Atomic Origins: Chapter Problems

Big Bang

Class Work

1. How old is the Universe?
2. Name and describe the three subatomic particles.
3. Nuclear fusion reactions power stars. Name 2 elements that can be formed in Earth’s Sun.
4. "We are all made of stars" may actually be a true statement. Explain how you, your classmates, and your natural surroundings are composed of once galactic matter.

Homework

5. When did the first particles of matter (the subatomic particles) originate?
6. Compare and contrast the mass and charge of protons, electrons, and neutrons.
7. Where did large elements such as lead (Pb) and xenon (Xe) come from?
8. Some elements do not occur naturally. Give the atomic symbol for two elements that are man-made.

Electrons & Protons

Class Work

9. Describe how the electron was discovered.
10. How did scientists know that the cathode rays were negatively charged?
11. What about electrons allow them to be some of the fastest traveling sub atomic particles?
12. What did Robert A. Millikan discover?
13. Calculate the electric force between a proton and an electron in a hydrogen atom ($r_H = 53\text{pm}$).

Homework

14. Describe how the charge and mass of an electron were discovered.
15. Why do you think electrons were the first subatomic particle to be discovered?
16. How did scientists know that electrons had a small mass?
17. Compare anode rays to cathode rays.
18. Calculate the electric force between the 2 electrons and 2 protons in a helium atom ($r_{He} = 31\text{pm}$).

The Nucleus

Class Work

19. Describe the gold foil experiment and its results.
20. Based off of the first experiments into the composition of atoms, why were neutrons the last particles to be discovered?
21. What is the mass of a proton in atomic mass units, u (give your answer to the thousandths place)?
22. A carbon nucleus contains 6 protons and 7 neutrons. What is its mass in kilograms? In atomic mass units?
23. When determining the mass of an atom we typically ignore the mass of the atom’s electrons. Why?
24. Which element contains 21 protons?
25. Which element contains 11 protons?
26. Which element contains 104 protons?
27. How many protons are in Carbon?
28. How many protons are in Tungsten?
29. How many protons are in Indium?
30. How many neutrons are in an atom of Al-27?
31. Determine the atomic number, the mass number, the number of protons, and the number of neutrons for $^{144}_{58}Sm$.
32. Determine the atomic number, the mass number, the number of protons, and the number of neutrons for $^{56}_{26}Fe$.
33. Identify the element $^{89}_{35}X$. State its atomic number, and the number of neutrons in the nucleus.

Homework

34. What is the plum pudding model of the atom?
35. Name the three types of radiation. What type was used to discover the nucleus?
36. What is the atom made of?
37. What caused Rutherford to suspect the presence of the neutron?
38. What is the mass of a neutron in atomic mass units, u (give your answer to the thousandths place)?
39. A lithium nucleus contains 3 protons and 4 neutrons. What is its mass in kilograms? In atomic mass units?
40. Which element contains 35 protons?
41. Which element contains 18 protons?
42. Which element contains 84 protons?
43. How many protons are in Magnesium?
44. How many protons are in Gold?
45. How many protons are in Silver?
46. Determine the atomic number, the mass number, the number of protons, and the number of neutrons for $^{102}_{44}Ru$.
47. Determine the atomic number, the mass number, the number of protons, and the number of neutrons for $^{59}_{27}Co$.
48. Identify the element $^{33}_{16}X$. State its atomic number, and the number of neutrons in the nucleus.

Formation of the Elements

Class Work

49. Why do nuclear fusion reactions release energy?
50. *Calculate the binding energy of deuterium (hydrogen-2). $M_D = 2.01410178 \text{ u}$
51. *Calculate the binding energy of carbon-12.  $M_C = 12.0000 \text{ u}$
52. Outline the steps for the production of Helium from Hydrogen.
53. *How much energy is released in the production of Helium? $M_{\text{He}} = 4.002602 \text{ u}$
54. Complete the following fusion reaction: $^{13}_{6}C + ^{1}_{1}H \rightarrow _____ + \gamma$
55. Complete the following fusion reaction: $^{3}_{2}He + ^{3}_{2}He \rightarrow _____ + \gamma$
56. In a nuclear weapon what type of nuclear reaction is occurring?
57. Complete the following fission reaction: $^{1}_{0}n + ^{235}_{92}U \rightarrow ^{141}_{56}Ba + ^{92}_{36}Kr + _____ ^{1}_{0}n$
58. *Calculate the amount of energy produced in the above reaction.  $M_{U} = 235.0439299 \text{ u}; M_{Ba} = 140.914411009 \text{ u}; M_{Kr} = 91.92615621 \text{ u}$
59. Complete the following fission reaction: $^{239}_{94}Pu + ^{1}_{0}n \rightarrow ^{100}_{42}Mo + _____ + 6 ^{1}_{0}n$

**Homework**

60. Define binding energy.
61. *Calculate the binding energy of tritium (hydrogen-3).  $M_{T} = 3.0160492 \text{ u}$
62. *Calculate the binding energy of uranium-235.  $M_{U} = 235.0439299 \text{ u}$
63. Define the Law of Conservation of Nucleon Number and explain how it applies to nuclear fusion reactions.
64. Complete the following fusion reaction: $^{8}_{3}Be + ^{4}_{2}He \rightarrow _____ + \gamma$
65. Complete the following fusion reaction: _____ + $^{4}_{2}He \rightarrow ^{16}_{8}O + \gamma$
66. What is a positron?  What affect does it have on a nuclear reaction?
67. In a nuclear reactor what type of nuclear reaction is occurring?
68. Complete the following fission reaction: $^{1}_{0}n + ^{235}_{92}U \rightarrow ^{94}_{38}Sr + ^{140}_{54}Xe + _____ ^{1}_{0}n$
69. *Calculate the amount of energy produced in the above reaction.  $M_{U} = 235.0439299 \text{ u}; M_{Sr} = 93.915361312 \text{ u}; M_{Xe} = 139.921640943 \text{ u}$
70. Describe how nuclear engineers can control a fission reaction.

**Isotopes**

**Class Work**

71. What do isotopes of an element have in common?  How do they differ?
72. $^{12}_{6}C$ is an isotope of Carbon; what is the atomic number and the atomic mass number?
73. Write the atomic symbols for nitrogen-14 and nitrogen-15.
74. Two atoms are found to contain the same number of neutrons.  Can we use this information to determine that they are the same element?  Explain.
75. The average mass of all fluorine atoms is 18.998 u.  Do you think most fluorine atoms have 9 neutrons or 10 neutrons?  Explain.
76. Use the table below find the average atomic mass of mercury, Hg.

<table>
<thead>
<tr>
<th>Isotope</th>
<th>% Abund.</th>
<th>Atomic Mass</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hg-196</td>
<td>0.146%</td>
<td>195.965813</td>
</tr>
<tr>
<td>Hg-198</td>
<td>10.01%</td>
<td>197.966760</td>
</tr>
<tr>
<td>Hg-199</td>
<td>16.84%</td>
<td>198.968268</td>
</tr>
</tbody>
</table>

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Hg-200  23.13%  199.968316
Hg-201  13.22%  200.970293
Hg-202  29.81%  201.970632
Hg-204  6.844%  203.973481

77. Use the table below to find the average atomic mass of oxygen, O.

<table>
<thead>
<tr>
<th>Isotope</th>
<th>% Abund.</th>
<th>Atomic Mass</th>
</tr>
</thead>
<tbody>
<tr>
<td>O-16</td>
<td>99.75%</td>
<td>15.994916</td>
</tr>
<tr>
<td>O-17</td>
<td>00.04%</td>
<td>16.999132</td>
</tr>
<tr>
<td>O-18</td>
<td>00.21%</td>
<td>17.999153</td>
</tr>
</tbody>
</table>

78. Chromium has four stable isotopes. Three of these are: Cr-50 with a percent abundance of 4.35%; Cr-52 with a percent abundance of 83.8%; Cr-53 with a percent abundance of 9.5%. What is the percent abundance and mass number of the fourth isotope?

Homework
79. How does the mass number and the atomic mass given on the periodic table differ?
80. $^{63}_{29}$Cu is an isotope of Copper; what is the atomic number and the atomic mass number?
81. $^{18}_{8}$O is an isotope of Oxygen; how many neutrons, protons and electrons does it have?
82. Write the atomic symbols for phosphorus-30 and phosphorus-31.
83. Two atoms are found to contain the same number of protons. Can we use this information to determine that they are the same element? Explain.
84. Two atoms are found to contain the same number of electrons. Can we use this information to determine that they are the same element? Explain.
85. The average mass of all carbon atoms is 12.011 u. What is the most abundant isotope of carbon?
86. Use the table below to find the average atomic mass of neon, Ne.

<table>
<thead>
<tr>
<th>Isotope</th>
<th>% Abund.</th>
<th>Atomic Mass</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neon-20</td>
<td>90.62%</td>
<td>19.992439</td>
</tr>
<tr>
<td>Neon-21</td>
<td>02.6%</td>
<td>20.993845</td>
</tr>
<tr>
<td>Neon-22</td>
<td>9.12%</td>
<td>21.991384</td>
</tr>
</tbody>
</table>

87. Use the table below to find the average atomic mass of bromine, Br.

<table>
<thead>
<tr>
<th>Isotope</th>
<th>% Abund.</th>
<th>Atomic Mass</th>
</tr>
</thead>
<tbody>
<tr>
<td>Br-79</td>
<td>50.69%</td>
<td>78.9183371</td>
</tr>
<tr>
<td>Br-81</td>
<td>49.31%</td>
<td>80.9168041</td>
</tr>
</tbody>
</table>

88. Rubidium has two naturally occurring isotopes. Rb-85 is stable and has a natural abundance of 72.2%. The second isotope is radioactive. What is this isotope's percent abundance and mass number?

Radioactive Decay
Class Work
89. As more and more protons enter the nucleus of an atom, increasing ratios of neutrons are needed. Why do you think this is?
90. $^{45}_{20}$Ca undergoes $\beta^-$ decay. Using a periodic table, find the resulting atom.
91. Fill in the missing component: \( ^{208}_{83}Bi \rightarrow ^{4}_{2}He + \) ______

92. Fill in the missing component: \( ^{32}_{15}P \rightarrow ^{32}_{16}S + \) ______

93. Fill in the missing component: \( ^{60}_{27}Co* \rightarrow ^{60}_{27}Co + \) ______

**Homework**

94. Why was it important to use alpha particles in order to discover the nucleus, as opposed to gamma rays or beta particles?

95. \( ^{22}_{11}Na \) undergoes \( \beta^+ \) decay. Using a periodic table, find the resulting atom.

96. Fill in the missing component: \( ^{35}_{16}S \rightarrow ^{0}_{-1}e + \) ______

97. Fill in the missing component: \( ^{212}_{84}Po \rightarrow ^{208}_{82}Pb + \) ______

98. Fill in the missing component: \( \) ______ \( \rightarrow ^{240}_{94}Pu + \gamma \)

**Half-Life**

**Class Work**

99. Unstable nuclei decay into other nuclei. What is the time it takes for half of the nuclei to decay called?

100. An isotope of Bi has a half-life of 2 minutes. How much of this isotope will be left after 8 minutes from a starting sample of 800 g?

101. Nitrogen-13 has a half-life of 10 minutes. How long will it take for a sample of 500 g to be reduced to 62.5 g?

102. Carbon-11 has a half-life of 20 minutes. How much of this isotope will be left after 60 minutes from a starting sample of 40 g?

103. A 1.5 kg sample of californium-253 undergoes radioactive decay. After 89 days 47 grams remain. What is the half-life of this isotope?

**Homework**

104. Fermium-257 has a half-life of 3 days. How long will it take for a sample of 200 g to be reduced to 25 g?

105. Lead-210 has a half-life of 22 years. How much of this isotope will be left after 110 years from a starting sample of 8.0 kg?

106. Radon-222 has a half-life of 3.8 days. How much of this isotope will be left after 19 days from a starting sample of 160 g?

107. A 350 g sample of nobelium-259 undergoes radioactive decay. After 116 minutes 87.5 g remain. What is the half-life of this isotope?

108. *A 50 g sample of radon-222 undergoes radioactive decay. After 5 days 20 g remain. What is the half-life of this isotope?
Free Response

1. Describe the development of nuclear model of the atom including:
   a. Cathode rays & anode rays
   b. Millikan oil drop experiment
   c. Gold foil experiment

2. An unknown element X has 5 stable isotopes. The isotopic masses (u) and percent abundance of the isotopes are given in the table below.

<table>
<thead>
<tr>
<th>Isotope</th>
<th>Mass (u)</th>
<th>Natural Abundance</th>
</tr>
</thead>
<tbody>
<tr>
<td>X₁</td>
<td>45.9526</td>
<td>8.25%</td>
</tr>
<tr>
<td>X₂</td>
<td>46.9518</td>
<td>7.44%</td>
</tr>
<tr>
<td>X₃</td>
<td>47.9480</td>
<td>73.72%</td>
</tr>
<tr>
<td>X₄</td>
<td>48.9479</td>
<td>5.41%</td>
</tr>
<tr>
<td>X₅</td>
<td>49.9448</td>
<td>5.18%</td>
</tr>
</tbody>
</table>

   a. Predict the identity of this element. Explain your prediction.
   b. Determine average atomic mass of this element.
   c. Identify the element. State the number of protons and neutrons in each isotope.
   d. This element has a radioactive isotope (X₆) with a half-life of 80.4 milliseconds. How long will it take for 60 g of the substance to decay to 3.75 g?
   e. This element was generated through a fusion reaction. Where in the universe did this fusion reaction occur?

3. Hydrogen has two stable isotopes, hydrogen-1 and hydrogen-2 (deuterium)

<table>
<thead>
<tr>
<th>Isotope</th>
<th>Mass (u)</th>
<th>Natural Abundance</th>
</tr>
</thead>
<tbody>
<tr>
<td>¹H</td>
<td>1.007825</td>
<td>?</td>
</tr>
<tr>
<td>²H</td>
<td>2.014101</td>
<td>?</td>
</tr>
</tbody>
</table>

   a. Which isotope is more naturally abundant? Defend your prediction.
   b. Determine the natural abundance of each isotope.
   c. Tritium (hydrogen-3) is an unstable isotope of hydrogen. Its half-life is 12.32 years. Beginning with a 37.5 g sample of tritium, how much will remain after 20 years?
   d. Tritium decays naturally to produce helium-3. Write the balanced nuclear reaction for this decay.
   e. Outline the role of these three isotopes in the formation of helium-4.
4. Helium-6 is an unstable isotope with a half-life of 806.7 ms.
   a. Write a balanced reaction for the β- decay of a helium-6 atom.
   b. Beginning with a 20 g sample of helium-6, how much will remain after 1 minute?
   c. At what point in the history of the universe did the first helium atoms appear?

5. When uranium-235 is bombarded with a neutron, nuclear fission can occur.
   a. Write a balanced reaction for fission of an \( ^{235}_{92}U \) atom which results in at least one
      atom of \( ^{141}_{56}Ba \).
   b. Discuss the differences between nuclear fission in a reactor and nuclear fission
      in a weapon.
   c. *Calculate the energy released from this fission reaction.
Answers

1. 14 billion years old.
2. Protons have a positive charge of $1.6 \times 10^{-19}$ C and a mass of $1.67 \times 10^{-27}$ kg. Electrons have a charge of $-1.6 \times 10^{-19}$ C and a mass of $9.11 \times 10^{-31}$ kg. Neutrons have no charge and a mass of $1.68 \times 10^{-27}$ kg.
3. Hydrogen and helium.
4. All naturally occurring elements originated in stars. Since we are made up of naturally occurring elements, we are all made of stellar material.
5. In the first few seconds after the Big Bang, 14 billion years ago.
6. Protons and neutrons have nearly equal masses. There masses are $1835x$ greater than that of electrons.
7. Supernovae
8. Am, Cm, Bk, Cf, Es, Fm, Md, No, Lr
9. Cathode rays were able to be deflected by electric and magnetic fields. Scientists were able to determine that these rays were actually streams of negatively charged particles.
10. The cathode rays were repelled by negatively charged plates and attracted to positively charged plates.
11. Electrons have a very small mass.
12. The Millikan oil drop experiment determined the charge on an electron.
13. $8.2 \times 10^{-8}$ N
14. The charge and mass ratio of an electron was discovered using the effect of electric and magnetic fields on cathode rays. Millikan used x-rays to knock electrons off air molecules and onto oil drops. He found that the charge on the drop was always a multiple of $1.6 \times 10^{-19}$ giving him the charge of an electron. Using the charge/mass ratio the mass of an electron was found to be $9.11 \times 10^{-31}$ kg.
15. Electrons were probably the first subatomic particles discovered because they are charged and they have a small mass, which mean they are deflected easily.
16. The cathode rays were very easily deflected which meant the electrons had to have either a very large charge or a very small mass.
17. Anode rays are emitted from the positive electrode (protons) and cathode rays are emitted from the negative electrode (electrons).
18. $9.6 \times 10^{-7}$ N
19. Gold foil was bombarded with alpha particles and the scatter patterns observed. Most alpha particles went straight through but some bounced back, leading to the discovery of the nucleus.
20. Because neutrons have no charge.
21. $1.673 \times 10^{-27}$ kg
22. $2.176 \times 10^{-26}$ kg, $13.104$ u
23. Because the mass of an electron is very small compared to the mass of a proton and neutron.
24. Sc
25. Na
26. Rf
27. 12
28. 74
29. 49
30. 14
31. 62; 144; 62; 82
32. 26; 56; 26; 30
33. K; 19; 20
34. The plum pudding model was the original model of the atom in which a positively charged sphere was imbedded with negatively charged electrons.
35. Alpha particles, beta particles, and gamma rays; alpha particles
36. A small positively charged nucleus with electrons orbiting it in mostly empty space.
37. The nucleus was heavier than expected.
38. 1.675x10^{-27} kg
39. 1.172x10^{-26} kg; 7.060 u
40. Br
41. Ar
42. Po
43. 12
44. 79
45. 47
46. 44; 102; 44; 58
47. 27; 59; 27; 32
48. S; 16; 17
49. The mass of the nucleus is less than the mass of the protons and neutrons it contains. This mass defect is released as energy.
50. 3.57x10^{-13} J
51. 1.47x10^{-11} J
52. Step 1: Two H-1 atoms fuse to produce H-2, a positron, and a neutrino. Step 2: A H-1 atom fuses with the H-2 atom to produce He-3 and a gamma ray. Step 3: Two He-3 atoms fuse to produce He-4 and two H-1 atoms.
53. 4.53x10^{-12} J
54. $^{14}_{7}N$
55. $^{9}_{4}Be$
56. Uncontrolled nuclear fission
57. 3
58. $2.78 \times 10^{-11}$ J
59. $^{134}_{52}$Te
60. The amount of energy released when protons and neutrons combine to form a nucleus.
61. $1.36 \times 10^{-12}$ J
62. $2.86 \times 10^{-10}$ J
63. The Law of Conservation of Nucleon Number says that in a nuclear reaction the number of nucleons (protons + neutrons) must be conserved.
64. $^{12}_{6}$C
65. $^{12}_{6}$C
66. A positron is the anti-particle to an electron. It has a positive charge and in a nuclear reaction its emission converts a proton to a neutron.
67. Controlled nuclear fission
68. 2
69. $2.96 \times 10^{-11}$ J
70. Cadmium and boron control rods can be used and adjusted to absorb the correct amount of neutrons giving the nuclear engineer control of the reaction.
71. Isotopes of a given element have the same number of protons but different numbers of neutrons; this means they also have different masses.
72. 6; 12
73. $^{14}_{7}$N; $^{15}_{7}$N
74. No. Different elements can have the same number of neutrons.
75. 10 neutrons; Fluorine has 9 protons, since the average atomic mass of F is almost 19, the majority of F atoms must have 10 neutrons.
76. 200.592 u
77. 15.999 u
78. 2.35%; 54
79. The mass number is the number of nucleons in the atom, its value is very close to the actual mass of the isotope in atomic mass units. The mass value given on the periodic table is that average mass of all isotopes of that element. It does not reflect the actual mass of any single atom.
80. 29; 63
81. 8; 8; 8
82. $^{30}_{15}$P; $^{31}_{15}$P
83. Yes. All atoms of a given element have the same number of protons.
84. No. It is possible for atoms of a given element to have different numbers of electrons; these are called ions. It is also possible for atoms/ions of different elements to have the same number of electrons; these are called isoelectric.
85. Carbon-12
86. 20.18 u
87. 79.904 u
88. 27.8%; 87
89. Since protons are positive and like charges repel one another, another type of particle is needed to keep the protons apart from one another while still binding them to the nucleus.
90. $^{45}_{21}$Sc
91. $^{208}_{83}$Tl
92. $^{0}_{-1}$e
93. γ
94. Since alpha particles are the only form of radiation that is positive and has a mass it would be the only particle that would bounce off of a positive nucleus.
95. $^{22}_{10}$Ne
96. $^{35}_{17}$Cl
97. $^{3}$He
98. $^{240}_{94}$Pu*
99. Half-life
100. 50 g
101. 30 min
102. 5 g
103. 17.8 days
104. 9 days
105. 0.25 kg
106. 5 g
107. 58 min
108. 3.8 days

Free Response
1. Atomic structure
   a. Cathode rays were able to be deflected by electric and magnetic fields. Scientists were able to determine that these rays were actually streams of negatively charged particles. Anode rays behave oppositely. Cathode rays were in fact electrons, anode rays – protons. The deflection was used to determine the charge/mass ratio for these particles.
   b. Millikan used x-rays to knock electrons off air molecules and onto oil drops. He found that the charge on the drop was always a multiple of $1.6 \times 10^{-19}$ giving him the charge of an electron. Using the charge/mass ratio the mass of an electron was found to be $9.11 \times 10^{-31}$ kg.
   c. After the discovery of protons and electrons, the plum pudding model was put forth in which a positively charged sphere was imbedded with negatively charged electrons. In the gold foil experiment, gold foil was bombarded with alpha particles and the scatter patterns observed. Most alpha particles went
straight through but some bounced back, leading to the discovery of the nucleus. The new nuclear model had a positively charged nucleus at the center of an atom made up mostly of empty space. The electrons orbited the nucleus. The atoms were heavier than expected leading to the discovery of neutrons inside the nucleus.

2. Unknown element
   a. Titanium because the majority of this element’s atoms have an atomic mass of 47.9480 u. The element on the periodic table with the closest average atomic mass to this is Ti with a value of 47.867 u
   b. 47.86674944 u
   c. Titanium. All isotopes have 22 protons. \( X_1 - 24 \) neutrons; \( X_2 - 25 \) neutrons; \( X_3 - 26 \) neutrons; \( X_4 - 27 \) neutrons; \( X_5 - 28 \) neutrons
   d. 321.6 ms
   e. This element could have been generated in very large stars or supernovae.

3. Hydrogen
   a. H-1 is more abundant because the average atomic mass of hydrogen is 1.008 u
   b. Hydrogen-1 99.99%; hydrogen-2 0.01%
   c. 12.38 g
   d. \( \frac{3}{1}H \rightarrow \frac{3}{2}He + \bar{e} \)
   e. Step 1: Two H-1 atoms fuse to produce H-2, a positron, and a neutrino. Step 2: A H-1 atom fuses with the H-2 atom to produce He-3 and a gamma ray. Step 3: Two He-3 atoms fuse to produce He-4 and two H-1 atoms.

4. Helium
   a. \( \frac{6}{2}He \rightarrow \frac{6}{3}Li + \bar{e} \)
   b. 8x10^-22 g
   c. In the first few seconds after the Big Bang

5. Uranium
   a. \( \frac{235}{92}U + \frac{1}{0}n \rightarrow \frac{141}{56}Ba + \frac{92}{36}Kr + 3\frac{1}{0}n \)
   b. Nuclear fission in a reactor is controlled through the use of rods which absorb excess neutrons. In nuclear weapons the fission reactions are uncontrolled.
   c. 2.9x10^-11 J