

# Training for Educators

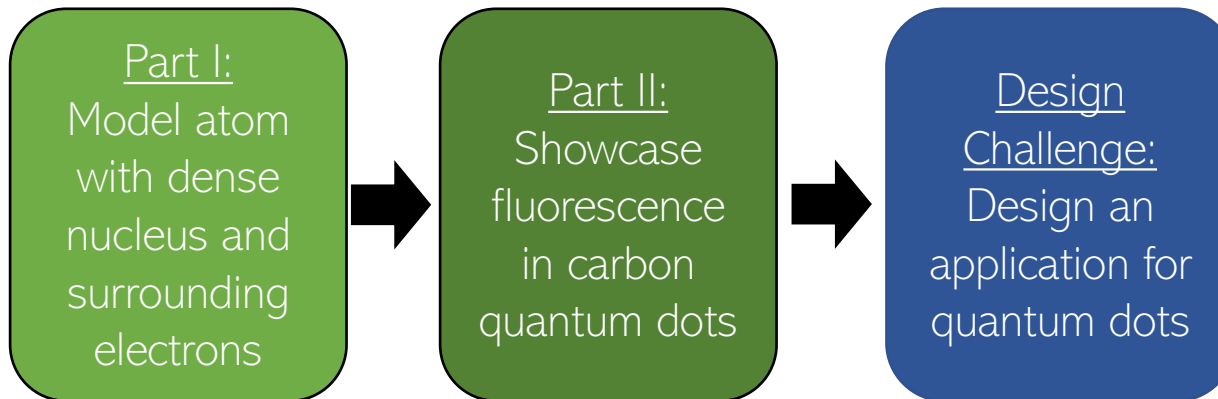
## Quantum Chemistry

Secondary Level  
Ages 12-18

# Purpose of the lab

- The purpose of this lab kit is to enable students to understand atoms and nanosized matter through theory, demonstration, and experiments. The manual introduces the students to atomic models before discussing quantum dots and the unique ways in which light interacts with them.
- The main takeaways are:
  - The Rutherford atomic model has a dense nucleus of protons and neutrons, and electrons surround the nucleus.
  - Carbon quantum dots have fluorescence, which means they emit light by absorbing light and the emission is short-lived.

# Summary of experiments



There are 2 experiments/activities in total.

# Supplies list

- Sugar
- Water
- Source of heat (microwave oven, hot plate, stove top, flame)
- Pyrex conical flask
- Clear jar
- Test tubes (or small clear sample holders)
- Parafilm (or plastic wrap)
- Light sources (UV flashlight, green laser, red laser)
- Cotton swabs
- Paper
- Lemon juice
- Spherical-like candies of three colors (or compressed foil balls of three colors)
- Toothpicks
- Dark string (or pipe cleaners)
- Marker

# Safety considerations

Before the students begin the laboratory, please take into consideration the following safety concerns:

- Students should never look directly at a UV flashlight or laser point, as this can permanently damage their eyes due to the laser intensity and emission as a tight beam.
- Students should be careful handling hot glassware and should use potholders or protective gloves to move hot glassware.
- Students should not eat or taste items during experiments.

# Setting up your space

- Gather your supplies and separate by experiment(s) on your table.
- These are our recommendations:
  - Each student should have a pencil or pen.

Groups of 2-4 students can be given the following supplies:

- Spherical-like candies of three colors (at least 8 per group) (or compressed foil/paper balls of three colors)
- Several toothpicks
- Length of dark string (approx. ~0.5 m) (or ~4-5 pipe cleaners)
- Paper (at least 2 pieces)
- 3 test tubes (or clear containers)
- 3 small pieces of parafilm (or plastic wrap)
- 3 cotton swabs
- Pen/pencil

The class can share the following supplies:

- Light sources (UV flashlight, lasers)
- Heating source (microwave, hot plate)
- Pre-made sugar solution (needs: Pyrex flask, 1 g of sugar, water)

# Part I. Candy Atomic Models

- Set-up:
  - Each group of 2-4 students gets spherical-like candies of three colors (at least 8 each), toothpicks, dark string, and paper.
- Procedure:
  - Students should join together candies of two colors in a dense ball and use two lengths of string to make concentric circles around the nucleus. Students should then place candies of the third color on the inner and outer circles of string.
- Results:
  - Students will see that they have created a Rutherford model of the atom. If the students use 8 of each candy, they will have modelled the oxygen atom.

The takeaway is that the Rutherford atomic model has a dense nucleus of protons and neutrons, and electrons surround the nucleus.

# Part I. Candy Atomic Models



Example of candy atom model

# Part II. Carbon Quantum Dots in the Kitchen

- Set-up:
  - Each group (2-4 students) will need prepared solutions, 3 test tubes (or clear sample holders), parafilm, cotton swabs, and paper.
  - How to prepare the carbon quantum dot (Cdot) sugar solution: place 1 g of sugar into conical Pyrex flask; add 10 g of water and stir until sugar is dissolved; place flask in heat source for 10 min (should have sap like consistency); add 50 g of water to flask and swirl
  - How to prepare the sugar water solution: add 1 g of sugar to 10 g of water and stir
- Procedure:
  - Students should shine light sources on solutions to see if any fluoresce. Students should also try saturating cotton swabs in solutions and writing/drawing on paper. Once the writing/drawing has dried, students should shine light sources on the marking to see if any fluoresce.
- Results
  - Students should see that light sources with enough energy (like a UV light or green laser) likely caused the Cdot solutions/markings to fluoresce. Lower energy light sources (like a red laser) likely did not have enough energy to cause fluorescence.

The takeaway is carbon quantum dots have fluorescence, which means they emit light by absorbing light and the emission is short-lived.



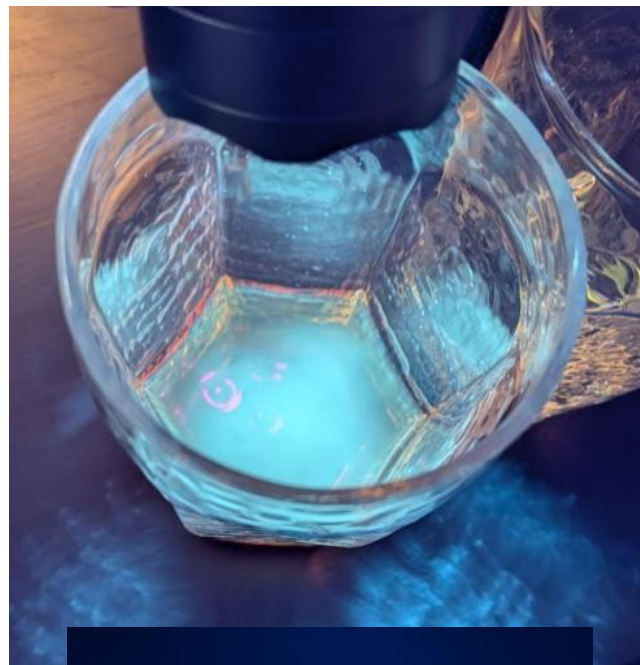
Example of sugar+water solution that has been heated.

# Part II: Carbon Quantum Dots in the Kitchen (Expected Results)

Sugar+water (no heat)  
UV light



Sugar+water (after heating)  
UV light



# Part II: Carbon Quantum Dots in the Kitchen

- Resources for Part II:
  - PhysicsQuest (2025): The Secret Glow of Nanobit from the Kitchen (American Physical Society PhysicsQuest)
    - <https://www.aps.org/learning-resources/secret-glow-nanobits-kitchen>
  - United States Naval Academy Chemistry Department, Experiment #490: Synthesis and Properties of Quantum Dots. 2024.
    - [https://intranet.usna.edu/ChemDept/\\_files/documents/integrated-labs/SC364/2024\\_Documents/S24\\_SC364\\_EXP\\_490\\_Quantum\\_Dots\\_FV9.pdf](https://intranet.usna.edu/ChemDept/_files/documents/integrated-labs/SC364/2024_Documents/S24_SC364_EXP_490_Quantum_Dots_FV9.pdf)

# Design challenge

- Students are asked to design another application for quantum dots. Students have learned that quantum dots can fluoresce when they absorb high enough energy light and that the color of the fluorescence can depend on the size of the quantum dot. With these concepts in mind, students should consider how quantum dots could be useful in their lives.
- Questions to ask the students (encourage creativity)
  - How does the fluorescence color depend on the size of the quantum dot? Are there any other things that could impact the color?
  - How could you potentially change the synthesis conditions of quantum dots to change their fluorescence color?
  - What role does the energy of the absorbed light play in fluorescence?
  - How could the properties of fluorescence be used in applications? Brainstorm many ideas and share and discuss with your classmates.

# Appendix

**PERIODIC TABLE**  
**Atomic Properties of the Elements**

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

**Frequently used fundamental physical constants**  
For the most accurate values of these and other constants, visit [physics.nist.gov/constants](http://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 <sup>133</sup>Cs

speed of light in vacuum *c* 299 792 458 m s<sup>-1</sup> (exact)  
Planck constant *h* 6.626 07 × 10<sup>-34</sup> J s (*h* = *h*/2π)  
elementary charge *e* 1.602 177 × 10<sup>-19</sup> C  
electron mass *m<sub>e</sub>* 9.109 38 × 10<sup>-31</sup> kg  
*m<sub>e</sub>c<sup>2</sup>* 0.510 999 MeV  
proton mass *m<sub>p</sub>* 1.672 622 × 10<sup>-27</sup> kg  
fine-structure constant *α* 1/137.035 999  
Rydberg constant *R<sub>∞</sub>* 10 973 731.569 m<sup>-1</sup>  
*R<sub>∞</sub>c* 3.289 841 960 × 10<sup>15</sup> Hz  
*R<sub>∞</sub>hc* 13.605 69 eV  
Boltzmann constant *k* 1.380 6 × 10<sup>-23</sup> J K<sup>-1</sup>

Physical Measurement Laboratory [www.nist.gov/pml](http://www.nist.gov/pml)  
Standard Reference Data [www.nist.gov/srd](http://www.nist.gov/srd)

Legend:  
■ Solids  
■ Liquids  
■ Gases  
■ Artificially Prepared

Group 1 IA	PERIODIC TABLE																18 VIIIA										
1 <sup>1</sup> H Hydrogen 1.008 1s																	2 <sup>2</sup> He Helium 4.002602 1s <sup>2</sup>										
2 IIA	3 IIIB	4 IVB	5 VB	6 VIB	7 VIIB	8 VIII	9	10	11 IB	12 IIB	13 IIIA	14 IVA	15 VA	16 VIA	17 VIIA	18 VIIIA											
3 <sup>3</sup> Li Lithium 6.94 1s <sup>2</sup> 2s 5.3917	4 <sup>4</sup> Be Beryllium 9.0121831 1s <sup>2</sup> 2s <sup>2</sup> 9.3227	5 <sup>11</sup> Na Sodium 22.98976928 [Ne]3s <sup>1</sup> 5.1391	6 <sup>12</sup> Mg Magnesium 24.305 [Ne]3s <sup>2</sup> 7.6462	7 <sup>13</sup> Al Aluminum 26.9815385 [Ne]3s <sup>2</sup> 3p <sup>1</sup> 6.9858	8 <sup>14</sup> Si Silicon 28.0855 [Ne]3s <sup>2</sup> 3p <sup>2</sup> 8.1517	9 <sup>15</sup> P Phosphorus 30.9737620 [Ne]3s <sup>2</sup> 3p <sup>3</sup> 10.4667	10 <sup>16</sup> S Sulfur 32.06 [Ne]3s <sup>2</sup> 3p <sup>4</sup> 10.3600	11 <sup>17</sup> Cl Chlorine 35.45 [Ne]3s <sup>2</sup> 3p <sup>5</sup> 12.9676	12 <sup>18</sup> Ar Argon 39.948 [Ne]3s <sup>2</sup> 3p <sup>6</sup> 15.7596	13 <sup>19</sup> K Potassium 39.0983 [Ar]4s 4.3407	14 <sup>20</sup> Ca Calcium 40.078 [Ar]4s <sup>2</sup> 6.1132	15 <sup>21</sup> Sc Scandium 44.955908 [Ar]3d <sup>1</sup> 4s <sup>2</sup> 6.8281	16 <sup>22</sup> Ti Titanium 47.867 [Ar]3d <sup>2</sup> 4s <sup>2</sup> 6.8281	17 <sup>23</sup> V Vanadium 50.9415 [Ar]3d <sup>3</sup> 4s <sup>2</sup> 6.8281	18 <sup>24</sup> Cr Chromium 51.9961 [Ar]3d <sup>5</sup> 4s 7.4340	19 <sup>25</sup> Mn Manganese 54.938044 [Ar]3d <sup>5</sup> 4s <sup>2</sup> 7.9025	20 <sup>26</sup> Fe Iron 55.845 [Ar]3d <sup>6</sup> 4s 7.8810	21 <sup>27</sup> Co Cobalt 58.933194 [Ar]3d <sup>7</sup> 4s 7.6399	22 <sup>28</sup> Ni Nickel 58.9332 [Ar]3d <sup>8</sup> 4s 7.6399	23 <sup>29</sup> Cu Copper 63.546 [Ar]3d <sup>10</sup> 4s 7.7264	24 <sup>30</sup> Zn Zinc 65.38 [Ar]3d <sup>10</sup> 4s 9.3942	25 <sup>31</sup> Ga Gallium 69.723 [Ar]3d <sup>10</sup> 4s <sup>2</sup> 4p 5.9993	26 <sup>32</sup> Ge Germanium 72.630 [Ar]3d <sup>10</sup> 4s <sup>2</sup> 4p <sup>2</sup> 7.8994	27 <sup>33</sup> As Arsenic 74.921595 [Ar]3d <sup>10</sup> 4s <sup>2</sup> 4p <sup>3</sup> 9.7886	28 <sup>34</sup> Se Selenium 78.971 [Ar]3d <sup>10</sup> 4s <sup>2</sup> 4p <sup>4</sup> 9.7524	29 <sup>35</sup> Br Bromine 79.904 [Ar]3d <sup>10</sup> 4s <sup>2</sup> 4p <sup>5</sup> 11.8138	30 <sup>36</sup> Kr Krypton 83.796 [Ar]3d <sup>10</sup> 4s <sup>2</sup> 4p <sup>6</sup> 13.9996
4 <sup>37</sup> Rb Rubidium 85.4678 [Kr]5s 4.1771	5 <sup>38</sup> Sr Strontium 87.62 [Kr]5s <sup>2</sup> 5.6949	6 <sup>39</sup> Y Yttrium 88.90584 [Kr]4d <sup>1</sup> 5s <sup>2</sup> 6.2173	7 <sup>40</sup> Zr Zirconium 91.224 [Kr]4d <sup>2</sup> 5s <sup>2</sup> 6.8339	8 <sup>41</sup> Nb Niobium 92.90637 [Kr]4d <sup>4</sup> 5s 6.8339	9 <sup>42</sup> Mo Molybdenum 95.96 [Kr]4d <sup>5</sup> 5s 7.1194	10 <sup>43</sup> Tc Technetium (98) [Kr]4d <sup>5</sup> 5s 7.1194	11 <sup>44</sup> Ru Ruthenium 101.07 [Kr]4d <sup>7</sup> 5s 7.4595	12 <sup>45</sup> Rh Rhodium 102.90550 [Kr]4d <sup>8</sup> 5s 7.4595	13 <sup>46</sup> Pd Palladium 106.42 [Kr]4d <sup>10</sup> 8.3369	14 <sup>47</sup> Ag Silver 107.8682 [Kr]4d <sup>10</sup> 5s 7.3702	15 <sup>48</sup> Cd Cadmium 112.414 [Kr]4d <sup>10</sup> 5s 5.2654	16 <sup>49</sup> In Indium 114.818 [Kr]4d <sup>10</sup> 5s <sup>2</sup> 5p 5.2654	17 <sup>50</sup> Sn Tin 118.710 [Kr]4d <sup>10</sup> 5s <sup>2</sup> 5p <sup>2</sup> 7.2439	18 <sup>51</sup> Sb Antimony 121.760 [Kr]4d <sup>10</sup> 5s <sup>2</sup> 5p <sup>3</sup> 6.6284	19 <sup>52</sup> Te Tellurium 127.60 [Kr]4d <sup>10</sup> 5s <sup>2</sup> 5p <sup>4</sup> 9.0007	20 <sup>53</sup> I Iodine 126.90447 [Kr]4d <sup>10</sup> 5s <sup>2</sup> 5p <sup>5</sup> 10.4513	21 <sup>54</sup> Xe Xenon 131.293 [Kr]4d <sup>10</sup> 5s <sup>2</sup> 5p <sup>6</sup> 12.1298										
5 <sup>55</sup> Cs Cesium 132.9054520 [Xe]6s 3.8939	6 <sup>56</sup> Ba Barium 137.327 [Xe]6s <sup>2</sup> 5.2117	7 <sup>72</sup> Hf Hafnium 178.49 [Xe]4f <sup>14</sup> 5d <sup>2</sup> 6s <sup>2</sup> 6.8251	8 <sup>73</sup> Ta Tantalum 180.94788 [Xe]4f <sup>14</sup> 5d <sup>3</sup> 6s <sup>2</sup> 7.5496	9 <sup>74</sup> W Tungsten 183.84 [Xe]4f <sup>14</sup> 5d <sup>4</sup> 6s <sup>2</sup> 7.8640	10 <sup>75</sup> Re Rhenium 186.207 [Xe]4f <sup>14</sup> 5d <sup>5</sup> 6s <sup>2</sup> 7.8335	11 <sup>76</sup> Os Osmium 190.23 [Xe]4f <sup>14</sup> 5d <sup>6</sup> 6s <sup>2</sup> 8.4382	12 <sup>77</sup> Ir Iridium 192.227 [Xe]4f <sup>14</sup> 5d <sup>7</sup> 6s <sup>2</sup> 8.9670	13 <sup>78</sup> Pt Platinum 195.084 [Xe]4f <sup>14</sup> 5d <sup>9</sup> 6s <sup>1</sup> 9.2256	14 <sup>79</sup> Au Gold 196.966569 [Xe]4f <sup>14</sup> 5d <sup>10</sup> 6s <sup>1</sup> 10.4375	15 <sup>80</sup> Hg Mercury 200.592 [Xe]4f <sup>14</sup> 5d <sup>10</sup> 6s <sup>2</sup> 10.4375	16 <sup>81</sup> Tl Thallium 204.38 [Hg]6p <sup>1</sup> 6.1083	17 <sup>82</sup> Pb Lead 207.2 [Hg]6p <sup>2</sup> 7.4167	18 <sup>83</sup> Bi Bismuth 208.98040 [Hg]6p <sup>3</sup> 7.2855	19 <sup>84</sup> Po Polonium (209) [Hg]6p <sup>4</sup> 8.414	20 <sup>85</sup> At Astatine (210) [Hg]6p <sup>5</sup> 9.31751	21 <sup>86</sup> Rn Radon (222) [Hg]6p <sup>6</sup> 10.7485											
6 <sup>87</sup> Fr Francium (223) [Rn]7s 4.0727	7 <sup>88</sup> Ra Radium (226) [Rn]7s <sup>2</sup> 5.2764	8 <sup>104</sup> Rf Rutherfordium (261) [Rn]5f <sup>14</sup> 6d <sup>2</sup> 7s <sup>2</sup> 6.01	9 <sup>105</sup> Db Dubnium (268) [Rn]5f <sup>14</sup> 6d <sup>3</sup> 7s <sup>2</sup> 6.8	10 <sup>106</sup> Sg Seaborgium (271) [Rn]5f <sup>14</sup> 6d <sup>4</sup> 7s <sup>2</sup> 7.8	11 <sup>107</sup> Bh Bohrium (272) [Rn]5f <sup>14</sup> 6d <sup>5</sup> 7s <sup>2</sup> 7.7	12 <sup>108</sup> Hs Hassium (270) [Rn]5f <sup>14</sup> 6d <sup>6</sup> 7s <sup>2</sup> 7.8	13 <sup>109</sup> Mt Meitnerium (276) [Rn]5f <sup>14</sup> 6d <sup>7</sup> 7s <sup>2</sup> 7.8	14 <sup>110</sup> Ds Darmstadtium (281) [Rn]5f <sup>14</sup> 6d <sup>8</sup> 7s <sup>2</sup> 7.8	15 <sup>111</sup> Rg Roentgenium (280) [Rn]5f <sup>14</sup> 6d <sup>9</sup> 7s <sup>2</sup> 7.8	16 <sup>112</sup> Cn Copernicium (285) [Rn]5f <sup>14</sup> 6d <sup>10</sup> 7s <sup>2</sup> 7.8	17 <sup>113</sup> Uut Ununtrium (284) [Rn]5f <sup>14</sup> 6d <sup>10</sup> 7s <sup>2</sup> 7p <sup>1</sup> 7.8	18 <sup>114</sup> Fl Flerovium (289) [Rn]5f <sup>14</sup> 6d <sup>10</sup> 7s <sup>2</sup> 7p <sup>2</sup> 7.8	19 <sup>115</sup> Uup Ununpentium (293) [Rn]5f <sup>14</sup> 6d <sup>10</sup> 7s <sup>2</sup> 7p <sup>3</sup> 7.8	20 <sup>116</sup> Lv Livermorium (294) [Rn]5f <sup>14</sup> 6d <sup>10</sup> 7s <sup>2</sup> 7p <sup>4</sup> 7.8	21 <sup>117</sup> Uus Ununseptium (294) [Rn]5f <sup>14</sup> 6d <sup>10</sup> 7s <sup>2</sup> 7p <sup>5</sup> 7.8	22 <sup>118</sup> Uuo Ununoctium (294) [Rn]5f <sup>14</sup> 6d <sup>10</sup> 7s <sup>2</sup> 7p <sup>6</sup> 7.8											
7 <sup>57</sup> La Lanthanum 138.90547 [Xe]5d <sup>1</sup> 6s <sup>2</sup> 5.5769	8 <sup>58</sup> Ce Cerium 140.116 [Xe]4f <sup>1</sup> 5d <sup>1</sup> 6s <sup>2</sup> 5.5386	9 <sup>59</sup> Pr Praseodymium 140.907 [Xe]4f <sup>2</sup> 6s <sup>2</sup> 5.473	10 <sup>60</sup> Nd Neodymium 144.242 [Xe]4f <sup>3</sup> 6s <sup>2</sup> 5.5250	11 <sup>61</sup> Pm Promethium (145) [Xe]4f <sup>4</sup> 6s <sup>2</sup> 5.582	12 <sup>62</sup> Sm Samarium 150.36 [Xe]4f <sup>6</sup> 6s <sup>2</sup> 6.1498	13 <sup>63</sup> Eu Europium 151.964 [Xe]4f <sup>7</sup> 6s <sup>2</sup> 6.1498	14 <sup>64</sup> Gd Gadolinium 157.25 [Xe]4f <sup>7</sup> 5d <sup>1</sup> 6s <sup>2</sup> 6.1498	15 <sup>65</sup> Tb Terbium 158.92535 [Xe]4f <sup>9</sup> 6s <sup>2</sup> 5.9391	16 <sup>66</sup> Dy Dysprosium 162.500 [Xe]4f <sup>10</sup> 6s <sup>2</sup> 6.0215	17 <sup>67</sup> Ho Holmium 164.93033 [Xe]4f <sup>11</sup> 6s <sup>2</sup> 6.1077	18 <sup>68</sup> Er Erbium 167.259 [Xe]4f <sup>12</sup> 6s <sup>2</sup> 6.1843	19 <sup>69</sup> Tm Thulium 168.93422 [Xe]4f <sup>13</sup> 6s <sup>2</sup> 6.2542	20 <sup>70</sup> Yb Ytterbium 173.054 [Xe]4f <sup>14</sup> 6s <sup>2</sup> 6.2542	21 <sup>71</sup> Lu Lutetium 174.967 [Xe]4f <sup>14</sup> 5d <sup>1</sup> 6s <sup>2</sup> 6.2529													
8 <sup>89</sup> Ac Actinium (227) [Rn]6d <sup>1</sup> 7s <sup>2</sup> 5.3802	9 <sup>90</sup> Th Thorium 232.0377 [Rn]6d <sup>2</sup> 7s <sup>2</sup> 6.3067	10 <sup>91</sup> Pa Protactinium 231.03688 [Rn]5f <sup>1</sup> 6d <sup>1</sup> 7s <sup>2</sup> 5.89	11 <sup>92</sup> U Uranium 238.02891 [Rn]5f <sup>3</sup> 6d <sup>1</sup> 7s <sup>2</sup> 6.1941	12 <sup>93</sup> Np Neptunium (237) [Rn]5f <sup>4</sup> 6d <sup>1</sup> 7s <sup>2</sup> 6.2655	13 <sup>94</sup> Pu Plutonium (244) [Rn]5f <sup>6</sup> 7s <sup>2</sup> 6.2658	14 <sup>95</sup> Am Americium (243) [Rn]5f <sup>7</sup> 7s <sup>2</sup> 5.9914	15 <sup>96</sup> Cm Curium (247) [Rn]5f <sup>8</sup> 7s <sup>2</sup> 6.1978	16 <sup>97</sup> Bk Berkelium (247) [Rn]5f <sup>9</sup> 7s <sup>2</sup> 6.2817	17 <sup>98</sup> Cf Californium (251) [Rn]5f <sup>10</sup> 7s <sup>2</sup> 6.3676	18 <sup>99</sup> Es Einsteinium (252) [Rn]5f <sup>11</sup> 7s <sup>2</sup> 6.50	19 <sup>100</sup> Fm Fermium (257) [Rn]5f <sup>12</sup> 7s <sup>2</sup> 6.50	20 <sup>101</sup> Md Mendelevium (258) [Rn]5f <sup>13</sup> 7s <sup>2</sup> 6.58	21 <sup>102</sup> No Nobelium (259) [Rn]5f <sup>14</sup> 7s <sup>2</sup> 6.85	22 <sup>103</sup> Lr Lawrencium (262) [Rn]5f <sup>14</sup> 7s <sup>2</sup> 7p <sup>1</sup> 4.90													

Atomic Number, Ground-state Level, Symbol, Name, Standard Atomic Weight, Ground-state Configuration, Ionization Energy (eV)

<sup>1</sup>Based upon <sup>12</sup>C, ( ) indicates the mass number of the longest-lived isotope. <sup>2</sup>LUPAC conventional atomic weights; standard atomic weights for these elements are expressed in intervals; see [lupac.org](http://lupac.org) for an explanation and values.

For a description of the data, visit [physics.nist.gov/data](http://physics.nist.gov/data)  
NIST SP 966 (September 2014)

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