime, strand of hair, container of milk, container of orange juice, square of cotton cloth, nickel, crayon, quarter, container of soda, golf ball, sheet of paper, baseball, marble, leaf, paper clip.
2. Organize these items into several columns based on their similarities to create your own periodic table.

#### Analysis

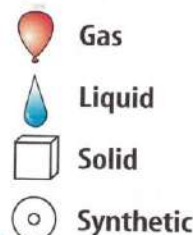
1. Explain the system you used to group your items.
2. Were there any items on the list that did not fit into any of your columns?
3. Infer how your activity modeled Mendeleev's work in developing the periodic table of the elements.





# PERIODIC TABLE OF THE ELEMENTS

Columns of elements are called groups. Elements in the same group have similar chemical properties.



|                                |                                 |                                  |                                     |                                 |                                  |                                 |                                 |                                  |
|--------------------------------|---------------------------------|----------------------------------|-------------------------------------|---------------------------------|----------------------------------|---------------------------------|---------------------------------|----------------------------------|
| 1                              | 2                               | 3                                | 4                                   | 5                               | 6                                | 7                               | 8                               | 9                                |
| Hydrogen<br>1<br>H<br>1.008    |                                 |                                  |                                     |                                 |                                  |                                 |                                 |                                  |
| Lithium<br>3<br>Li<br>6.941    | Beryllium<br>4<br>Be<br>9.012   |                                  |                                     |                                 |                                  |                                 |                                 |                                  |
| Sodium<br>11<br>Na<br>22.990   | Magnesium<br>12<br>Mg<br>24.305 |                                  |                                     |                                 |                                  |                                 |                                 |                                  |
| Potassium<br>19<br>K<br>39.098 | Calcium<br>20<br>Ca<br>40.078   | Scandium<br>21<br>Sc<br>44.956   | Titanium<br>22<br>Ti<br>47.867      | Vanadium<br>23<br>V<br>50.942   | Chromium<br>24<br>Cr<br>51.996   | Manganese<br>25<br>Mn<br>54.938 | Iron<br>26<br>Fe<br>55.845      | Cobalt<br>27<br>Co<br>58.933     |
| Rubidium<br>37<br>Rb<br>85.468 | Strontium<br>38<br>Sr<br>87.62  | Yttrium<br>39<br>Y<br>88.906     | Zirconium<br>40<br>Zr<br>91.224     | Niobium<br>41<br>Nb<br>92.906   | Molybdenum<br>42<br>Mo<br>95.94  | Technetium<br>43<br>Tc<br>(98)  | Ruthenium<br>44<br>Ru<br>101.07 | Rhodium<br>45<br>Rh<br>102.906   |
| Cesium<br>55<br>Cs<br>132.905  | Barium<br>56<br>Ba<br>137.327   | Lanthanum<br>57<br>La<br>138.906 | Hafnium<br>72<br>Hf<br>178.49       | Tantalum<br>73<br>Ta<br>180.948 | Tungsten<br>74<br>W<br>183.84    | Rhenium<br>75<br>Re<br>186.207  | Osmium<br>76<br>Os<br>190.23    | Iridium<br>77<br>Ir<br>192.217   |
| Francium<br>87<br>Fr<br>(223)  | Radium<br>88<br>Ra<br>(226)     | Actinium<br>89<br>Ac<br>(227)    | Rutherfordium<br>104<br>Rf<br>(261) | Dubnium<br>105<br>Db<br>(262)   | Seaborgium<br>106<br>Sg<br>(266) | Bohrium<br>107<br>Bh<br>(264)   | Hassium<br>108<br>Hs<br>(277)   | Meitnerium<br>109<br>Mt<br>(268) |

Element  
Atomic number  
Symbol  
Atomic mass  
State of matter

The first three symbols tell you the state of matter of the element at room temperature. The fourth symbol identifies elements that are not present in significant amounts on Earth. Useful amounts are made synthetically.

Rows of elements are called periods. Atomic number increases across a period.

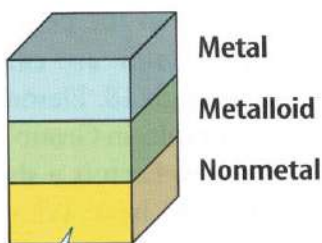
The arrow shows where these elements would fit into the periodic table. They are moved to the bottom of the table to save space.

Lanthanide series

Actinide series

|                                |                                     |                                 |                                 |                                |
|--------------------------------|-------------------------------------|---------------------------------|---------------------------------|--------------------------------|
| Cerium<br>58<br>Ce<br>140.116  | Praseodymium<br>59<br>Pr<br>140.908 | Neodymium<br>60<br>Nd<br>144.24 | Promethium<br>61<br>Pm<br>(145) | Samarium<br>62<br>Sm<br>150.36 |
| Thorium<br>90<br>Th<br>232.038 | Protactinium<br>91<br>Pa<br>231.036 | Uranium<br>92<br>U<br>238.029   | Neptunium<br>93<br>Np<br>(237)  | Plutonium<br>94<br>Pu<br>(244) |





The color of an element's block tells you if the element is a metal, nonmetal, or metalloid.

| 10  |                                    |                                      | 11  | 12                                      | 13                                     | 14  | 15                                     | 16                                     | 17  | 18                                   |
|---|------------------------------------|--------------------------------------|---|---|--|---|--|--|---|--------------------------------------|
| Nickel<br>28<br><b>Ni</b><br>58.693         |                                    |                                      | Copper<br>29<br><b>Cu</b><br>63.546         | Zinc<br>30<br><b>Zn</b><br>65.409       | Boron<br>5<br><b>B</b><br>10.811       | Carbon<br>6<br><b>C</b><br>12.011           | Nitrogen<br>7<br><b>N</b><br>14.007    | Oxygen<br>8<br><b>O</b><br>15.999      | Fluorine<br>9<br><b>F</b><br>18.998         | Helium<br>2<br><b>He</b><br>4.003    |
| Palladium<br>46<br><b>Pd</b><br>106.42      |                                    |                                      | Silver<br>47<br><b>Ag</b><br>107.868        | Cadmium<br>48<br><b>Cd</b><br>112.411   | Aluminum<br>13<br><b>Al</b><br>26.982  | Silicon<br>14<br><b>Si</b><br>28.086        | Phosphorus<br>15<br><b>P</b><br>30.974 | Sulfur<br>16<br><b>S</b><br>32.065     | Chlorine<br>17<br><b>Cl</b><br>35.453       | Neon<br>10<br><b>Ne</b><br>20.180    |
| Platinum<br>78<br><b>Pt</b><br>195.078      | Gold<br>79<br><b>Au</b><br>196.967 | Mercury<br>80<br><b>Hg</b><br>200.59 | Gallium<br>31<br><b>Ga</b><br>69.723        |   |  | Germanium<br>32<br><b>Ge</b><br>72.64       | Arsenic<br>33<br><b>As</b><br>74.922   | Selenium<br>34<br><b>Se</b><br>78.96   | Bromine<br>35<br><b>Br</b><br>79.904        | Argon<br>18<br><b>Ar</b><br>39.948   |
| Darmstadtium<br>110<br><b>Ds</b><br>(281)   |                                    |                                      | Ununium<br>* 111<br><b>Uuu</b><br>(272)     | Ununium<br>* 112<br><b>Uub</b><br>(285) | Indium<br>49<br><b>In</b><br>114.818   |   |  | Tellurium<br>52<br><b>Te</b><br>127.60 | Iodine<br>53<br><b>I</b><br>126.904         | Krypton<br>36<br><b>Kr</b><br>83.798 |
| Americium<br>95<br><b>Am</b><br>(243)       |                                    |                                      | Curium<br>96<br><b>Cm</b><br>(247)          | Berkelium<br>97<br><b>Bk</b><br>(247)   | Tin<br>50<br><b>Sn</b><br>118.710      |   |  | Antimony<br>51<br><b>Sb</b><br>121.760 | Xenon<br>54<br><b>Xe</b><br>131.293         |                                      |
| Californium<br>98<br><b>Cf</b><br>(251)     |                                    |                                      | Einsteinium<br>99<br><b>Es</b><br>(252)     | Fermium<br>100<br><b>Fm</b><br>(257)    | Lead<br>82<br><b>Pb</b><br>207.2       |   |  | Bismuth<br>83<br><b>Bi</b><br>208.980  | Radon<br>86<br><b>Rn</b><br>(222)           |                                      |
| Mendelevium<br>101<br><b>Md</b><br>(258)    |                                    |                                      | Nobelium<br>102<br><b>No</b><br>(259)       | Lawrencium<br>103<br><b>Lr</b><br>(262) | Thallium<br>81<br><b>Tl</b><br>204.383 |   |  | Polonium<br>84<br><b>Po</b><br>(209)   | Astatine<br>85<br><b>At</b><br>(210)        |                                      |
| Ununquadium<br>* 114<br><b>Uuq</b><br>(289) |                                    |                                      | Ununquadium<br>* 116<br><b>Uuq</b><br>(289) |   |  | Ununquadium<br>* 118<br><b>Uuq</b><br>(289) |  |  | Ununquadium<br>* 118<br><b>Uuq</b><br>(289) |                                      |

\* The names and symbols for elements 111–114 are temporary. Final names will be selected when the elements' discoveries are verified.

\*\* Elements 116 and 118 were thought to have been created. The claim was retracted because the experimental results could not be repeated.

|  |   |                                       |  |   |                                      |  |  |   |
|--|---|---------------------------------------|--|---|--------------------------------------|--|--|---|
| Europium<br>63<br><b>Eu</b><br>151.964 | Gadolinium<br>64<br><b>Gd</b><br>157.25 | Terbium<br>65<br><b>Tb</b><br>158.925 | Dysprosium<br>66<br><b>Dy</b><br>162.500 | Holmium<br>67<br><b>Ho</b><br>164.930   | Erbium<br>68<br><b>Er</b><br>167.259 | Thulium<br>69<br><b>Tm</b><br>168.934    | Ytterbium<br>70<br><b>Yb</b><br>173.04 | Lutetium<br>71<br><b>Lu</b><br>174.967  |
| Americium<br>95<br><b>Am</b><br>(243)  | Curium<br>96<br><b>Cm</b><br>(247)      | Berkelium<br>97<br><b>Bk</b><br>(247) | Californium<br>98<br><b>Cf</b><br>(251)  | Einsteinium<br>99<br><b>Es</b><br>(252) | Fermium<br>100<br><b>Fm</b><br>(257) | Mendelevium<br>101<br><b>Md</b><br>(258) | Nobelium<br>102<br><b>No</b><br>(259)  | Lawrencium<br>103<br><b>Lr</b><br>(262) |

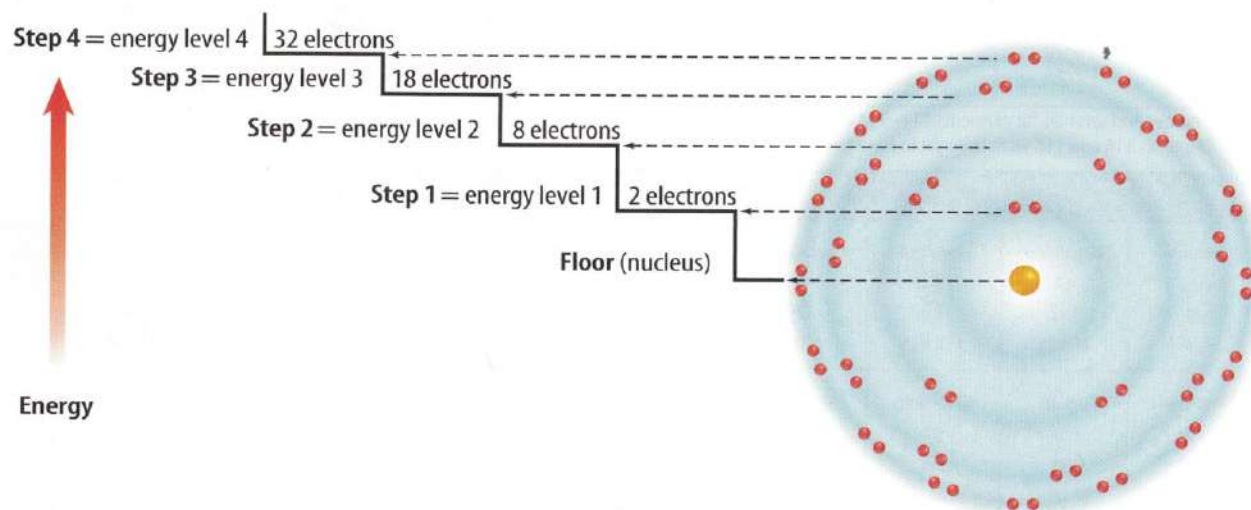




### INTEGRATE Career

**Research Physicist** The study of nuclear interactions is shared by chemists and physicists. Research physicists use their knowledge of the physical laws of nature to explain the behavior of the atom and its composition. Explain in your Science Journal why physicists would study the amount of energy that electrons contain.

**Figure 10** Energy levels in atoms can be represented by a flight of stairs. Each stair step away from the nucleus represents an increase in the amount of energy within the electrons. The higher energy levels contain more electrons.



## The Atom and the Periodic Table

Objects often are sorted or grouped according to the properties they have in common. This also is done in the periodic table. The vertical columns in the periodic table are called **groups**, or families, and are numbered 1 through 18. Elements in each group have similar properties. For example, in Group 11, copper, silver, and gold have similar properties. Each is a shiny metal and a good conductor of electricity and heat. What is responsible for the similar properties? To answer this question, look at the structure of the atom.

**Electron Cloud Structure** You have learned about the number and location of protons and neutrons in an atom. But where are the electrons located? How many are there? In a neutral atom, the number of electrons is equal to the number of protons. Therefore, a carbon atom, with an atomic number of six, has six protons and six electrons. These electrons are located in the electron cloud surrounding the nucleus.

Scientists have found that electrons within the electron cloud have different amounts of energy. Scientists model the energy differences of the electrons by placing the electrons in energy levels, as in **Figure 10**. Energy levels nearer the nucleus have lower energy than those levels that are farther away. Electrons fill these energy levels from the inner levels (closer to the nucleus) to the outer levels (farther from the nucleus).


Elements that are in the same group have the same number of electrons in their outer energy level. It is the number of electrons in the outer energy level that determines the chemical properties of the element. It is important to understand the link between the location on the periodic table, chemical properties, and the structure of the atom.



**Energy Levels** These energy levels are named using numbers one to seven. The maximum number of electrons that can be contained in each of the first four levels is shown in **Figure 10**. For example, energy level one can contain a maximum of two electrons. Energy level two can contain a maximum of eight electrons. Notice that energy levels three and four contain several electrons. A complete and stable outer energy level will contain eight electrons. In elements in periods three and higher, additional electrons can be added to inner energy levels although the outer energy level contains only eight electrons.

**Rows on the Table** Remember that the atomic number found on the periodic table is equal to the number of electrons in an atom. Look at **Figure 11**. The first row has hydrogen with one electron and helium with two electrons both in energy level one. Because energy level one is the outermost level containing an electron, hydrogen has one outer electron. Helium has two outer electrons. Recall from **Figure 10** that energy level one can hold only two electrons. Therefore, helium has a full or complete outer energy level.

The second row begins with lithium, which has three electrons—two in energy level one and one in energy level two. Lithium has one outer electron. Lithium is followed by beryllium with two outer electrons, boron with three, and so on until you reach neon with eight outer electrons. Again, looking at **Figure 10**, energy level two can only hold eight electrons. Therefore, neon has a complete outer energy level. Do you notice how the row in the periodic table ends when an outer energy level is filled? In the third row of elements, the electrons begin filling energy level three. The row ends with argon, which has a full outer energy level of eight electrons.

 **Reading Check** How many electrons are needed to fill the outer energy level of sulfur?

|                    |                       |
|--------------------|-----------------------|
| Hydrogen<br>1<br>H |                       |
| Lithium<br>3<br>Li | Beryllium<br>4<br>Be  |
| Sodium<br>11<br>Na | Magnesium<br>12<br>Mg |

|                      |                     |                       |                   |                      |                   |
|----------------------|---------------------|-----------------------|-------------------|----------------------|-------------------|
|                      |                     |                       |                   |                      | Helium<br>2<br>He |
| Boron<br>5<br>B      | Carbon<br>6<br>C    | Nitrogen<br>7<br>N    | Oxygen<br>8<br>O  | Fluorine<br>9<br>F   | Neon<br>10<br>Ne  |
| Aluminum<br>13<br>Al | Silicon<br>14<br>Si | Phosphorus<br>15<br>P | Sulfur<br>16<br>S | Chlorine<br>17<br>Cl | Argon<br>18<br>Ar |

 Scienceonline

**Topic: Atomic Energy Level Structure**

Visit [gpscience.com](http://gpscience.com) for Web links to information about the structure of atomic energy levels.

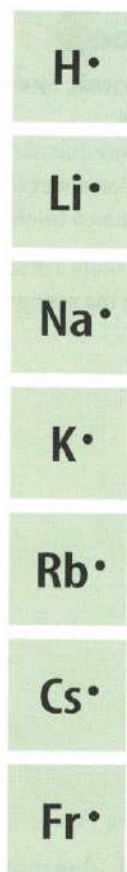
**Activity** Draw a diagram that details how the energy levels are structured.

**Figure 11** One proton and one electron are added to each element as you go across a period in the periodic table.

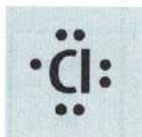
**Explain** what the elements in the last column share in relation to their outer energy levels.



**Figure 12** The elements in Group 1 have one electron in their outer energy level. This electron dot diagram represents that one electron.



**Figure 13** Electron dot diagrams show the electrons in an element's outer energy level.



The electron dot diagram for Group 17 consists of three sets of paired dots and one single dot.

**Electron Dot Diagrams** Did you notice that hydrogen, lithium, and sodium have one electron in their outer energy level? Elements that are in the same group have the same number of electrons in their outer energy level. These outer electrons are so important in determining the chemical properties of an element that a special way to represent them has been developed. American chemist G. N. Lewis created this method while teaching a college chemistry class. An **electron dot diagram** uses the symbol of the element and dots to represent the electrons in the outer energy level. **Figure 12** shows the electron dot diagram for Group 1 elements. Electron dot diagrams are used also to show how the electrons in the outer energy level are bonded when elements combine to form compounds.

**Same Group—Similar Properties** The elements in Group 17, the halogens, have electron dot diagrams similar to chlorine, shown in **Figure 13**. All halogens have seven electrons in their outer energy levels. Since all of the members of a group on the periodic table have the same number of electrons in their outer energy level, group members will undergo chemical reactions in similar ways.

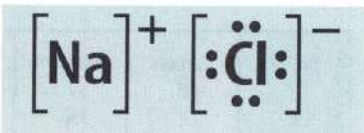
A common property of the halogens is the ability to form compounds readily with elements in Group 1. Group 1 elements have only one electron in their outer energy level. **Figure 13** shows an example of a compound formed by one such reaction. The Group 1 element, sodium, reacts easily with the Group 17 element, chlorine. The result is the compound sodium chloride, or NaCl—ordinary table salt.

Not all elements will combine readily with other elements. The elements in Group 18 have complete outer energy levels. This special configuration makes Group 18 elements relatively unreactive. You will learn more about why and how bonds form between elements in the later chapters.

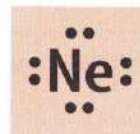


**Reading Check**

*Why do elements in a group undergo similar chemical reactions?*



Sodium combines with chlorine to give each element a complete outer energy level in the resulting compound.



Neon, a member of Group 18, has a full outer energy level. Neon has eight electrons in its outer energy level, making it unreactive.



## Regions on the Periodic Table

The periodic table has several regions with specific names. The horizontal rows of elements on the periodic table are called **periods**. The elements increase by one proton and one electron as you go from left to right in a period.

All of the elements in the blue squares in **Figure 14** are metals. Iron, zinc, and copper are examples of metals. Most metals exist as solids at room temperature. They are shiny, can be drawn into wires, can be pounded into sheets, and are good conductors of heat and electricity.

Those elements on the right side of the periodic table, in yellow, are classified as nonmetals. Oxygen, bromine, and carbon are examples of nonmetals. Most nonmetals are gases, are brittle, and are poor conductors of heat and electricity at room temperature. The elements in green are metalloids or semimetals. They have some properties of both metals and nonmetals. Boron and silicon are examples of metalloids.

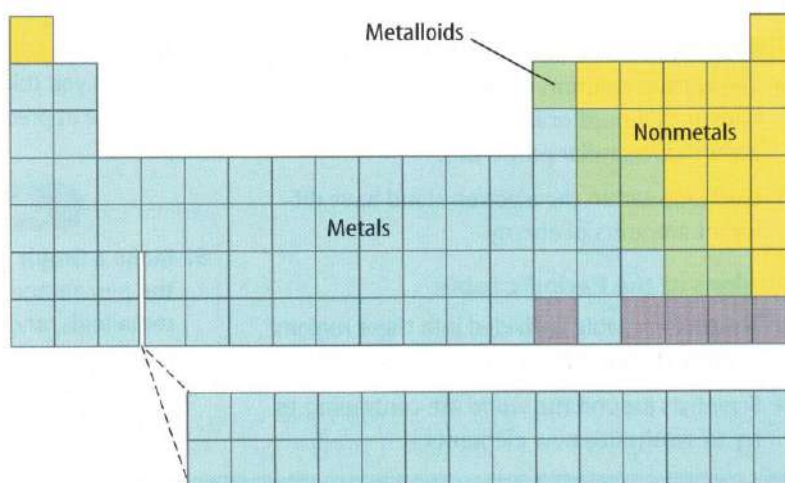


### Reading Check

*What are the properties of the elements located on the left side of the periodic table?*

**A Growing Family** Scientists around the world are continuing their research into the synthesis of elements. In 1994, scientists at the Heavy-Ion Research Laboratory in Darmstadt, Germany, discovered element 111. As of 1998, only one isotope of element 111 has been found. This isotope had a life span of 0.002 s. In 1996, element 112 was discovered at the same laboratory. As of 1998, only one isotope of element 112 has been found. The life span of this isotope was 0.00048 s. Both of these elements are produced in the laboratory by joining smaller atoms into a single atom. The search for elements with higher atomic numbers continues. Scientists think they have synthesized elements 114 and 116. However, the discovery of these elements has not yet been confirmed.

**Figure 14** Metalloids are located along the green stair-step line. Metals are located to the left of the metalloids. Nonmetals are located to the right of the metalloids.

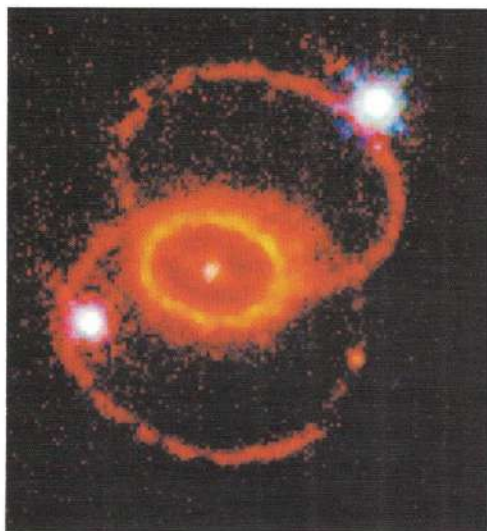


### Topic: New Elements

Visit [gpscience.com](http://gpscience.com) for Web links to information about newly synthesized elements.

**Activity** Write a paragraph explaining how several new elements were synthesized and who synthesized them.





**Figure 15** Scientists think that some elements are found in nature only within stars.

## Elements in the Universe



INTEGRATE  
Astronomy

Using the technology that is available today, scientists are finding the same elements throughout the universe. They have been able to study only a small portion of the universe, though, because it is so vast. Many scientists believe that hydrogen and helium are the building blocks of other elements. Atoms join together within stars to produce elements with atomic numbers greater than 1 or 2—the atomic numbers of hydrogen and helium. Exploding stars, or supernovas, shown in **Figure 15**, give scientists evidence to support this theory. When stars go supernova a mixture of elements, including the heavy elements such as iron, are flung into the galaxy. Many scientists believe that supernovas have spread the elements that are found throughout the universe. Promethium, technetium, and elements with an atomic number above 92 are rare or are not found on Earth. Some of these elements are found only in trace amounts in Earth's crust as a result of uranium decay. Others have been found only in stars.

### section 3 review

#### Summary

##### Organizing the Elements

- Mendeleev organized the elements using increasing atomic mass and chemical and physical properties.
- Mendeleev left blank spaces in his table to allow for elements that were yet undiscovered.
- Moseley corrected the problems in the periodic table by arranging the elements in order of increasing atomic number.

##### The Atom and the Periodic Table

- The vertical columns in the periodic table are known as groups or families. Elements in a group have similar properties.
- Electrons within the electron cloud have different amounts of energy.

##### Regions of the Periodic Table

- The periodic table is divided into these regions: periods, metals, nonmetals, and metalloids.
- Scientists around the world are continuing to try to synthesize new elements.

#### Self Check

1. **Identify** Use the periodic table to find the name, atomic number, and average atomic mass of the following elements: N, Ca, Kr, and W.
2. **List** the period and group in which each of these elements is found: nitrogen, sodium, iodine, and mercury.
3. **Classify** each of these elements as a metal, a nonmetal, or a metalloid and give the full name of each: K, Si, Ba, and S.
4. **Think Critically** The Mendeleev and Mosely periodic charts have gaps for the as-yet-undiscovered elements. Why do you think the chart used by Mosely was more accurate at predicting where new elements would be placed?

#### Applying Math

5. **Make a Graph** Construct a circle graph showing the percentage of elements classified as metals, metalloids, and nonmetals. Use markers or colored pencils to distinguish clearly between each section on the graph. Record your calculations in your Science Journal.